1-2009

Eighteenth Year of the Gulf of Maine Environmental Monitoring Program

Lawrence A. LeBlanc
University of Maine School of Marine Sciences

Christian Krahforst
Massachusetts Bays National Estuary Program

Jamie Aube
Environment Canada

Shawn Roach
Department of Fisheries and Oceans

Guy Brun
Environment Canada

See next page for additional authors

Authors
Lawrence A. LeBlanc, Christian Krahforst, Jamie Aube, Shawn Roach, Guy Brun, Gareth Harding, Peter Hennigar, David Page, Stephen H. Jones, Susan Shaw, James Stahlnecker, Jack Schwartz, Darrell Taylor, Bruce Thorpe, and Peter Wells

Gulfwatch 2008 Data Report:

EIGHTEENTH YEAR OF THE

GULF OF MAINE ENVIRONMENTAL MONITORING PROGRAM

Prepared for

Gulf of Maine Council on the Marine Environment

January 2009

By: Lawrence A. LeBlanc[1] Christian Krahforst[2], Jamie Aube[3], Shawn Roach[4], Guy Brun[3], Gareth Harding[5], Peter Hennigar[6], David Page[7], Stephen Jones[8], Susan Shaw[9], James Stahlnecker[10], Jack Schwartz[11], Darrell Taylor[12], Bruce Thorpe[13], and Peter Wells[14]

[1]University of Maine School of Marine Sciences, Orono, ME, USA
[2]Massachusetts Bays National Estuary Program, Boston, MA, USA
[3]Environment Canada, Moncton, NB, CA
[4]Department of Fisheries and Oceans, Halifax, NS, CA
[5]Bedford Institute of Oceanography, Fisheries and Oceans, Dartmouth, NS, CA
[6]Environment Canada, Dartmouth, NS, CA
[7]Dept. of Chemistry, Bowdoin College, Brunswick, ME, USA
[8]University of New Hampshire, Durham, NH, USA
[9]Marine Environmental Research Inst., Blue Hill, ME, USA
[10]Maine Dept. Environmental Protection, Augusta, ME, USA
[11]Massachusetts Division of Marine Fisheries, Gloucester, MA, USA
[12]Nova Scotia Department of Environment, Halifax, NS, CA
[13]New Brunswick Department of Agriculture, Fisheries, and Aquaculture, St. George, NB, CA
[14]OceansOne, Halifax, NS, CA

TABLE OF CONTENTS

LIST OF FIGURES

List of Tables

APPENDICES

1.0 INTRODUCTION

This report summarizes the metals and organic contaminant data associated with the collection and analyses of blue mussel (*Mytilus edulis*) tissue from selected sites along the Gulf of Maine coast during the 2008 sampling season. Contaminant monitoring is conducted by the Gulfwatch Program for the Gulf of Maine Council on the Marine Environment (GOMC). A subset of these data is compared with analytical results from earlier Gulfwatch monitoring (2001-2007). Statistical analyses are limited to descriptive measures of replicates from selected sampling sites and include: arithmetic means, and appropriate measures of variance. The primary purpose of this report is to present the current annual results, present graphical representation of spatial and temporal trends and identify potential outliers in order to provide investigators and other interested persons with contemporary information concerning water quality in the Gulf of Maine, as reflected by uptake into resident shellfish (mussels and clams).

1.1 PROGRAMMATIC RATIONALE

The Gulf of Maine is the region of the North Atlantic Ocean that extends from Cape Sable, Nova Scotia, through New Brunswick, Maine, and New Hampshire to Cape Cod, Massachusetts; and includes the Bay of Fundy and Georges Bank. The Gulf of Maine ecosystem is one of the world's most productive ecosystems with an extensive and diverse array of plants and animals (Census of Marine Life - Gulf of Maine Area, 2008) that support important economic activities including commercial catch and aquaculture fisheries, recreational fishing, shipping, and tourism. The Gulf of Maine ecosystem includes large watersheds draining from western Nova Scotia, southwestern New Brunswick, and the states of Maine, southern and eastern New Hampshire, and eastern Massachusetts. Several urban industrialized areas lie within those watersheds, including: Boston, Massachusetts; Portsmouth, New Hampshire; Portland and Bangor, Maine: and Saint John, New Brunswick.

Increases in industrial, commercial, and expanding residential development along the Gulf of Maine coast and the subsequent discharge of chemical contaminants have contributed to deterioration of water quality in some near shore areas (Dow and Braasch, 1996). Many of these contaminants have been shown to bioaccumulate and biomagnify throughout the food web, resulting in elevated concentrations in organisms, especially those at higher trophic levels (Chen et al., 2008; Shaw et al., 2006, 2005 and 2003; Mallory et al., 2005; Aguilar et al., 2002; Weisbrod et al., 2000). When critical body burdens are reached (exact concentrations differ with contaminant and organism) contaminants have been shown to adversely affect the growth, reproduction, and survival of marine organisms (Kawaguchi et al. 1999, Wells and Rolston 1991). Contaminant bioaccumulation serves therefore as an indicator of the status of ecosystem health with implications for human health, especially for those who derive the benefits of food, recreation, and other uses from the near shore marine environment (Dolan at al., 2005).

It is for this purpose that individual jurisdictions around the Gulf of Maine have implemented steps to control the discharge of chemical contaminants to the Gulf of Maine. The Gulfwatch monitoring program provides region-wide tracking of contaminant exposure (spatial status and time trends) for both urban and less populated areas within all five Gulf of Maine jurisdictions. Gulfwatch informs the GOMC member jurisdictions in the U.S. and Canada on the status and trends of contaminant accumulation in mussels. The Gulfwatch monitoring program is thus responsive to the goals articulated by the Council that seek to balance environmental integrity and human uses in the Gulf of Maine. The GOMC (http://www.gulfofmaine.org/) was established by the *Agreement on the Conservation of the Marine Environment of the Gulf of Maine* which was signed in December 1989 by the premiers of Nova Scotia and New Brunswick and the governors of Maine, New Hampshire and Massachusetts. The GOMC's mission is to maintain and enhance the Gulf's marine ecosystem, its natural resources and environmental quality. To achieve the GOMC's mission statement, the Gulf of Maine Environmental Quality Monitoring Committee was formed and charged with the development of the Gulf of Maine Environmental Quality Monitoring Program. The program is based on the mission statement endorsed by the GOMC:

"Using mussel tissue monitoring of toxic chemical contaminants, the Gulfwatch Program will contribute to the provision of high quality and relevant data to allow for characterization of the condition of ecosystems in the GOM for enhancing marine resource management and protecting public health."

The Gulfwatch program is charged with the assessment component of the GOMC's 2007-2012 Action Plan Goal 2 (of 3): *Environmental conditions in the Gulf of Maine support ecosystem and human health***.** Two monitoring goals were established to help meet the goals of the current Action Plan and the mission of the Gulfwatch Program:

(1) Conduct regional contaminant monitoring using the blue mussel (*Mytilus edulis)* as an indicator of exposure to organic and inorganic contaminants
(2) Assess the status and trends of chemical contaminants in coastal habitats of the Gulf of Maine and Bay of Fundy.

The hypotheses that guide the Program are as follows:

- Concentrations of chemical contaminants in mussel tissues are the same at all sites in the Gulf of Maine;
- No changes in mussel tissue contaminant concentrations occur with time at each sampling site.

Gulfwatch uses the blue mussel, *Mytilus edulis*, as an indicator for habitat exposure to organic and inorganic contaminants. Bivalves, including blue mussel, have been successfully used as an indicator organism in environmental monitoring programs throughout the world (McIntosh et al., 2004; Glynn et al., 2004; Airas, 2003; Monirith et al., 2003; NAS, 1980; NOAA, 1991; Widdows et al., 1995, Widdows and Donkin, 1992; O'Connor and Lauenstein, 2006; O'Connor, 2002 and 1998). Blue mussels were selected because they are:

(1) abundant within and across each of the five Gulf of Maine jurisdictions and are relatively easy to collect and process.
(2) comparatively well studied and reported in the scientific and technical literature.

(3) commercially harvested for food and may be used to evaluate human exposure to chemical contamination.
(4) sedentary, thereby reducing sources of data variability associated with mobile species.
(5) suspension feeders that pump large volumes of water and concentrate many chemicals in their tissues both directly and indirectly from the water column. This increases the ability to measure chemical contaminants found at lower concentrations in other environmental matrices.

Contaminant accumulation in mussel tissue represents the biologically available proportion that is not always apparent from measurement of contaminants in other environmental matrices such as water, sediment, and suspended particles.

Gulfwatch also reports on shell size and the growth condition using the condition index (CI); the latter has a potential for use in normalizing the contaminant concentration data. CI is traditionally used as an indicator of the physiological status of mussels (Widdows, 1985). CI relates the tissue's wet weight to shell volume. The effect of gonadal weight on total body weight and CI values (i.e., high CI values can be due to ripe gonads present just prior to spawning), and implications to the interpretation of metal and organic contaminant tissue concentrations has been covered in other Gulfwatch reports (e.g., Gulfwatch, 2006 report, GOMC, 2009).

2.0 METHODS

2.1 New 12-year Sampling Design

The year 2008 is year three of the 12-year sampling design (2005-2016) developed by the Gulfwatch committee, which modified the original 9-year sampling strategy.

This design addresses the following two broad hypotheses:

1. No changes in mussel tissue contaminant concentrations occur with time at each sampling site.
2. Mussel tissue contaminant concentrations are the same at all sites.

The sampling design was modified from the tradition of four (4) replicate mussel tissue samples collected at all the sites, with the majority of sites having one sample, made from a composite from the four mussel site replicates. Two tiers of sampling were identified based on sampling intensity: once every two years (temporally intensive) and once every six years (spatial coverage). The sites are sampled on a rotating basis and repeated in each 6-year cycle resulting in three (3) "temporal" samples and one (1) "spatial" sample at the end of each 6-year cycle for designated sites. New Hampshire continued with sampling four site replicates for the temporally intensive sites sampled.

Sample Sites:

Sample sites were chosen after a review of all the sites sampled up to 2005. Opinions of environmental management and general scientific audiences from each jurisdiction were solicited, and new sites chosen, older sites retained or discarded based upon the following criteria:

- management interest or activity (sewage treatment, new industry, oil spill, dredging, locating aquaculture sites, etc,)
- a relatively pristine (reference) site in each jurisdiction,
- potential or suspect contamination of site,
- high population/industrial activity, or,
- other reasons articulated by the management and science communities why detecting a temporal trend or intensive scrutiny would be necessary.

2.2 2008 SAMPLING STATIONS

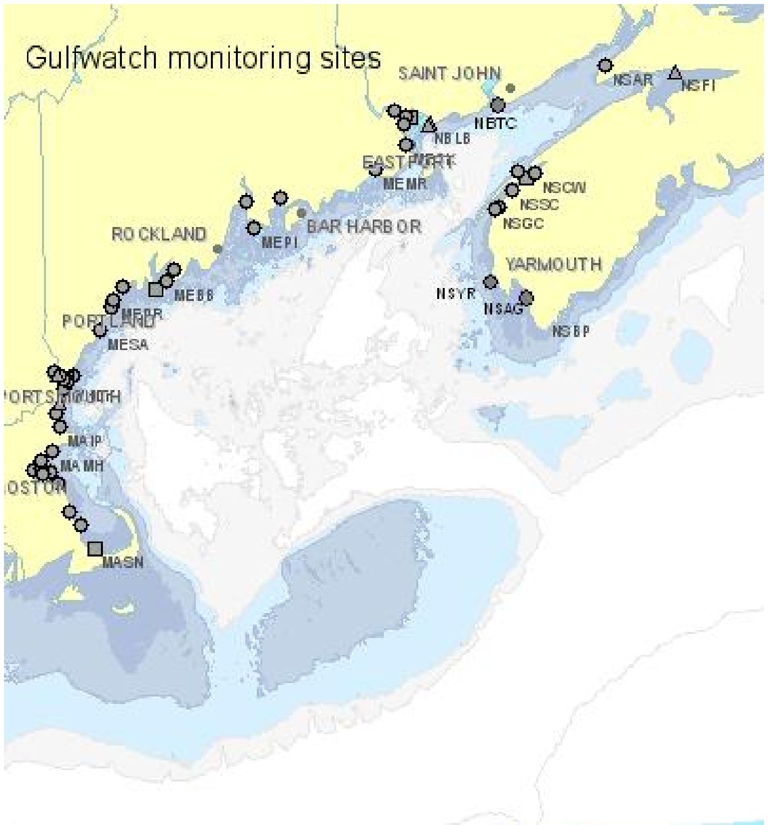
The 2008 Gulf of Maine Gulfwatch mussel survey somewhat followed the above mentioned survey plan. Most of the sites planned for 2008 were sampled, however Marblehead, MA (MAMH), Little Harbor and Pierce Island, New Hampshire (NHLH and NHPI), Saco River, ME (MESA), Manawagonish, NB (NBMI) and Argyle Sound, NS (NSAG), were not sampled as originally planned. However, several other sites were sampled throughout all regions, resulting in continuation of sampling at sites sampled in 2007, including Sandwich, MA (MASN), Kennebec River, ME (MEKN), Portland Harbor, ME (MEPH), Tin Can Beach, NB (NBTC) and Digby, NS (NSDI) as well as planned sampling sites Hampton/Seabrook (NHHS), Dover Point (NHDP) and Clark's Cove (MECC, Table 1). A total of 25 sites were sampled during 2008; 21 sites for mussels and 4 sites for softshell clams. Softshell clams (*Mya arenaria)* were sampled at North Mill Pond (NHMN) and Woodman Cove (NHWC) in NH and Thomaston (METS) and from the Harraseeket River (MEHR) in Maine. Locations of all sampling sites are presented, by state and province, in Figures 1-5.

Table 1. Gulfwatch stations visited during the 2008 sampling year.

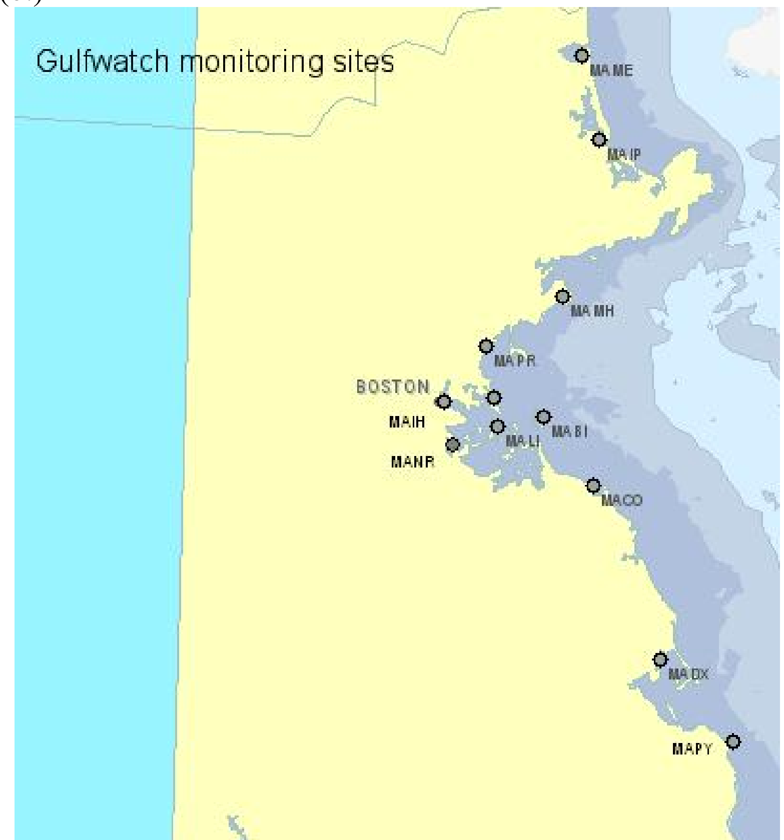
Site Code	Site Name	Site type	Lat	Lon	years sampled
Massachusetts					
MASN	Sandwich	Trend (**Benchmark**)	41.75000	70.4000	92-95, 2002-2004, 2007, 2008
MANR	Neponset River	Rotational	42.2977	71.0443	2008
MABI	Brewster Island	Rotational	42.34250	70.8780	2003, 2008
MAME	Merrimack River	Trend	42.80833	70.8233	93, 2002, 2006-2008
New Hampshire					
NHHS	Hampton/Seabrook Harbor	Trend (multi-yr)	42.89717	70.8163	
NHNM	North Mill Pond (Mya)	Rotational	43.07500	70.7600	2002, 2005, 2008
NHWC	Woodman Cove (Mya)	Rotational	43.07547	70.84114	2008
NHSS	Schiller Station	Rotational	43.10167	70.7883	
NHDP	Dover Point	Trend (multi-yr)	43.11960	70.8267	94, 96-98, 2002-2004, 2006-2008
NHFP	Fox Point	Rotational	43.12015	70.8589	99, 2001, 2008
Maine					
MECC	Clark's Cove	Trend (**Benchmark**)	43.07740	70.7244	93-95, 2002-2004, 2006-2008
METS	Thomaston (Mya)	Rotational	44.06601	69.17073	2008
MEHR	Harraseeket River (Mya)	Rotational	43.83921	70.09606	2008
MEPH	Portland Harbor	Trend (multi-yr)	43.63917	70.2590	94, 97, 2000, 2003, 2005, 2007,2008
MEKN	Kennebec River	Trend (**Benchmark**)	43.78500	69.7845	92-2004, 2006-2008
MEBB	Boothbay Harbor	Trend (multi-yr)	43.85067	69.6727	91, 98, 2004, 2006-2008
MEDM	Damariscotta	Spatial	43.93834	69.5817	95, 2004, 2008
MEMR	Machais River	Rotational	44.71367	67.4035	94, 2003, 2008
MECK	Cobscook Bay	Spatial	44.90450	67.0543	94, 2003, 2008
New Brunswick					
NBSC	St. Croix River	Trend (multi-yr)	45.16750	67.1638	93, 96, 99, 2002, 2003, 2006-2008
NBTC	Tin Can Beach	Trend (multi-yr)	45.26250	66.0570	98, 2004, 2005, 2007, 2008
Nova Scotia					
NSYR	Yarmouth	Trend (multi-yr)	43.81767	66.1448	93, 96, 99, 2002, 2004, 2006-2008
NSDI	Digby	Trend (**Benchmark**)	44.61700	65.7523	92,93,94, 96-2005,2007, 2008
NSFI	Five Islands	Spatial	45.39750	64.0660	93,94, 2002, 2008
NSAR	Apple River	Trend (multi-yr)	45.47000	64.8350	94, 97, 2000, 2003, 2006-2008

Figure 1. Locations of Gulfwatch sampling sites: (a.) Gulf of Maine (b.) Massachusetts. Tables 1 and A.2 in the appendix provide latitudinal and longitudinal coordinates for more precise site location.

(a.)



(b.)



(c.)

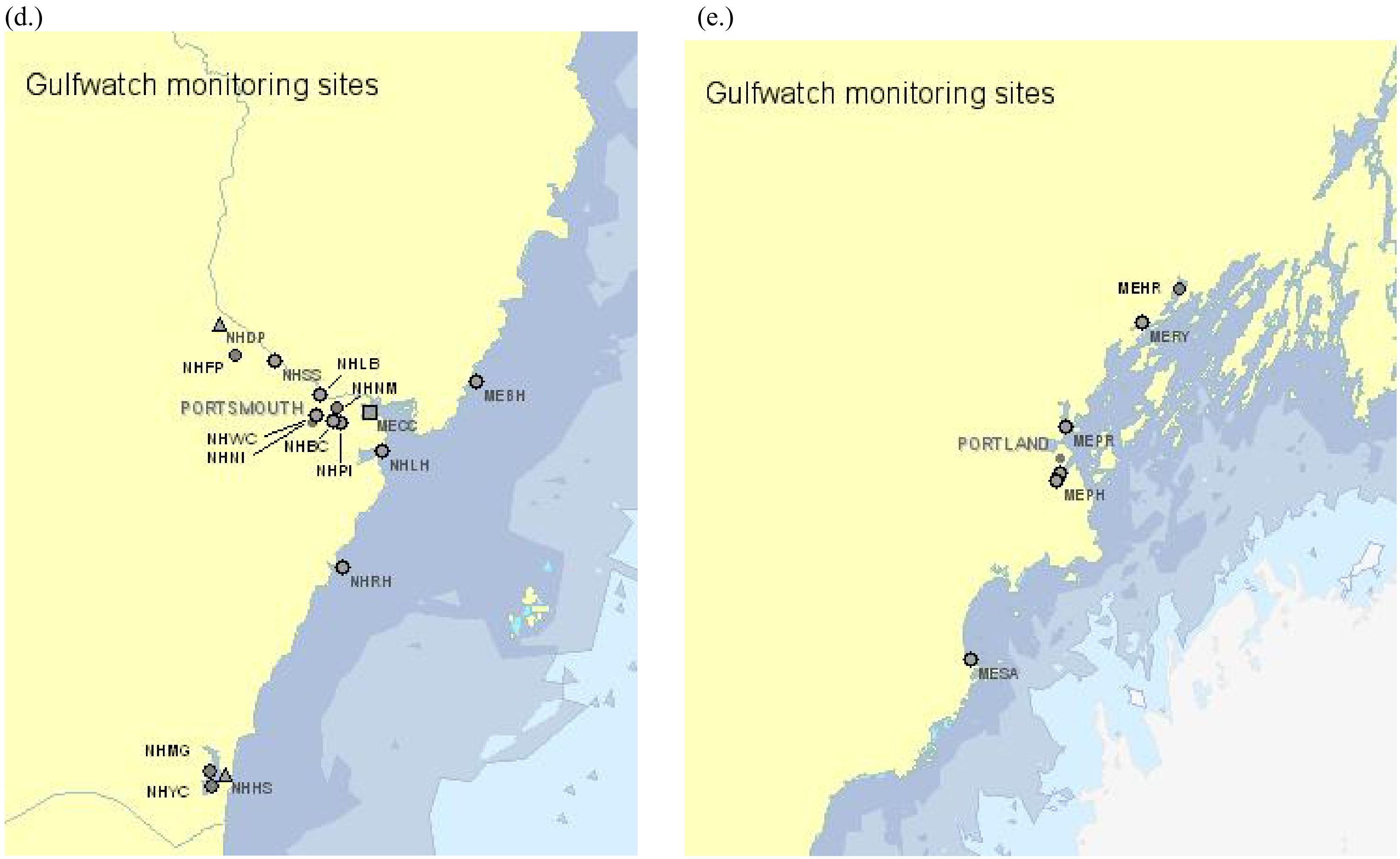
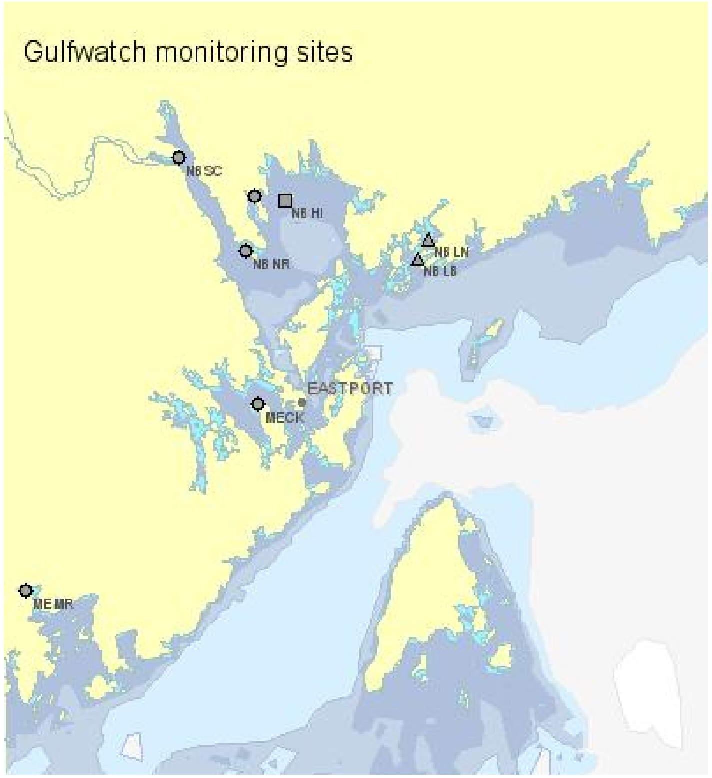
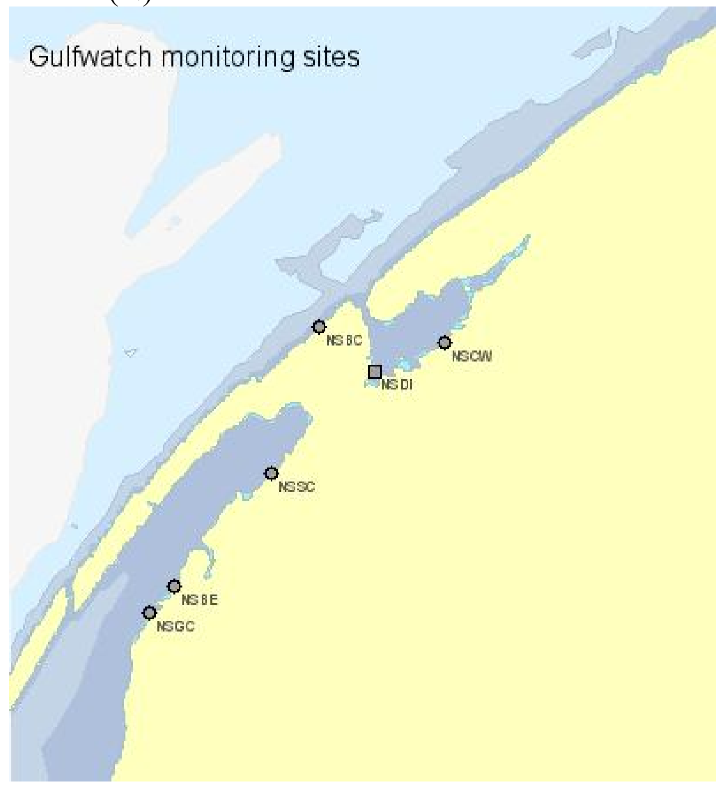


Figure 1 (cont'd). Locations of Gulfwatch sampling sites (d.) New Hampshire. (e.) Maine. Tables 1 and A.2 in the appendix provide latitudinal and longitudinal coordinates for more precise site location.

(f.)



(h.)



(g.)

(g.)

(i.)

Figure 1 (cont'd). Locations of Gulfwatch sampling sites: (f.) sites in downeast Maine and New Brunswick (g.) closeup of station NBTC & sites in northeastern Nova Scotia (h.) southwest coast of Nova Scotia and (i.) on the southern tip of western Nova Scotia. Tables 1 and A.2 in the appendix provide latitudinal and longitudinal coordinates for more precise site location.

2.3 FIELD AND LABORATORY PROCEDURES

Details regarding the mussel collection, measurement, and sample preparation are published in Sowles et al. (1997) and are summarized briefly here. Field sampling occurred between mid-September and late October (Appendix A, Table A.1). In past years and in 2008 in New Hampshire sampling was conducted as follows: Mussels were collected from four discrete areas within a short stretch of shoreline to be representative of the mussel bed(s) at each site. Using a polycarbonate gauge or a ruler, four (4) replicates, each consisting of 45-50 mussels having shell lengths within the range of 50-60 mm, were placed in field containers and transported in coolers with ice packs to labs for processing. One half of those mussels predestined for organic analysis were wrapped in pre-combusted aluminum foil prior to placing in field containers. Mussels were not depurated prior to processing.

A somewhat different collection and processing procedure was used starting in 2007. For each site in Massachusetts, Maine, New Brunswick and Nova Scotia, three batches of 60 mussels were collected, each from a distinct area within the sampling site mussel bed. Each of these 60 mussels was separated into 3 batches of 20, one for metals analysis, one for organics and one that was used to make up a composite sample for each site. Twenty mussels from each of the three distinct areas at each site were shucked for metal analysis. Mussels were washed with deionized water in the laboratory while removing any loose external growth, sediment, and debris. If tissue sample processing was not logistically possible within 24 hours of sampling, excess seawater was drained from their mantles with either plexiglass or stainless steel spatulas and samples were frozen for later processing of metals or organics, respectively. Another 20 mussels from each of the three distinct samples were shucked for organics analysis. A composite sample composed of mussels from all three areas (20 total, 6 or 7 animals from each replicate) was processed for trace metal and another for organic chemical analyses. Mussel shell length was recorded for all mussels. Individual mussels were measured to the nearest 0.1mm for length (anterior umbo to posterior growing lip) and their soft tissue removed and combined in their respective organic or metals composite. In addition to shell length, shell height, width (mm), and soft tissue wet weight (to the nearest 0.01g) measurements were typically performed on three (3) subsets of ten mussels destined for the metal analysis composite for determining Condition index (CI). Also (wet weight-based) condition index (CI) measurements were conducted on each of 10 (out of the 20 total) individual mussels from two areas. This provided twenty total CI measurements per site.

The CI is calculated using the following formula (after Seed, 1968):

*Condition index (CI) = wet tissue weight (mg) / [length (mm) * width (mm) * height (mm)]*

All samples for trace metal and organic contaminant analyses were placed in pre-cleaned or quality-assured bottles (see Sowles et al., 1997). These composite samples (20 mussels/composite; 4 composites/station) were capped, labeled and stored at -15°C for 3-6 months prior to analysis. Gulfwatch sample identification numbers, field replicates, species, and dates collected are summarized in Appendix A.

2.4 Analytical Procedures

Analytical procedures were the same as those reported in previous years (Sowles et al., 1997). An overview of the analytical methods used for the 2008 samples for both organic and inorganic analytes is described below. Table 2 contains a summary of trace metal and organic compounds determined from tissue samples of collected organisms.

2.4.1 Metals

Samples collected during 2008 for metals were analyzed by Battelle Marine Sciences Laboratory (MSL, Sequim, WA). The samples were analyzed for the ten metals chosen by the program: silver (Ag), aluminum (Al), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn).

