



NOAA NATIONAL STATUS & TRENDS

MUSSEL WATCH PROGRAM

An Assessment of Two Decades of Contaminant Monitoring in the Nation's Coastal Zone



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Citation for this Report

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.

AN ASSESSMENT OF TWO DECADES OF CONTAMINANT MONITORING IN THE NATION'S COASTAL ZONE

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DIRECTOR'S SUMMARY

It is with great pleasure that I welcome you to the National Status & Trends Program's "Mussel Watch: An Assessment of Two Decades of Contaminant Monitoring in the Nation's Coastal Zone." Based upon one of the National Oceanic and Atmospheric Administration (NOAA) foundational data sets, and one of the nation's longest running ecosystem monitoring programs, this report is the first in what will become a series of routine updates. The National Status and Trends Program is part of NOAA's mandate called for by Congress under the National Coastal Monitoring Act and is a crucial component of NOAA's mission. Mussel Watch is but one of the many scientific activities undertaken by NOAA's National Ocean Service and its National Centers for Coastal Ocean Science (NCCOS). NCCOS' mission is to provide coastal managers with scientific information and tools needed to balance society's environmental, social, and economic goals, and this report takes a significant step in that direction by providing a clear and concise summary of coastal contamination levels over the past 20 years. The report examines the impacts of regulating contaminants on their presence, distribution and levels in our coastal and Great Lakes waters, as well as other intriguing interpretations of why the levels are what they are today.

National scale assessments such as this are of immense value, but they are rare in the ecological world. They provide a science based approach to highlight and quantify connectivity that is otherwise lost in a local or regional study alone. As can be seen with mercury contamination in the US coastal zone, what happens in one region can affect localities thousands of miles away. Linking localities, regions and ecosystems together is an important and necessary part of solving environmental problems. The long-term data collections (monitoring) necessary for assessments are expensive and difficult to sustain. These kinds of long-term, data collections are not the kind of glamorous, short-term items that gain much of society's everyday attention. But, the benefits of having these types of data over the long-term far outweigh the costs of continuing them. Without these data, the kinds of scientifically based assessments presented in this report are not even possible.

NCCOS performs a wide range of coastal and Great Lakes characterization activities, including coral reef ecosystem assessments, land use impact assessments on coastal resources in the form of an annual oxygen depleted area ("dead zone") forecast, and harmful algal bloom (HAB) detection and forecasts, among many others. This impressive range of scientific endeavor is made possible through a world-class staff of scientists that work in laboratories and offices throughout the United States, including in Maryland, North and South Carolina, Alaska and Hawaii, and through its strength in partnership with other Federal, State, Territorial, Academic, Tribal and non-governmental organizations, and with private sector partners the world over. This collective body of work is intended to provide a basis for sound coastal management. By providing relevant and timely information and creative approaches for examining ecological issues, we strengthen the linkage between sound science and management. By using NCCOS' scientific information and tools, managers can balance the impacts of ecosystem stressors with social and economic goals. NCCOS is committed to implementing this vision by providing world-class science that is credible, relevant, and timely. The Mussel Watch Program is central to this vision, and we stand committed to continuing this important activity for years to come. I hope you find the information provided herein to be both enlightening and useful, and welcome your comments on the first ever National Status & Trends Program summary of coastal contamination.

Gary Matlock, Ph.D.
Director
National Center for Coastal Ocean Science





EXECUTIVE SUMMARY

Information found in this report covers the years 1986 through 2005. Mussel Watch began monitoring a suite of trace metals and organic contaminants such as DDT, PCBs and PAHs. Through time additional chemicals were added, and today approximately 140 analytes are monitored. The Mussel Watch Program is the longest running estuarine and coastal pollutant monitoring effort conducted in the United States that is national in scope each year. Hundreds of scientific journal articles and technical reports based on Mussel Watch data have been written; however, this report is the first that presents local, regional and national findings across all years in a Quick Reference format, suitable for use by policy makers, scientists, resource managers and the general public.

Pollution often starts at the local scale where high concentrations point to a specific source of contamination, yet some contaminants such as PCBs are atmospherically transported across regional and national scales, resulting in contamination far from their origin. Findings presented here showed few national trends for trace metals and decreasing trends for most organic contaminants; however, a wide variety of trends, both increasing and decreasing, emerge at regional and local levels. For most organic contaminants, trends have resulted from state and federal regulation. The highest concentrations for both metal and organic contaminants are found near urban and industrial areas.

