

Federal seafood safety response to the *Deepwater Horizon* oil spill

Gina M. Ylitalo^{a,1}, Margaret M. Krahn^a, Walton W. Dickhoff^a, John E. Stein^a, Calvin C. Walker^b, Cheryl L. Lassitter^b, E. Spencer Garrett^b, Lisa L. Desfosse^c, Karen M. Mitchell^c, Brandi T. Noble^c, Steven Wilson^d, Nancy B. Beck^e, Ronald A. Benner^f, Peter N. Koufopoulos^g, and Robert W. Dickey^f

^aNorthwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, WA 98112; ^bNational Seafood Inspection Laboratory, and ^cMississippi Laboratories, Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Pascagoula, MS 39567; ^dSeafood Inspection Program, National Marine Fisheries Service, Silver Spring, MD 20910; ^eOffice of Information and Regulatory Affairs, Office of Management and Budget, Washington, DC 20503; ^fDivision of Seafood Science and Technology, Gulf Coast Seafood Laboratory, Center for Food Safety and Applied Nutrition, US Food and Drug Administration, Dauphin Island, AL 36528; and ^gDivision of Seafood Safety, Center for Food Safety and Applied Nutrition, US Food and Drug Administration, College Park, MD 20740

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Following the 2010 *Deepwater Horizon* oil spill, petroleum-related compounds and chemical dispersants were detected in the waters of the Gulf of Mexico. As a result, there was concern about the risk to human health through consumption of contaminated seafood in the region. Federal and Gulf Coast State agencies worked together on a sampling plan and analytical protocols to determine whether seafood was safe to eat and acceptable for sale in the marketplace. Sensory and chemical methods were used to measure polycyclic aromatic hydrocarbons (PAHs) and dispersant in >8,000 seafood specimens collected in federal waters of the Gulf. Overall, individual PAHs and the dispersant component dioctyl sodium sulfosuccinate were found in low concentrations or below the limits of quantitation. When detected, the concentrations were at least two orders of magnitude lower than the level of concern for human health risk. Once an area closed to fishing was free of visibly floating oil and all sensory and chemical results for the seafood species within an area met the criteria for reopening, that area was eligible to be reopened. On April 19, 2011 the area around the wellhead was the last area in federal waters to be reopened nearly 1 y after the spill began. However, as of November 9, 2011, some state waters off the Louisiana coast (Barataria Bay and the Delta region) remain closed to fishing.

On April 22, 2010, 2 d after the explosion on the *Deepwater Horizon* (DWH) drilling platform, the rig collapsed and the wellhead failed. The explosion resulted in the loss of human life and the uncontrolled release of >200 million gallons of Louisiana light crude oil occurring ~5,000 feet below the sea surface. DWH was declared a *Spill of National Significance* on April 29, 2010 and became the largest oil spill in US history (1). Among the significant human and environmental impacts of the spill, marine fisheries and supporting marine and estuarine ecosystems were subjected to contamination by crude oil, compromising the safety of seafood resources (1). An immediate and coordinated federal and state response ensued to safeguard seafood safety. Federal and state agencies mobilized personnel and resources to begin sampling seafood on April 28, 2010. Federal and state fishery closures were guided by observations of where oil was seen and forecasted to spread on the basis of climatic and hydrographic models (2). Seafood was collected around the periphery of the closed areas and from dockside and seafood market outlets across the Gulf coast and analyzed for oil-spill related contaminants to assess the effectiveness of the fishery closures. When the flow of oil was stopped on July 15, 2010 and the oil began to dissipate, sampling and analyses were conducted to determine whether seafood from previously closed areas was safe for harvest and human consumption. Sampling of reopened areas in federal waters continued through June 2011. We describe how federal agencies, working with the states, developed seafood safety criteria and protocols. In addition, sampling schemes, analyses, and data reporting for seafood safety efforts

conducted in federal waters are provided. Results of testing the seafood collected in federal waters are also discussed.

