ENVIRONMENTAL CONTAMINANT MONITORING IN THE GULF OF MAINE

A discussion paper presented at the Northeast Coastal Monitoring Summit, Durham, NH
December 10-12, 2002

M.J. Hameedi, A.S. Pait, R.A. Warner
Center for Coastal Monitoring and Assessment
National Oceanic and Atmospheric Administration
Silver Spring, Maryland

THE ISSUE

Judging from scientific reviews and recommendations, results of public opinion polls and enactment of federal legislation, it is obvious that coastal contamination is a widespread and serious concern. The affected waterbodies include streams, lakes, harbors, estuaries and coastal embayments. They have been impacted through years of maritime commerce, runoff from adjacent and upstream sources, atmospheric deposition, and local municipal and industrial discharges.

Coastal contamination is a globally pervasive phenomenon. Even the most remote sites and endemic fauna in the Arctic have shown levels of certain contaminants that approach or exceed thresholds associated with adverse biological effects. However, the distribution of contaminants is not uniform; it is determined by local point sources, convergence of physical and biological transport pathways, food chains promoting selective uptake, transfer and biomagnification, and accumulation in sediment. In sufficiently high concentrations, the contaminant-laden sediments pose serious health threats to coastal ecosystems, the sustainability of renewable resources, and human health. Within the sediment matrix, contaminants may be resuspended, transported, and redeposited in areas far from the original source. Under some circumstances, contaminants may be desorbed and released into water, making the bottom sediment not only a sink but also a source of contaminants far from their origin. Therefore, contaminants associated with sediments constitute major areas of emphasis in environmental research, monitoring and assessment programs, including the National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program.

Generally, five major types of sediment contaminants are recognized. Directly or indirectly they cause a wide range of adverse biological effects in plants and animals, including people, through direct chemical toxicity, genotoxicity, physiological dysfunction, and behavioral abnormalities. Contaminants include:

- Bulk organics, including organic wastes from sewage treatment plants, oil and grease, other deoxygenating substances, and humic materials.
- Halogenated hydrocarbons or persistent organic contaminants, such as DDTs and PCBs that have accumulated in the environment long after discontinuation of their use.
- Polycyclic aromatic hydrocarbons (PAHs), contaminants associated with crude oil and distillate products, burning of fossil fuels, municipal and industrial effluents, and natural sources.
- Metals, such as copper, iron, zinc, lead and mercury, and metalloids such as arsenic and selenium.
- Nutrients, through unwanted algal growth, oxygen depletion in overlying waters, and altered food chains or species succession.

NOAA's NS&T Program routinely measures a broad suite of chemical contaminants in bivalve tissues collected nationwide. These chemicals include toxic metals and metalloids, organochlorine pesticides, polychlorinated biphenyls, and polycyclic aromatic hydrocarbons. As part of the program's "Bioeffects Studies" additional contaminants, such as dioxins and furans, are measured on a site-specific basis. A recent study to assess sediment toxicity and its associated adverse biological effects in Puget Sound, Washington, 158 chemicals and sediment parameters were measured. A listing of selected contaminants, sources, and potential effects is presented in Table 1.

It is generally recognized that it is not enough just to measure the types and amounts of contaminants in sediment or tissues, one must also look at "biological effects". Reflecting the hierarchical and concentric organization of biological systems, the effects of chemical contaminants may occur at all levels of biological organization, from cells to ecosystems. Effects on biological populations, communities and ecosystems, either directly from contaminant exposure or indirectly through habitat degradation, seem to have more relevance in terms of environmental management and protection of resources. Such effects are difficult to ascertain, in part due to problems in distinguishing between natural and anthropogenic causes, and also due to a lack of comprehensive design of monitoring and assessment studies. It can be reasonably argued that widespread mortality and population-level effects manifest themselves long after biochemical dysfunction, physiological abnormalities, growth impairment, and ecologically important changes have occurred as a result of environmental degradation. Thus, application and further development of biomarkers and ecological indicators as initial assessment tools have become new, key areas of emphasis for determining the cause-effect relationship between an environmental stressor and observed biological response. Over the past 15 years, the NS&T Program has sponsored studies to apply or further develop over 30 different biomarkers as environmental assessment tools. However most biomarkers need further development and nearly all of them lack a definition of "normal range" under different natural environmental conditions or ecosystems. In fact, the reciprocal objectives of increased understanding (toward the molecular or cellular level) or increased relevance (toward the population or ecosystem level) still remains a core issue in assessment of biological effects of pollution.