In addition to monitoring throughout the nation's coastal shores and Great Lakes, Mussel Watch samples are stored in a specimen bank so that trends can be determined retrospectively for new and emerging contaminants of concern. For example, there is heightened awareness of a group of flame retardants that are finding their way into the marine environment. These compounds, known as polybrominated diphenyl ethers (PBDEs), are now being studied using historic samples from the specimen bank and current samples to determine their spatial distribution. We will continue to use this kind of investigation to assess new contaminant threats.

We hope you find this document to be valuable, and that you continue to look towards the Mussel Watch Program for information on the condition of your coastal waters.

Gunnar G. Lauenstein, Ph.D., Mussel Watch Program Manager



REPORT DESCRIPTION

This report is designed to present background information, results and data interpretations in a clear and concise format. The results include a guide with the information needed to interpret the maps and graphs. Appendix 2 summarizes the information for each site by state.

ACKNOWLEDGEMENTS

This report could not have been completed without the cooperation, time and effort contributed by many, whose collective input has resulted in a document far superior to that which we envisioned on our own. We would like to thank all of the reviewers and collaborators for their invaluable assistance.

Richard Batuik	U.S. Environmental Protection Agency
Benoit Beliaeff	IFREMER - Institut français de recherche pour l'exploitation de la mer
Ken Buja	National Oceanic and Atmospheric Administration
Chris Caldwell	Consolidated Safety Services, Inc.
Eric Carr	Consolidated Safety Services, Inc.
Alicia Clark	National Oceanic and Atmospheric Administration
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Russ Flegal	University of California, Santa Cruz
Mike Fulton	National Oceanic and Atmospheric Administration
Dominic Gregorio	California Water Resources Control Board
Carl Hershner	Virginia Institute of Marine Science, College of William & Mary
Katherine Nielsen	National Oceanic and Atmospheric Administration
John Macauley	U.S. Environmental Protection Agency
Keith Maruya	Southern California Coastal Water Resources Project
Tom McDonald	Texas A&M University
Terry McTigue	National Oceanic and Atmospheric Administration
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Christine Negra	The H. John Heinz III Center for Science, Economics and the Environment
Tony Pait	National Oceanic and Atmospheric Administration
Oren Perez	Aster Engineering Inc.
Gerhardt Riedel	Smithsonian Environmental Research Center
Larry Robinson	Florida A&M University
Michele Schantz	National Institute of Standards and Technology
Jack Schwartz	Division of Marine Fisheries, Massachusetts, Annisquam River Marine Fisheries Station
Michelle Tomlinson	National Oceanic and Atmospheric Administration
Terry Wade	Texas A&M University
Dave Whittall	National Oceanic and Atmospheric Administration
Ed Wirth	National Oceanic and Atmospheric Administration



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BACKGROUND



NOAA's Mussel Watch Program was designed to monitor the status and trends of chemical contamination of U.S. coastal waters, including the Great Lakes. The Program began in 1986 and is one of the longest running, continuous coastal monitoring programs that is national in scope. The Program is based on yearly collection and analysis of oysters and mussels. These bivalves are sessile organisms that filter and accumulate particles from water; thus, measuring contaminant levels in their tissue is a good indicator of local contamination. Mussel Watch data are useful for characterizing the environmental impact of new and emerging contaminants, extreme events (hurricanes and oil spills), and for assessing the effectiveness of legislation, management decisions and remediation of coastal contamination levels.

NOAA established Mussel Watch in response to a legislative mandate under Section 202 of Title II of the Marine Protection, Research and Sanctuaries Act (MPRSA) (33 USC 1442), which called on the Secretary of Commerce to, among other activities, initiate a continuous monitoring program "to assess the health of the marine environment, including monitoring of contaminant levels in biota, sediment and the water column." As part of the NOAA Authorization Act of 1992, the overall approach and activities of NOAA's National Status and Trends Program (NS&T), including Mussel Watch, were codified under provisions of the National Coastal Monitoring Act (Title V of the MPRSA).

In 1986, the inaugural year of the Mussel Watch Program, 145 sites were sampled. Today, Mussel Watch is comprised of nearly 300 monitoring sites, where more than 140 chemical contaminants, chosen through consultation with experts and scientists from academia and government, are measured. Many of these contaminants are listed as Environmental Protection Agency (EPA) Priority Pollutants (Keith and Teillard, 1979). Legislation has been passed to regulate most of the

PROGRAM GOAL

To support ecosystem-based management through an integrated nationwide program of environmental monitoring, assessment and research to describe the status and trends of our nation's estuaries and coasts.