Collaboration Among Federal and State Agencies to Develop a Protocol

The US Food and Drug Administration (FDA) operates a mandatory hazard analysis and critical control point (HACCP) safety program for all fish and fishery products under the provisions of the Federal Food, Drug, and Cosmetic Act (21 U.S.C. 301 *et seq.*), the Public Health Service Act (42 U.S.C. 201 *et seq.*), and related regulations. The National Oceanic and Atmospheric Administration (NOAA), under provisions of the Magnuson–Stevens Fishery Conservation and Management Act (16 U.S.C. 1801 *et seq.*), has the authority to close and open, with concurrence of the FDA, federal waters for seafood harvest. Marine resource and public health agencies of states bordering the Gulf of Mexico retain jurisdiction and responsibility for the health and safety of fish and fishery products within their respective territorial waters (3 miles from coastline except for Florida, which is 9 miles from coastline). Under these guidelines, should an oil spill occur, federal and state agencies, including the NOAA and the FDA, determine whether seafood is at risk for contamination and, if so, when seafood from a previously contaminated area may once again be safe for harvest and human consumption.

As the oil spread and fisheries were closed as a result of the spill, scientists and risk managers from all of the affected state and federal agencies convened to develop a comprehensive protocol to ensure the safety of Gulf seafood before impacted areas could be reopened for harvest for the American public. The NOAA publication titled *Managing Seafood Safety After an Oil Spill* provides agencies guidance in such situations (3). This guidance and current information from the FDA, the NOAA, the Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention, and counterpart Gulf state agencies were used to establish a unified DWH seafood protocol (4). The DWH seafood safety risk assessment, an integral component of the protocol, was built upon an approach taken by the FDA in 1990 after the *Exxon Valdez* oil spill in Prince William Sound, Alaska (3). The protocol was implemented, by agreement of all federal and state authorities, in the reopening of commercial and recreational fisheries in both federal and state waters.

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¹To whom correspondence should be addressed. E-mail: gina.ylitalo@noaa.gov.

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Selection of Toxic Crude Oil Chemical Indicators

Crude oil is composed of a complex mixture of hundreds of compounds. Among them, polycyclic aromatic hydrocarbons (PAHs) are recognized internationally as the oil constituents of greatest human health concern because of their persistence in the environment and their potential for toxic or carcinogenic effects in humans (5). Consequently, 13 PAHs and their alkylated homologs were selected as the appropriate chemical indicators of the human health risk posed by crude oil residues in seafood (see *SI Text, List of Polycyclic Aromatic Hydrocarbon (PAH) Chemical Indicators*).

Development of Health Risk Assessment

A human health risk assessment of PAHs in seafood was undertaken to develop maximum exposure levels that are believed to be safe or associated with negligible risk. Uncertainty is inherent in any risk assessment process due to interspecies, intraspecies, or high-to-low dose extrapolations required for risk estimation. Various assumptions must be made to extrapolate data from animal or human studies using models to estimate human population risks. Some subpopulations, such as young children, may be at higher risk due to higher seafood consumption per unit body weight. Other subpopulations, such as elderly people with certain diseases, may be more susceptible to PAH effects from seafood consumption due to compromised health (3). However, many of the inputs used in this health risk assessment were derived to be overly protective to account for uncertainty and variability (e.g., upper 95% confidence bound on cancer risk values and inter- and intraspecies uncertainty factors on reference doses for noncarcinogenic PAHs).

Of the 13 PAHs and alkylated homologs selected for critical analysis of potentially impacted seafood, the criteria agreed upon for 7 PAHs with cancer endpoints provided conservative estimates of contamination levels and consumption rates that, if sustained for a period of 5 y, may result in an upper bound consumer lifetime cancer risk of 1×10^{-5} . The agreed-upon criteria for 6 PAHs with noncancer endpoints were derived from EPA reference doses of daily exposure expected to have no significant risk of adverse effect during a lifetime of exposure (4). The EPA reference doses are derived to be protective of the human population, including sensitive subgroups such as children and pregnant women (see http://www.epa.gov/iris/help_gloss.htm for reference value definitions).

Values for event-specific variables were determined for seafood consumption, average body weight, exposure duration, and averaging time. Seafood consumption data specific only to Gulf Coast populations were not available during development of the protocol and therefore the National Health and Nutrition Examination Survey (NHANES) 90th percentile consumption data for national seafood eaters only were used and were adjusted for consumption frequency (6). Meal portion and frequency (16.4 seafood meals per month) were converted to annualized daily equivalents. The average US adult body weight of 80 kg (7) and averaging time of 78 y (8) were assumed. For purposes of risk assessment, average adult body weight may be viewed as an estimate of average lifetime body weight—and averaging time as average life span—of people composing a population. An exposure duration of 5 y was selected in consideration of the nature of the spilled oil (i.e., light crude), physical conditions (e.g., 29.5 °C water temperature), spill location (50 miles offshore), and metabolic capacities of seafood species likely to be impacted.