AGENCY RESPONSIBILITIES

The issue of assessing environmental impacts of coastal contamination is sufficiently complex that no single federal agency is responsible for addressing and resolving the issue. More than 10 different laws give the National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, the Army Corps of Engineers, and other federal and state agencies and tribal entities authority to address environmental contamination issues, notably sediment contamination. From NOAA's point of view, the Marine Protection, Research and Sanctuaries Act, the Coastal Zone Management Act, the Harmful Algal Bloom and Hypoxic Research and Control Act, and the Clean Water Act are noteworthy.

As directed by Federal legislation and under institutional authorities of agencies, the problem of sediment contamination is being addressed by:

- Identifying the spatial extent and severity of sediment contamination in U.S. coastal waters.
- Providing an appropriate degree of uniformity and quality control in coastal monitoring programs and ensuring flexibility in such programs to address region-specific needs.

Table 1. Selected environmental contaminants, their potential effects and possible sources in coastal waters. Abbreviations: PAHs (polycyclic aromatic hydrocarbons), DDTs (dichloro-diphenyl-trichloroethane and its metaboblites), PCBs (polychlorinated biphenyls), PBDEs (polybrominated diphenyl ethers), PFOS (perfluoro-octane sulfonate), and APEs (alkylphenol ethoxylates).

Contaminant	Adverse Biological Effects	Possible Sources
Cadmium	Acute toxicity; long biological half-life, which makes it a cumulative toxin; kidney lesions and renal dysfunction; occupational exposure linked to cancer (prostate and pulmonary carcinomas); no consensus on genotoxicity	Electroplating, plastics, batteries, ceramic pigments, and sewage; also human exposure through consumption of grains and cereals; smoking
Chromium	Acute toxicity; putative mammalian carcinogen; corrosive ulceration; hypersensitivity reactions; renal tubular necrosis	Coal combustion; smelting; electroplating / metal finishing; tanneries; alloys and pigments; wastewater, urban runoff, phosphate fertilizers
Copper	Acute toxicity; DNA damage (binds with phosphate on nucleotides and nucleic acids); putative mutagen and carcinogen; possible synergism with known mutagens	Shipbuilding and repair facilities; oil/fuel combustion, antifouling paints, metals cleaning, plating, pigments and dyes, pipes, wood preservatives, and sewage
Lead	Acute toxicity, enzyme suppression; chronic effects (reduced growth, anorexia and anemia in birds); human health hazard (neurologic, blood and renal systems)	Atmospheric deposition, ceramics and metal industries, paints, batteries, sewage
Mercury	Acute toxicity, behavioral toxin, reduced growth and development	Atmospheric deposition, incinerators, paints, batteries, electrical switches
Zinc	Acute toxicity; abnormal amounts associated with cancer risks in animals and humans (positive and negative association); retards protective effects of selenium against cadmium carcinogenesis; reduced survival of early life stages; toxic co-factor.	Iron and steel industries; metal coatings, batteries, printing industry; municipal wastewater, sludge, industrial effluents, and urban runoff
Arsenic	Acute and wide-ranging chronic toxicity; inhibition of ATP synthesis; impaired cardiovascular and nervous systems; skins lesions and depigmentation; genotoxic	Iron, copper and gold smelting; coal combustion; pesticides; poultry feed; electronic devices; phosphate minerals

Table 1. Selected environmental contaminants, their potential effects and possible sources in coastal waters (continued).