HIGHLIGHT

Many mussel Watch sites are coincident with the 1976-1978 EPA Mussel Watch sites.

Program staff consulted with state officials, academic professionals and others when sites were established.

Many sites are located in or near NOAA-managed areas (National Estuarine Research Reserves, National Marine Sanctuaries).

Sites were selected in shellfish beds large enough for repeated sampling.

Samples are only collected from natural substrates, caged mussels are not used.

Municipal sewage outfalls or industrial effluents are generally avoided when sites are established.

organic contaminants analyzed by the Mussel Watch Program. Most are toxic to aquatic organisms, and some are taken up and stored in animal tissues with the potential to be transferred through food chains to humans.

This first ever national summary brings together twenty years of Mussel Watch data on contaminant levels in mussels and oysters, and is intended for use by resource managers, policy makers, legislators and concerned citizens. This report compares the status and trends of chemical concentrations at the national level to those found locally or regionally. In cases where no human consumption guidelines are available for shellfish, comparisons can be used to determine if the concentrations are high relative to the rest of the nation.

More detailed information can be accessed at <http://NSandT.noaa.gov>.



PROGRAM DESIGN



Mussels and oysters are widely distributed along the coasts, minimizing the problems inherent in comparing data from markedly different and mobile species, and making them better integrators of contaminants in a given area (Berner et al., 1976; Farrington et al., 1980; Farrington, 1983; and Tripp and Farrington, 1984). They are good surrogates for monitoring environmental quality because contaminant levels in their tissue respond to changes in ambient environmental levels and accumulate with little metabolic transformation (Roesijadi et al., 1984; Sericano, 1993).

Mussel Watch sites were selected to represent large coastal areas that can be used to construct a nationwide assessment. Sites selected for monitoring are generally 10 to 100 km apart along the entire U.S. coastline, including the Great Lakes, Puerto Rico and Hawaii. Where possible, sites were selected to coincide with historical mussel and oyster monitoring locations from other programs, such as the U.S. EPA's Mussel Watch sites that were sampled from 1976 to 1978 (Goldberg et al., 1983), and to complement sites sampled through state programs, such as the California Mussel Watch Program (Martin, 1985).

Because one single species of mussel or oyster is not common to all coastal regions, a variety of species are collected to gain a national perspective. A target species is identified for each site based on abundance and ease of collection. Mussels (*Mytilus species*) are collected from the North Atlantic and Pacific coasts, oysters (*Crassostrea virginica*) from the mid-Atlantic (Delaware Bay) southward and along the Gulf Coast, and zebra mussels (*Dreissena species*), an invasive species, are collected from sites in the Great Lakes (Figure 1; Table 1; Appendix 2).

In spite of the number of sites for a coastline as large as that of the U.S., relatively few species are required to determine a national contaminant perspective. For organic contaminants it is possible to compare across all sites because Mussel Watch species have a similar ability to bioaccumulate contaminants. For trace metals there are clear differences in bioaccumulation abilities between coastal mussels and oysters. Oysters have a greater affinity for zinc, copper and silver while mussels are better able to accumulate lead and chromium.

PROGRAM AT A GLANCE

- Approximately 300 active monitoring sites in the continental U.S., Alaska, Puerto Rico and Hawaii.
- Stations 10 to 100 km apart along the entire U.S. coastline.
- Approximately 140 contaminants monitored in resident bivalve populations



Table 1. Mussel and oyster species used to assess national coastal contamination.

REGION	NUMBER OF SITES*	TARGET SPECIES	NAME USED IN THIS REPORT
Northeast, Southwest, Northwest and Alaska	108	<i>Mytilus edulis</i> , <i>Mytilus californianus</i> , <i>Mytilus galloprovincialis</i> and <i>Mytilus trossulus</i>	Mussels
Southeast and Gulf of Mexico	105	<i>Crassostrea virginica</i>	Oysters
Great Lakes	23	<i>Dreissena polymorpha</i> and <i>Dreissena bugensis</i>	Zebra Mussels

* A subset of sites were used in this report.