Tissue samples were digested according to Battelle SOP MSL-I-024, *Mixed Acid Tissue Digestion*. An approximately 500-mg aliquot of each dried, homogeneous sample was combined with nitric and hydrochloric acids (aqua regia) in a Teflon vessel and heated in an oven at 130ºC (±10ºC) for a minimum of eight hours. After heating and cooling, deionized water was added to the acid-digested tissue to achieve analysis volume and the digestates were submitted for analysis by three methods.

Digested samples were analyzed for Hg by cold-vapor atomic absorption spectroscopy (CVAA) according to Battelle SOP MSL-I-016, *Total Mercury in Tissues and Sediments by Cold Vapor Atomic Absorption*, which is based on EPA Method 245.6, *Determination of Mercury in Tissue by Cold Vapor Atomic Absorption Spectrometry*. Digested samples were analyzed for Al, Cr, Cu, Fe, Ni, and Zn using inductively coupled plasma optical emissions spectroscopy (ICP-OES) according to Battelle SOP MSL-I-033, *Determination of Elements in Aqueous and Digestate Samples by ICPOES*. This procedure is based on two methods modified and adapted for analysis of low level samples: EPA Method 6010B and 200.7.

Digested samples were analyzed for Ag, Cd, and Pb using inductively coupled plasma-mass spectrometry (ICP-MS) according to Battelle SOP MSL-I-022, *Determination of Elements in Aqueous and Digestate Samples by ICP/MS*. This procedure is based on two methods modified and adapted for analysis of low-level solid sample digestates: EPA Method 1638, *Determination of Trace Elements in Ambient Waters by Inductively Coupled Plasma-Mass Spectrometry* and EPA Method 200.8, *Determination of Trace Elements in Water and Wastes by Inductively Coupled Plasma – Mass Spectrometry.* All results were determined and reported in units of µg/g on a dry-weight basis.

The MSL reported method detection limits (MDLs, µg/g dry weight) are as follows; Ag, 0.01; Cd, 0.01; Cr, 0.1; Cu, 0.1; Fe, 0.5; Hg, 0.005; Ni, 0.05; Pb, 0.02; Zn, 0.6; and Al, 1.3. A summary of method detection limits and reporting limits are further described in Appendix B. A copy of the MSL QA/QC report is reprinted in Appendix C.

2.4.2 Organic Contaminants

Organic contaminants in mussel samples were analyzed at the Environment Canada Atlantic Laboratory for Environmental Testing - Environmental Science Centre in Moncton, New Brunswick. The analyte detection limits ranged from 4 -15 ng/g for polycyclic aromatic hydrocarbons (PAHs) and from 1-4 ng/g for polychlorinated biphenyl (PCB) congeners and chlorinated pesticides (Appendix B).

Twenty one of the twenty four PCB congeners identified and quantified correspond to congeners monitored by the U.S. National Oceanographic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program. Other organic compounds (i.e., PAH and organochlorine compounds) selected for analysis are also consistent, for the most part, with NOAA National Status and Trends mussel monitoring (NOAA, 1989). The summed quantities ΣPAH_{24} and ΣPAH_{40} (= total PAHs), the sum of 24 PAH compounds and 40 PAH compounds respectively, are consistent with what is reported by the National Status and Trends program, as is the sum of 21 chlorinated pesticide analytes ($\Sigma PEST_{21}$).

A description of the full analytical protocol and accompanying performance-based QA/QC procedures are found in Sowles et al. (1997), and Jones et al. (1998). Briefly, tissue samples were extracted by homogenization with polytron ultrasonic probes using dichloromethane (DCM) solvent and filter-dried over sodium sulfate salt to remove residual water. Biomatrix interference was removed through automated size exclusion gel permeation chromatography using S-X3 Bio-Beads (200-400 mesh) resin. Purified extracts were then subjected to silica gel liquid chromatography for a better clean-up of macro molecular biomatrix effects prior to the initial analysis.

After clean-up, samples were calibrated to final volume with internal standards added for polyaromatic hydrocarbon (PAH) analysis. A 100uL aliquot was extracted from this calibrated final volume and analyzed for PAHs by high-resolution gas chromatography/mass spectrometry (HRGC/MS) in Single Ion Monitoring mode (SIM) for best sensitivity. Quantifying and Qualifier ions for each compound of interest can be found in Table 3.0.

The remaining volume of the extract was then further fractionated using a larger silica gel bed for the liquid chromatographic separation of non-polar and polar compounds. This final step provided a relatively non-polar PCB/chlorinated pesticides fraction using a hexane mobile phase, and a more polar chlorinated pesticide fraction using a 1:1 hexane:DCM mobile phase. PCBs and pesticides analysis were then performed on two calibrated fractions using high-resolution dual column gas chromatography/electron capture detection (HRGC/ECD). Simultaneous analysis of each fraction on a different polarity thin liquid phase chromatographic columns allowed for quantification and confirmation of target compounds via external calibration.

Table 2. Inorganic and organic compounds analyzed in mussel tissues from the Gulf of Maine, 2008.

INORGANIC CONTAMINANTS			
Ag, Al, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Zn			
ORGANIC CONTAMINANTS			
Aromatic Hydrocarbons		***Chlorinated Pesticides***	***PCB Congeners***
Naphthalene[1,2]	Fluoranthene[1,2]	α–BHC	8;5[3,4]
C1-Naphthalenes[2]	Pyrene[1,2]	HCB	18;15[3,4]
C2-Naphthalene[2]	C1-FP	γ–HCH(Lindane)	29[3,4]
C-3 Naphthalene[2]	C2-FP	Heptachlor	50[3,4]
C4-Naphthalene	Benzo(a)Anthracene[1,2]	Aldrin	28[3,4]
Biphenyl[1,2]	Chrysene[1,2]	Heptachlor Epoxide	52[3,4]
Acenaphthylene[1,2]	C1-Chrysene	γ-Chlordane	44[3,4]
Acenaphthene[1,2]	C2-Chrysene	o,p'-DDE	66;95[4]
Fluorene[1,2]	C3-Chrysene	α-Endosulfan	101;90[3,4]
C1- Fluorene	C4-Chrysene	cis-Chlordane	87[3,4]
C2-Fluorene	Benzo(b)Fluoranthene[1,2]	trans-Nonachlor	77[3,4]
C3- Fluorene	Benzo(k)Fluoranthene[1,2]	p,p'_DDE	118[3,4]
C4- Fluorene	Benzo(e)Pyrene[1]	Dieldrin	153;132[3,4]
Dibenzothiophene[1,2]	Benzo(a)Pyrene[1,2]	o,p'-DDD	105[3,4]
C1-Dibenzothiophene	Perylene[1,2]	Endrin	138[3,4]
C2- Dibenzothiophene	Indeno(1,2,3-cd)Pyrene[1,2]	β-Endosulfan	126[4]
C3-Dibenzothiophene	Dibenz(a,h)Anthracene[1,2]	p,p'-DDD	187[3,4]
Phenanthrene[1,2]	Benzo(ghi)Perylene[1,2]	o,p'-DDT	128[3,4]
Anthracene[1,2]		p,p'-DDT	180[3,4]
C1-Phenanthrene[2]		Metoxychlor	169[4]
C2-Phenanthrene		Mirex	170;190[3,4]
C3-Phenanthrene		**DDTs**	195;208[3,4]
C4-Phenanthrene		2,4'-DDT, 4, 4'-DDT	206[3,4]
		2,4' DDE; 4,4'-DDE	209[3,4]
		2,4'-DDD; 4, 4'-DDD	
Summed parameters and diagnostic ratios			
[1]**ΣPAH_{19}** (= the sum of the unsubstituted, i.e., non-alkylated PAH compounds)			
[2]**ΣPAH_{24}** (= the sum of the 19 unsubstituted PAHs, and a few alkyl-substituted PAHs, as indicated. This quantity is the total PAH number of previous Gulfwatch reports).			
Total PAH (= the sum of all 40 PAH compounds listed in Table 2, = ΣPAH_{40})			
Flu+Pyr/Σ(FP C2-C4-P) = The sum of fluoranthene + pyrene/fluoranthene+pyrene+C2-C4 alkylphenanthrene.			
ΣPEST21 = sum of all chlorinated pesticide and DDTs			
[3]**ΣPCB_{21}** = the sum of 21 congeners, calculated to be consistent with the sum of PCBs calculated by NOAA National Status and Trends. [4]**ΣPCB_{24} =** sum of 24 congeners**.** Numbers represent IUPAC designation of individual PCB congeners. Double numbers represent co-elution or congeners that are quantified together as one peak on the GC.			

Table 3.0. List of target ions and quantification ions for GC/MS analysis of mussel tissue extracts for unsubstituted and alkyl-substituted polyaromatic hydrocarbons.

Compound[1]	***Target Ions***[2]	***Qions***[3]
Naphthalene	128	127
C1-Naph	142	141
C2-Naph	156	141
C3-Naph	170	155
C4-Naph	184	169
Biphenyl	154	153
Acenaphthalene	152	151
Acenaphthene	153	154
Dibenzothiophene	184	185
C1-Dibenz	198	197
C2-Dibenz	212	197
C3-Dibenz	226	197
Fluorene	166	165
C1-Fluor	180	165
C2-Fluor	194	165
C3-Fluor	208	165
C4-Fluor	222	165
Anthracene	178	176
Phenanthrene	178	176
C1-Phen	192	191
C2-Phen	206	191
C3-Phen	220	205
C4-Phen	234	219
Fluoranthene/Pyrene	202	200
C1-FP	216	217
C2-FP	230	215
Pyrene	202	200
Benzo(a) Anthracene	228	226
Chrysene	228	226
C1-Chry	242	241
C2-Chry	256	241
C3-Chry	270	241
C4-Chry	284	241
benzo(b) Fluoranthene	252	250
benzo(k) Fluoranthene	252	250
benzo(e)Pyrene	252	250
benzo(a)Pyrene	252	250
Perylene	252	250
Indeno(1,2,3-cd)Pyrene	276	277
Dibenzo(a,h) Anthracene	278	276

[1]Analytes in bold are summed to yield the quantity ΣPAH_{24}, [2]Target ions are used in GCMS analysis for compound identification, [3]Q ions = quant ions are used for quantification in GC/MS analyses.

2.4.3 Ancillary parameters

Ancillary measurements and determinations from each site included as part of the annual Gulfwatch mussel monitoring are:

- individual shell length,;
- Tissue wet weight and shell width and height on a subset (~30) of individual mussels for condition index calculations;
- moisture content of tissue composites; and
- percent lipid content of tissue composites.

Moisture content was determined gravimetrically at the Battelle lab for each replicate composite either by freeze- or oven-drying. A tissue sub-sample (~5-20 g) was placed in a drying oven (at 105°C) for a minimum of 8 hrs, then placed in a dessicator, allowed to reach room temperature, and weighed until constant weight is achieved. For freeze-drying, the sub-sample is frozen to -68°C for two - four days and periodically weighed until a constant weight is observed. Percent moisture is determined from the ratio of tissue dry weight to tissue wet weight.

Lipid content of tissue samples was also determined gravimetrically. A sub-sample (~15 g) of each tissue sample was extracted with three portions of dichloromethane. The combined solvent extract was then reduced to a measured volume of 6 mL from which 1 mL was quantitatively removed and placed in a tared aluminum dish. The dish was then placed in a clean environment for solvent evaporation and dried to a constant weight. This residue represents one sixth (1/6) of the total extractable organics (TEO) in the original sample.

TEO was calculated as follows:

$$\%TEO = \frac{6 * WtR}{WtDry} * 100$$

Where WtR = the weight in grams of the residue and
Wt Dry = the dry weight of the original sample, calculated using the percent moisture.
The lipid residue number is multiplied by 6 to correct for the $1/6^{th}$ aliquot taken for the measurement.

Lipid-normalized concentrations of organic compounds can be used to interpret tissue concentration comparisons between sites or over time, since organic contaminants tend to partition into organism lipids. Normalizing to lipid weight can help minimize variability in chemical concentrations caused by differences in lipid content due to reproductive stage and other factors. Here we report these observations as percent lipids (or TEO).

2.5 QUALITY ASSURANCES / QUALITY CONTROL

Standard operating procedures for the analysis of mussel samples and related laboratory quality control performance criteria are described in *Gulfwatch Project Standard Procedures: Field and Laboratory* (Sowles et al., 1997). Quality assurance (QA) provisions described in the manual serve as a guide for generating acceptable analytical data by the Gulfwatch program. The quality control (QC) results, when compared to Gulfwatch data quality objectives, also present data users with measures of accuracy and precision when comparing among annual Gulfwatch monitoring results as well as a comparative measure for other environmental contaminant monitoring programs.

Appendix C contains the trace metal contaminant QC sample results and a brief QA/QC summary for the 2006 Gulfwatch samples, and Appendix D contains the organic contaminant QC sample results and summary for the 2006 Gulfwatch samples. Laboratory QC measures reported in Appendices C and D include procedural blanks, duplicate sample analyses, contaminant surrogate sample spikes, sample matrix spikes, and the analysis of certified reference material. The analytical organic laboratory performance of the 2007 National Institute of Standards and Technology organic contaminants inter-calibration exercise is available upon request.

2.6 Data Presentation

Summed parameters were calculated from the sum of all individual analytes that had values greater than compound detection limits. Summed parameters included ΣPAH_{19}, which is the sum of the unsubstituted (non-alkylated) aromatic ring compounds, ΣPAH_{24}, which is the total PAH quantity that has traditionally been used for the Gulfwatch program prior to 2007, and includes a few alkyl-substituted PAHs (such as methyl and ethyl-naphthalenes and methyl phenanthrenes) in addition to the unsubstituted (aromatic ring) PAH analytes. Starting in 2007, more alkyl-substituted PAH compounds were included in the analysis, and so a new total PAH number (ΣPAH_{40}) has also been calculated. One important difference in the quantitation of PAHs in 2008 versus prior years, is that formerly, only two C1-naphthalene compounds (1-methylnaphthalene and 2 methylnaphthalene), one C2-naphthalene compound (2,6-dimethylnaphthalene) and one C3 naphthalene compound was quantified, whereas starting in 2007, the sum of all C1-naphthalenes, C2-naphthalenes and C3-naphthalenes were quantified. Likewise, formerly only one C1 phenanthrene analyte was quantified, while beginning in 2007, the sum of all detected methylphenanthrenes was quantified. This may result in slight differences in the summed parameter ΣPAH_{24} for 2008 compared to data from 2006 and before.

Other summed parameters include ΣDDT_6, the sum of DDT and metabolites, $\Sigma PEST_{21}$, the sum of all the chlorinated pesticide analytes, and ΣPCB_{24}, the sum of the PCB congeners (congeners which co-elute on the GC column are summed together as one peak) quantified in the analysis. Differences exist between the ΣPCB_{24} parameter calculated in Gulfwatch and the ΣPCB_{21} quantity provided by NS&T (PCB congeners 66, 126 and 169 are not quantified in the NS&T Program). To make a better comparison, three congeners are eliminated from the Gulfwatch summed PCB values, and the quantity is called ΣPCB_{21}. Other differences which may exist between the two programs, due to differing co-elutions of congeners on different analytical columns, are expected to be very small. All of the target analytes and summed quantities are listed in Table 2.

Inorganic and organic analytes in which all replicate measurements were below the detection limit were treated as zero and recorded as not detected (ND). However, if at least two of the replicates were greater than the detection limit, then the other replicates were treated as having a value equal to ½ the method detection limit (MDL) for simple statistical computations. From each site, arithmetic means, standard deviations (SD), and geometric means were calculated for all metal and organic contaminants. Analytical duplicates were not used in the computation of the above statistical parameters. Results of duplicate analyses are presented in the QA/QC section of the appendix. Graphs of arithmetic mean concentrations (± standard deviation) are presented for all stations and are compared with medians and 85^{th} percentiles of data from the 2008 National Status and Trends Mussel Watch Program. These data are presented in tabular format as well in the next section. The medians and 85th percentiles for the Gulf of Maine have been calculated to allow comparison of Gulfwatch results with the National Musselwatch National Status and Trends (NS&T) program. The 85th percentiles are taken to represent "high" concentrations (O'Connor and Beliaeff, 1995; Cantillo, 1998; Lauenstein et al., 2002). In the Gulfwatch program, a target analyte is considered "elevated" and of concern if the concentration is equal to or greater than the NS&T national 85th percentile.

For interpretive purposes, Clark Cove, Maine (MECC) serves as the trend (benchmark) site for the group of New Hampshire sites because of its location in the Great Bay / Piscataqua River watershed and, therefore, is more comparable to sites in New Hampshire. Gulfwatch mean data for the stations sampled in 2008 are summarized beginning from 2001 in graphic form, along with all annual data for the trend sites, in order to help evaluate potential temporal trends and spatial extent of contaminant exposure along the rim of the Gulf of Maine.

3.0 RESULTS AND DISCUSSION

3.1 2008 Field Operations and Logistics Summary

Mussel samples were collected at 21 sites in 2008. Eight of the stations slated for sampling in 2008 according to the Gulfwatch 12-year sampling design were sampled in 2008; exceptions to the original plan are detailed above. Thirteen trend sites were sampled: Sandwich (MASN) and Merrimack River (MAME) in Massachusetts, Hampton/Seabrook Harbor (NHHS) and Dover Point (NHDP) from New Hampshire, Clark's Cove (MECC), Kennebec River (MEKN), Portland Harbor (MEPH) and Boothbay Harbor (MEBB) in Maine, Saint Croix River (NBSC) and Tin Can Beach (NBTC) in New Brunswick, and Digby (NSDI), Apple River (NSAR) and Yarmouth (NSYR) in Nova Scotia. The remaining eight mussel sites were for spatial analysis, usually sampled on a regular (3 yr) or more occasional basis (Table 1). Samples of softshell clams (*Mya arenaria)* were collected at North Mill Pond (NHNM) and Woodman Cove (NHWC) in New Hampshire and Thomaston (METS) and the Harraseeket River (MEHR) in Freeport, Maine.

All 2008 tissue composites were frozen and delivered to the University of New Hampshire prior to shipping to the analytical laboratories. (Note, the Canadian samples destined for organic analyses were delivered directly to Environmental Canada in Moncton, since the 2008 organic analyses were performed there). Appropriate field and initial sample preparation information from each jurisdiction were forwarded to the Program Coordinators shortly after sample collection and composite preparations.

3.2 TRACE METAL CONCENTRATIONS

Table 4 contains the metal concentrations for site replicates (arithmetic means ± SD, µg/g dry weight) and site composite samples (single value) for mussels sampled in 2008. Summary statistics were generated using the field replicate values. In only three cases (MECC, NHHS and NHDP) were field replicates taken. The mean and standard deviation of the three site replicates from these sites are compared with a fourth value which is a site composite in Table 4. At all other sites, replicates were composited as previously described to form one site composite (labeled in Table 4 as "site name-comp"). Metal analytes were detected in all samples. Metal concentrations in mussel tissue of each individual composite sample (field replicates) are further detailed in Appendix E.

In addition, metal concentrations for all mussels are also reported as medians and the 85th percentile (85th P) in Table 5 to allow for a program-level comparison with NOAA NS&T concentrations. Tables 4 and 5 also provide the median and the 85th percentile data of the national Mussel Watch data for 2008. Almost half (116 out of 240 values) of the summarized Gulfwatch metals concentrations were higher than the NS&T median. Forty values were above the NS&T 85^{th} percentile, with the majority being either mercury (20) or lead (10), with a few aluminum concentrations (5), silver (2) iron (2) and chromium (1). Numbers above the NS&T 85^{th} percentile are considered by the Gulfwatch program to be elevated, and are highlighted in red in Table 4. Comparison of metal concentrations with NS&T median values shows that several sites had concentrations at or higher than median values for Hg, Pb, Al, Cr, and Fe and Cd and Ag (indicated in bold, Table 4). Almost no sites had values higher than the NS&T median or 85^{th} percentile for Cu, Ni and Zn. The range of concentrations over all sites are also presented in Table 5, and show concentrations of certain elements, such as Pb, Al, Cr, Cu, Fe, Ni and Zn can vary by a factor of 10 across sites sampled in 2008. Elevated concentrations of iron and aluminum, known to be crustally-derived (Burdige, 2006) can result from the ingestion of sediment, especially in the vicinity of the Bay of Fundy where there is a high degree of sediment resuspension. Since these elements are not retained by the mussels, their appearance may be due to the mussels not being depurated prior to extraction.

Table 4. Summary data of tissue metal concentrations (μg g^{-1} dry wt) in mussels from Gulfwatch 2008 stations. Those with site replicates have calculated means and standard deviations, while site composites have only a single value. Values in red are higher than the 85th percentile values for National Status and Trends, those in bold are higher than NS&T median values. Stations in red have at least one analyte higher than the NOAA S&T 85^{th} percentile values.

		Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Al	Hg
Station Code		(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)	(μg/g)
NS&T median[1]		**0.152**	**2.01**	**1.06**	**20.1**	**366**	**2.02**	**0.894**	**160**	**185**	**0.065**
NS&T 85th P[1]		**2.01**	**5.28**	**2.98**	**147**	**870**	**7.66**	**2.61**	**2190**	**473**	**0.134**
MABI-comp[2]		0.146	1.77	**2.04**	6.500	**410**	1.08	**3.12**	124	**367**	**0.327**
MAME-comp		0.054	**2.29**	**1.52**	6.780	**405**	1.03	**3.61**	121	169	**0.170**
MASN-comp		**0.228**	1.61	0.693	5.460	179	0.648	**3.27**	92.5	85.3	**0.107**
MANR-comp		**0.248**	1.77	**1.78**	10.4	**486**	0.879	**6.80**	119	**277**	**0.169**
NHHS-comp		0.036	**2.05**	**1.11**	6.35	288	0.908	**1.92**	127	**201**	**0.135**
NHHS 1N-3N	Mean	0.035	1.89	1.02	5.94	304	0.791	**1.91**	112	**239**	**0.126**
	Stdev	0.007	0.111	0.213	0.157	65.6	0.113	0.327	9.07	86.7	0.004
NHDP-comp		0.033	**2.13**	**1.72**	6.06	319	1.22	**1.48**	83.3	155	**0.223**
NHDP 1N-3N	Mean	0.027	2.00	**1.66**	6.56	317	1.23	**1.47**	99.8	183	**0.224**
	Stdev	0.005	0.118	0.196	0.557	30.2	0.163	0.103	7.49	34.5	0.010
NHFP-comp		0.032	1.84	**1.53**	5.49	**402**	1.06	**1.36**	92.3	**300**	**0.207**
NHSS		0.031	1.50	**1.66**	6.37	361	1.51	**1.67**	101	**222**	**0.264**
MECC-comp		0.037	1.65	**1.71**	6.47	**436**	1.30	**3.59**	123	**295**	**0.237**
MECC 1N-3N	Mean	0.048	1.87	**1.90**	6.78	**478**	1.28	**3.44**	124	**337**	**0.253**
	Stdev	0.014	0.075	0.370	0.910	89.5	0.082	**0.955**	14.6	78.2	0.020
MECK-comp		0.013	1.61	0.709	10.6	289	0.747	**1.10**	77.3	**286**	**0.086**
MEKN-comp		0.077	**3.58**	**1.31**	6.84	**371**	1.53	**1.56**	74.2	163	**0.200**
MEBB-comp		0.030	1.12	0.844	8.71	276	0.611	**10.4**	132	133	**0.201**
MEPH-comp		0.024	1.48	**1.40**	8.08	**606**	1.06	**5.16**	139	**483**	**0.196**
MEDM-comp		0.070	1.70	**1.36**	5.55	**527**	1.55	**2.09**	76.1	**402**	**0.149**
MEMR-comp		0.040	1.78	**1.36**	5.70	**630**	1.16	**1.12**	51.5	**403**	**0.281**

Table 4 (cont'd).

		Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Al	Hg
		(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)
NBTC-comp		0.022	**2.88**	**3.27**	6.74	**1490**	**3.25**	**3.00**	87.8	**1196**	**0.399**
NBSC-comp		0.050	**2.26**	**1.34**	5.45	**465**	1.22	**1.19**	83.1	**291**	**0.154**
NSDI-comp		0.039	1.28	**1.06**	5.40	**471**	0.976	**2.36**	68.5	**410**	**0.092**
NSAR-comp		0.035	**3.44**	**1.82**	6.26	**688**	**2.04**	**1.57**	80.4	**757**	**0.234**
NSFI-comp		0.020	**2.27**	**2.32**	5.75	**1198**	**2.05**	**1.56**	64.1	**1465**	**0.141**
NSYR-comp		0.076	1.75	**1.41**	6.24	**631**	1.47	**2.75**	102	**494**	**0.165**

[1]Percentile and median data from received from NOAA National Status and Trends Program upon written request.
[2]comp refers to a site composite. Three areas within a site were sampled for mussels and composited, as described in section 2.3.

Table 5. Gulf of Maine median and 85th percentile values, compared with 2008 National Status and Trends data.

	Ag	Cd	Cr	Cu	Fe	Ni	Pb	Zn	Al	Hg
	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)	(µg/g)
2008 Gulfwatch										
range	0.013-0.248	1.12-3.58	0.693-3.27	5.40-10.6	179-1490	0.611-3.25	1.10-10.4	51.5-139	85.3-1465	0.086-0.399
median	0.037	1.87	1.52	6.35	405	1.16	2.09	102	286	0.200
85th P	0.073	2.28	1.89	7.43	618	1.52	3.69	127	451	0.264
2008 NOAA NS&T										
median	0.152	2.01	1.06	20.1	366	2.02	0.894	160	185	0.0647
85th P	2.01	5.28	2.98	147	870	7.66	2.61	2190	473	0.134

3.3 ORGANIC CONTAMINANT CONCENTRATIONS

The total concentration of detectable polynuclear aromatic hydrocarbons (ΣPAH_{40}), along with other summations of PAH analytes (ΣPAH_{19} and ΣPAH_{24}) described in section 2.6, polychlorinated biphenyls (ΣPCB_{24}), and organochlorine pesticides ($\Sigma PEST_{21}$) measured in mussel tissue samples collected during 2008 are presented in Table 6. Individual analyte concentrations of each compound class for field replicates and composite samples are reported by station and given in Appendix F.

Pyrogenic (combustion-derived) PAH have high relative concentrations of unsubstituted PAH species relative to alkyl-substituted PAH species, while petrogenic (petroleum-derived) PAH are dominated by alkyl-substituted PAH (NRC, 1985). These characteristics can be used to differentiate between petrogenic and pyrogenic PAH sources in environmental samples. The concentration ratio: (fluoranthene + pyrene)/[(fluoranthene + pyrene) + (C2+C3+C4 phenanthrenes)], expressed as FP:(FP+C24P), is a useful pyrogenic indicator for sediments and tissues (Burns et al., 1997; Neff et al., 2005) whose value varies from 0.00 (petrogenic) to 1.00 (pyrogenic). Samples with FP:(FP+C24P) ratios greater than ~0.2 are interpreted to have a pyrogenic PAH component. Petroleum-sourced PAHs generally have values <0.1 (Neff et al., 2005). Table 6 contains mean values of this ratio for site replicate samples, and individual values for site composites.

Overall gulf-wide medians and the 85th percentile of the organic contaminant concentrations for indigenous mussels are also presented to allow for program-level comparisons with NOAA NS&T concentrations (Table 7). The 2008 Gulfwatch concentrations (single composite values or arithmetic means) for summed organic contaminants (PAH, PCB, and chlorinated pesticides) were compared with 2008 NS&T median values and 85^{th} percentile (Table 6). One site in Massachusetts, Neponset River (MANR) exceeded 85^{th} percentile NS&T values for PAHs and PCBs and were the highest concentrations seen in the 2008. The Boothbay Harbor site in Maine (MEBB) also had high PAH concentrations, with the sum of the unsubstituted PAHs (ΣPAH_{19}) exceeding the NS&T 85^{th} percentile criteria for an 'elevated' concentration. A number of sites (10 out of 21) in Massachusetts, New Hampshire and Maine had PAH concentrations that were higher than NS&T median concentrations. A lesser number of sites (7/21) had PCB concentrations and pesticide concentrations (1/21) higher than the NS&T median values.

Median values for summed PAHs in tissues from the Gulf of Maine were lower than National Status and Trends median values. The PAH indicator ratio mentioned above shows no indication of petrogenic inputs at any site. Median PCB values were comparable and slightly lower than the 2008 Status and Trend national median and pesticide median values were lower than the NS&T median concentration, by more than a factor of two. Gulfwatch 85^{th} percentile values were lower than the corresponding Status and Trends 85^{th} percentile values for all summed organic parameters.

Table 6. Summary data of tissue summed organic contaminant concentrations for Gulfwatch 2008 stations. Those sites with site replicates have calculated means and standard deviations, while site composites only have a single value. Values in red are higher than the NS&T 85th percentile, those in bold are higher than the NS&T median. Stations in red have at least one value higher than the NS&T 85th percentile value.