Sampling Scheme for Federal Waters

At the greatest extent of the oil spill, most state waters extending from Louisiana to the panhandle of Florida were closed to fishing. By June 2, 2010 ~37% (88,522 square miles) of federal waters in the Gulf Exclusive Economic Zone were closed (Fig. 1) (9). Commercial, recreational, and subsistence harvest areas in federal waters that were likely to be in the path of the spilled oil were selected for sample collection in the NOAA National Marine Fisheries Service seafood sampling plan (10). Initially, the survey design for reopening the closed fishing areas was based on selection of random stations in preoil spill nearshore waters along the coastlines of Louisiana, Mississippi, Alabama, Texas, and Florida. However, a more formal survey design was developed and implemented in May 2010 due to the increased area closed to fishing. In this design, the closed region in federal waters was separated into three broad areas on the basis of the extent of cumulative oil inundation from the initial days of the spill. A fourth “perimeter” area was also established to account for uncertainty in the extent of the spill and fish movement and to provide a baseline of samples from preoil conditions for comparison. Each area was further divided into 30 × 30 nautical mile “grids” extending from the state–federal boundary to the outer boundary of the closed area (Fig. 2) (10).

Grids exhibiting heavy cumulative oil inundation were targeted for more intensive sampling than areas with minimal and

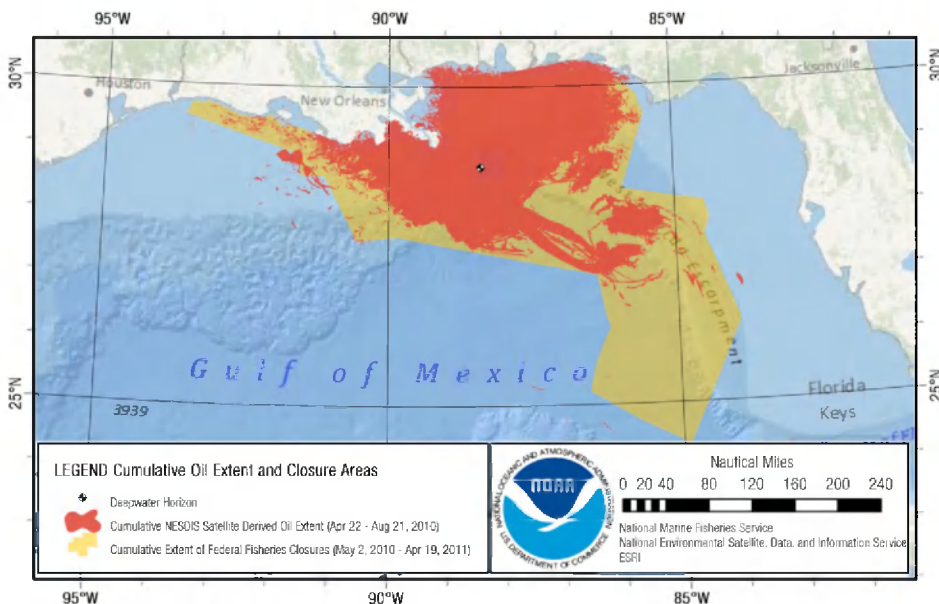


Fig. 1. Gulf of Mexico map showing the extent of oiling that occurred from April 22 through August 21, 2010 after the *Deepwater Horizon* platform explosion occurred on April 20, 2010. The black-and-white circle indicates the wellhead location. The orange shaded areas show the cumulative National Environmental Satellite, Data and Information Service (NESDIS) satellite footprints of the oil. The yellow polygon overlay shows how the federal fisheries closure areas aligned with the oil distribution.