PAHs	Direct chemical toxicity and gentoxicity; complete carcinogens; impaired olfactory responses and behavior; reduced survival; inhibited reproduction; changes in species populations and community composition	Fossil fuel [incomplete] combustion; oil production and transportation, oil spills; oil seeps; urban runoff; sewage and industrial effluents; diagenesis of organic matter.
DDTs	Highly toxic, with extensive mortality in non-target organisms; embryotoxicity; eggshell thinning and depressed reproduction in birds.	Extensively used worldwide for pest control; globally distributed and highly persistent in soils and sediments; long half-life in animals. Its use is banned or severely curtailed in N. America and Europe since the 1970s.
PCBs	Acute toxicity; bioaccumulative; reproductive and developmental failure; immune system suppression; endocrine disruption; neurotoxic thyroid hyperplasia; other cancers.	Extensively used worldwide in hydraulic fluids, lubricants, dielectric fluids, transformers and capacitors, and as plasticizers. Globally distributed and highly persistent in environment; new use is banned or severely curtailed
PBDEs	Moderately persistent in the environment, bioaccumulative and toxic. Poorly absorbed in tissues; neurotoxic, estrogenic, impaired liver and thyroid function	A group of flame retardant chemicals used worldwide in polymer, textile, polyurethane foam, and electronic industries. Other, similar chemicals are used extensively in circuit boards. Found in sewage sludge and near industrial and municipal outfalls.
PFOS	Environmentally stable, long biological half life; its ionic, polar properties facilitate binding with blood proteins and accumulation in blood and liver; lowered metabolism; reproductive impairment; peroxisome proliferation.	Metabolite of chemicals used for surface treatment of textiles (stain repellant), paper products; fire-fighting foams, oil well surfactants, floor polishers, shampoos; wastewater streams, landfills
APEs	Low bioaccumulation; acute toxicity to fish and invertebrates; estrogenic (induction of vitellogenin, intersex, altered steroid metabolism)	Cleaning agents or surfactants used in household items and a variety of industrial applications (detergents, wool washing, pulp and paper, lubricating oils, agricultural pesticides, adhesives, antioxidant for polymers, paints, tires and rubber, etc.). Input via sewage treatment plants, untreated effluents or runoff. Degradation products are more persistent, lipophilic, toxic and estrogenic than parent compounds.

- Developing technological tools, such as computer-based models, or scientific guidelines to assess current environmental conditions and forecast changes under different resource management scenarios.
- Implementing remediation strategies that will most effectively reduce the risk associated with coastal contamination.

Interagency cooperation (more focused efforts for documenting environmental change and providing solutions to environmental problems and conflicts), federal-state partnerships (for more effective implementation of environmental policy and resource management strategies), and government-academia cooperation (for integrating monitoring and assessment with research, and developing new procedures and technologies) have often been recommended as the means to improve existing environmental monitoring programs. Several efforts are underway that relate to these recommendations as well as the requirements set forth for quality control and dissemination of data.