		ΣPAH19 (ng/g)	ΣPAH24 (ng/g)	ΣPAH40 (ng/g)	ΣFP/ΣFPC24P	ΣPCB21 (ng/g)	ΣPEST21 (ng/g)
NS&T median[1]		**180**	**247**	**353**		**29.2**	**22.9**
NS&T 85th P[1]		**1104**	**1216**	**1674**		**141**	**128**
MABI-comp		123	135	196	0.78	**96.4**	10.8
MAME-comp		**261**	**277**	**359**	0.83	**34.1**	10.6
MASN-comp		24.4	70.3	100	0.00	27.2	14.2
MANR-comp		**1300**	**1351**	**1759**	0.84	**708**	**69.4**
NHHS-comp		49.9	49.9	80.3	0.65	6.35	3.52
NHHS-1N-3N	mean	38.9	48.0	71.1	0.67	6.01	3.44
	stdev	4.14	8.54	6.45	0.01	0.25	0.12
NHDP-comp		**419**	**458**	**596**	0.74	**37.9**	14.5
NHDP-1N-3N	mean	**409**	**457**	**588**	0.77	28.0	11.5
	stdev	40	37	57	0.04	1.18	0.41
NHFP-comp		**509**	**560**	**706**	0.78	**45.7**	13.1
NHSS-comp		**298**	**331**	**411**	0.76	24.0	4.02
MECC-comp		**243**	**269**	340	0.73	26.7	11.0
MECC-1N-3N	mean	**254**	**281**	347	0.75	25.0	10.1
	stdev	31.9	32.9	39.3	0.00	0.98	0.32
MEPH-comp		**805**	**862**	**996**	0.89	**61.0**	9.16
MEKN-comp		135	148	210	0.63	2.91	2.74
MEDM-comp		19.1	42.7	79.2	0.00	**30.1**	2.11
MEBB-comp		**1118**	**1203**	**1361**	1.00	0.00	10.6
MEMR-comp		173	**254**	320	0.69	4.71	0.00
MECK-comp		25.2	42.3	65.7	0.00	24.1	2.82
NBTC-comp		**220**	**275**	345	0.69	5.94	8.55
NBSC-comp		32.8	51.9	64.4	0.00	9.27	1.96
NSDI-comp		63.6	78.8	98.3	0.75	0.00	0.00
NSAR-comp		28.2	48.4	67.0	0.00	0.00	0.00
NSFI-comp		22.3	33.8	44.5	0.00	0.00	4.12
NSYR-comp		57.9	77.4	98.4	0.61	0.00	0.00

[1]Data received from NOAA NS&T office upon written request.

Table 7. Comparison of median and 85 percentile values of tissue concentrations of summed organic analytes from Gulfwatch 2008 sites and National Status and Trends 2008 sites.

	ΣPAH19 (ng/g)	ΣPAH24 (ng/g)	ΣPAH40 (ng/g)	ΣPCB21 (ng/g)	ΣPEST21 (ng/g)
Gulfwatch 2008					
median	154	198	260	24.1	9.9
85th P[1]	429	476	618	35.4	14.3
National Status and Trends 2008					
Median	180	247	353	29.2	22.9
85th P	1104	1216	1674	141	128

[1]85[th] P = 85[th] percentile, data obtained from NOAA NS&T office upon written request

3.4 Contaminant Concentrations In Other Shellfish

As part of the New Hampshire Gulfwatch 2008 program, and in cooperation with the regional Gulfwatch 2008 Program, softshell clams (*Mya arenaria*) were sampled at the following sites: North Mill Pond (NHNM) and Woodman Cove (NHWC). In addition, soft shell clams were sampled in Maine at the Harraseeket River (MEHR) and Thomaston (METS) as part of a regional clam study at UNH. Single values from composite samples are presented in Table 8 for metals and Table 9 for summed organic parameters.

Table 8. Metals concentrations in softshell clam samples taken at New Hampshire and Maine sites and analyzed for the Gulfwatch 2008 program.

GOM Site	Ag (µg/g)	Cd (µg/g)	Cr (µg/g)	Cu (µg/g)	Fe (µg/g)	Ni (µg/g)	Pb (µg/g)	Zn (µg/g)	Al (µg/g)	Hg (µg/g)
NHNM	2.06	2.34	3.26	17.9	2812	1.65	8.49	96.0	943	0.311
NHWC	2.05	0.492	7.00	17.0	5368	3.15	9.12	121	1858	0.243
METS	0.713	0.376	2.60	12.2	10469	1.86	6.26	82.8	1447	0.122
MEHR	0.473	0.400	5.22	10.4	16213	2.95	6.19	86.5	2779	0.125

Table 9. Summed PAH, PCB and chlorinated pesticide concentrations in softshell clam samples taken at New Hampshire and Maine sites and analyzed for the 2008 Gulfwatch Monitoring Program.

	ΣPAH19 (ng/g)	ΣPAH24 (ng/g)	ΣPAH40 (ng/g)	ΣFP/ΣFPC24P (ng/g)	ΣPCB21 (ng/g)	ΣPEST21 (ng/g)
NHNM	1156	1217	1355	0.89	9.07	12.0
NHWC	259	290	328	0.83	0.00	2.87
METS	151	166	190	0.88	0.00	2.11
MEHR	108	122	139	1.00	0.00	0.00

With the exception of clams from North Mill Pond, summed concentrations of total PAH (ΣPAH_{40}) and other PAH summed parameters, as well as the sum of PCBs and pesticides were of the same order of magnitude as seen in New Hampshire mussels. Concentrations of a number of metals were up to 10x higher in softshell clams (Ag was 100x higher). High concentrations of Fe and Al suggest that ingested sediment by the clams (which were not depurated) had an impact on measured concentrations. Interestingly, the more soluble metals (including Cu, Zn and Cd) were more similar in concentration between in clams and mussels collected at New Hampshire sites.

4.0 2006 DISTRIBUTIONS OF CONTAMINANTS IN *MYTILUS EDULIS*

4.1 SPATIAL PATTERNS

Figures 2 through 11 show the concentration of the metals determined in the tissue of *M. edulis* from the 2008 Gulfwatch sampling sites. The data are displayed geographically beginning clockwise around the GOM from Sandwich, Massachusetts, and ending with the southern-most station sampled in Nova Scotia (See Fig. 1 above). Overall, the concentrations of most metals appear relatively evenly distributed around the Gulf of Maine, with no apparent spatial trends and an occasional hot spot of elevated concentrations. Exceptions to this general pattern and further details for individual metals and organic contaminant categories are noted in the following individual sections.

4.1.1 Silver (Ag)

Silver concentrations ranged from 0.013 µg/g dry weight at the Cobscook Bay, ME site (MECK) to 0.248 µg/g dry weight at the Neponset River, MA site (MANR) (Table 4; Figure 2). Mussels from the MANR site as well as the Sandwich, MA (MASN) site had concentrations higher than the NS&T national median. The 2008 levels were all below the NOAA NS&T 85th percentile values, which are used in Gulfwatch as criteria for an "elevated" concentration (Figure 2, dashed and solid lines, respectively). Higher silver concentrations in sediments and water column samples have been shown to coincide with regions receiving municipal sewage (Sanudo-Wilhelmy and Flegal, 1992; Buchholz ten Brink et al., 1997).

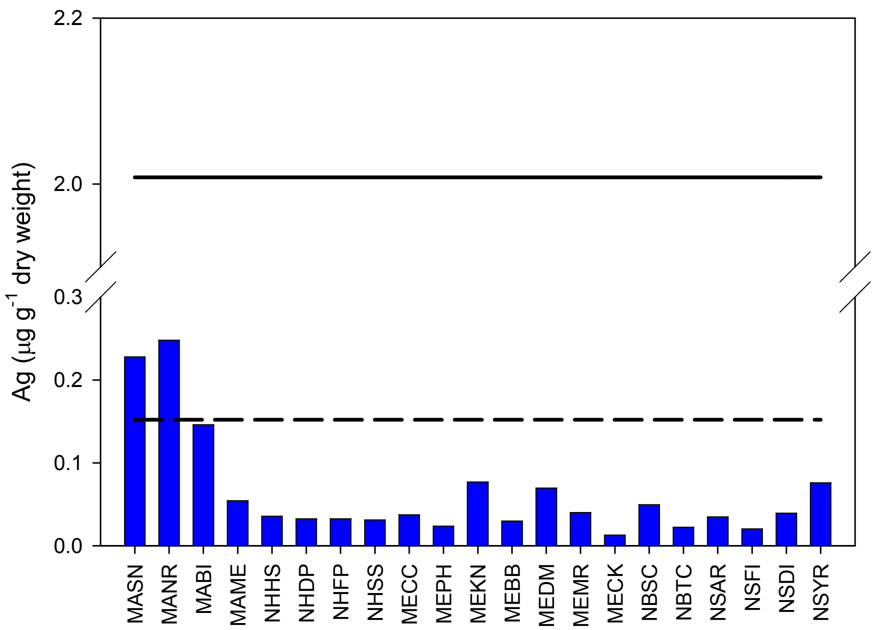


Figure 2. Distribution of silver tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.2 Cadmium (Cd)

The concentration of cadmium in mussel tissue ranged from 1.12 µg/g dry weight at Boothbay Harbor, ME (MEBB) to 3.58 µg/g dry weight at the Kennebec River, ME site (MEKN) (Table 4; Figure 3) and were generally close to or higher than the 2008 NS&T median. Eight sites were had concentrations above the NS&T national median: MAME in Massachusetts, NHHS and NHDP in New Hampshire, MEKN in Maine, and NBSC and NBTC in New Brunswick, and NSAR and NSFI in Nova Scotia. Differences seen between stations may reflect localized sources. Globally, about half of the Cd released to the environment occurs through weathering of rocks and subsequent transport by rivers; some Cd is released into air through forest fires and volcanoes. This would be expected to provide an even distribution across stations if these were the only sources. The remaining significant release occurs via human activities, such as manufacturing, fossil fuel combustion (including those from automotive use), and agriculture (Bruland and Lohan, 2004; Bruland and Franks, 1983). All sites had values well below the NS&T 85th percentile value.

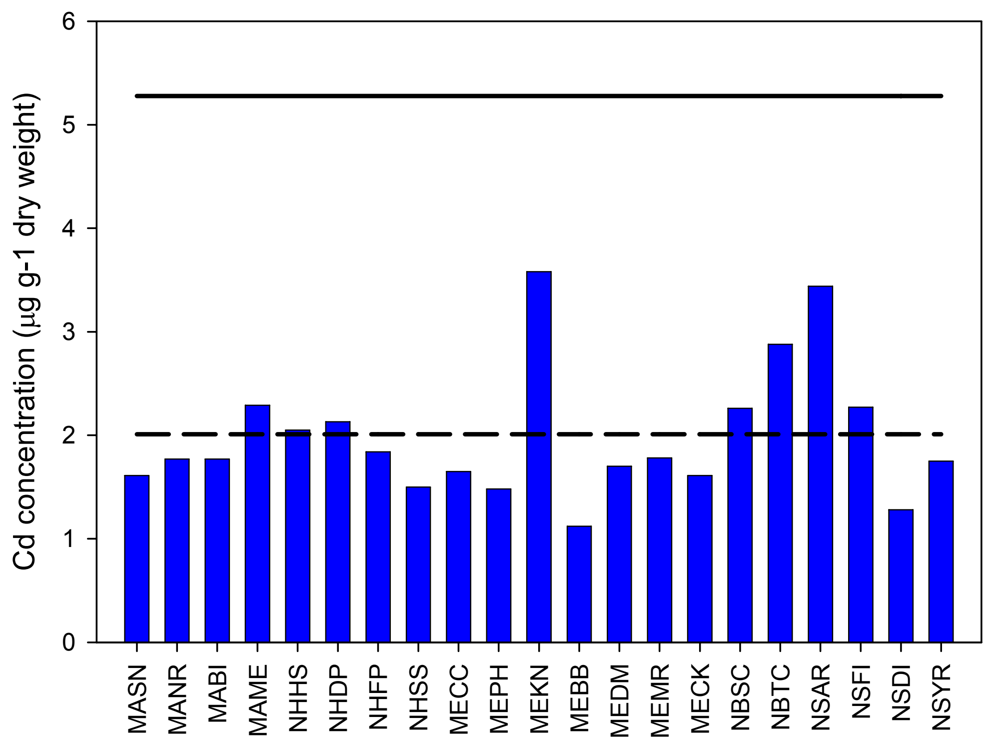


Figure 3. Distribution of cadmium tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.3 Chromium (Cr)

Chromium concentrations in mussel tissue for the Gulf of Maine for 2008 ranged from 0.693 µg/g dry weight at the Sandwich, MA site (MASN) to 3.27 µg/g at the Tin Can Beach, NB site (NBTC). Most sites were close to or exceeded the Musselwatch NS&T median tissue concentrations. One site, Tin Can Beach in New Brunswick (NBTC) exceeded the NS&T 85th percentile (Table 4, Figure 4). Chromium is the primary agent used in tanning processes and discharged with untreated tannery wastes throughout much of the nineteenth and twentieth centuries (Capuzzo, 1974). Chromium persists in the environment at elevated concentrations in the sediments near such sources (Capuzzo, 1974; NCCOSC, 1997).

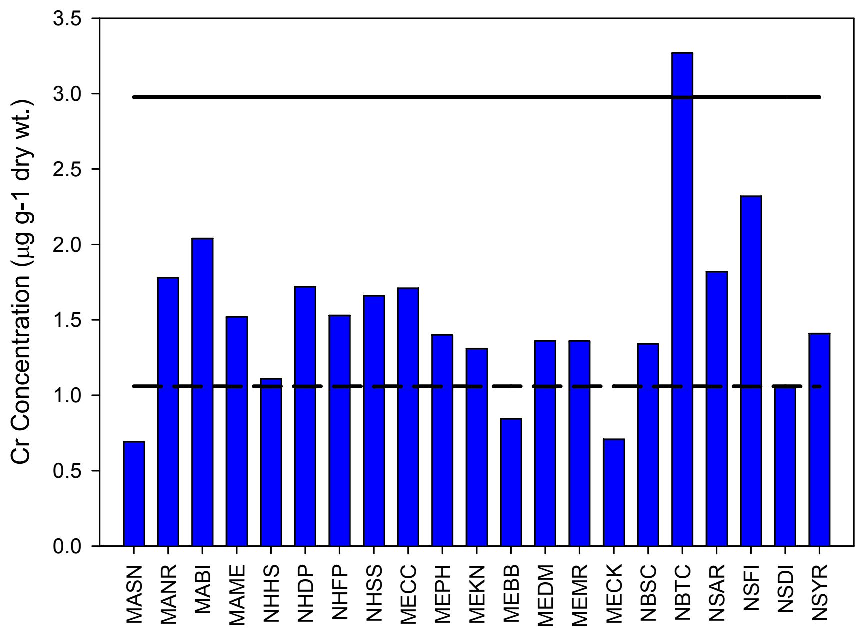


Figure 4. Distribution of chromium tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.4 Copper (Cu)

The 2008 copper concentrations in *M. edulis* ranged from 5.40 µg/g dry wt at the Digby, NS site (NSDI) to 10.6 µg/g dry wt at the Cobscook Bay, ME site (MECK, Table 4, Figure 5). Gulfwatch Cu levels were fairly uniform in distribution throughout the study region (site to site differences varied by less than a factor of two). No tissue concentrations exceeded NS&T median or 85th percentile concentrations.

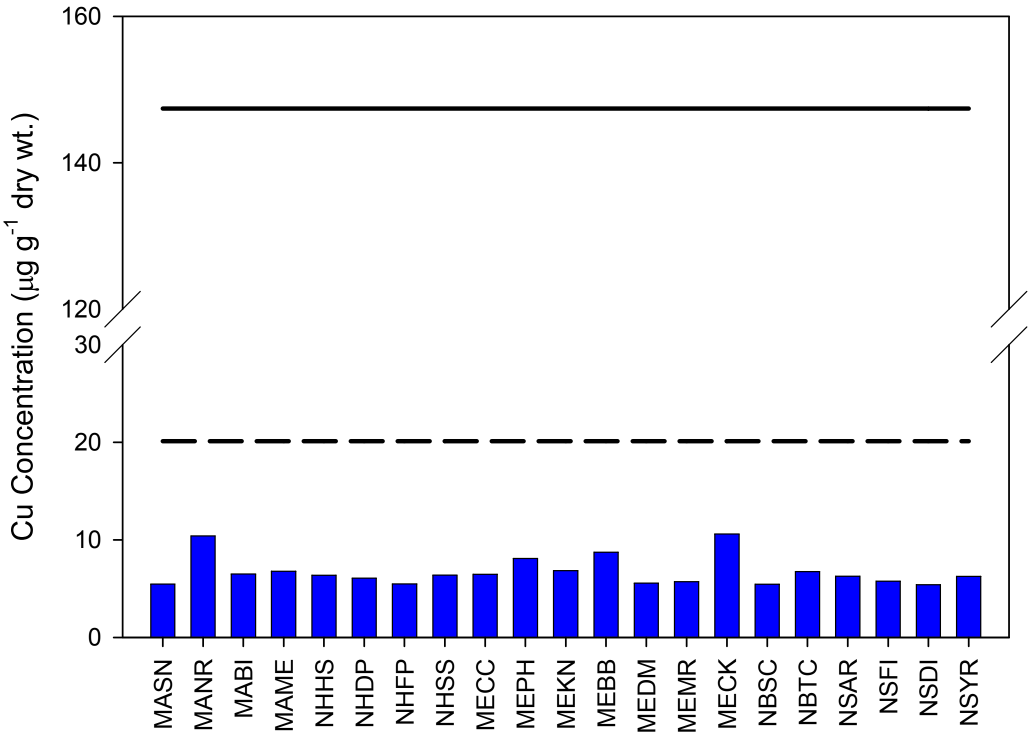


Figure 5. Distribution of copper tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.5 Iron and Aluminum (Fe & Al)

For 2008, the highest concentrations for both iron and aluminum were found at sites in New Brunswick and Nova Scotia. Tin Can Beach, NB had the highest tissue concentrations of Fe and relatively high concentrations of Al, exceeded only by the Five Islands site, NS (NSFI). Two sites exceeded the NS&T 85th percentile criteria for Fe (NBTC and NSFI) and four sites exceeded the national NS&T 85th percentile value for Al: MEPH, NBTC, NSFI along and NSAR. Concentrations of Fe ranged from 179 µg/g dry weight at Sandwich MA (MASN) to 1490 µg/g dry wt at NBTC. Tissue concentrations of Al ranged from 85.3 µg/g dry wt at MASN (Sandwich, MA) to 1465 µg/g dry wt at NSFI. Because of the high abundance of these elements in crustal material (Wedepohl, 1995), Al and Fe tissue concentrations may or may not be derived from anthropogenic inputs. Many of the Gulfwatch sites had tissue concentrations that were near to or exceeded NS&T median values, which may reflect the aluminosilicate composition sediments in northeastern North America. Aluminum concentrations can be valuable as a way to normalize to background concentrations derived from continental crustal material and enhance differences in concentration due uptake of localized (non-crustal derived) sources. Previous reports have mentioned the greater exposure of mussels near the top of the Gulf of Maine to higher frequencies and intensities of tidally-induced sediment resuspension. Also mentioned was that such sediment may not truly be incorporated into tissues, since mussels are known to be particle-selective and will void undesirable ingested particulates as pseudofeces (Barnes, 1974) bypassing digestion in the gut. It is possible that non-depurated mussels may contain a sediment signal not reflective of true metal incorporation, and such a normalizing parameter may aid in the gulf-wide comparisons of tissue concentrations. Caution has been urged in prior reports to evaluate Al recoveries, which in 2008 were adequate (see Appendix C).

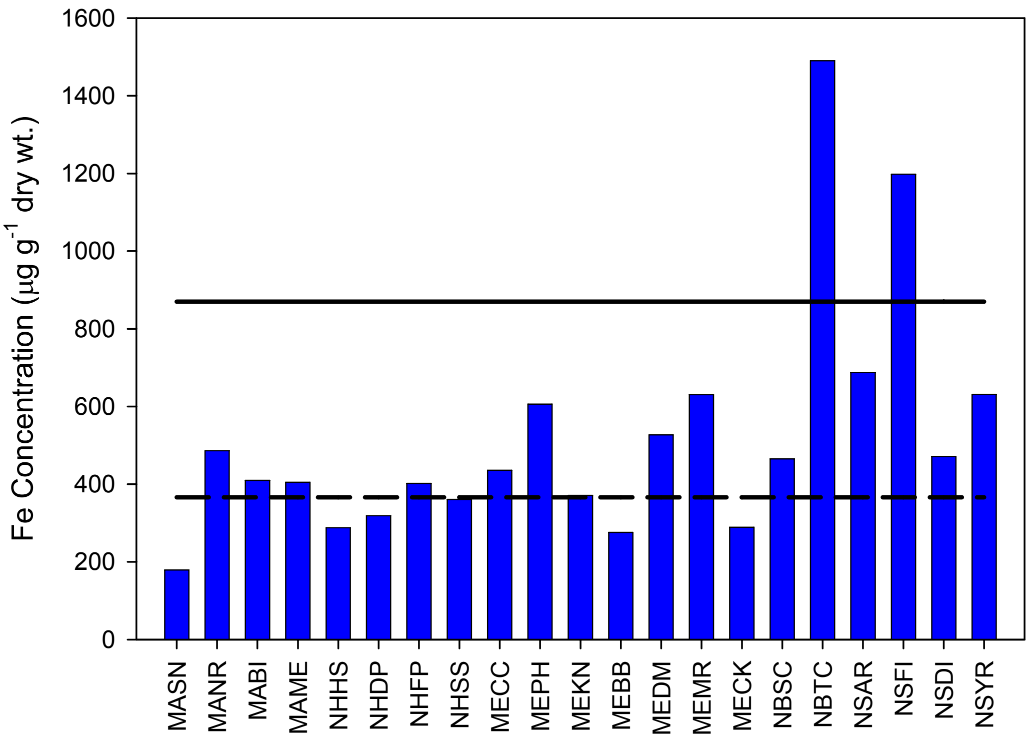


Figure 6. Distribution of iron tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

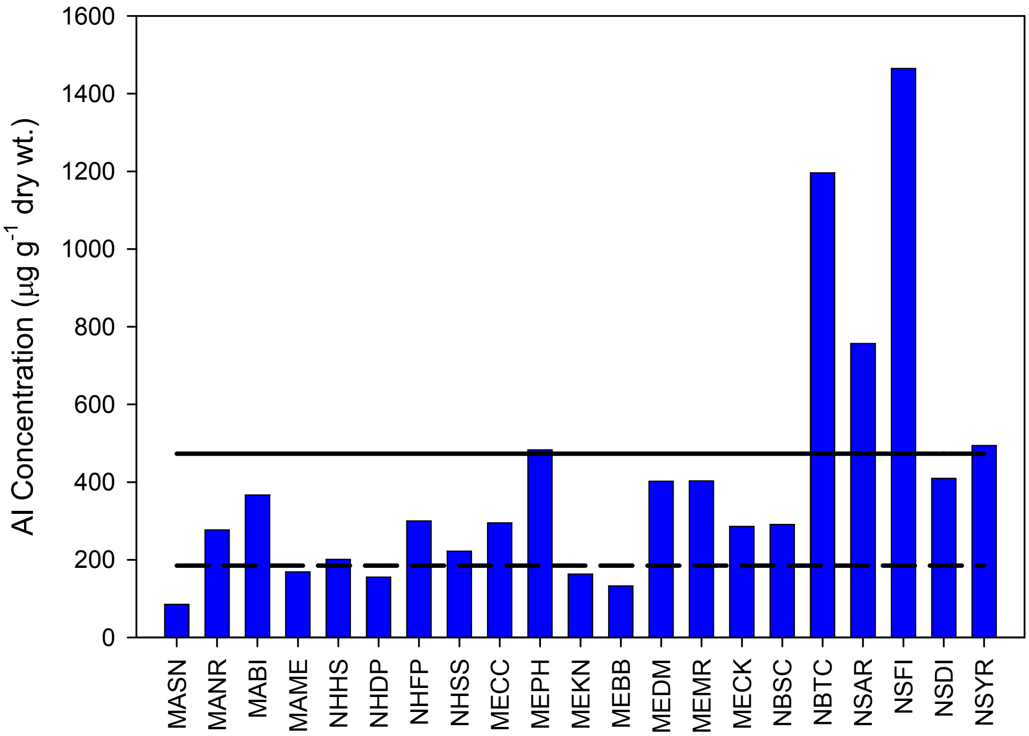


Figure 7. Distribution of aluminum tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.6 Nickel (Ni)

The concentration of nickel ranged from 0.61 µg/g dry wt at MEBB to 3.25 µg/g dry wt at NBTC (Table 4; Figure 8). No concentrations exceed the NS&T 85th percentile values, although NBTC exceeded the national median value. Concentrations at Nova Scotia sites NSAR and NSFI were at the median value.

4.1.7 Lead (Pb)

As in 2006 and 2007, all sites visited in 2008 had tissue concentrations that exceeded the 2008 NS&T median value of 0.89 µg/g dry wt. Lead concentrations ranged from 1.10 µg/g dry wt at the Cobscook Bay, ME site (MECK) to 10.40 µg/g dry wt at Boothbay Harbor, ME site (MEBB, Table 4, Figure 9). Several of the sites (9 out of 21) visited by Gulfwatch were elevated for Pb, (i.e., above the NS&T 85th percentile value of 2.61 µg/g dry wt). Tissue Pb concentrations from MANR and MEBB exceeded 85th percentile values by a factor of two or greater.

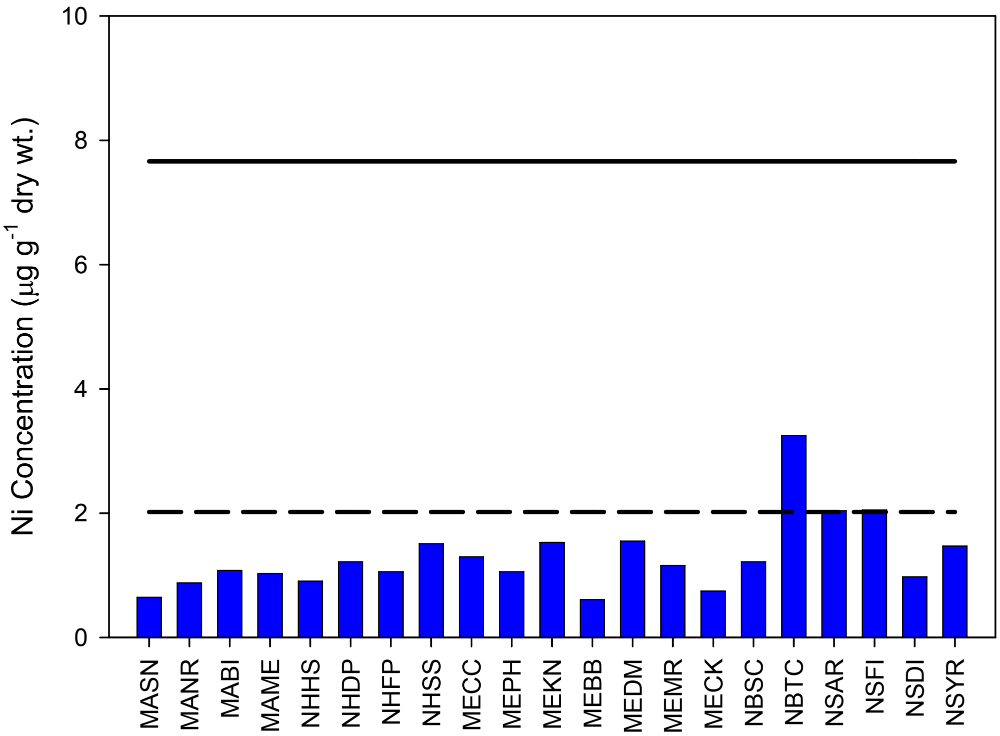


Figure 8. Distribution of nickel tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

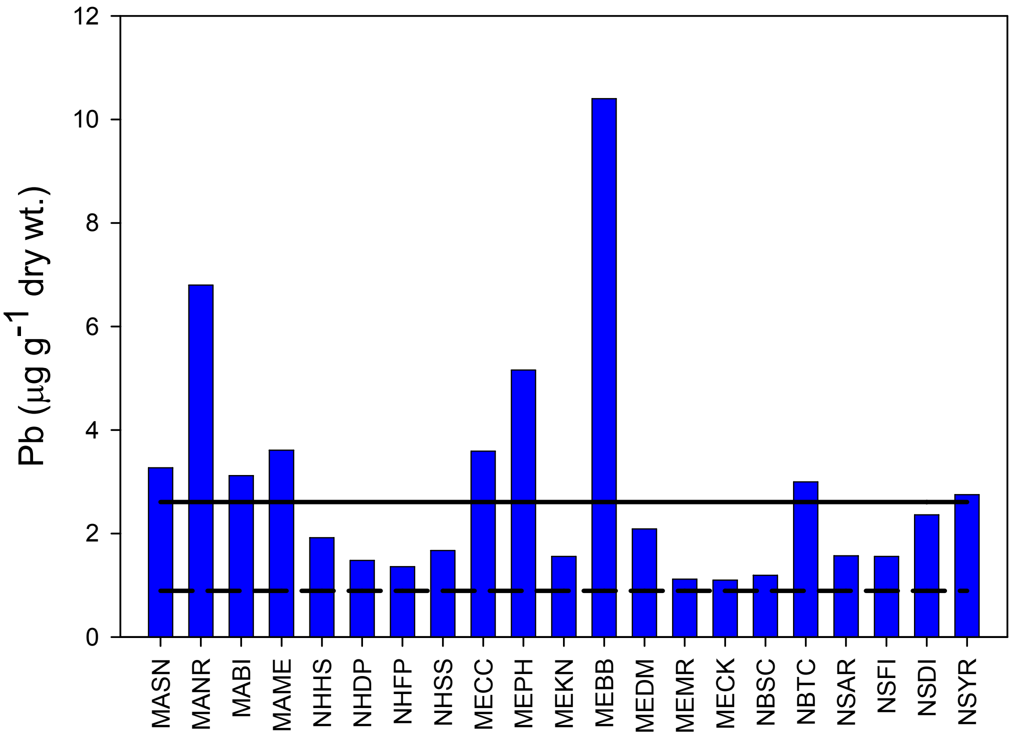


Figure 9. Distribution of lead tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85^{th} percentile.

4.1.8 Zinc (Zn)

Concentrations of zinc ranged from a low value of 51.5 µg/g dry wt in mussels from the Machias River site, ME (MEMR) to a high of 139 µg/g dry wt in mussels from the Portland Harbor, ME (MEPH) site (Table 4, Figure 10). No sites had zinc concentrations exceeding the 85^{th} percentile value from the 2008 NS&T sampling program. Zinc is a ubiquitous environmental contaminant generally reflecting a wide range of land-based activities (tire wear, galvanized materials, industrial waste discharges, etc.).