Zebra Mussels



Oysters

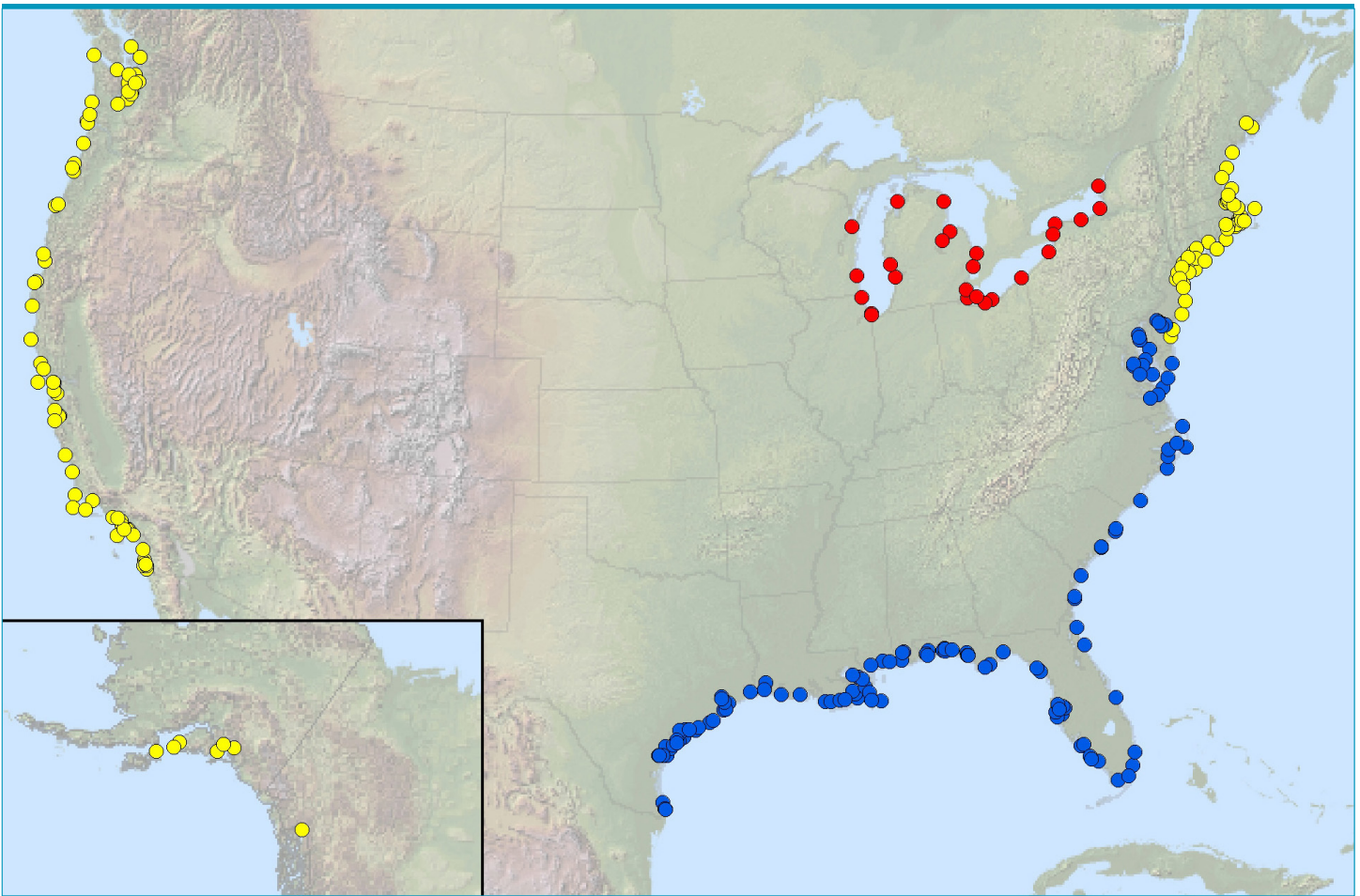


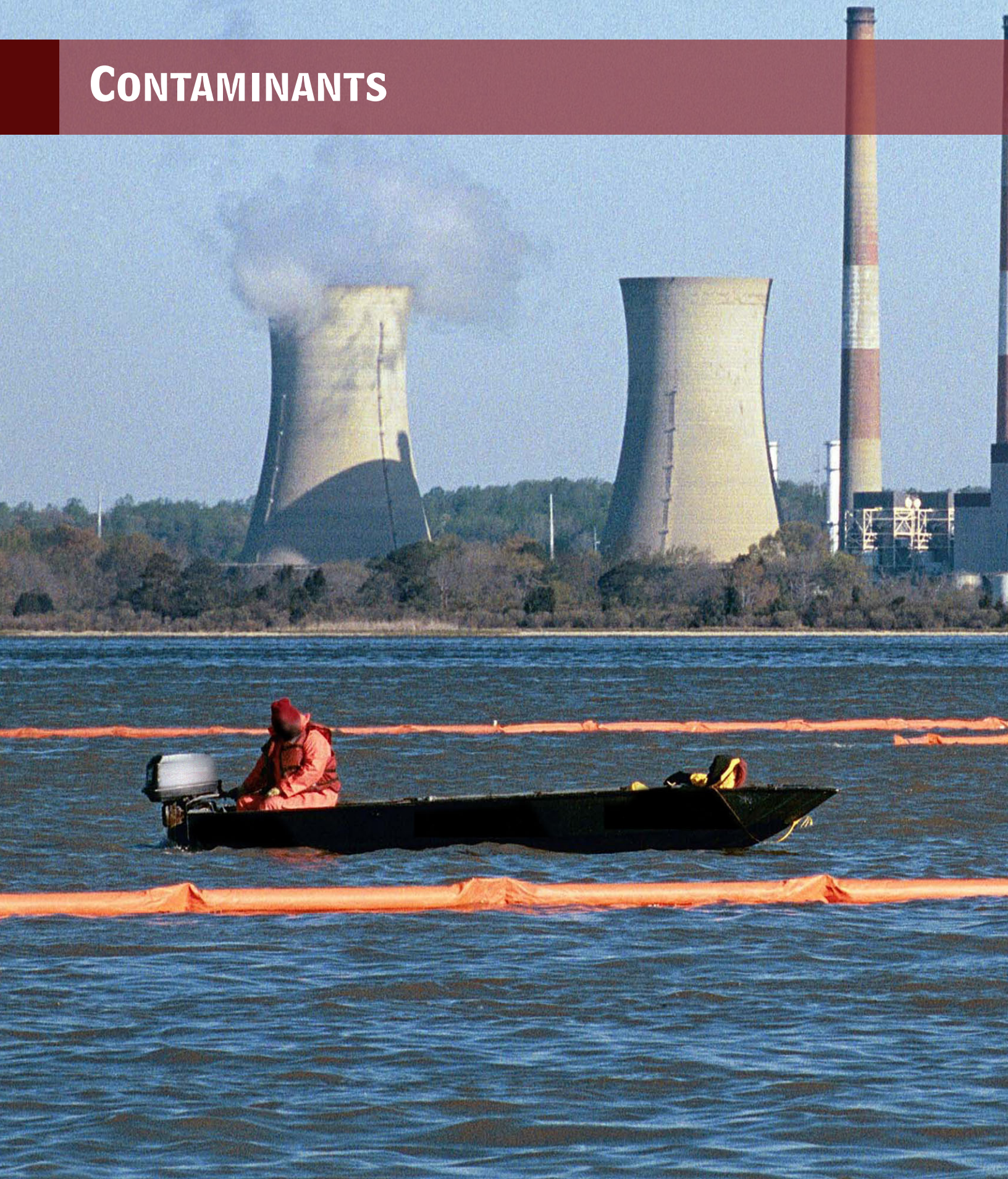
FIGURE 1. Distribution of oysters (*Crassostrea virginica*), mussels (*Mytilus species*), and zebra mussels (*Dreissena species*) collected and measured as part of the Mussel Watch Program.

- **MUSSELS (*MYTILUS SPECIES*)**
- **OYSTERS (*CRASSOSTREA VIRGINICA*)**
- **ZEBRA MUSSELS (*DREISSENA SPECIES*)**

The oysters and mussels analyzed are collected by hand or dredged from intertidal to shallow subtidal zones, brushed clean, packed in iced containers and shipped to analytical laboratories within two days of collection. Sample collection protocols are described in detail in McDonald et al., (2006), Lauenstein et al., (1997), and Lauenstein and Cantillo (1993a-d and 1998). Sample preparation, extraction techniques and analytical methods are too voluminous to report in this document. Detailed analytical methods used by the Mussel Watch Program are available (Kimbrough and Lauenstein, 2006; Kimbrough et al., 2006) online at <http://NSandT.noaa.gov>.

Along with partner laboratories, sampling and analytical methods for monitoring chemicals in oysters, mussels and sediment have been developed. The Mussel Watch Program uses a performance based quality assurance (QA) process to ensure data quality. This effort has been in operation since 1985 and is designed to document sampling protocols, analytical procedures and laboratory performance. Analytical laboratories used by the Mussel Watch Program are required to participate in exercises with assistance from the National Institute of Standards and Technology (NIST) and the National Research Council of Canada (NRC) to ensure data are comparable in accuracy and precision (Willie, 2000; Schantz et al., 2000).

CONTAMINANTS





CONTAMINANTS

The Mussel Watch Program monitors approximately 140 contaminants including both metals and organic compounds.