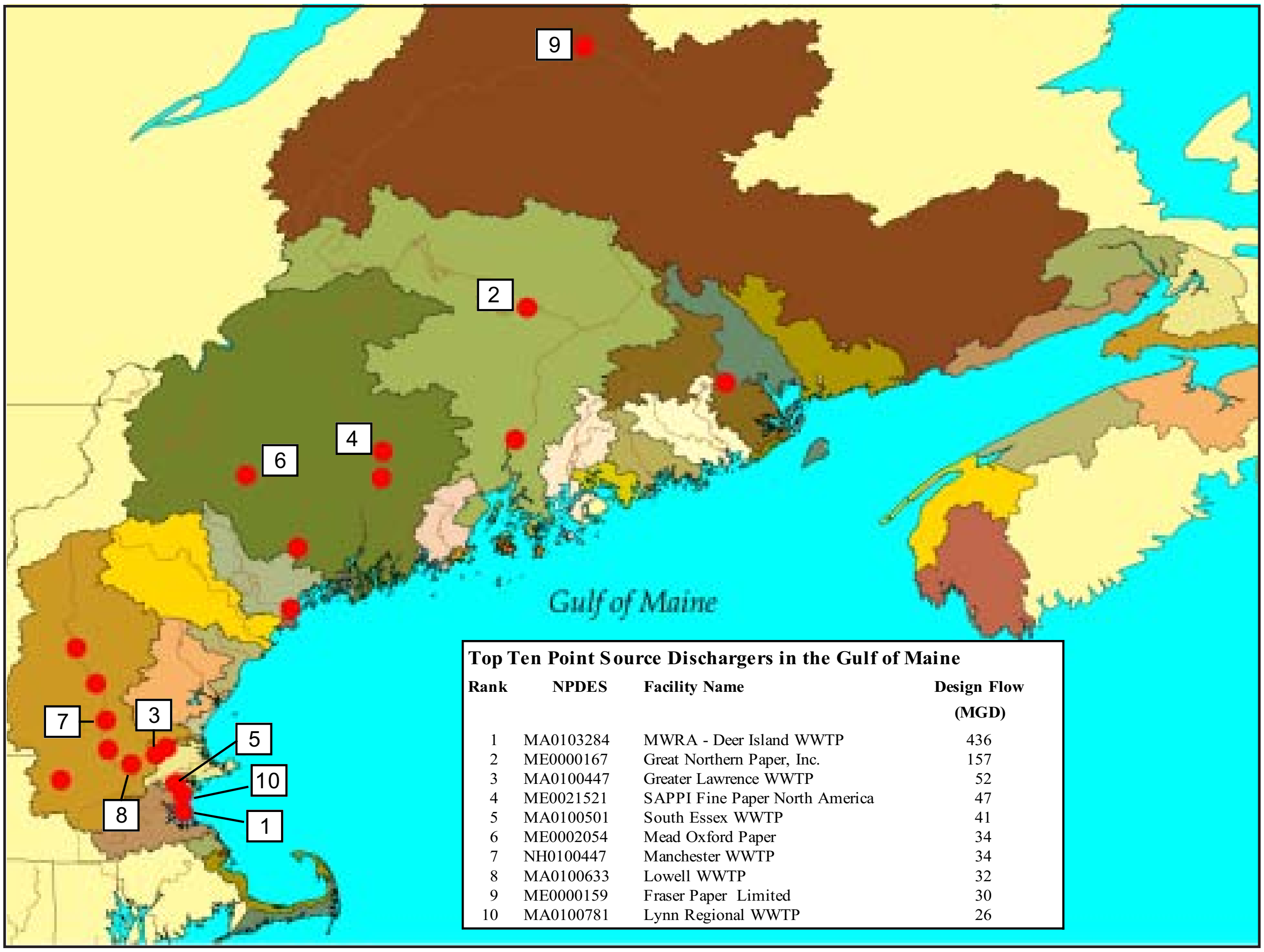
GULF OF MAINE

Although not obvious from its geomorphology, the Gulf of Maine is oceanographically quite discrete, with an area of 90,700 sq. km and an average depth of 150m. Its interior waters are isolated from the northeast Atlantic Ocean by Georges and Brown Banks and Nantucket Shoals. These banks are quite shallow, with typical depths between 20 and 60 m although in some places the minimum depth is less than 5m. The Northeast Channel, a 230m deep depression situated between Georges Bank and Brown Bank, connects the Gulf of Maine to the deeper waters of the Atlantic Ocean. The other main connection, the Great South Channel, situated between Georges Bank and Nantucket Shoal, is only about 75m deep. The Gulf is also characterized by numerous basins and sub-basins, whose sill depths range from 59 to 242m and areas between 30 to 11,000 sq. km. Twenty-one basins are recognized although only three of them are sufficiently large to influence water circulation and residence time in the Gulf: Jordan Basin, Georges Basin and Wilkinson Basin.

Considerable spatial heterogeneity in oceanographic features, seasonally varying inflow of Atlantic Ocean water, freshwater discharge, and heat flux, and interaction between eastern and western coastal currents make for a complex and highly variable circulation regime in the Gulf of Maine. Although surface water circulation in the Gulf is predominantly cyclonic during spring and summer, it is also characterized by cyclonic or anticyclonic gyres over the three main basins and on the banks. Assuming that the circulation is principally estuarine, it can affect the levels and persistence of globally or hemispherically distributed contaminants, for example, organochlorine pesticides and radionuclides, respectively. This would be particularly relevant to contaminants that adsorb to fine sediment particles. It has been shown that radionuclides such as cesium-137 and plutonium-239 and 240 are accumulated in certain parts of the Gulf in excess of the relative amounts in atmospheric fallout, suggesting offshore waters as a quasi-continuous source. No such information is available for other contaminants.