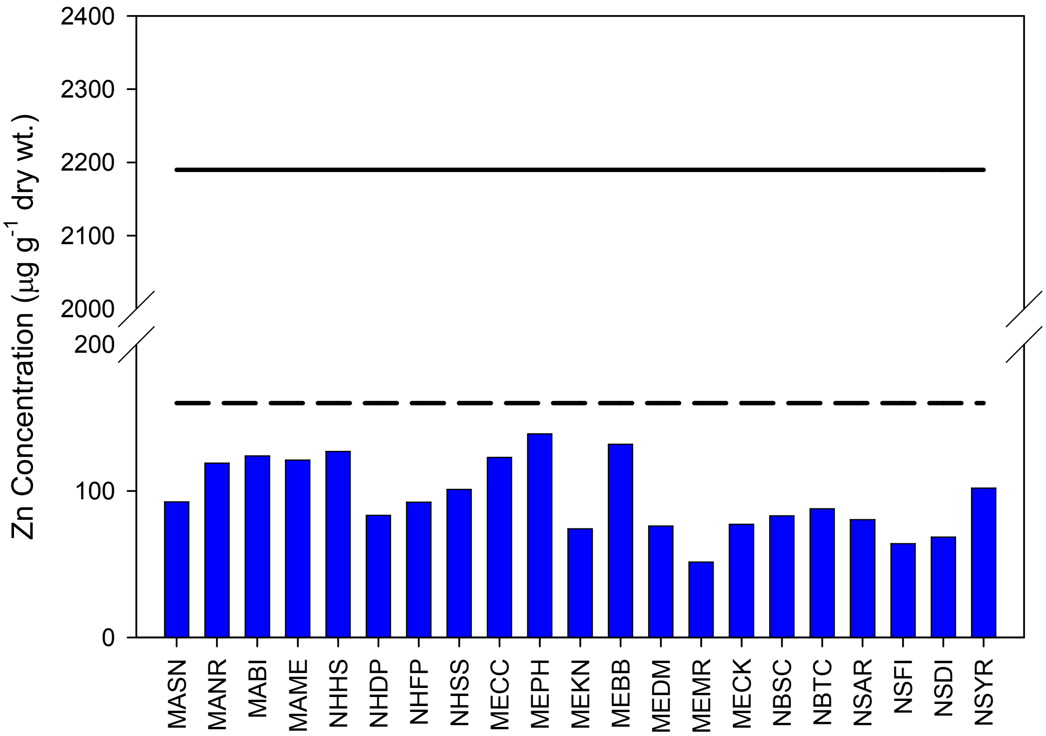


Figure 10. Distribution of zinc tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile value.

4.1.9 Mercury (Hg)

Mercury was detected in mussels collected at all 2008 Gulfwatch stations. Concentrations ranged from a low of 0.086 µg/g dry wt at the Cobscook Bay, ME site (MECK) to a high of 0.399 µg/g dry wt at the Tin Can Beach, NB (NBTC) site. All 2008 site concentrations (18/21) except for three (MASN, MECK and NSDI) were above the NS&T 2008 85th percentile value of 0.134 µg Hg/g dry weight (Table 4, Figure 11).

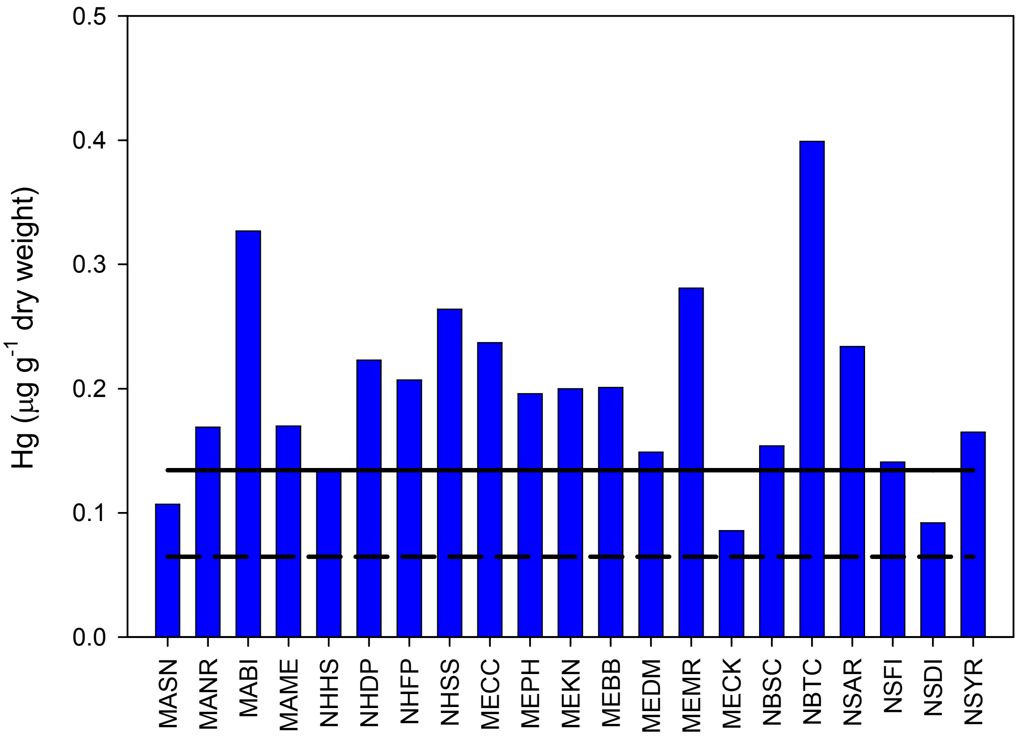


Figure 11. Distribution of mercury tissue concentrations in mussel sample site composites (one per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

4.1.10 Organic Contaminants

In 2008 samples, enough PAH analytes were present in sufficient quantity such that every site had a value for the summed quantities (Table 6 and Figures 12-14). There is a pattern of higher concentrations of ΣPAHs in the New England States compared to the Canadian Provinces, with Massachusetts having sites with the highest concentrations. However concentrations approaching NS&T 85th percentile values were also found in Maine. The Neponset River, MA site (MANR) exceeded the NS&T 85th percentile concentration for all three summed PAH quantities. Two sites in Maine, Portland Harbor (MEPH) and Boothbay Harbor (MEBB) had values close to, but not exceeding the 85th percentile concentration criteria (Figure 12, Table 6). The pattern seen for the sum of 40 PAH analytes (which includes a greater quantity of alkyl-substituted PAHs) is nearly identical to the graph of ΣPAH24. Ten Gulfwatch sites out of the 21 sampled had PAH concentrations that were close to or higher than the national median concentration.

Composite samples from Brewster Island and Merrimack River Massachusetts (MABI and MAME), Dover Point and Fox Point, New Hampshire (NHDP and NHFP) and Portland Harbor and Damariscotta, Maine (MEPH and MEDM) had PCB concentrations higher than the NS&T national median concentration of 29.2 ng/g dry weight. The Neponset River, MA site had a higher ΣPCB_{21} concentration than all other Gulfwatch composite samples. The value of 708 μg/g exceeded the NS&T national 85th percentile value by a factor of 5 or greater, and comparatively can be considered as having extremely elevated tissue concentrations. PCBs were not detected in mussel tissues from the four sites sampled in Nova Scotia. ΣPCB_{21} tissue concentrations ranged from not detected at sites in Nova Scotia to 708 ng/g at Neponset River (MANR).

Tissue concentrations of ΣPEST21 ranged from ND at all Nova Scotia sites to 69 ng/g dry wt at the Neponset River, MA site (MANR, Table 9, and Figure 14). The sum of the DDTs (ΣDDT_6), and most notably p, p'-DDE, a degradation product of DDT, was the main contributors to the sum of the chlorinated pesticides. The distribution pattern was somewhat bimodal, with the highest levels observed in Massachusetts (MANR) and Maine (MEPH and MEDM). No concentrations exceeded the NS&T 85th percentile criteria.

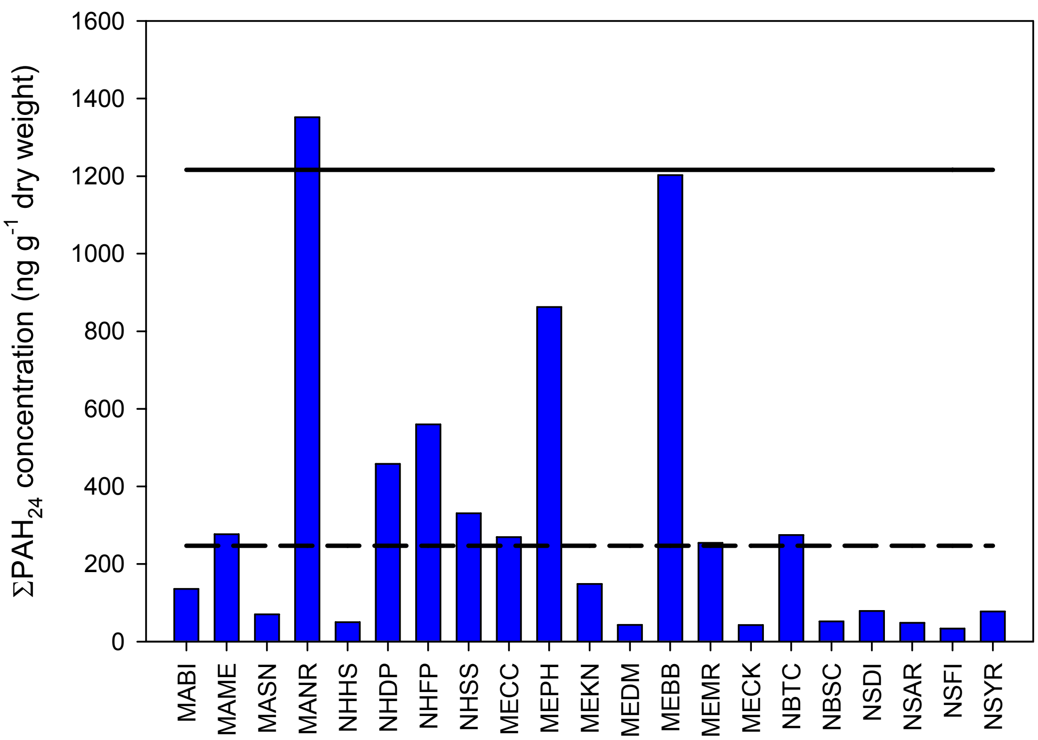


Figure 12. Distribution the sum of 24 PAHs in tissues from mussel sample site composites (one composite sample per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

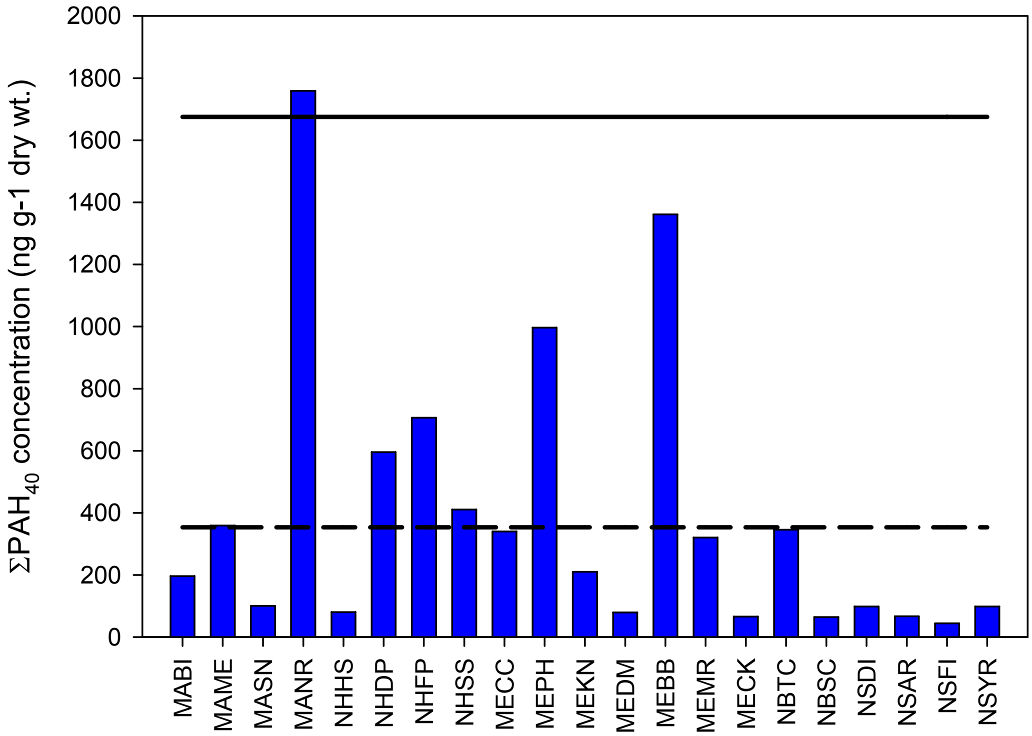


Figure 13. Distribution the sum of 40 PAHs in tissues from mussel sample site composites (one composite sample per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile.

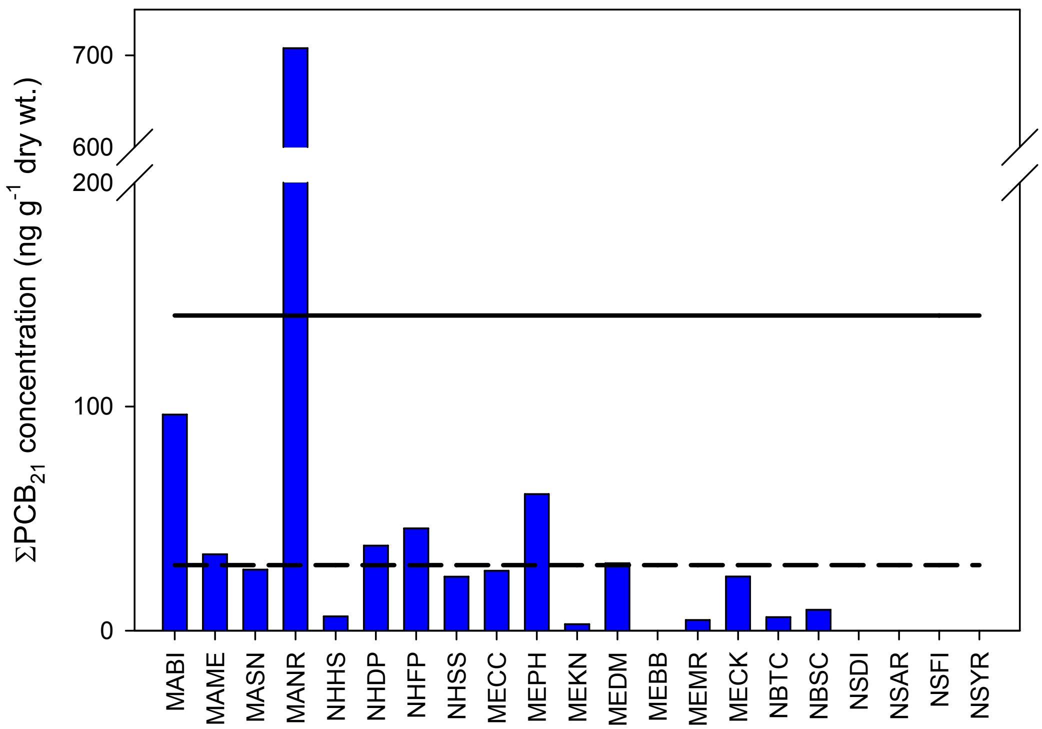


Figure 14. Distribution the sum of 24 PCB congeners in tissues from mussel sample site composites (one composite sample per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85th percentile (for the sum of 21 PCB congeners).

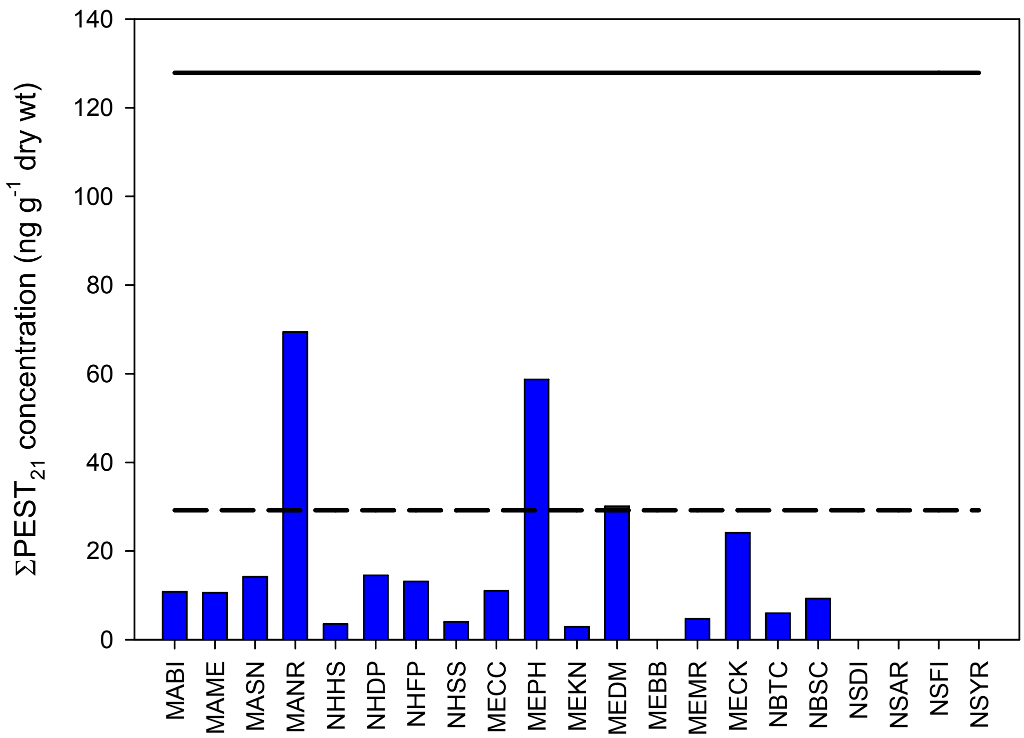


Figure 15. Distribution the sum of 21 chlorinated pesticides in tissues from mussel sample site composites (one composite sample per site) at Gulfwatch sites in 2008. Dashed line = 2008 Mussel Watch National median; Solid line = 2008 Mussel Watch 85^{th} percentile.

4.2 Temporal Patterns

This section presents the distribution of inorganic and organic contaminants in mussel tissue collected trend sites along the Gulf of Maine, from 2001 to 2008. The temporal distribution of station means is plotted for each contaminant or class of contaminants, and compared to individual tissue concentrations from year 2008 site composite samples in Figures 16-26. All individual replicate results for each 2008 site are provided in Appendices E and F. The distribution of contaminants in mussels from the four of the five traditional benchmark sites (MASN, MECC, MEKN, and NSDI) and 9 trend sites (MAME, NHHS, NHDP, MEPH, MEBB, NBSC, NBTC, NSAR and NSYR) is updated with data from mussels collected in 2008.

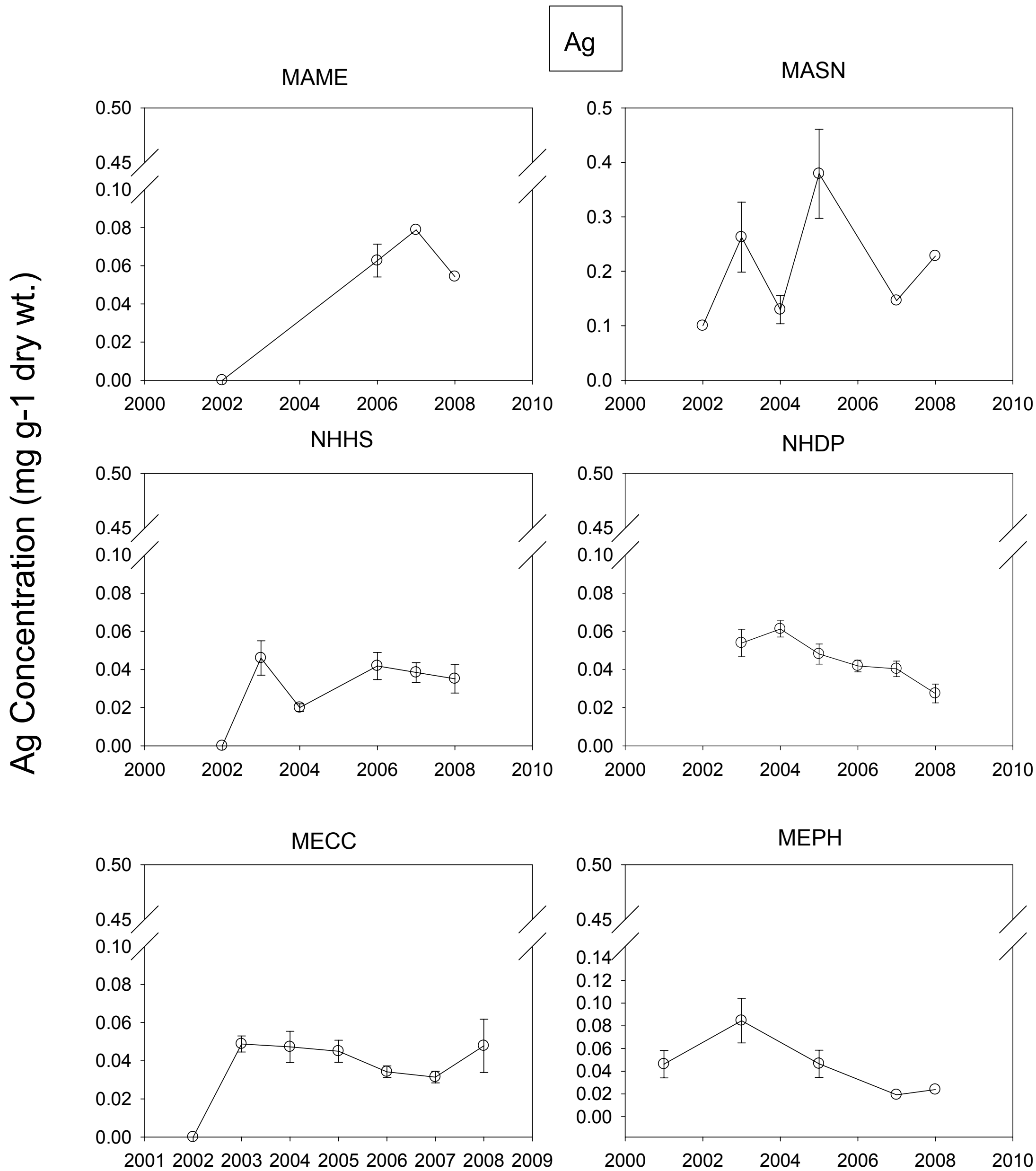


Figure 16. Distribution of silver tissue concentrations in μg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHBC, NHDP, NHHS and MECC.

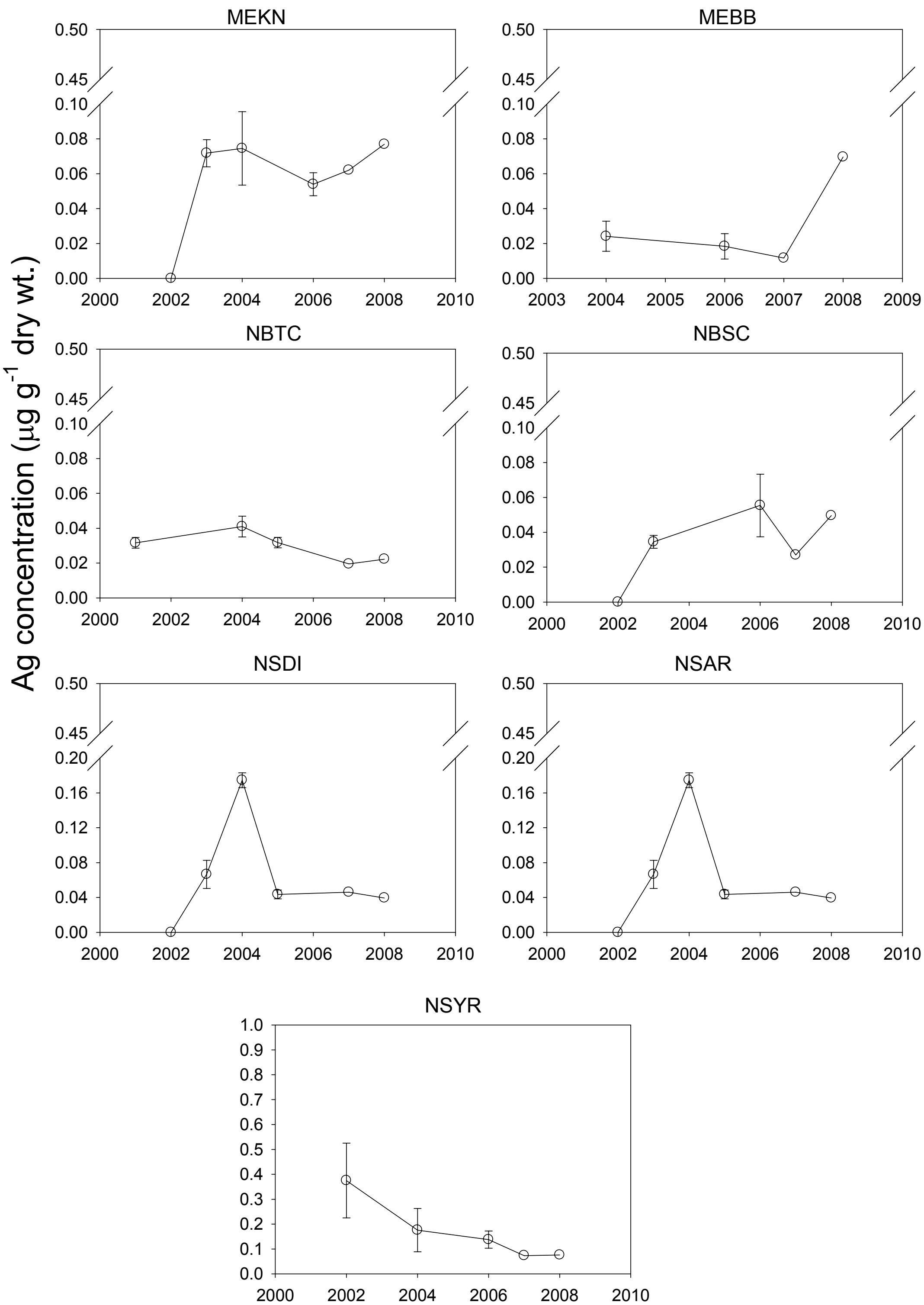


Figure 16 (cont'd). Distribution of silver tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHBC, NHDP, NHHS and MECC.

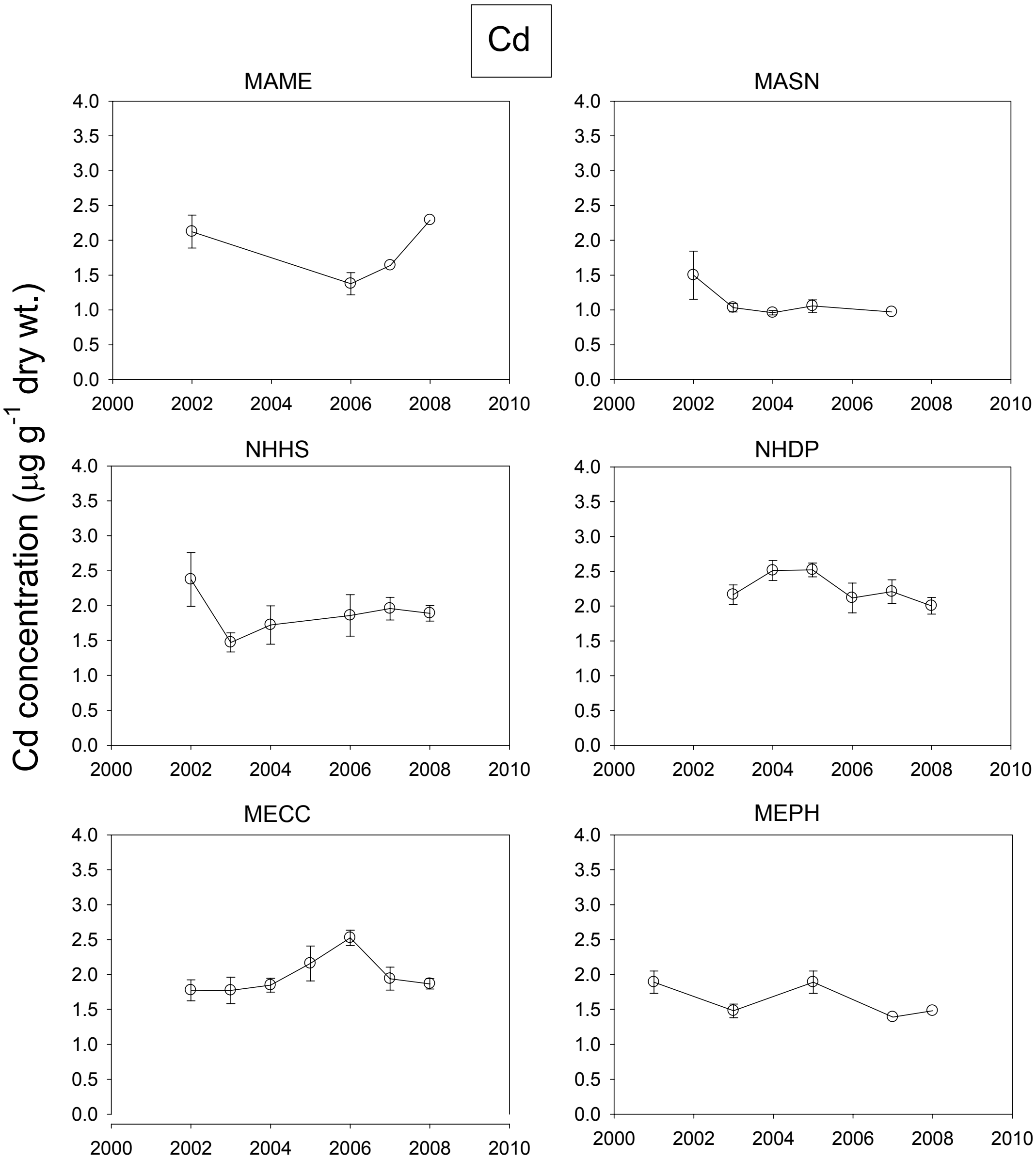


Figure 17. Distribution of cadmium tissue concentrations in µg/g dry weight (arithmetic mean $\pm$ standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHBC, NHDP, NHHS and MECC.