A subset of this broad suite of contaminants was chosen for presentation in this report, drawing from compounds that have the greatest geographic and temporal extent, and contemporary relevance. Eight metals (Table 2), representing 35% of all metals evaluated by the Mussel Watch Program, and 61 unique organic contaminants aggregated into eight chemical classes are reported here (Table 3; Appendix 2).

Table 2. Metals measured in the Mussel Watch Program. Those in bold type are included in this report because of their spatial and temporal extent of coverage and relevance.

SYMBOL	ELEMENT
Al	Aluminum
Sb	Antimony
As	Arsenic
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Pb	Lead
Mn	Manganese
Hg	Mercury
Ni	Nickel
Se	Selenium
Si	Silicon
Ag	Silver
Tl	Thallium
Sn	Tin
Zn	Zinc

* For simplicity, the term metal is used without distinction between the true metals and metalloids (elements with metal-like properties, e.g., antimony, arsenic and silicon).

METALS

Metals occur naturally in the environment, but human use of metals, particularly since the industrial age, has resulted in excessive releases. How metals are released into the environment is most important in determining distribution and concentration. Anthropogenic sources of metals include fossil fuel and waste burning, mining and ore processing, chemical production, and agriculture. These sources are largely responsible for the elevated environmental concentrations observed in coastal waters. Transport of metals to coastal and estuarine water occurs primarily from runoff and atmospheric deposition. The relative contribution from each mechanism varies by metal, proximity to sources, and chemical phase (dissolved or particulate-bound). Metals can exist in the environment in several forms of varying toxicity. The analytical methods used by the Mussel Watch Program do not distinguish between these various forms, but instead report values as total metal (aggregation of all species of a metal).

We have chosen to present a subset of the status and trends for trace metals in this report. There are two principal reasons for this, 1) several of these elements are considered to be abundant “earth metals” and 2) the current state of science and associated methods are less certain of guaranteeing accurate and precise quantitation of several metals. Chromium (Cr), Antimony (Sb), Silver (Ag) and Thallium (Tl) can be counted among those difficult to quantify. Moreover, Thallium is generally found in such low concentrations that our ability to detect its mere presence is restricted. Aluminum (Al), Iron (Fe), Silicon (Si) and Manganese (Mn) are all abundant earth metals. As such, the overriding signal for these chemicals tends to be a direct correlation to local earth crustal composition.



Creosote piling are sources of polycyclic aromatic hydrocarbons.

ORGANICS

Organic chemicals reported here are mostly manufactured and released to the environment either intentionally (e.g., pesticides) or through manufacturing or disposal processes, such as PCBs. Others, such as PAHs, occur both naturally and as a result of human activities. Some of

the chemicals presented here are industrial byproducts and represent major components of other manufactured chemicals. An example of this is the pesticide dieldrin, which itself is a pesticide but also a degradation product of aldrin.

Table 3. Organic contaminant classes summarized in this report. A complete list of the organic contaminants monitored by the Mussel Watch Program is available online at <http://NSandT.noaa.gov>.

COMPOUND CLASS	ORGANIC COMPOUND
PCB* (Sum of 18 PCBs) Polychlorinated biphenyls	PCB8/5, PCB18, PCB28, PCB44, PCB52, PCB66, PCB101/90, PCB105, PCB118, PCB128, PCB138, PCB153/132/168, PCB170/190, PCB180, PCB187, PCB195/208, PCB206, PCB209
PAH** Polycyclic aromatic hydrocarbons (Sum of 19 parent PAH compounds plus 19 groups of alkylated PAHs)	<p>Sum of 7 parent low molecular weight PAHs (with 2 or 3 rings): naphthalene, biphenyl, acenaphthene, acenaphthylene, fluorene, phenanthrene, anthracene</p> <p>plus the sum of 12 parent high molecular weight PAHs (4 or more rings): fluoranthene, pyrene, benz[<i>a</i>]anthracene, chrysene, benzo[<i>b</i>]fluoranthene, benzo[<i>k</i>]fluoranthene, benzo[<i>e</i>]pyrene, benzo[<i>a</i>]pyrene, perylene, dibenz[<i>a,h</i>]anthracene, indeno[<i>1,2,3-cd</i>]pyrene, benzo[<i>ghi</i>]perylene</p> <p>plus the sum of 19 groups of alkylated PAHs: C1-Chrysenes, C1-Dibenzothiophenes, C1-Fluoranthenes/Pyrenes, C1-Fluorenes, C1-Naphthalenes, C1-Phenanthrenes/Anthracenes, C2-Chrysenes, C2-Dibenzothiophenes, C2-Fluorenes, C2-Naphthalenes, C2-Phenanthrenes/Anthracenes, C3-Chrysenes, C3-Dibenzothiophenes, C3-Fluorenes, C3-Naphthalenes, C3-Phenanthrenes/Anthracenes, C4-Chrysenes, C4-Naphthalenes, C4-Phenanthrenes/Anthracenes</p>
DDT (Sum of 6 compounds)	2,4'-DDD; 2,4'-DDE; 2,4'-DDT; 4,4'-DDD; 4,4'-DDE; 4,4'-DDT
Butyltin (Sum of 3 compounds)	Monobutyltin, Dibutyltin, Tributyltin
Chlordane (Sum of 4 compounds)	Alpha-Chlordane, Heptachlor, Heptachlor-Epoxyde, Trans-Nonachlor
Dieldrin (Sum of 2 compounds)	Aldrin, Dieldrin