CONTAMINANT SOURCES

Although atmospheric deposition and accumulation of certain offshore-derived contaminants in the Gulf of Maine is considered a likely source, the principal sources of coastal contaminants in the Gulf appear to be municipal outfalls, industrial effluents, and river discharges. Boston Harbor, for example, has consistently shown some of the highest levels of PAHs and PCBs in the region and



Top Ten Point Source Dischargers in the Gulf of Maine

Rank	NPDES	Facility Name	Design Flow (MGD)
1	MA0103284	MWRA - Deer Island WWTP	436
2	ME0000167	Great Northern Paper, Inc.	157
3	MA0100447	Greater Lawrence WWTP	52
4	ME0021521	SAPPI Fine Paper North America	47
5	MA0100501	South Essex WWTP	41
6	ME0002054	Mead Oxford Paper	34
7	NH0100447	Manchester WWTP	34
8	MA0100633	Lowell WWTP	32
9	ME0000159	Fraser Paper Limited	30
10	MA0100781	Lynn Regional WWTP	26

Figure 1. Major point source dischargers in the Gulf of Maine. Data taken from EPA's PCS database (November 2002). Shaded areas represent estuarine drainage areas. Power plants which typically have large cooling water discharges are not included in this map. Values represent design flow, actual daily flow is typically less than the design flow.

Salem Harbor is generally very high in levels of pesticides such as hexachlorobenzene, heptachlor, chlordane and aldrin. Rivers such as the Sasco River contained high amounts of chromium that was used in tanneries.

Recent data have shown elevated levels of silver in sediment and mussel tissues from Boston Harbor and adjacent areas. Silver, often considered a sewage marker in coastal waters, is extensively used in consumer products (for example, batteries, mirror backings, jewelry, breath mints and lozenges), medical applications (for example, photographic and radiographic film processing, dental amalgams, disinfection), and in the electronics and chemical industries. Typical of many metals, silver enrichment in sediment increases with decreasing sediment particle size. There are extensive data on silver toxicity in laboratory mammals and humans; the disease argyria (silver deposition in various tissues) is the most commonly recognized ailment. Silver toxicity to freshwater organisms has also been recognized but data on coastal and marine fauna are very few.

Figure 1 shows the locations of some of the largest (>10 million gallons/day design flow) point source facilities in the Gulf of Maine region. The major watersheds or estuarine drainage areas are