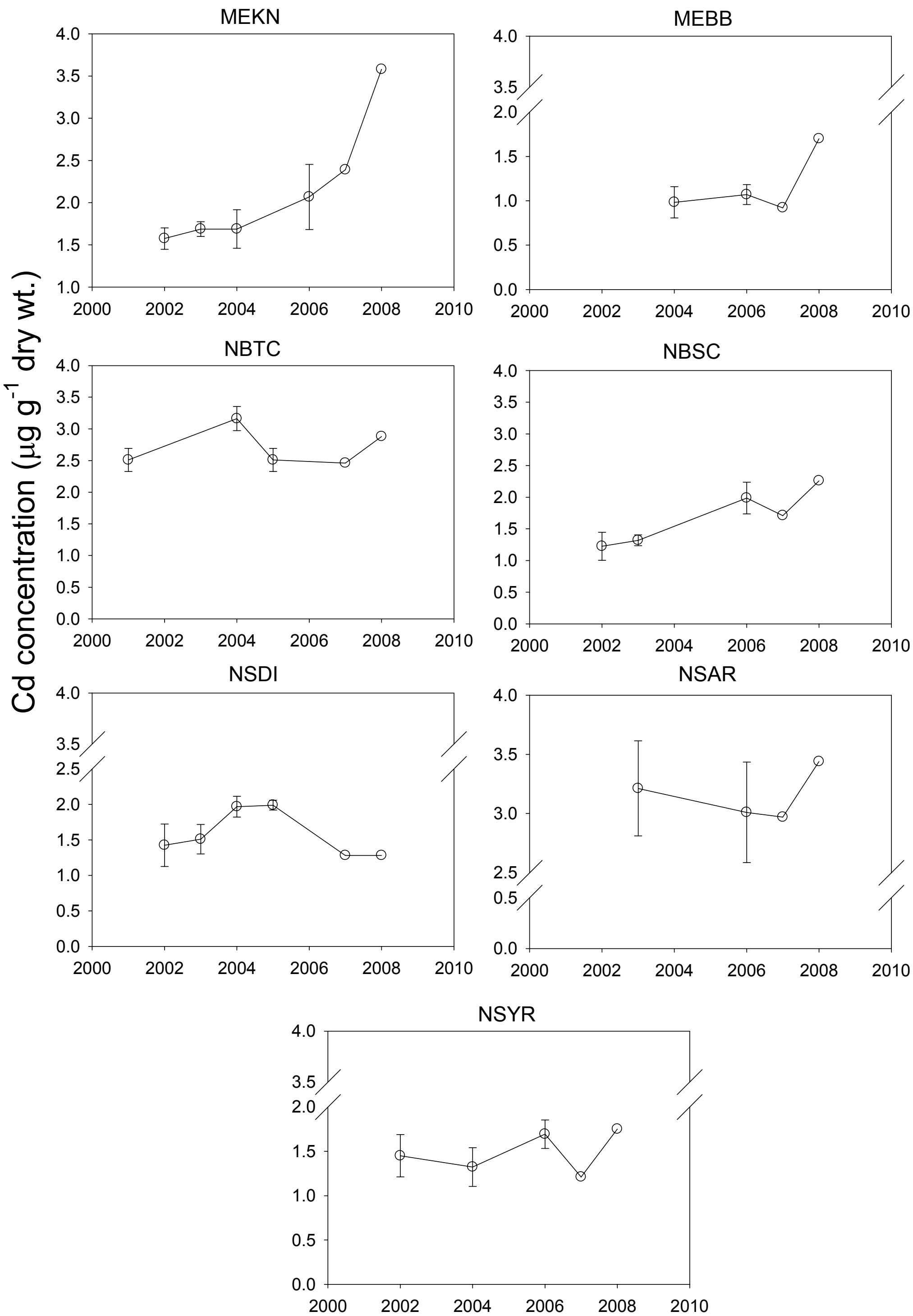


Figure 17 (cont'd). Distribution of cadmium tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHBC, NHDP, NHHS and MECC.

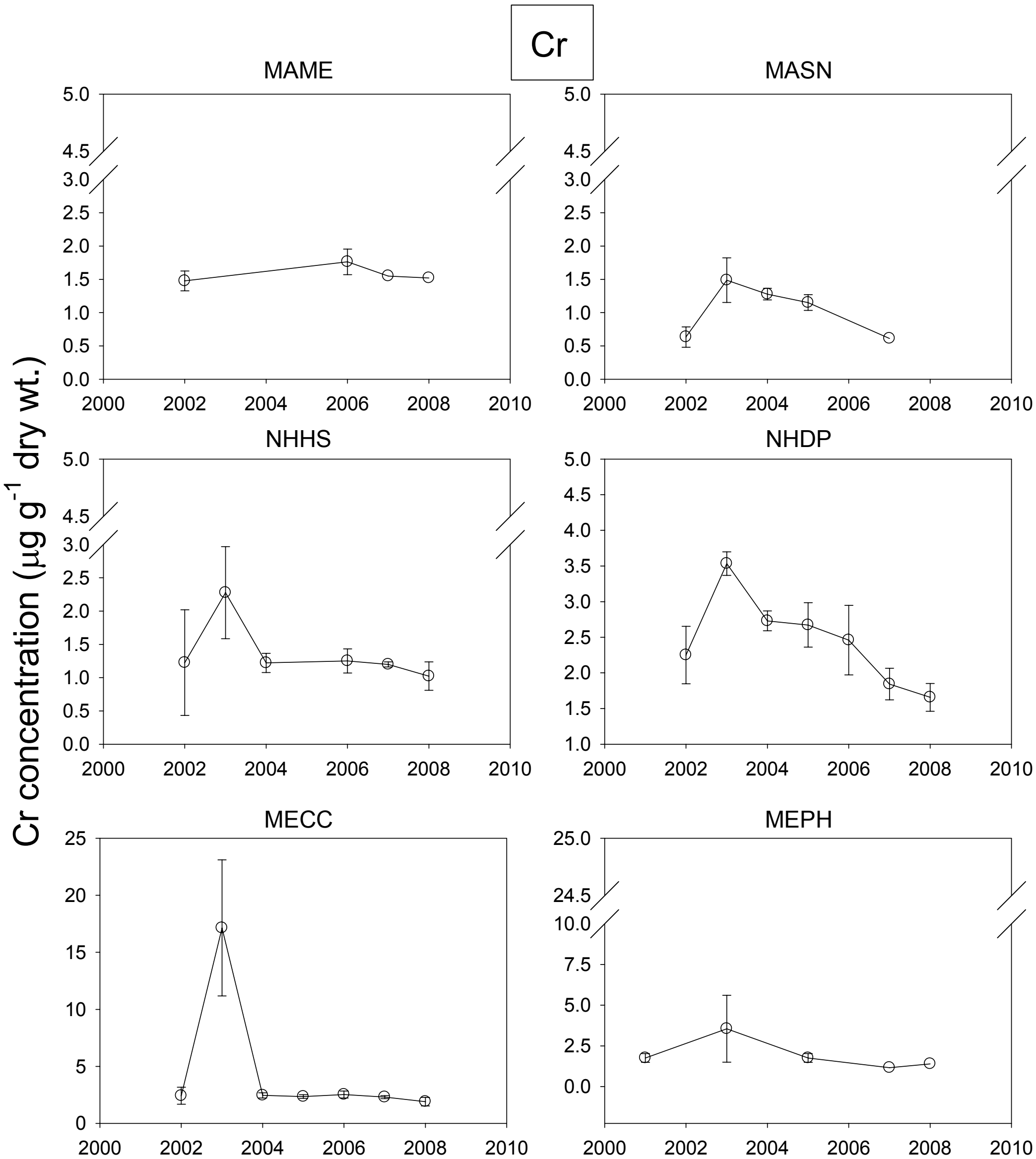


Figure 18. Distribution of chromium tissue concentrations in µg/g dry weight (arithmetic mean $\pm$ standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

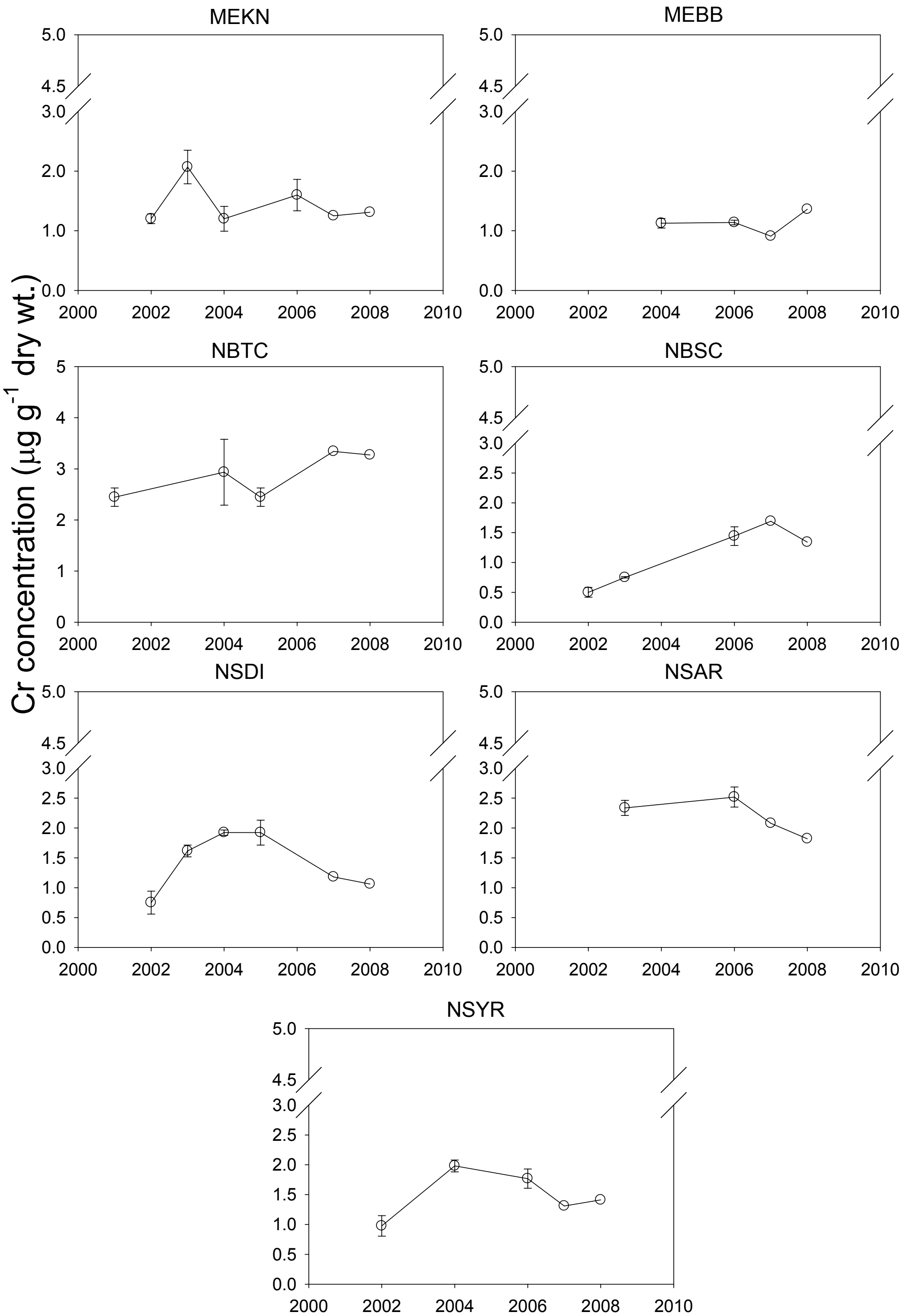


Figure 18 (cont'd). Distribution of chromium tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

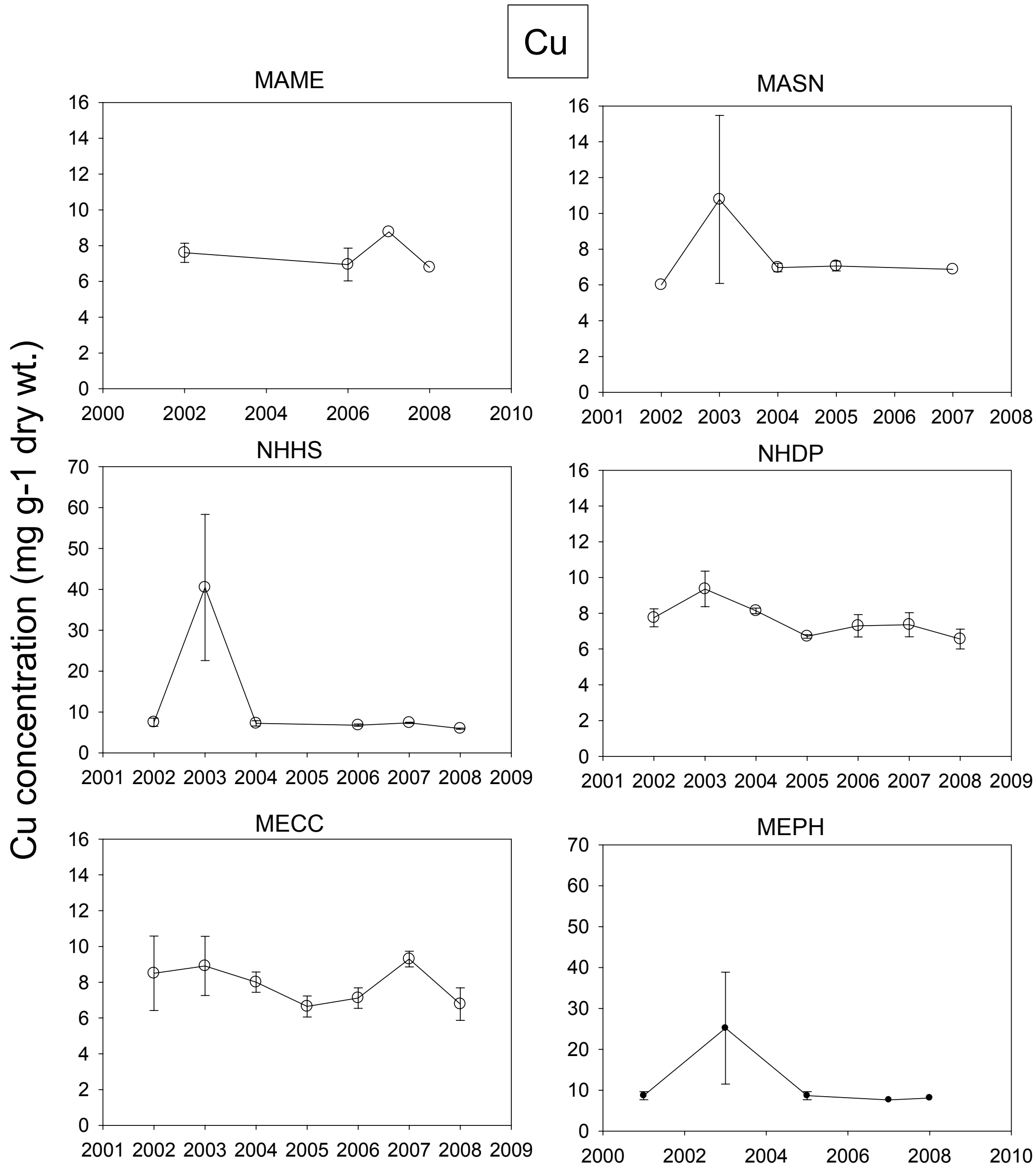


Figure 19. Distribution of copper tissue concentrations in μg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

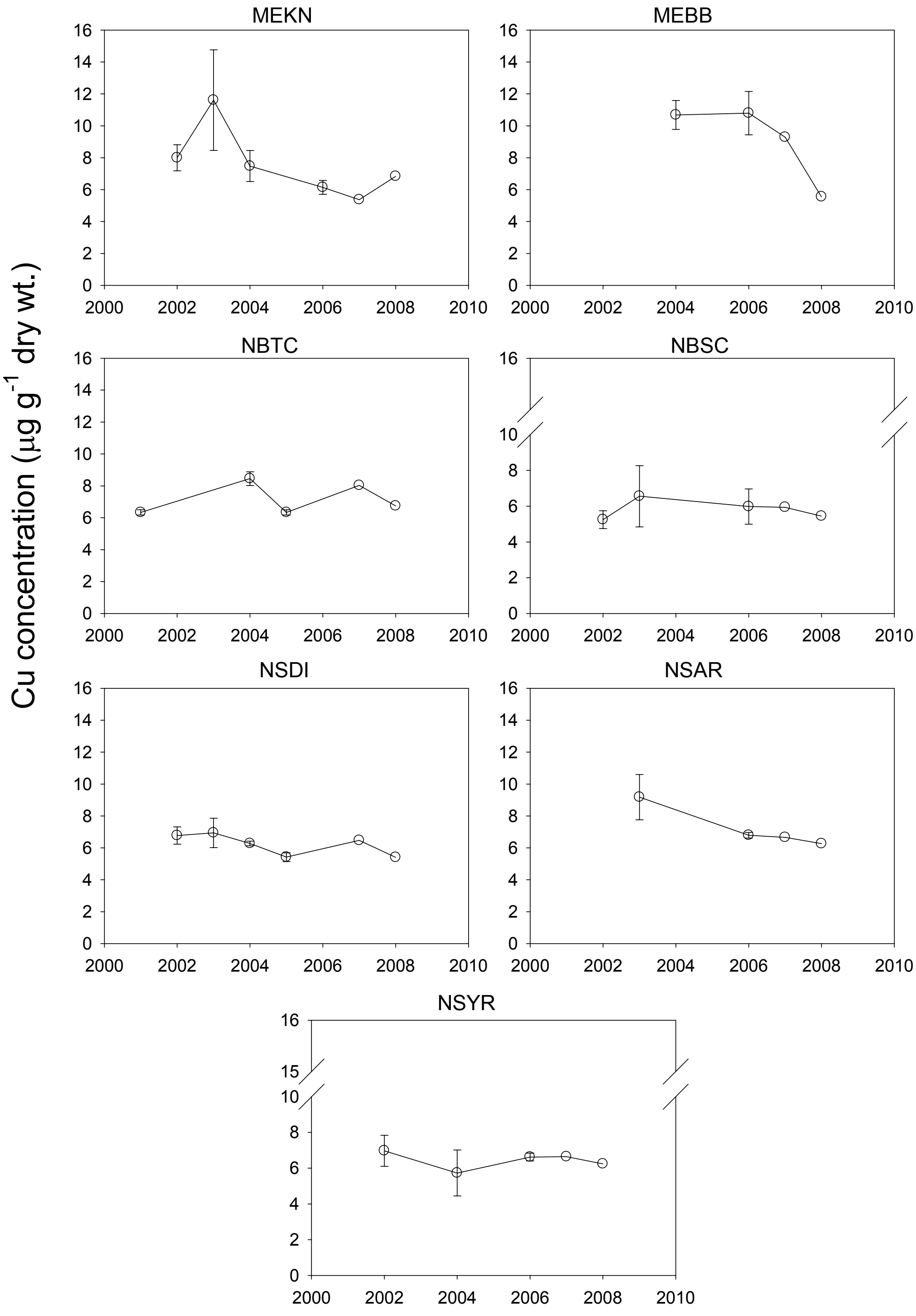


Figure 19 (cont'd). Distribution of copper tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

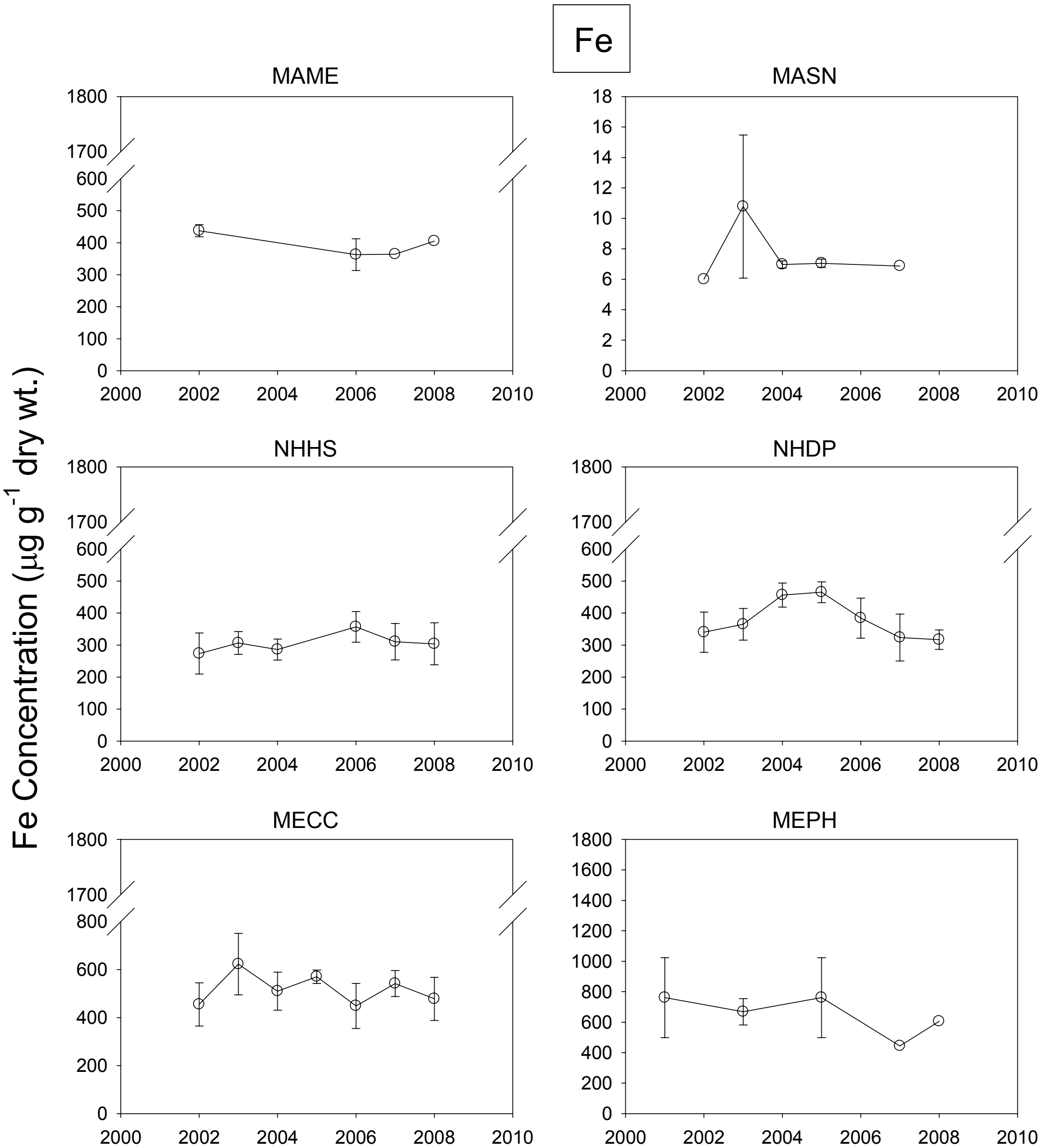


Figure 20. Distribution of iron tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

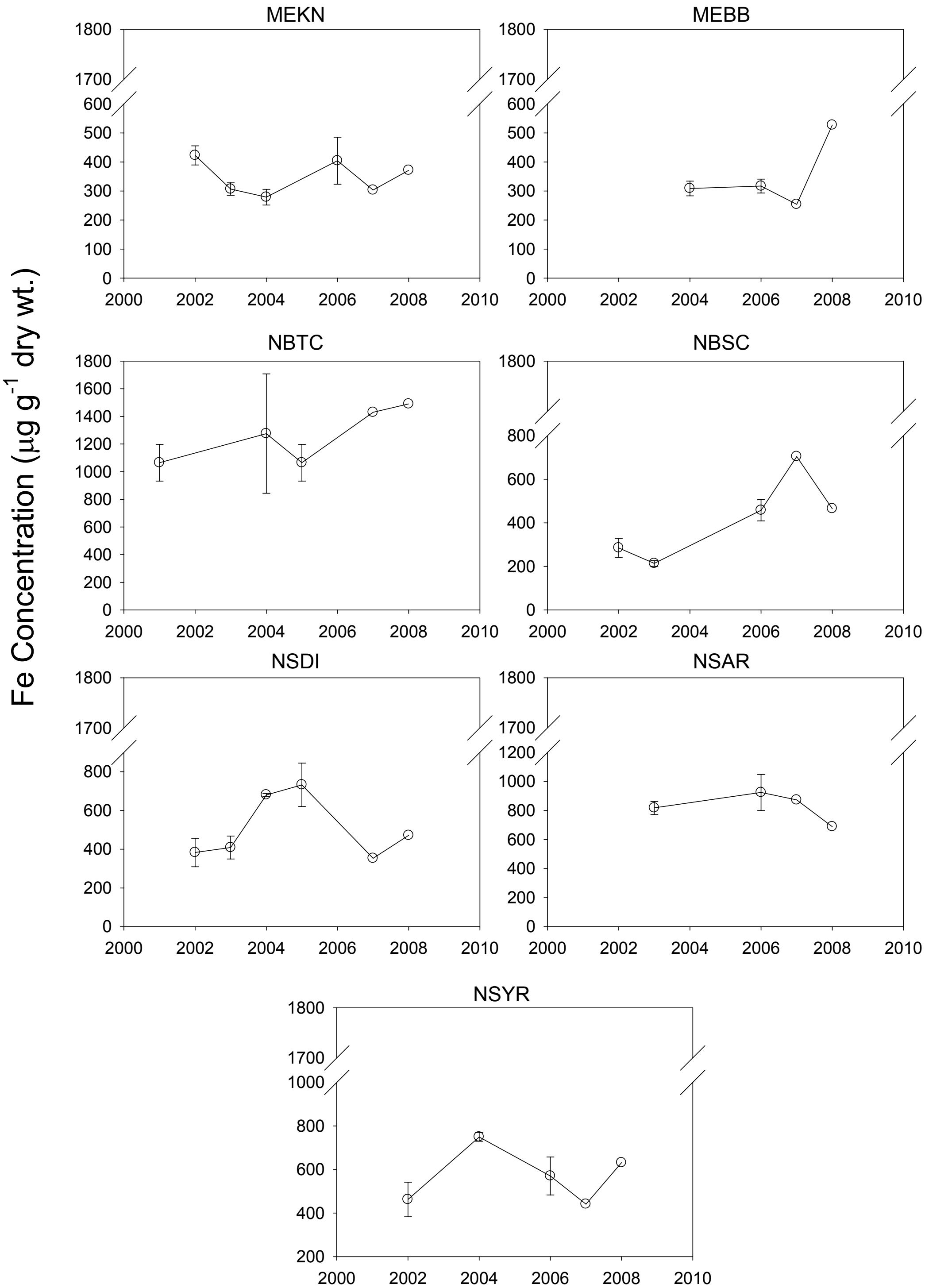


Figure 20 (cont'd). Distribution of iron tissue concentrations in μg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

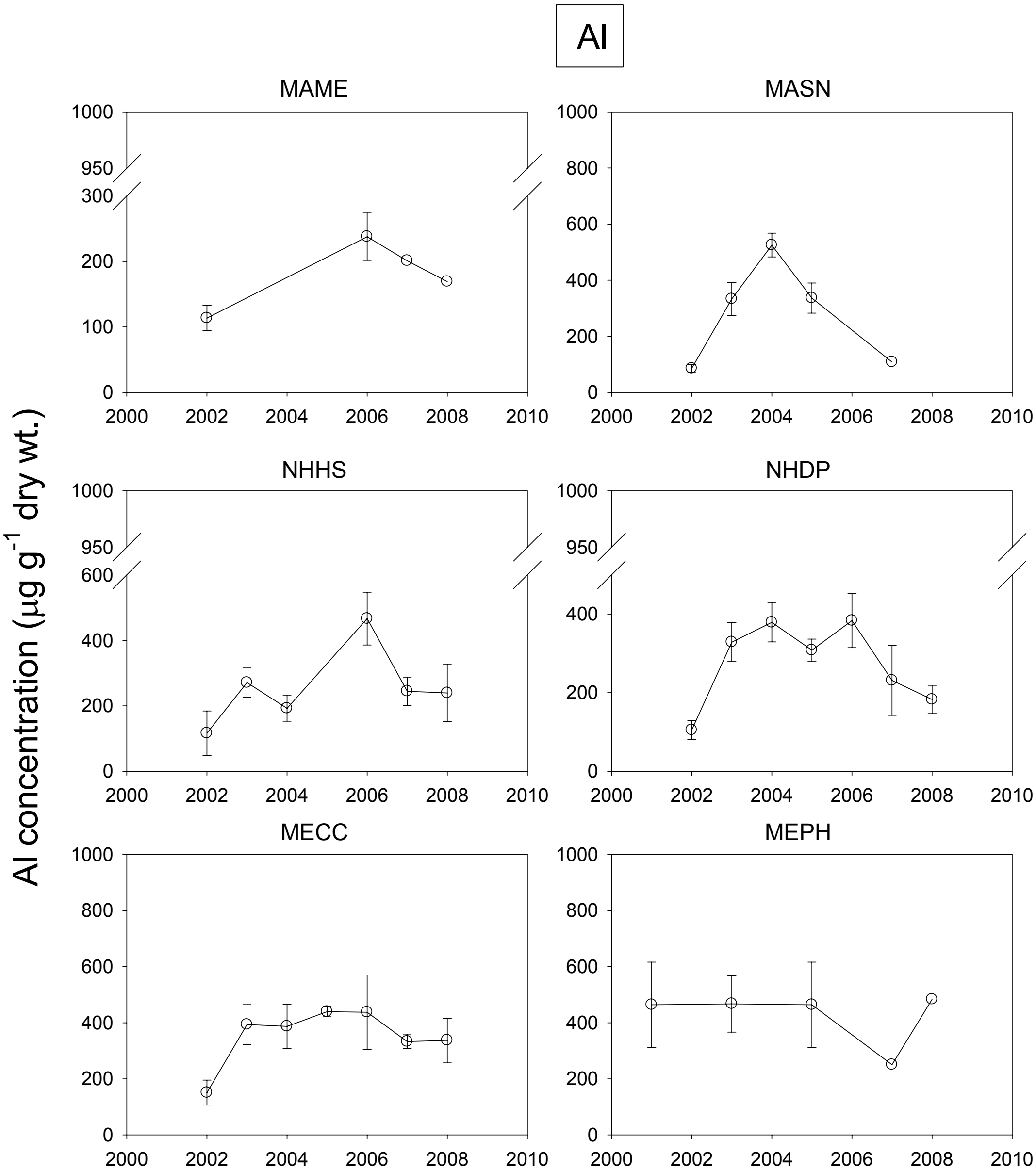


Figure 21. Distribution of aluminum tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