* Currently 51 PCB congeners are quantified by the program.

** Currently 65 PAHs are quantified by the program.



▼ CHEMICAL BEHAVIOR

Chemical contaminants enter the environment through point or non-point sources. Point source pollution, such as industrial and municipal effluents from a pipe or smokestack, are more easily regulated. In contrast, pollution from non-point sources are diffuse releases of chemicals to the environment such as runoff from agricultural and urban lawns and volatilization of chemicals from land or water to the atmosphere. As a result, non-point source pollution is difficult to measure and regulate.

Once released, a chemical will interact with its environment based upon its unique chemical and physical properties, and the prevailing environmental conditions. These properties can be used to predict a chemical's movement (transport) and its transformation (fate) into other chemicals of greater or lesser environmental consequence. Once a chemical is regulated, over time one would expect a net decrease in the contaminant (parent compound) and net increase in transformation products. These processes can result in dilution and/or concentration of chemicals in specific environmental media, such as water, sediment or biota. Fate and transport processes are briefly summarized here. For a more detailed discussion, see Manahan (2005).

Atmospheric Fate and Transport

Atmosphere releases can occur from both point and nonpoint sources such as smokestack emission, motor vehicle exhaust, volatilization of pesticides from soil and plants, volcanic eruptions, and forest fires. Many chemical contaminants spend part of their life in the atmosphere bound to airborne particles and transported short or long distances. Contamination of remote environments including coastal areas occurs in the form of wet and dry deposits of particles.

Atmospheric transport, in contrast to other forms of chemical transport, results in diffuse regional, intercontinental and global distribution of contaminants, especially for persistent compounds that degrade slowly. Wide dispersion results in ambient levels being found globally. The "grasshopper effect" (global distillation) is a type of atmospheric transport whereby volatile chemicals released to the environment in lower (warmer) latitudes volatilize from land and surface waters and are transported in the atmosphere and redeposited in higher (cooler) latitudes. The process is repeated in "hops" and leads to a net gain in concentration at higher latitudes where these chemicals remain trapped. The Arctic and near Arctic environments have become a sink for some chemicals far from where they were used or released by human activities.

Aquatic Fate and Transport

Point and non-point sources of pollution to our streams, rivers and coastal waters have left a legacy of pollution in some areas from industrial discharges, along with agricultural and urban runoff. Contaminants that enter water may become more reactive, attach to suspended particles, settle to the bottom or be taken up by organisms. Resuspension of sediments can reintroduce contaminants to the overlying water column, thereby making sediments both a source and a sink for contaminants. In addition, sediment accumulation is also associated with permanent storage of contaminants.

Bioaccumulation

An organism's behavior and physiology, coupled with a chemical contaminant's physico-chemical properties and bioavailability, determine which compounds are taken up by an organism and the associated biological effects. Some chemicals may be toxic to an organism while others may simply accumulate in tissue without harm. Metals tend to accumulate in selected tissues such as liver, kidney or bone, while organic contaminants usually accumulate in fat tissues. Carnivores, particularly those at the top of the food chain (including humans), can be exposed to large amounts of contaminants that are accumulated in tissue of their prey. Mussels and oysters accumulate contaminants across their gills and by ingestion of particles. For some metals, mussels and oysters do not regulate concentrations in their tissue, but instead respond to changes in their immediate environment. Zebra mussels may have elevated levels of some metals as a result of differences between fresh and saline water chemistry.