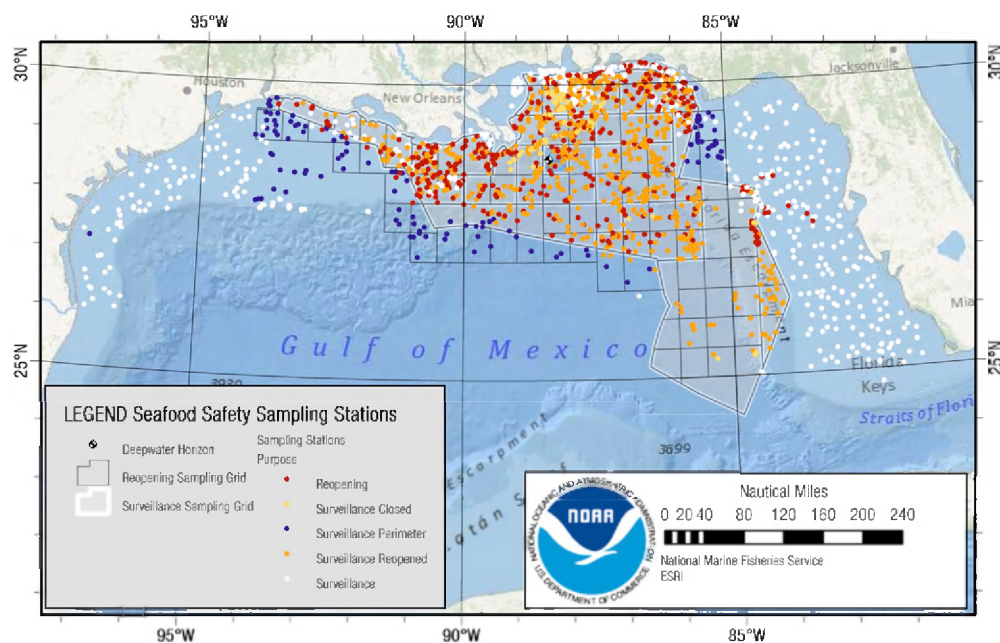


Fig. 2. Gulf of Mexico map showing the constellation of seafood samples collected. The black-and-white circle indicates the wellhead location. The red dots show stations sampled for reopening from June 23, 2010 through March 31, 2011. The yellow, blue, and white dots show stations sampled for surveillance closed, surveillance perimeter, and surveillance, respectively, from April 28, 2010 through January 15, 2011. The orange dots show stations sampled for surveillance of reopened areas from August 13, 2010 through January 9, 2011.

moderate cumulative oil inundation (10). Sampling intensity was measured as the minimum number of stations successfully sampled per grid that then relates to the target sample size. Two stations were successfully sampled in grids with minimal oil inundation whereas five stations were successfully sampled in grids with heavy oil inundation. Stations were generally chosen by random selection for all vessels, with the exception of the pelagic longline sampling, which targets highly migratory species. Due to the amount of area (10–20 miles) covered by the longline gear and the large migratory range of these species within the Gulf, sampling by random stations in a grid was not relevant. For reopening closed areas in federal waters, the number of days needed to collect adequate numbers of representative seafood varied by area, depending upon weather conditions, fishing success, and other factors. Sample collection in some areas was completed within a couple of days whereas in other areas sampling occurred over several weeks (>4 wk in some cases).

NOAA ships and contract vessels were used to collect seafood via trawls, hand lines, and longlines. Nearshore grids were typically sampled for finfish and shrimp, whereas offshore grids (>200 m) were sampled only for finfish (10). A list of key species, including shrimp, snappers, porgies, and groupers, as well as highly migratory finfish such as tuna, dolphin fish, wahoo, jack, and swordfish, was developed on the basis of their importance to commercial and recreational fishing, their prevalence, and their role in the ecosystem (10). Sampling was targeted to collect these key species; however, the species collected varied by area depending on habitat type, depth, and other factors.

By June 2011, >8,000 seafood specimens collected in federal waters had been processed and subjected to sensory testing and chemical analysis. Seafood samples collected at sea were held on ice or frozen onboard vessels and brought to NOAA's National Seafood Inspection Laboratory (NSIL) in Pascagoula, Mississippi for processing. Seafood samples consisted of edible parts of whole fish or groups of individual small shellfish, e.g., shrimp, consisting of at least 227 g composite samples. In general, individual fish specimens of similar type, e.g., red snapper and gray snapper, and the same location were often combined in equal amounts into composite samples for chemical analysis. Compositing was appropriate as the sampling and decision point was to determine if an area could be reopened to fishing.