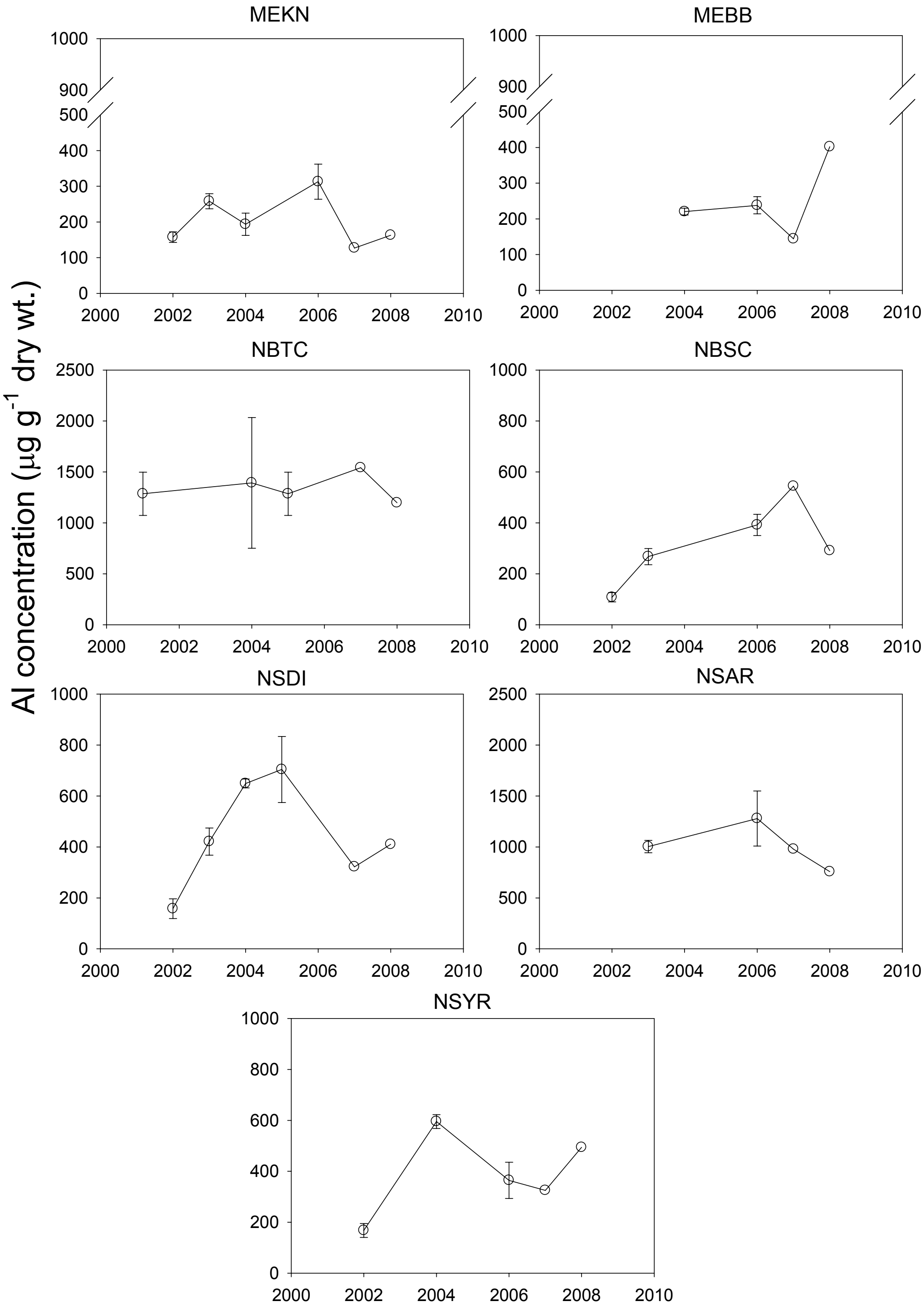


Figure 21 (cont'd). Distribution of aluminum tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

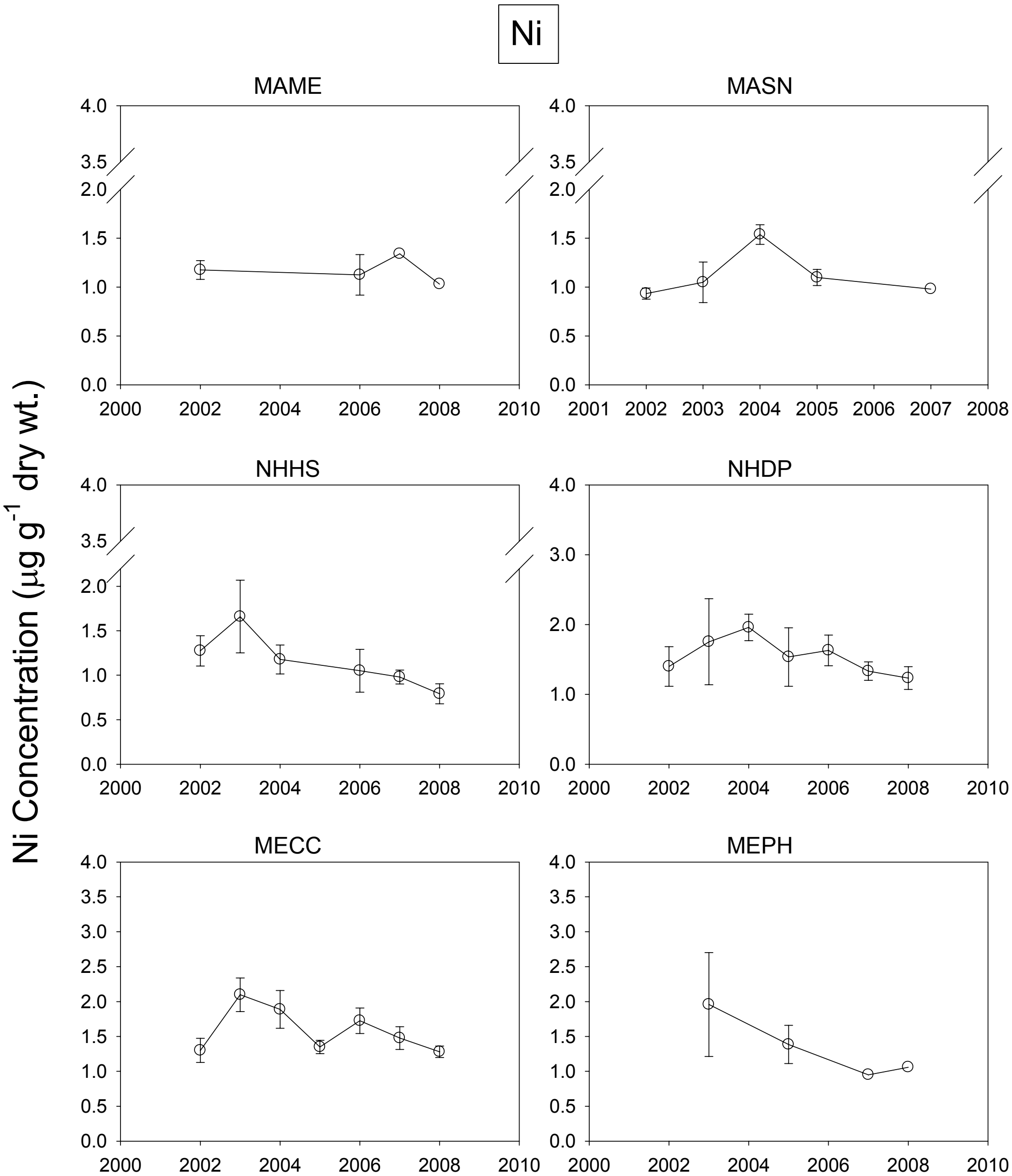


Figure 22. Distribution of nickel tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

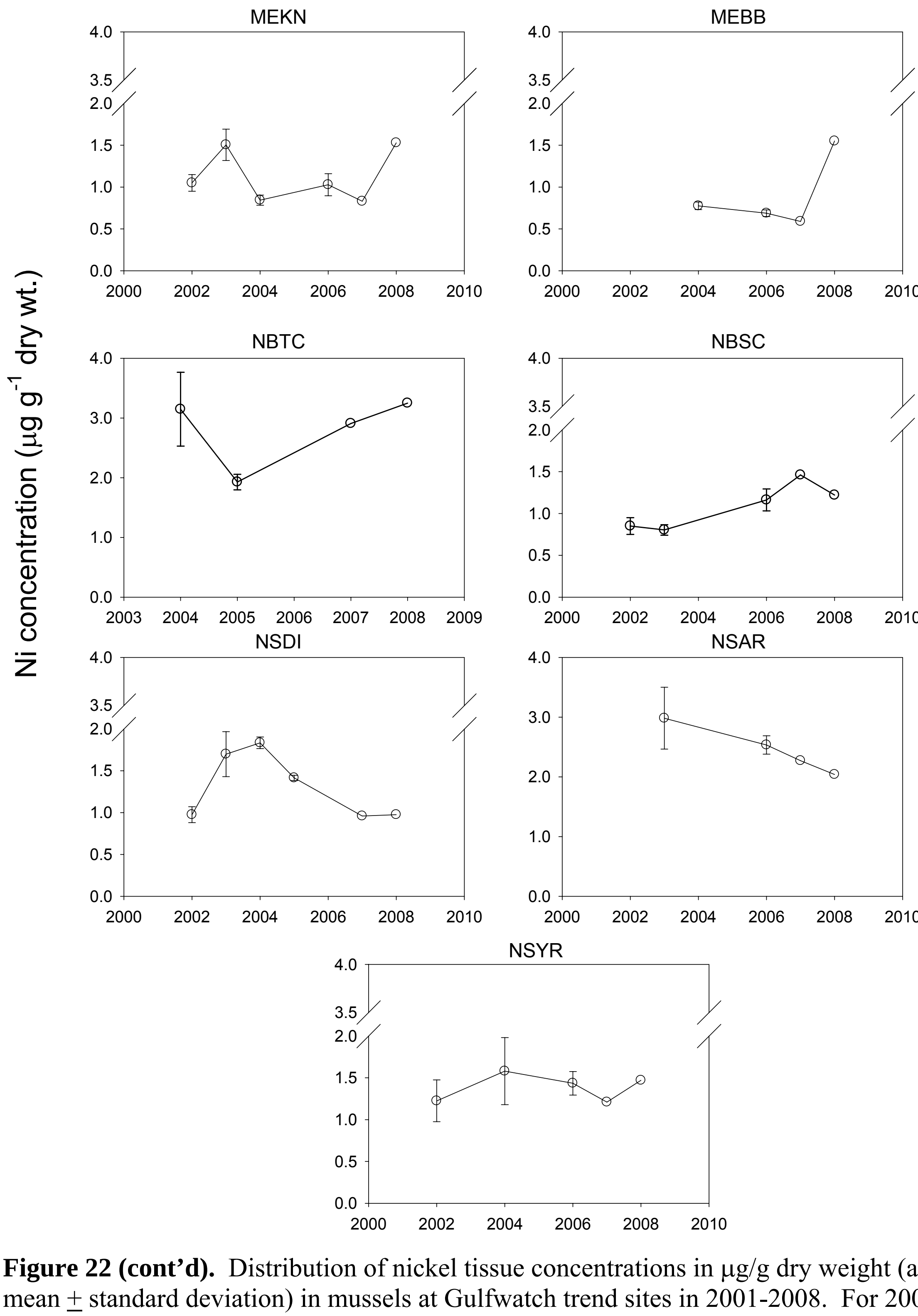


Figure 22 (cont'd). Distribution of nickel tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

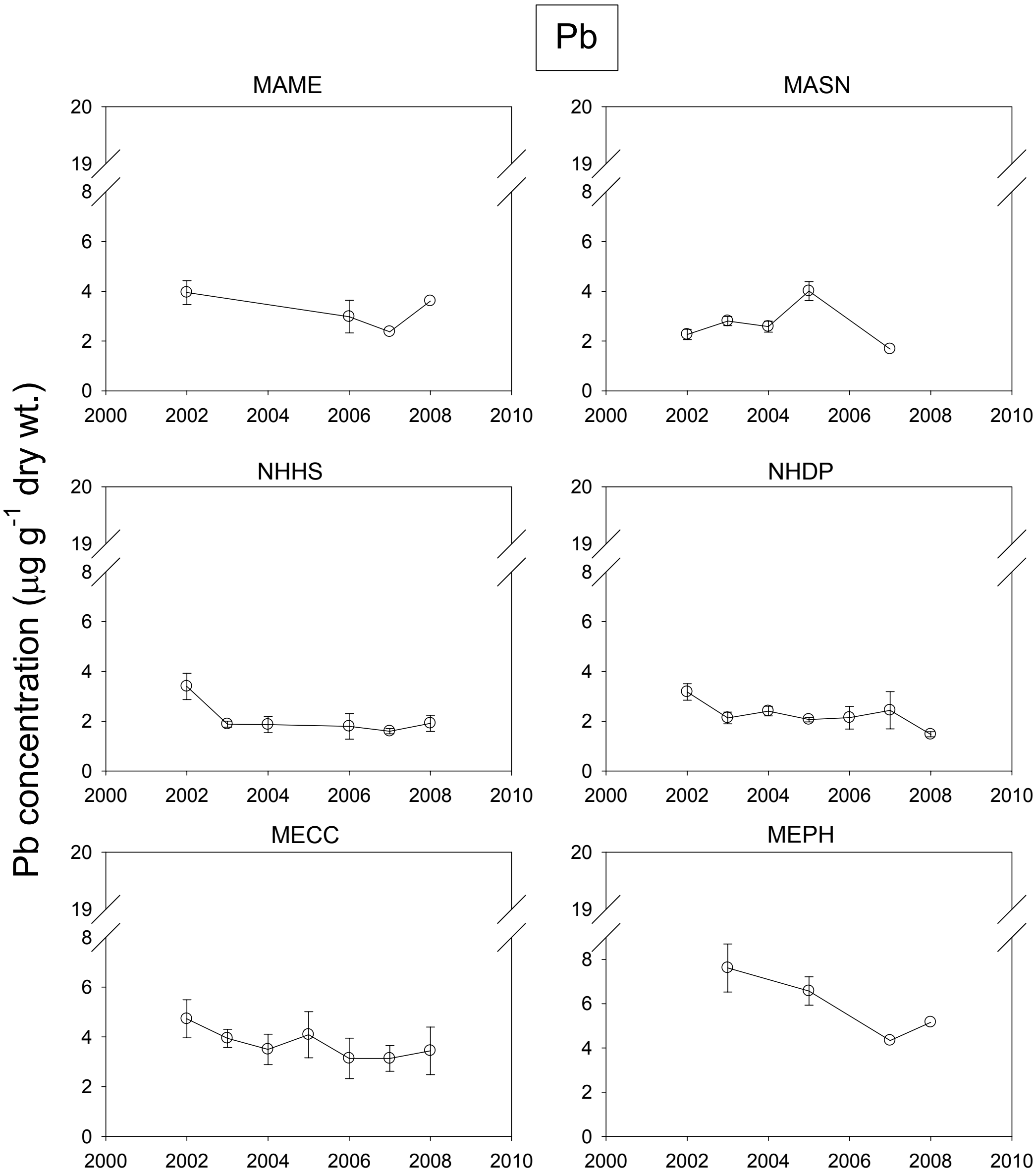


Figure 23. Distribution of lead tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

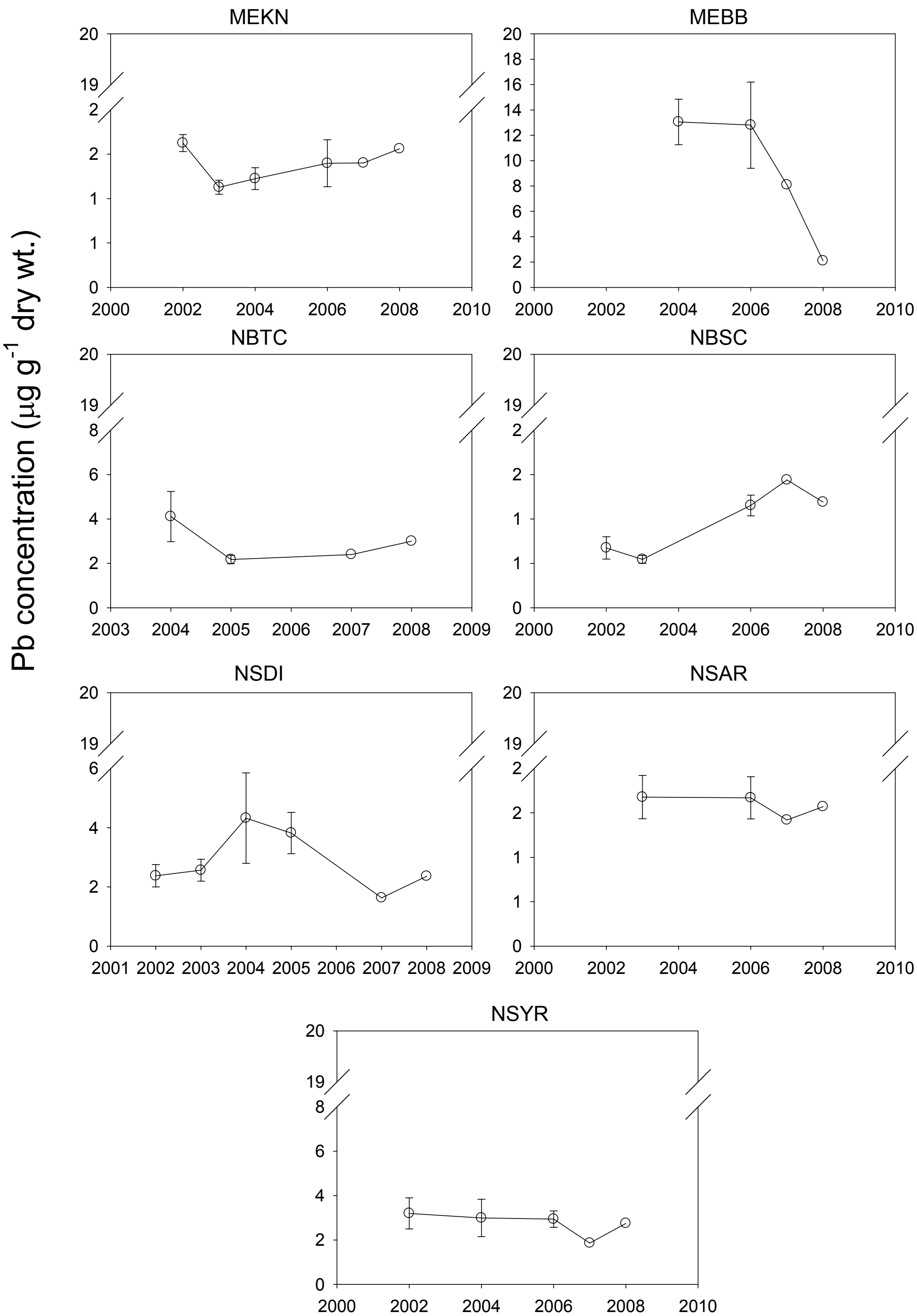


Figure 23 (cont'd). Distribution of lead tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

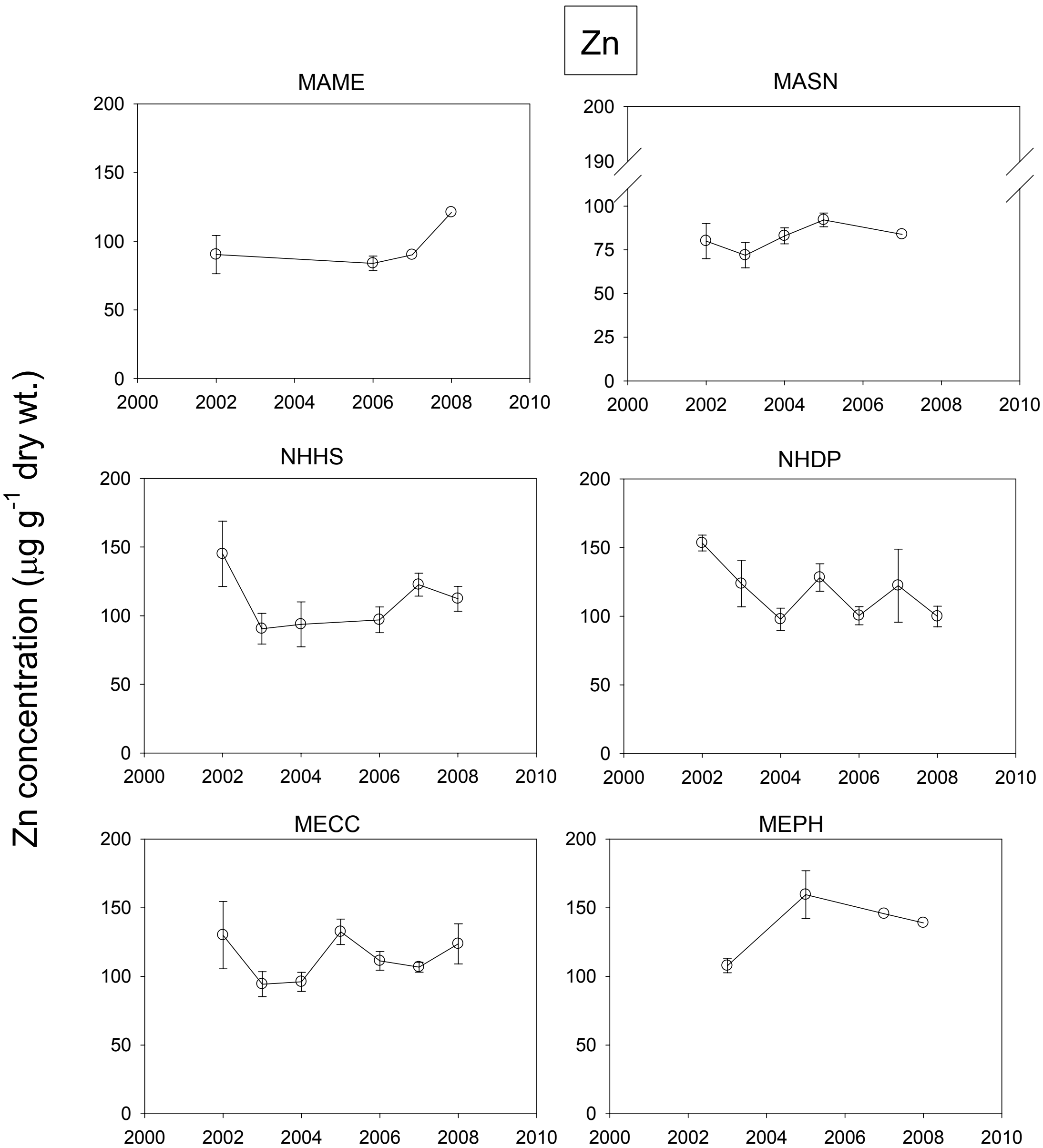


Figure 24. Distribution of zinc tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

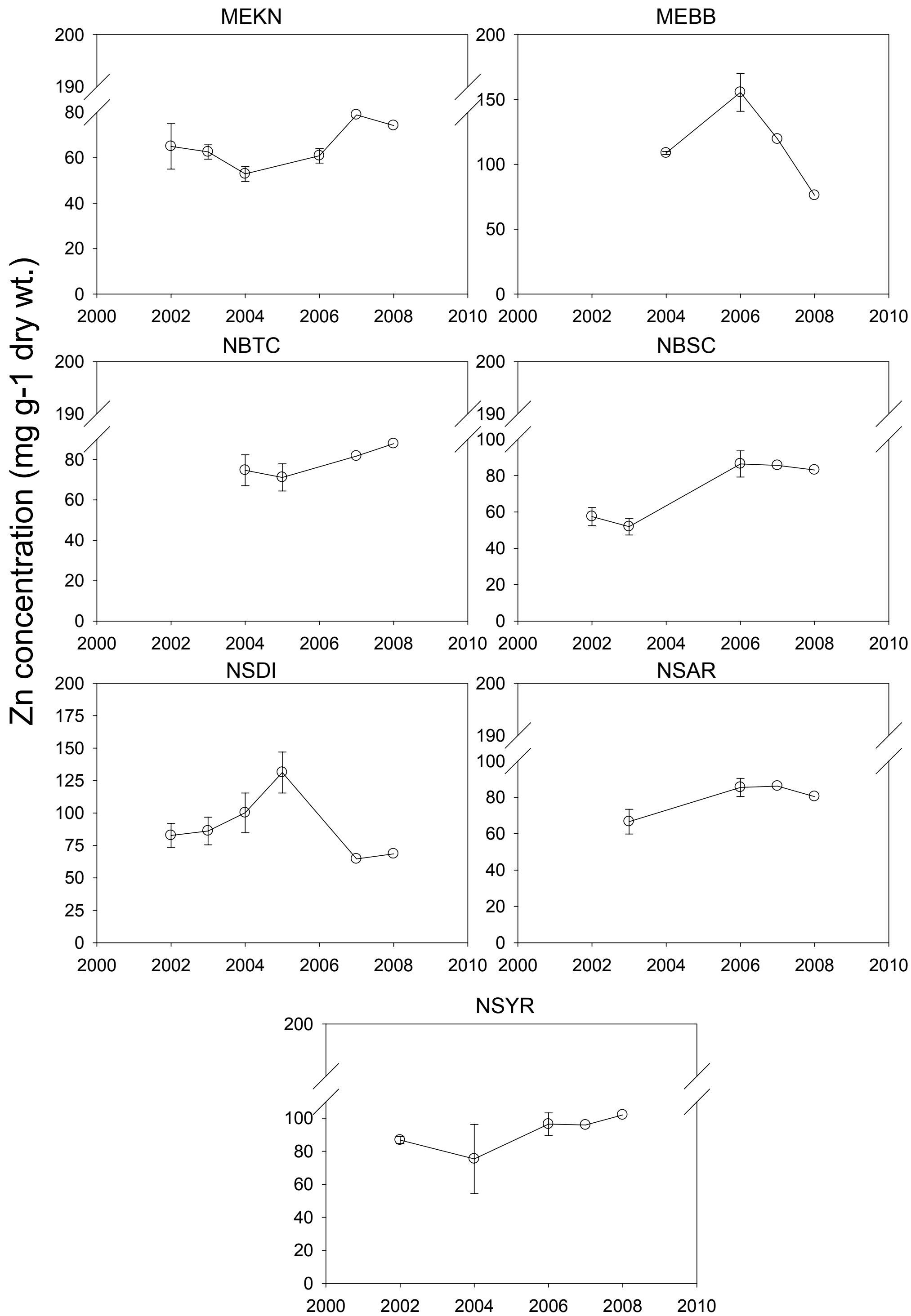


Figure 24 (cont'd). Distribution of zinc tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

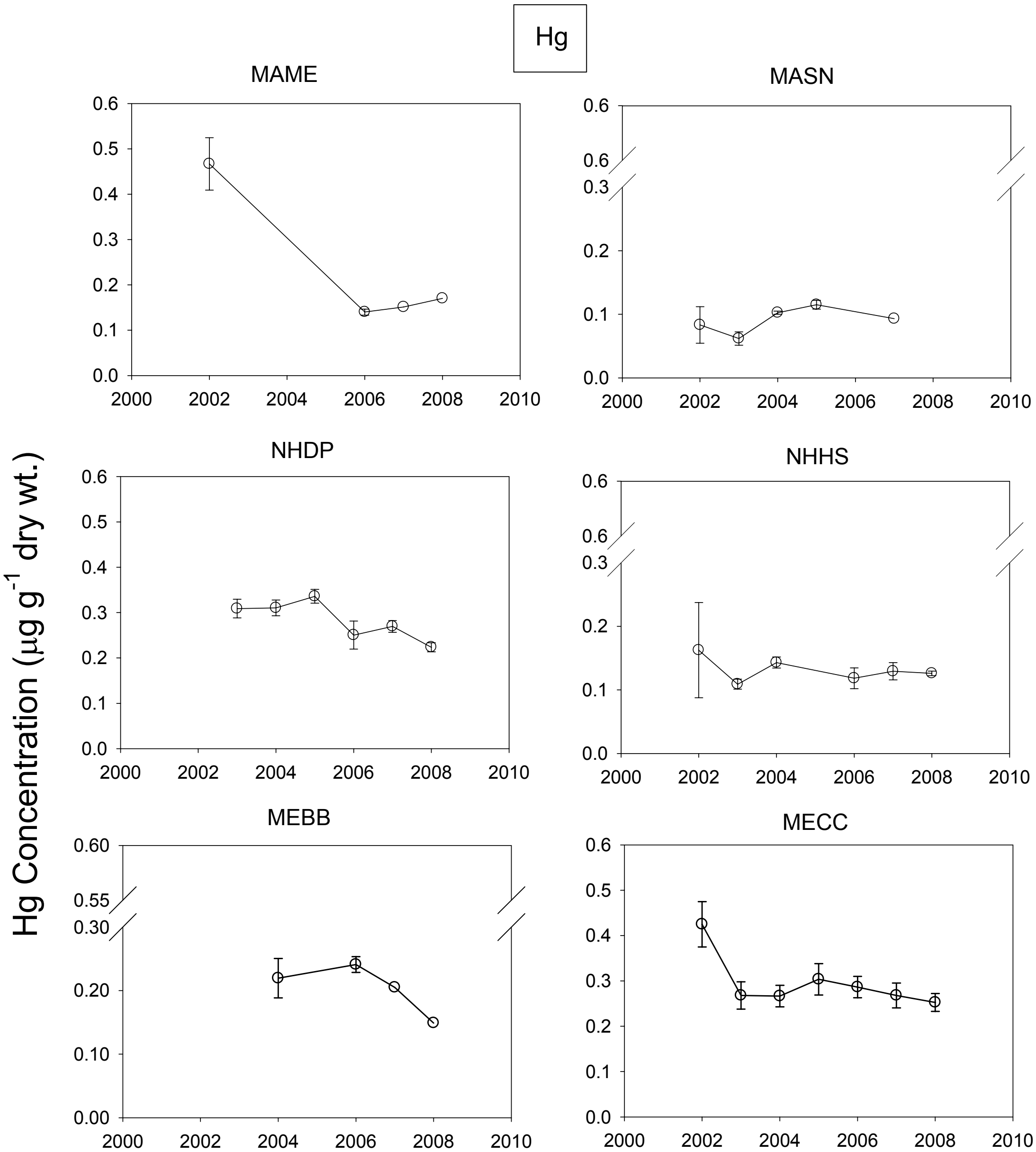


Figure 25. Distribution of mercury tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