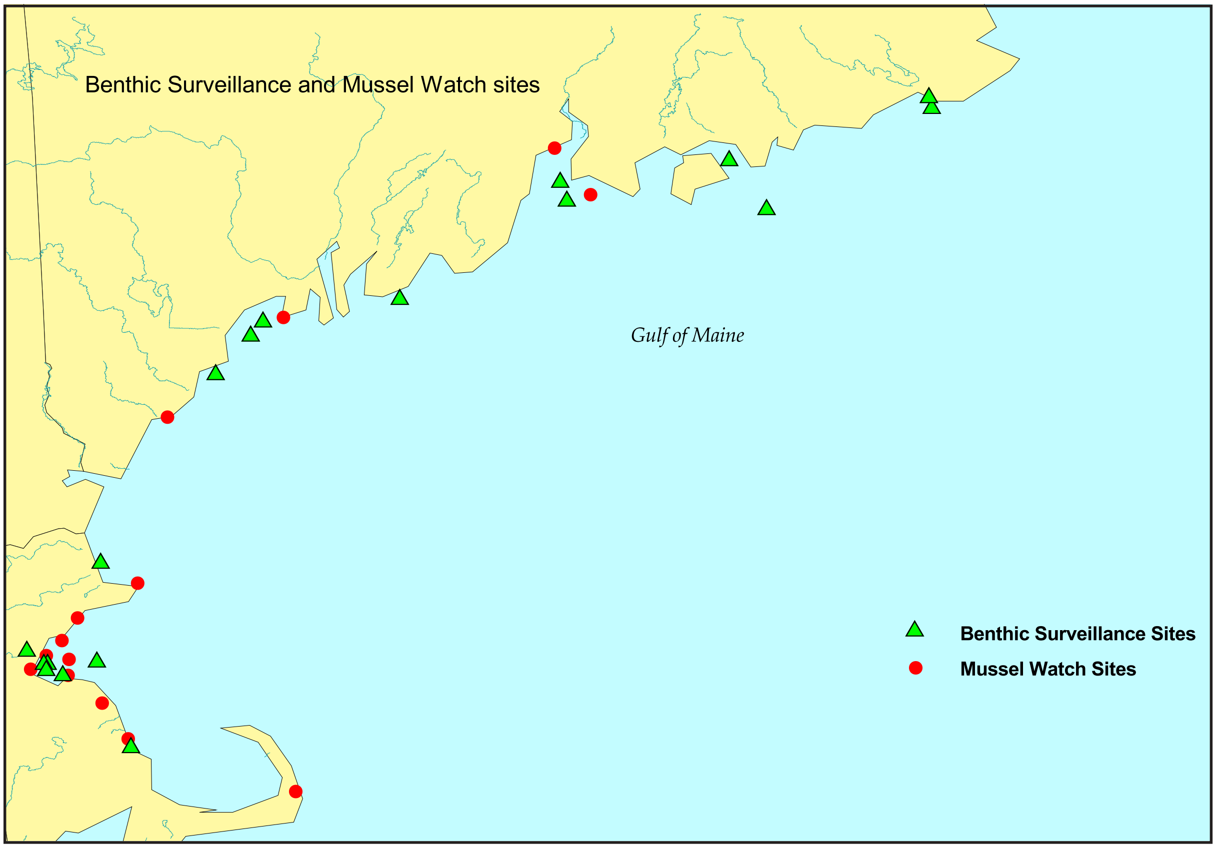


Figure 2. NOAA Mussel Watch and Benthic Surveillance sites in the Gulf of Maine.

also identified in the map. Point source information was derived from EPA's Permit and Compliance System (PCS). Additional information can be found at: www.epa.gov/enviro/html/pcs. Power plants were not included as the majority of their discharge is once-through cooling water which has little net addition of pollutants. In 1994, NOAA completed an inventory of point source facilities in the Gulf of Maine, which is available at: spo.nos.noaa.gov/projects/gomaine.

The major point source dischargers in the Gulf of Maine are wastewater treatment plants (WWTPs) and paper mills. The largest discharger in the region is the recently completed Deer Island WWTP complex in Boston, Massachusetts. This facility discharges approximately 390 million gallons of secondary treated water per day to Massachusetts Bay through a 9.5 mile outfall tunnel. A number of other facilities discharge to Massachusetts Bay or to rivers such as the Merrimack, Penobscot, Androscoggin and Saint John which empty into the Gulf of Maine.

NOAA NATIONAL STATUS AND TRENDS PROGRAM

The NS&T Program was initiated in 1984 in an effort to determine the status of and changes to the environmental conditions of coastal waters and estuaries of the United States. Data and reports from the program are available at: ccmaserver.nos.noaa.gov. The Mussel Watch Project within NS&T routinely monitors for 16 major and trace elements and over 75 organic contaminants in bivalves, at more than 250 sites along U.S. coasts. In the Gulf of Maine, there are 14 Mussel Watch sites (Figure 2). At these locations, the blue mussel *Mytilus edulis* is collected and analyzed for contaminants of interest. Sediments are also collected and analyzed periodically for contaminants.

In addition to the Mussel Watch sampling sites, "Gulfwatch" measures trace element and organic contaminants in blue mussel tissues at 56 sites in the Gulf of Maine. The two projects are generally similar in their respective analytical approaches but, unlike the Mussel Watch Project, Gulfwatch sampling sites are located near industrial wastewater discharge points, municipal outfalls, and urban centers. Further, only one site is sampled annually in each of the five states and provinces bordering the Gulf; the remaining sites are sampled less frequently.

The NS&T Program has also conducted intensive regional studies to define the incidence, severity, and spatial extent of biological impacts from contamination in coastal waters. In 1993, a sediment toxicity study was carried out in Boston Harbor. The study was based on a total of 55 sampling sites that encompassed 56 sq km. That study showed that toxicity, as inferred from sublethal endpoints, was pervasive throughout the study area; it was very restricted based on the amphipod mortality test. No systematic toxicity assessment has been carried out for the Gulf as a whole.

NOAA's National Benthic Surveillance Project (NBSP), another component of the NS&T Program has investigated contaminant-related effects in bottom-dwelling fish, and monitored chemical concentrations in fish and sediments at a number of sites around the U.S. The 18 locations where fish have been collected in the Gulf of Maine as part of NBSP are also shown in Figure 2. In addition to analyzing the concentration of contaminants in fish livers, a series of measures of biological effects of contaminant exposure were also made, including lesions and toxicopathic liver diseases such as neoplasms (tumors) and preneoplasms and other diseases involved in the process of liver neoplasia. Primarily due to funding constraints, the project has remained inactive since 1992. The project's data are useful as background information to evaluate current conditions in certain parts of the Gulf and could also form a basis to formulate future, cooperative research endeavors.