SPECIAL EVENT SAMPLING

Mussel Watch assesses environmental impacts in response to catastrophic events. By using historical Mussel Watch measurements, environmental impacts in affected areas are determined. Special event assessments include, but are not limited to:

- San Francisco Bay Cosco Busan oil spill
- Gulf Coast Hurricanes Katrina and Rita
- Delaware Bay Athos 1 oil spill
- Attack on the World Trade Center
- North Puget Sound Point Wells oil spill

MUSSEL WATCH HISTOPATHOLOGY



Ciliated parasites in *Crassostrea virginica*. Arrows indicate examples.

The histopathology component of the Mussel Watch Program, quantifies the stage of gamete development, and the prevalence of nearly 70 diseases and parasites found in mussels and oysters. Trends in histopathology data may help to assess the effects of global warming.



Mussel Watch site under bridge in Mississippi after Hurricane Katrina.



▼ DATA ANALYSIS AND INTERPRETATION

Results for each contaminant presented in this report are divided into two sections. Status provides a current measure of the degree of chemical contamination in the environment, while trends provides historical context about how concentrations have changed over time. This report provides our interpretation to help the reader better understand how human actions have resulted in what we see today. Armed with this information, the nation can take meaningful action to improve future coastal conditions. A short discussion of how we have chosen to convey both status and trends in this report follows. Understanding how these components are derived and presented is critical to the interpretation of information presented in results section of this report.

STATUS

The status of a contaminant was derived from the most recent (2004-

2005) chemical concentration measurements taken at each sampling site. These site-specific measurements were assigned to a concentration range: high, medium or low. Ranges were calculated using a statistical procedure called “clustering” – or statistical classification – that partitions contamination levels into groups so that the data in each subset share a common trait. Numbers contained within a group are more like each other than any number in a different group. Cluster values are not associated with action levels or human health advisory concentrations. Each designated classification shows relative differences between sites. Clustering was performed on regional, national and summarized data as described below.

Concentration ranges for each contaminant were determined separately for each species group - mussels (*Mytilus species*), oysters (*Crassostrea virginica*) and zebra mussels (*Dreissena species*) - to account for

species behavior and physiological differences that effect the levels of chemicals measured in their tissues. The results of these analyses appear in the Regional Species Comparison maps found in the Trace Metals and Organic Contaminant Status and Trends section. Species related concentration differences are found for some metals. For example, zinc and copper concentrations are usually 10 times higher in oysters than in mussels, whereas lead is often three times higher in mussels than in oysters. This implies that the presentation of Great Lakes results is distinct from the results of analysis of oysters, which are distinct from mussels. As such, it is equally important to note that each classification analysis will result in a separate high, medium or low category, and that when compared among species will not necessarily be the same range. As presented, the status can be viewed as a relative measure among locations that share a common species.

Towards developing an overall national summary, results of the aforementioned national assessment cluster analyses were used. Specifically, low, medium and high cluster results were numerically weighted by assigning each a value of 0, 1 and 2 respectively. For example, if a measurement for a metal was categorized as low it received a score of 0. For each site the numbers were added to determine the site with the most elevated concentrations of metals or organic contaminants. The results were grouped using cluster analysis, into three categories resulting in the low, medium and high categories that are found in the National Summary section of the results. Cluster analysis was applied to all concentration measurements, irrespective of species, to highlight national variability for each contaminant. This presentation can be used to make inter-species comparisons and assess national differences in contaminant concentration. Differences in species uptake will be apparent in the National Comparison Map and the Regional Comparison of Concentration bar charts.

TRENDS

Chemical concentration trends were assessed by correlating contaminant measurements with time. Spearman's rank correlation was used to evaluate whether concentrations co-varied predictably as a function of time (Zar, 1998). That is, as time progressed from the beginning of our monitoring records (1986) to the end of our records (2005), did the concentration of contaminants also progress in an increasing or decreasing manner? The Spearman's rank correlation procedure is a nonparametric technique that is free of assumptions about concentrations being normally distributed with a common variance about sites. The variables used for the Spearman's test were year and site concentration rank median ($n = 10$). Concentration was standardized by ranking to allow for inter-species comparison.

Spearman's rank correlation statistical test was used to evaluate individual contaminants at the site, regional and national scales. Results are presented as decreasing (▼), increasing (▲) or exhibiting no trend (●). The symbology allows the reader to quickly ascertain if concentrations are changing. It is important to note that "no trend" is not necessarily an indication of a lack of management. Rather, it is possible that some contaminants are already at very low levels and that significant reductions are unlikely. As such, it is critical to keep the status component in mind as the reader interprets the trends section.



Great Lakes field sampling.