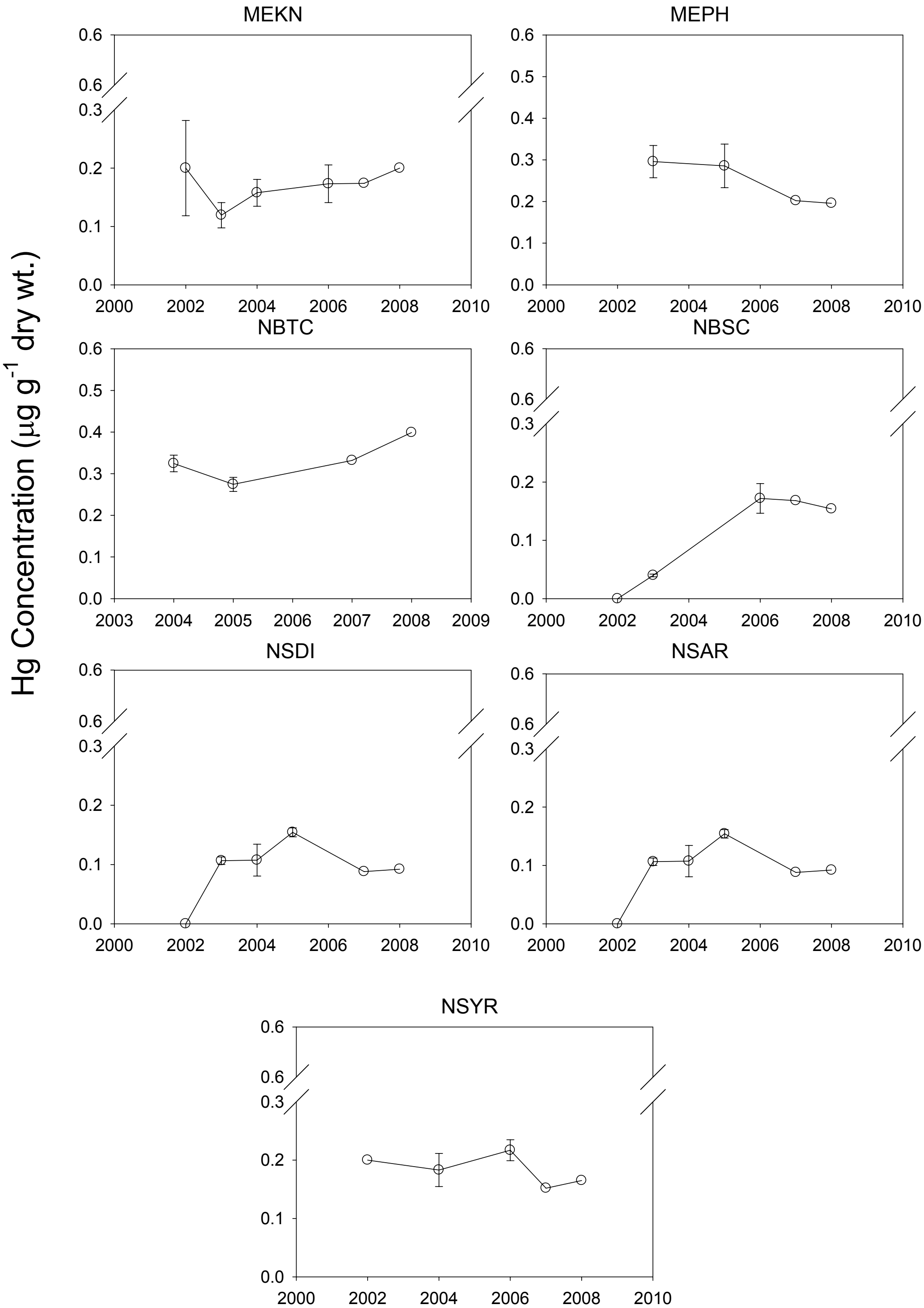


Figure 25 (cont'd). Distribution of mercury tissue concentrations in µg/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

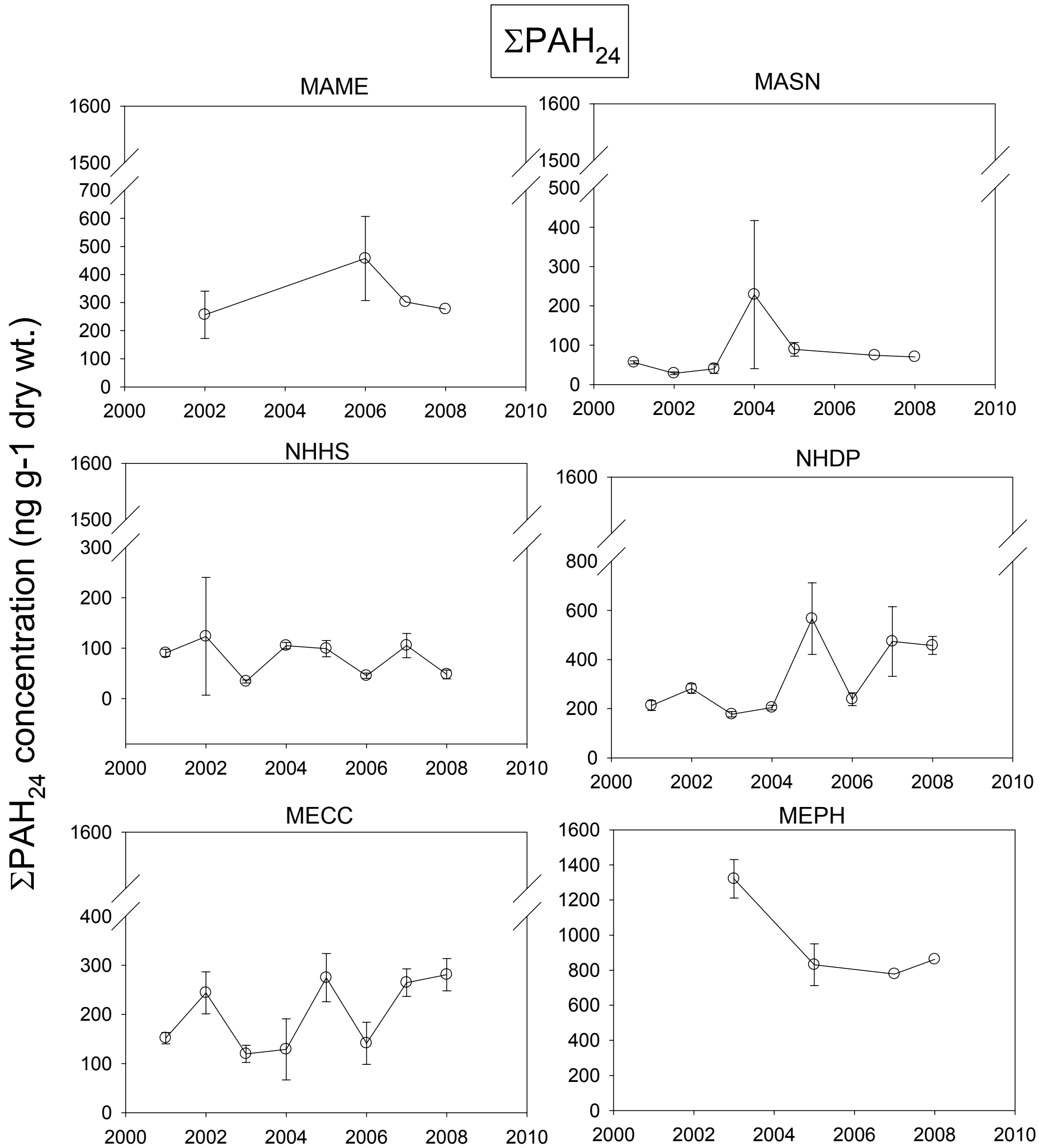


Figure 26. Distribution of the sum of 24 PAH compounds in ng/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

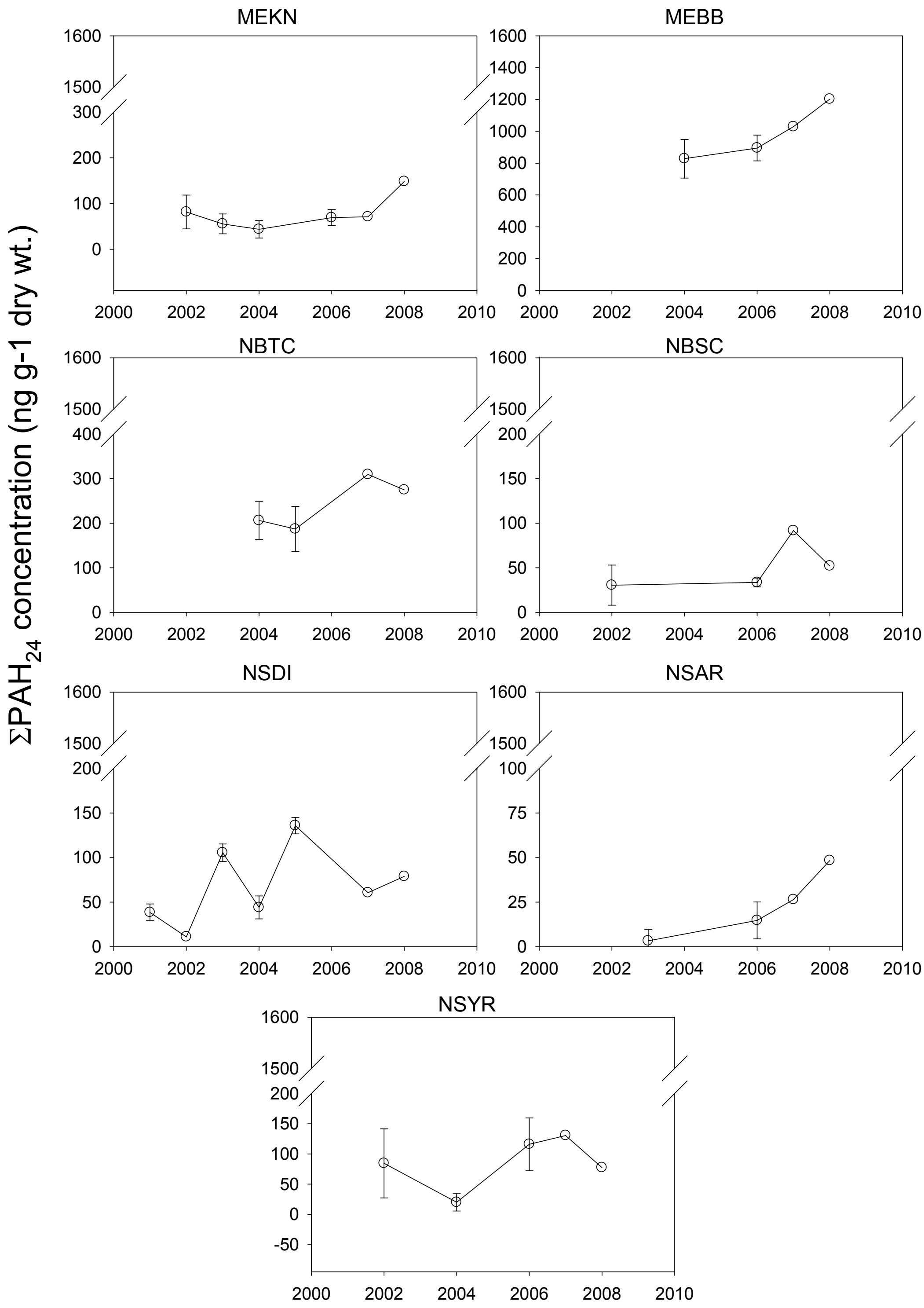


Figure 26 (cont'd). Distribution of the sum of 24 PAH compounds in ng/g dry weight (arithmetic mean + standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

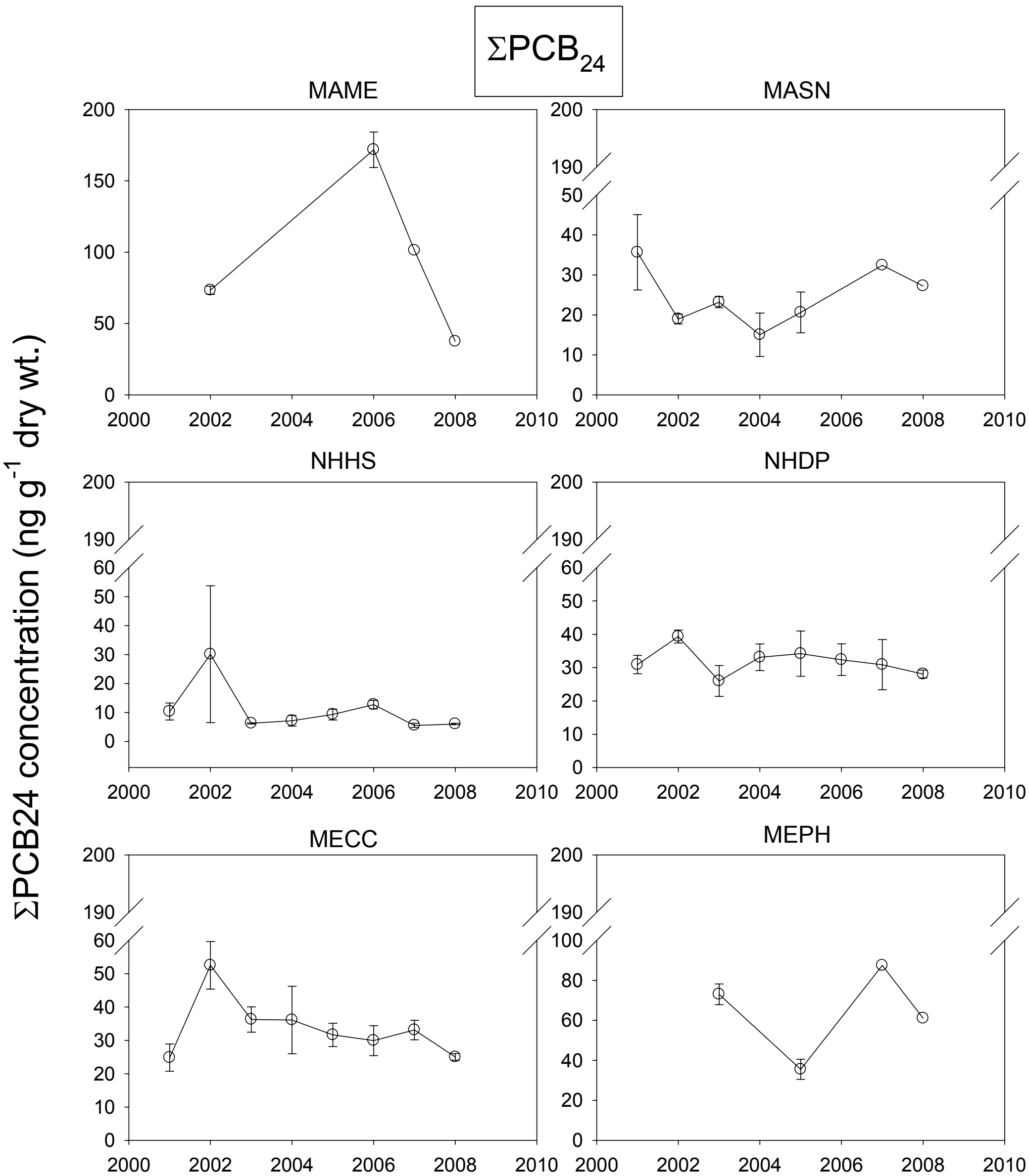


Figure 27. Distribution of the sum of 24 PCB congeners in ng/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

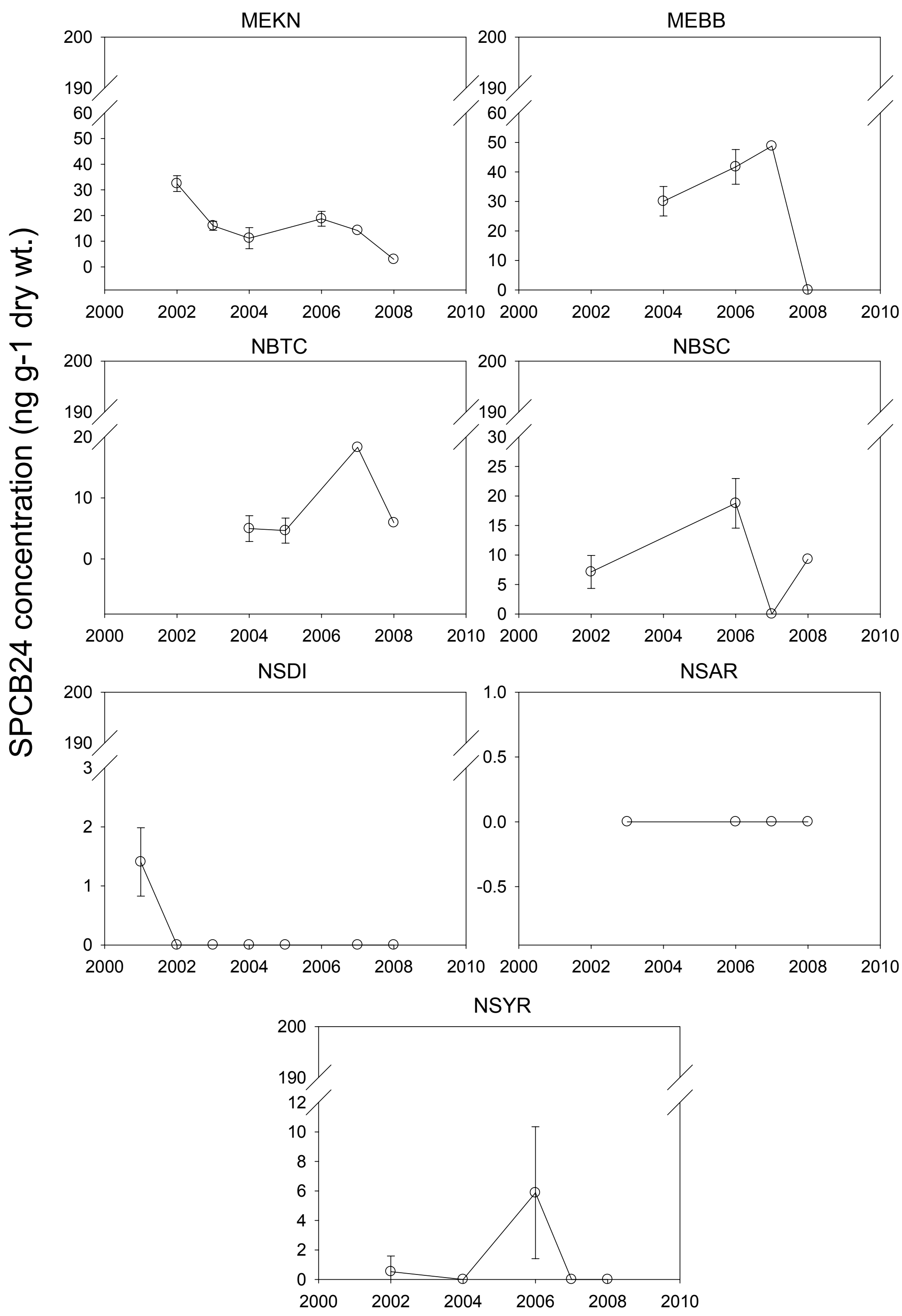


Figure 27 (cont'd). Distribution of the sum of 24 PCB congeners in ng/g dry weight (arithmetic mean + standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

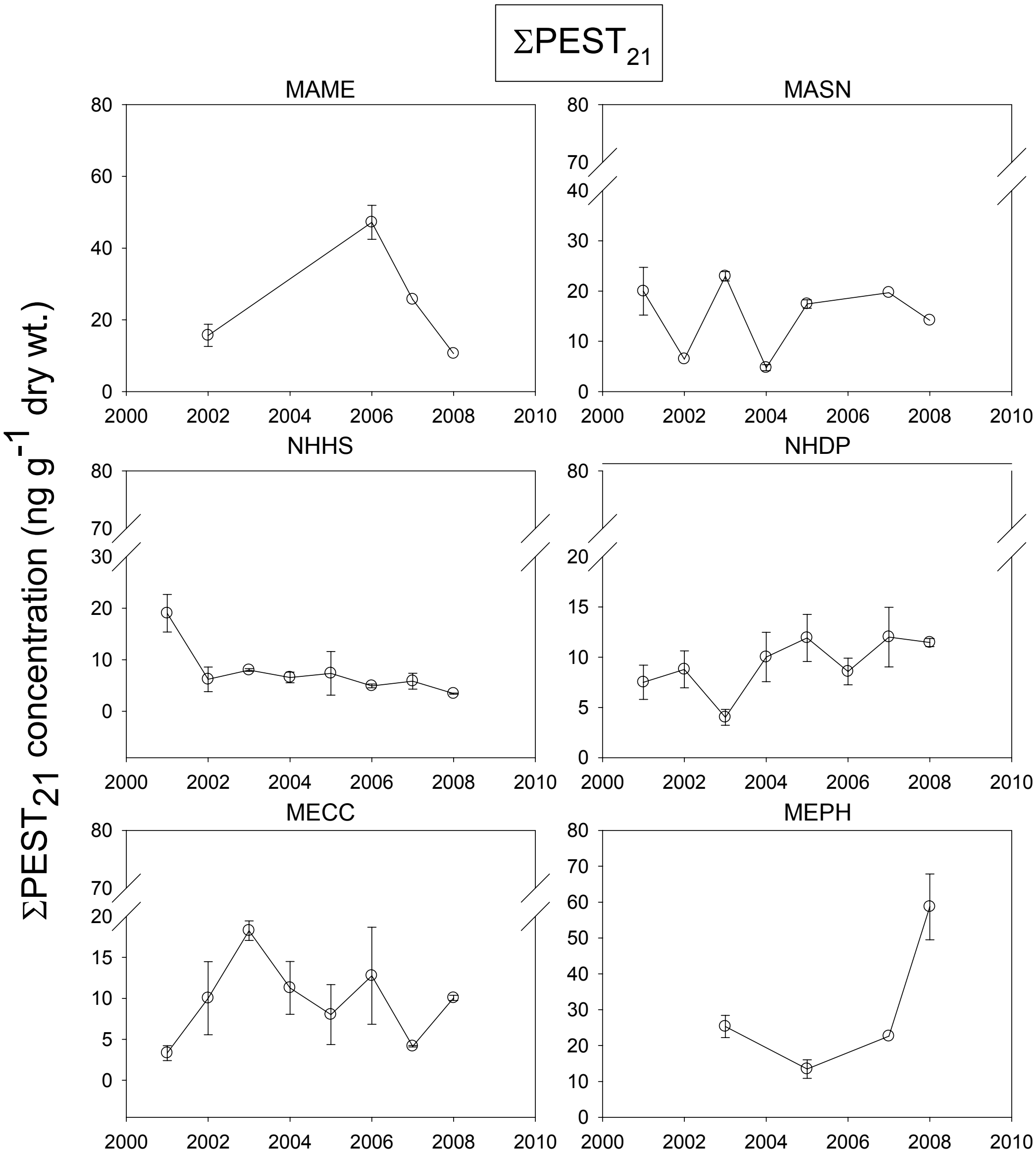


Figure 28. Distribution of the sum of 21 chlorinated pesticide compounds in ng/g dry weight (arithmetic mean ± standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

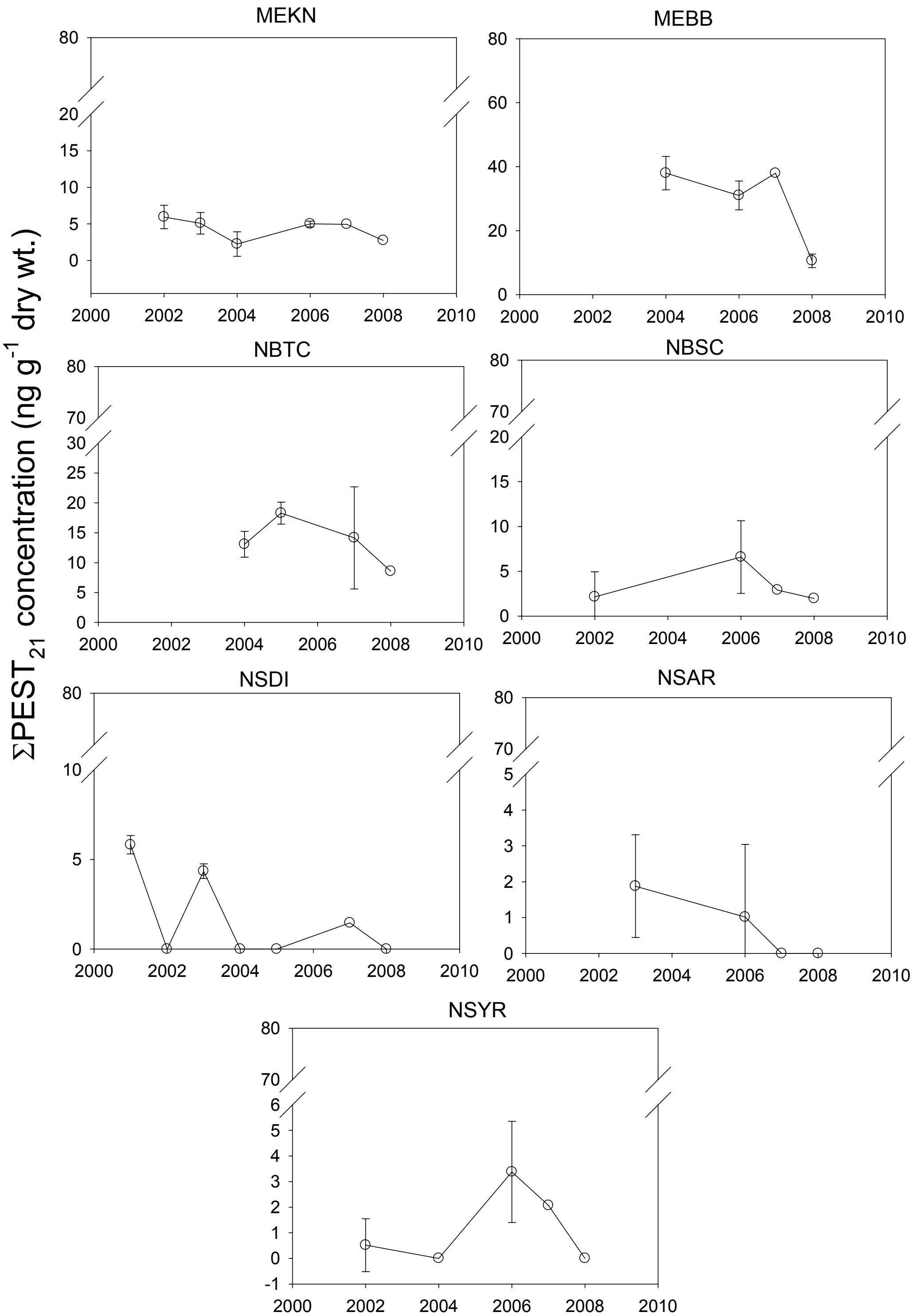


Figure 28 (cont'd). Distribution of the sum of 21 chlorinated pesticide compounds in ng/g dry weight (arithmetic mean + standard deviation) in mussels at Gulfwatch trend sites in 2001-2008. For 2007 and 2008 there are only single site composite values except for stations NHDP, NHHS and MECC.

4.3 Dry Weight and Lipid Fractions

Lipid content and percent wet weight (represented as % moisture) were determined on sub-samples of composites, typically between 5-15 g of wet tissue, after drying to a constant weight (See §2.4.3). The mean (± one standard deviation) % moisture and % lipids as a function of tissue mass are plotted in Figs. 29 and 30, respectively, where there are site replicate samples and/or analytical duplicates. These data can be found in table form in Appendices E and F. Percent moisture was between 80.5% - 91.3 % of the overall tissue mass. Percent lipid content was between 4.5 and 7.7 % of the tissue mass (Appendix F). O'Conner and Lauenstein (2006) reported an average of 8% lipid content for the mussels collected by the NOAA Mussel Watch program which is similar to the observed mean of 6.0 ± 0.85 % for the Gulfwatch Program for 2008.