Materials and Methods

Sampling Scheme for Federal Waters. In response to the DWH oil spill, seafood sampling in the Gulf started on April 28, 2010 and included collection of a number of sample types described in the sampling plan (10). The seafood included surveillance, surveillance-perimeter, surveillance-closed, surveillance-reopened, reopening, and dockside surveillance samples (see definitions in *SI Text, Sample Classifications for Federal Waters*).

Seafood Collection Criteria for Sensory Testing and Chemical Analyses. The criteria described in the protocol (4) for reopening samples subjected to sensory testing and chemical testing included collecting three to six subsamples per seafood type (e.g., oysters, shrimp, crabs, and finfish) at each sample location (*SI Text, Seafood Collection Criteria for Sensory Testing and Chemical Analyses*).

Sensory Testing and Chemical Analyses. A panel of seven NOAA- and FDA-trained sensory experts performed sensory testing of seafood samples for abnormal odor or taste (known as "taint"). Samples were sequentially evaluated for raw odor, cooked odor, and cooked flavor (*SI Text, Sensory and Chemical Testing*).

Seafood PAH analyses were conducted using both a detailed gas chromatography/mass spectrometry (GC/MS) method (11) and a more rapid "screening" liquid chromatography/fluorescence detection (LC-FLD) method (12). Gulf seafood was also analyzed for the dispersant component dioctyl sodium sulfosuccinate (DOSS) using a liquid chromatography/tandem mass spectrometry (LC-MS/MS) method (13, 14) that was developed and validated by the FDA and the NOAA (*SI Text, Sensory and Chemical Testing*).

Risk Assessment. To establish the safety of seafood following the DWH oil spill, standard FDA and EPA risk assessment methods for carcinogenic and noncarcinogenic PAHs were used.

A toxic equivalency approach was used to estimate the cancer risk for individual PAHs likely to be found in Gulf light crude oil. Tissue levels of carcinogenic PAHs were multiplied by their respective toxicity equivalency factor [relative to benzo(a)pyrene (BaP)] and added to the BaP level to determine the total BaP equivalent concentration. These data were used together with other factors (e.g., body weight, averaging time, seafood consumption rate, and cancer slope factor) to determine the human level of concern (LOC) for each carcinogenic PAH (*SI Text, Cancer risk*).

Noncancer risks were determined on the basis of the concentrations of anthracene, phenanthrene, fluoranthene, fluorene, naphthalene, and pyrene measured in seafood. Alkylated homologs of naphthalene, fluorene, and anthracene/phenanthrene were summed with the parent compounds and compared with the appropriate toxicity criterion. The LOC values for noncarcinogenic PAHs were estimated using reference dose, body weight, consumption weight, and a conversion factor (*SI Text, Noncancer risks*).

Results

Sensory Testing for Seafood from Federal Waters. Federal and state agencies used a tiered strategy to ensure that seafood from the Gulf was safe for consumption. Initially, if oil was visually found on the water surface, a fishery was recommended for closure, which included a precautionary zone around the visible surface sheen. Once no visible floating oil was observed on the sea surface, this strategy combined sensory testing—expected to detect a broad array of potential contaminating chemicals—with sensitive analytical methods that measured chemical contaminants.

For a closed area to be eligible for reopening, the following criteria had to be met (these criteria were based on past oil spill information and provided a high level of confidence that the seafood was not tainted by oil) (4). A minimum of 70% (five of seven) of the expert assessors had to have found no detectable petroleum or dispersant odor or flavor from each subsample. If a subsample failed, then the sample location failed, which in turn failed the grid. Second, if the area passed the sensory test, then samples would undergo chemical analyses. In federal waters 0.16% (6 of 3,810) seafood samples failed sensory testing. This low failure rate was expected because an area was not sampled for reopening testing until there was no visible oil with minimal risk of reoiling.

Chemical Analyses for Seafood from Federal Waters. The GC/MS method measured individual PAHs at low detection levels (<1 ng/g) and provided data on alkylated homologs. The LC-FLD screening method is six times faster than GC/MS and provided reliable measurements of the targeted carcinogenic and non-carcinogenic PAHs in seafood, but did not have the specificity of the GC/MS method to confirm the PAH analyte identity. Thus, if a sample analyzed by screening had a PAH level approaching the LOC for that compound, then the sample was reanalyzed using GC/MS to confirm this finding. Although the LC-FLD method increased laboratory capacity, the method provided limited information on the levels of certain alkylated PAH homologs. Therefore, subsets of seafood samples were selected to be reanalyzed by GC/MS to confirm the PAH results and provide more information on alkylated homologs.