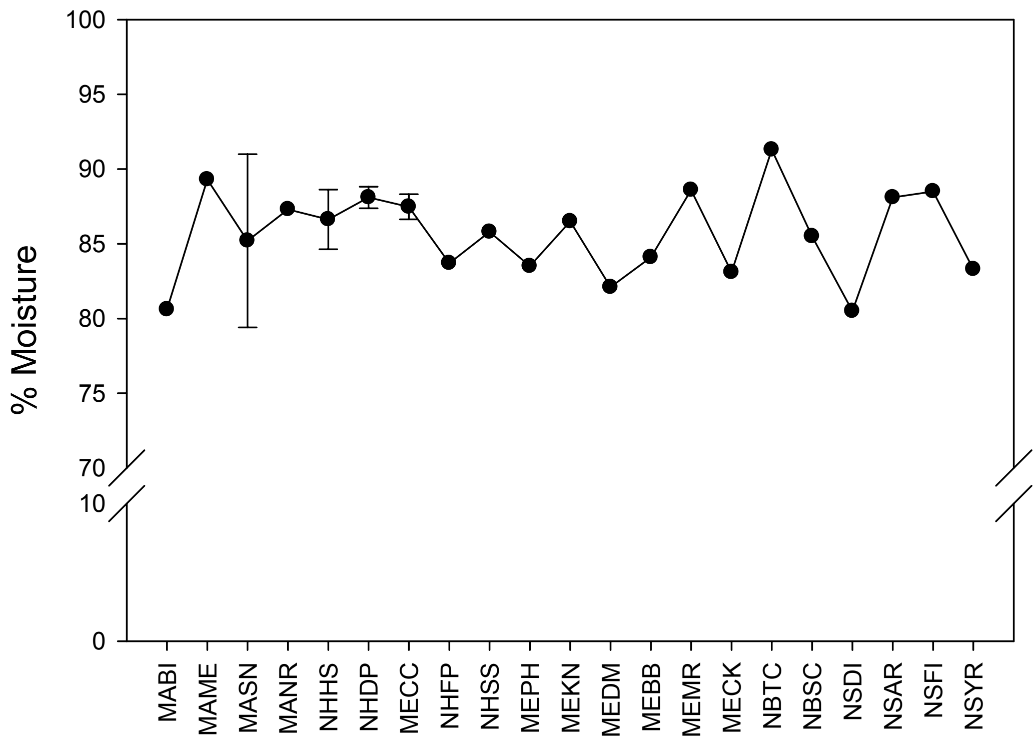


Figure 29. Mean and standard deviation of % moisture in Gulfwatch mussels collected during 2008.

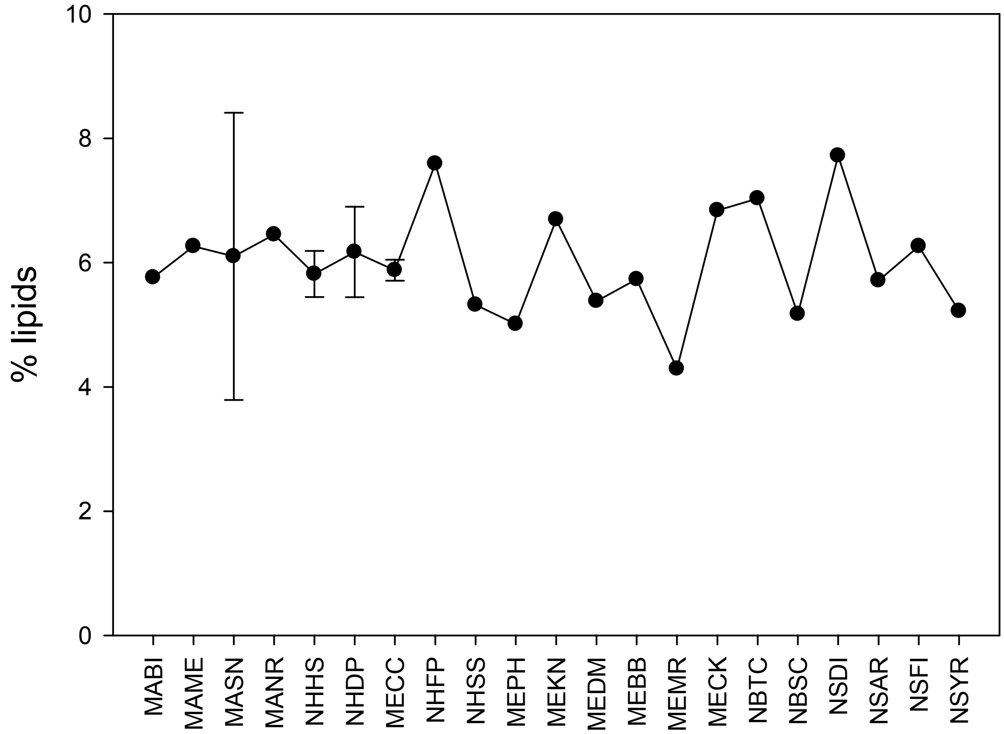


Figure 30. Mean and standard deviation of lipid content (% of tissue dry weight) in Gulfwatch mussels collected during 2008.

4.4 SHELL LENGTH AND CONDITION INDEX

Table 10 contains a summary of the morphological measurements and condition indices for mussels collected at each site in 2008. Mean condition index is plotted for all of the 2008 stations in Figure 32.

4.4.1 Shell Morphology

Gulfwatch field collection protocol recommends collecting *M. edulis* within the length range of 50-60 mm. The gulf-wide mean shell length (±SD) from the 2008 sites was 54.7± 3.04 mm.

Table 10. Morphometric determinations and statistics (arithmetic mean, standard deviation) on mussels collected along the Gulf of Maine, 2008 Gulfwatch.

	CI[1]		Length (mm)		Height[3] (mm)		Width (mm)		
Station	Mean	Stdev[2]	Mean	Stdev	Mean	Stdev	Mean	Stdev	n[4]
MASN	0.1588	0.0322	53.4	2.9	29.1	4.5	29.3	2.1	10.0
MANR	0.1388	0.0214	56.3	2.5	22.0	1.8	29.0	2.1	10.0
MAME	0.1446	0.0161	56.2	2.4	22.9	2.2	26.7	1.3	10.0
MACO	0.1338	0.0174	55.2	2.7	28.2	1.9	23.6	1.6	20.0
NHHS	0.1532	0.0196	53.59	2.18	27.875	1.70	27.24	1.84	20
NHSS	0.1629	0.0332	55.49	2.52	28.65	1.67	22.205	1.62	20
NHDP	0.1390	0.0194	54.20	2.24	26.81	1.46	21.89	1.87	20
NHFP	0.1753	0.0185	54.73	3.23	28.92	2.05	23.53	1.87	20
MECC	0.1803	0.0534	54.68	2.34	28.79	1.40	21.95	1.73	20
MEPH	0.1421	0.0226	55.4	2.4	28.44	4.00	21.70	2.01	60
MEKN	0.1561	0.0211	55.2	2.7	28.04	1.80	22.44	1.51	60
MEBB	0.1449	0.0246	55.4	2.7	29.64	2.18	22.41	2.21	60
MEDM	0.1265	0.0242	55.7	2.9	29.24	4.21	21.87	2.28	60
MEMR	0.1598	0.0480	56.4	2.8	28.85	4.10	19.96	1.53	60
MECK	0.1480	0.0400	54.9	2.8	29.55	1.99	21.87	1.81	60
NBSC	0.1063	0.0208	55.31	4.51	29.14	3.70	23.06	2.28	20
NBTC	0.1033	0.0157	52.3	4.2	26.6	2.2	2.99	1.03	20
NSYR	0.1418	0.0152	53.95	2.68	29.10	1.60	22.34	1.41	20
NSDI	0.1601	0.0210	53.95	2.68	29.10	1.60	22.34	1.41	20
NSAR	0.1535	0.0169	54.21	2.62	27.68	1.90	20.97	1.29	20
NSFI	0.1298	0.0175	53.40	2.44	27.87	1.82	22.53	1.43	20

[1]CI = condition index = individual tissue weight (mg)/length (mm) * height (mm) * width (mm)
[2]Stdev = standard deviation, [3]Ht. = height (mm), [4]n = number of mussels measured for CI determinations

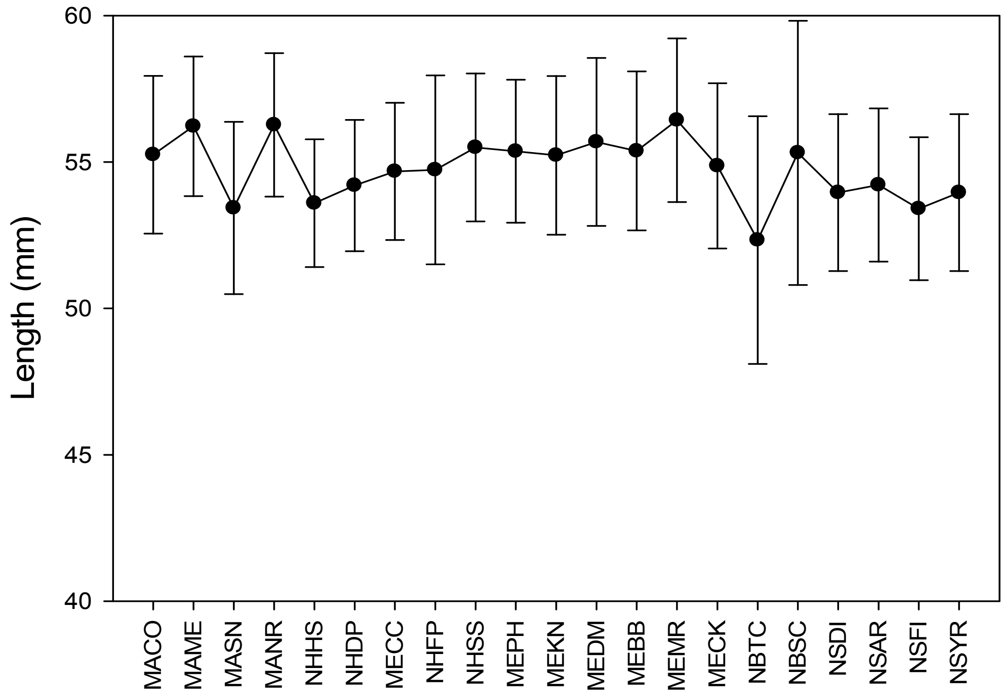


Figure 31. Mean and standard deviation of length (mm) in all Gulfwatch mussels collected for trace metal and organic analysis and archival during 2008.

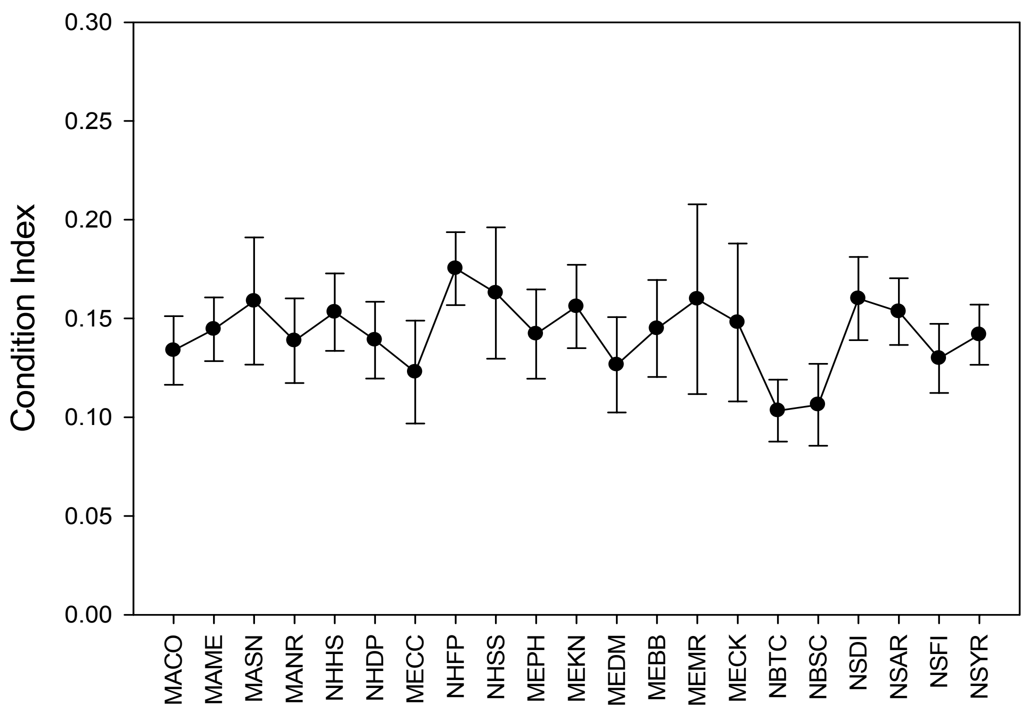


Figure 32. Mean and standard deviation condition index of Gulfwatch mussels collected during 2008.

5.0 2008 GULFWATCH SUMMARY

Monitoring of contaminants in the soft tissues of *M. edulis* from Massachusetts to Nova Scotia in the 18th year of the monitoring program continues to add information for the evaluation of temporal and spatial trends of contaminant exposure of aquatic organisms in the Gulf of Maine and, in part, meets the Goals (particularly #2) articulated in the 2007-2012 GOMC Action Plan. The 2008 Gulfwatch field season continues the modified sampling design begun in 2006, and includes four benchmark sites now re-classified as trend sites based on their unique sampling frequency (visited once every two years), nine other trend sites and eight rotational sites (to be visited once every 6 years). Softshell clams were sampled at two sites in New Hampshire and two sites in Maine. Samples were collected, processed, and analyzed in accordance with program QC/QA protocols. All data associated with the 2008 samples are provided in the accompanying appendices.

The Gulfwatch 2008 results were qualitatively reviewed in comparison to the NOAA National Status and Trends national median concentrations. The data were additionally examined relative to the 85th percentile of the NOAA national median for 2008 which is used by Gulfwatch as the criteria for a tissue concentration to be considered elevated and of concern.

Temporal distributions were reviewed for some analytes across the entire region for the designated trend sites. Beginning in 2003, quality assurance and control improved and were better documented for some metals, i.e. aluminum, chromium, nickel, and mercury when Gulfwatch acquired analytical services from Battelle Marine Science Laboratory, Sequim, WA. Where noted, the change in analyte concentrations should be taken into consideration for any future time trend analysis relative to pre-2003 QC/QA data quality objectives. Quantitative temporal and spatial analysis of the data is beyond the scope of this report.

Given the above caveats, the status of contaminants in near shore areas around the Gulf of Maine suggests the more heavily populated/industrialized coastal areas of the Gulf of Maine have higher contaminant levels compared to locations with smaller communities and less industrial activity. High concentrations are not confined solely to the south and western regions of the Gulf, as elevated concentrations were also observed at sites throughout the region. Lead and mercury exceeded the 85th percentile of the NOAA National Status and Trends dataset at several sites in all jurisdictions. Lead was elevated at MASN, MANR, MABI and MAME in Massachusetts, MEBB, MECC, and MEPH in Maine, NBTC in New Brunswick and NYSR in Nova Scotia. Mercury was found to be elevated at 18 of the 21 Gulfwatch sites sampled, with maxima seen in all jurisdictions. The highest Hg concentrations were found in mussels from Brewster Island (MABI) in Massachusetts and Tin Can Beach (NBTC) in New Brunswick. Kimbrough, et al., (2008) reported the status of lead and mercury contamination in blue mussel tissue on a regional and national basis. Overall, contaminants in mussels were considered high among sites in MA, and NH, and low in ME. However Gulfwatch monitoring detected elevated concentrations of lead at 3 sites in Maine, with MEBB having the highest concentration of any sites sampled. Mercury was elevated at all sites in Maine and New Hampshire, except for Cobscook Bay, Maine (MECK). Elevated mercury concentrations were also found in New Brunswick and Nova Scotia, with only Digby in NS not exceeding the NS&T 85th percentile value, and NBTC having the highest tissue Hg concentrations of all Gulfwatch sites. In Canada, elevated levels of aluminum were found at Tin Can Beach in New Brunswick (NBTC) and at three sites in Nova Scotia site (NSAR, NSFI and NSYR). Elevated chromium was found at

NBTC in New Brunswick, and 19 of 21 sites throughout the entire region had concentrations higher than the national median value.

Organic contaminants were highest overall in Massachusetts and Maine sites. Values exceeded the NS&T 85th percentile value for total PAHs at Neponset River, MA (MANR) and Boothbay Harbor, ME (MEBB) for the sum of the unsubstituted PAHs (ΣPAH_{19}). The MANR site also had high PCB concentrations, well in excess of the NOAA 85th percentile value. Pesticides were high at MANR as well, along with Portland Harbor, ME (MEPH) and Boothbay Harbor, where values did not exceed, but were close to the 85th percentile concentration. In the Maritime provinces, only the Tin Can Beach site (NBTC) has PAH levels (ΣPAH_{19} and ΣPAH_{24}) exceeding the 2008 National NS&T median value for organic contaminants.

Hot spots were apparent, with the Neponset River site in Massachusetts (MANR) being especially elevated in PAHs, PCBs, pesticides, lead and mercury. Neponset River was sampled for the first time in 2008 and is proximate to the Inner Boston Harbor site (MAIH) being separated by the peninsula which is South Boston. The elevated contaminant concentrations are similar to those found at the Inner Harbor site in previous years, and reflects the influence of the long history of industrialization that has occurred in Boston Harbor. In New Brunswick, Tin Can Beach was elevated in a number of metals, including aluminum, mercury, lead and chromium. Readers may wish to examine contaminant results in the appendices for further analyses.

When the Gulf of Maine Council was formed, it recognized the need to provide all jurisdictions with contaminant information to enable improved capability to assess, understand, and, where necessary, respond to issues involving contaminants, ecosystem health, and human health. Thus, the GOMC created the Gulfwatch Program which is the only marine contaminant monitoring program conducted jointly by the United Sates and Canada. Gulfwatch continues to monitor contaminants in the Gulf of Maine to address the goals established by the Council and articulated in their 2007-2012 Action Plan. The program continues to refine temporal and spatial sampling and analytical protocols to provide information for coastal resource managers who make decisions on issues related to contaminants in near shore waters of the Gulf of Maine. The Gulfwatch 2008 data report provides contaminant information for this purpose and to inform researchers and others living around the Gulf of Maine Environment.

6.0 REFERENCES

Aguilar, A., A. Borrell, P.J.H. Reijnders. 2002 Geographic and temporal variation in levels of organochlorine contaminants in marine mammals. *Mar. Environ. Res.* **53**, 425-452.

Airas, S. 2003. Trace metal concentrations in blue mussels *Mytilus edulis* (L.) in Byfjorden and the coastal areas of Bergen. M.S. Thesis. Institute for Fisheries and Marine Biology, University of Bergen, Bergen, Norway.

Barnes, R. D. 1074. *Invertebrate Zoology*, 3rd Edition, W.B. Saunders Company, Philadelphia, PA, pp. 374-385.

Bruland, K.W., and R.P. Franks, R. P. 1983. Manganese, nickel, copper, zinc, and cadmium in the western North Atlantic in *Trace Metals in Seawater* (Eds. Wong, C. S., Boyle, E. A., Bruland, K. W., Burton, J. D. & Goldberg, E. D.) (Plenum, New York) pp. 395−414.

Bruland, K.W. and M.C. Lohan. 2004. The control of trace metals in seawater. Chpt 2 in *The Oceans and Marine Geochemistry*, Vol. 6 (Ed. Harry Elderfield) in Treatise on Geochemistry (Eds. H.D. Holland and K.K. Turekian.

Buchholtz ten Brink, M., F.T. Manheim, J.C. Hathaway, S.H. Jones, L.G. Ward, P.F. Larsen, B.W. Tripp & G.T. Wallace. 1997. *Gulf of Maine Contaminated Sediment Database: Draft final report*. Regional Marine Research Program for the Gulf of Maine, Orono, ME.

Burdige, D.J. 2006. *Geochemistry of Marine Sediments*, Princeton University Press, Princeton, NJ, 630 pp.

Burns W.A., Mankiewicz P.J., Bence A.E., Page D.S., Parker K. 1997. A principal component and least-squares method for allocating sediment polycyclic aromatic hydrocarbons in sediment to multiple sources. *Environ Toxicol Chem* 16:1

Cantillo, A.Y., 1998. Comparison of results of mussel watch programs of the United States and France with worldwide Mussel Watch studies. Mar. Poll. Bull. **36**: 712–717.

Capuzzo, J.M. 1974. *The impact of chromium accumulation in an estuarine environment*. Ph.D. Thesis. University of New Hampshire, Durham, NH. 170p.

Capuzzo, J.M. 1996. Biological effects of toxic chemical contaminants in the Gulf of Maine. In *Proceedings of the Gulf of Maine Ecosystem Dynamics Scientific Symposium and Workshop*. Ed G.T. Wallace and E.F. Braasch, pp. 183-192. Regional Association for Research in the Gulf of Maine, Hanover, NH.

Census of Marine Life - Gulf of Maine Area, 2008. http://www.usm.maine.edu/gulfofmainecensus/.

Chen, C, Amirbahman, A., Fisher, N., Harding, G., Lamborg, C. , Nacci, D. and D. Taylor. 2009 (on line). Methylmercury in marine ecosystems: spatial patterns and processes of production, bioaccumulation, and biomagnifications. DOI: 10.1007/s10393-008-0201-1

Dolan, A.H., M. Taylor, B. Neis, R. Ommer, J. Eyles, D. Schneider, and B. Montevecchi. 2005. Restructuring and health in Canadian coastal communities. *EcoHealth* **2**: 195-2008.

Dow, D. & E. Braasch. 1996. *The Health of the Gulf of Maine Ecosystem: Cumulative Impacts of Multiple Stressors*. D. Dow and E. Braasch (Eds). Regional Association for Research on the Gulf of Maine (RARGOM) Report 96-1. April 30, 1996. 181 pp. plus appendices.

Glynn, D.E., E. McGovern, L. Tyrrell, B. McHugh, E. Monaghan, and J. Costello. 2004. A review of trace metals and chlorinated hydrocarbon concentrations in shellfish from Irish waters, 1993-2002. *In*: Book of Abstracts. 5th International Conference in Molluscan Shellfish Safety, 14-18 June, 2004. Galway, Ireland. P. 149.

Jones, S. H., M. Chase, J. Sowles, P. Hennigar, W. Robinson, G. Harding, R. Crawford, D. Taylor, K. Feeman, J. Pederson, L. Mucklow, and K. Coombs. 1998. Evaluation of

Gulfwatch: the first five years. The Gulf of Maine Council on the Marine Environment, State Planning Office, Augusta, ME.

Kawaguchi, T., D. Porter, D. Bushek & B. Jones. 1999. Mercury in the American oyster *Crassostrea virginica* in South Carolina, U.S.A., and public health concerns. *Mar. Poll. Bull.* **38**: 324-327.

Kimbrough, K.L., W.E. Johnson, G.G. Lauenstein, J.D. Christensen, and D.A. Apeti. 2008. An assessment of two decades of contaminant monitoring in the Nation's coastal zone. Silver Spring, MD. NOAA Technical Memorandum NOS NCCOS 74. 105 pp.

Mallory, M. L., B.M. Braune, M. Wayland, and K.G. Drouillard. 2005. Persistent organic pollutants in marine birds, arctic hare and ringed seals near Qikiqtarjuaq, Nunavut, Canada. *Mar. Poll. Bull*. **50**: 95-102.

McIntosh, A.D., J. Petrie, L. Webster, X. Bredzinski, and C.F. Moffat. 2004. Measurements of chemical contamination in shellfish from Scottish waters. *In*: Book of Abstracts. 5th International Conference in Molluscan Shellfish Safety, 14-18 June, 2004. Galway, Ireland. P. 153.

Monirith, I., D. Ueno, S. Takahashi, H. Nakata, A. Sudaryanto, A. Subramanian, S. Karrupiah, A. Ismail, M. Muchtar, J. Zheng, B. Richardson, M. Prudente, N.D. Hue, T.S. Tana, A. Tkalin, and S. Tanabe. 2003. Asia-Pacific mussel watch: monitoring contamination of persistent organochlorine compounds in coastal waters of Asian countries. *Mar. Poll. Bull*. **46**: 281-300.

NAS (National Academy of Sciences) 1980. The International Mussel Watch. National Academy of Sciences. Washington D.C. 248p.

National Research Council (NRC). 1985. *Oil in the Sea: Inputs, Fates, and Effects.* National Academy Press, Washington, D.C., 601 pp.

NCCOSC, Naval Command, Control, and Ocean Surveillance Center. 1997. Estuarine ecological risk assessment in Portsmouth Naval Shipyard, Kittery, ME, Vol 1: Technical Report. Revised Draft Final. Northern Division, Naval Facilities Engineering Command, Lester, PA.

Neff J.M., Stout S.A., Gunster D.G. 2005. Ecological risk assessment of PAHs in sediments. Identifying sources and toxicity. *Integrated Environmental Assessment and Management* 1:22-33.

NOAA, National Oceanic and Atmospheric Administration. 1989. *A summary of data on tissue contamination from the first three years (1986-1988) of the mussel watch project*. National Status and Trends Program for Marine Environmental Quality Progress Report. NOAA Technical Memorandum NOS OMA 49.

NOAA (National Oceanic and Atmospheric Administration), 1991. Mussel Watch Worldwide Literature Survey - 1991. NOAA Technical Memorandum NOS ORCA 63. Rockville, MD. 143 pp.

O'Connor, T.P. 1998. Mussel Watch Results from 1986 to 1996. *Mar. Poll. Bull* **37:** 14 19.

O'Connor, T.P. 2002. National distribution of chemical concentrations in mussels and oysters in the USA. *Mar. Environ. Res.* **53,** 117-143.

O'Connor, T.P., Beliaeff, B., 1995. Recent trends in coastal environment quality: results from the Mussel Watch Project. NOS ORCA Spec. Pub. NOAA/NOS/ORCA, Silver spring, MD, 44 pp.

O'Connor, T.P and G.G. Lauenstein. 2006. Trends in chemical concentrations in mussels and oysters collected along the US coast: update to 2003. *Mar. Environ. Res.* **62**, 261 285.

Sanudo-Wilhemy, S.A. & A.R. Flegal 1992. Anthropogenic silver in the southern California Bight: a new tracer of sewage in coastal waters. *Environ. Sci. Technol.* **26**: 2147-2151.

Seed, R. 1968. Factors influencing shell shape in *Mytilus edulis* L. *Journal of the Marine Biological Association U.K.* **48**, 561-584.

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

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

Shaw, S.D., D. Brenner, C.A. Mahaffey, S. De Guise, C.R. Perkins, G.C. Clark, M.S. Denison, and G.T. Waring. 2003. Persistent organic pollutants and immune function in US Atlantic coast harbor seals (*Phoca vitulina concolor*). *Organohalogen Compounds* **62**, 220-223.

Sowles, J., R. Crawford, P. Hennigar, et al., 1997. Gulfwatch Project Standard Procedures: Field and Laboratory, Gulfwatch Implementation Period 1993-2001. Gulf of Maine Council on the Marine Environment.

Weisbrod, A., D. Shea, M. Moore, and J. Stegeman. 2000. Organochlorine exposure and bioaccumulation in the endangered Northwest Atlantic right whale (*Eubalaena glacialis*) population. *Environ. Tox. Chem.* **19**, 654-666.

Wells, P.G. & Rolston, S.J. 1991. *Health of our Oceans. A status report on Canadian Marine Environmental Quality. Conservation and Protection*. Environment Canada, Ottawa, ON. and Dartmouth, N.S.

Widdows, J. 1985. Physiological measurements. In: The effects of stress and pollution on marine animals. B.L. Bayne, D.A. Brown, K. Burns, D.R. Dixon, A. Ivanovici, D.R. Livingstone, D.M. Lowe, M.N. Moore, A.R.D. Stebbing & J. Widdows, eds. Praeger Publishers, New York. Pp 3-39.

Widdows, J. & P. Donkin. 1992. Mussels and environmental contaminants: Bioaccumulation and physiological aspects. *In*: Gosling, E. (ed.) The mussel *Mytilus*: Ecology, physiology, genetics and culture. New York: Elsevier Science Publishers. pp. 383-424.

Widdows, J., Donkin, P., Brinsley, M.D., Evans, S.V., Salkeld, P.N., Franklin, A., Law, R.J. & Waldock, M.J. 1995. Scope for growth and contaminant levels in North Sea mussels *Mytilus edulis*. *Marine Ecology Progressive Series* **127**,131-148.

7.0 ACKNOWLEDGEMENTS

The authors are grateful to the following individuals for their help in sampling and processing the 2008 samples: Andrew Bagnall, Jay Baker, Jason Burtner , Todd Callaghan, Noel Carlson, Amber Currier, Paul Currier, Charles Elvin, Bob Gaudet, Sara Grady, Deb Lamson, Rob Livingston, Ronald MacDonald, Joanne McLaughlin, Tina Nims, Andrea Riley, Irma Simon, Jan Smith, Alan Tattrie, Don Walter, and Eric Williams. Further, we would like to thank the personnel contributions from numerous partners, organizations and agencies working in the region including, but not limited to: the Department of Fisheries and Oceans, Canada; Nova Scotia Environment; the Nova Scotia Department of Fisheries and Aquaculture; the New Brunswick Department of Agriculture, Fisheries, and Aquaculture; the Massachusetts Office of Coastal Zone Management; the Massachusetts Bays National Estuary Program; the Department of Environmental Services, NH; the University of New Hampshire; the Division of Marine Fisheries, ME; and the Maine State Planning Office for assistance in sample collection, sample preparation and laboratory analyses. This study was made possible through the diligent fieldwork of teams in Massachusetts, New Hampshire, Maine, New Brunswick and Nova Scotia. The study team gratefully acknowledges financial support from the U.S. Environmental Protection Agency through the U.S. Gulf of Maine Association and Environment Canada and the laboratory support for determinations of organic pollutants by Environment Canada.