Overall, individual carcinogenic PAHs (Fig. 3) and non-carcinogenic PAHs (Fig. 4) were found at low concentrations or below the limits of quantitation. When detected, the PAH concentrations were at least two orders of magnitude lower than the corresponding LOC for each PAH. Furthermore, DOSS was found only at low levels (ranging from 0.05 to 0.29 $\mu\text{g/g}$) or below the limits of quantitation. Once all sensory and chemical results for the grids within a seafood harvesting area met the criteria for reopening, that area was eligible to be reopened. For all seafood samples collected in a closure area that passed sensory testing, the concentration of each PAH must be below the FDA LOC as determined using the chemical analytical methods for the closed harvest area to be eligible for reopening (4). All seafood samples collected in federal waters met this criterion established in the protocol (4).

Discussion

No two oil spills are exactly alike and thus sampling protocols and fisheries reopening criteria to ensure seafood safety must be modified from previously established guidelines for each particular event (3). More than 4.9 million barrels of oil were spilled over the course of almost 3 mo before the capping of the DWH wellhead (1), so an immediate and well-coordinated seafood safety response was the highest priority for the NOAA, the FDA, and other responding agencies. Priority issues were (a) closing seafood harvesting areas affected by the spill, (b) developing criteria for reopening areas closed to harvesting, (c) planning for sampling and testing of important commercial and recreational seafood species from the closed areas and from reference areas for spill-related chemicals to determine whether the seafood had been contaminated by spill-related compounds, and (d) conveying the information on testing results to the public and issuing any health advice related to the consumption of seafood potentially contaminated with spill-related chemicals. It was essential that regulators and scientists work together to identify key questions that must be answered and to develop criteria for data that would be collected.

Following the establishment of the protocol (4), a seafood safety sampling plan that contained all relevant information for sampling in federal waters was developed (10). Important

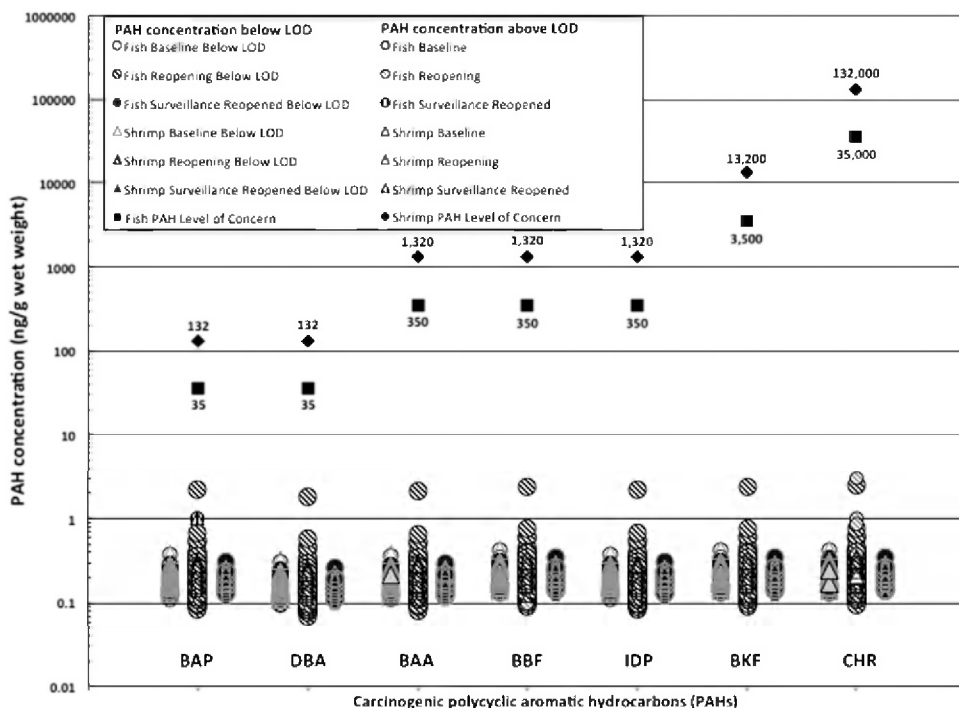


Fig. 3. Concentrations of carcinogenic polycyclic aromatic hydrocarbons (PAHs) measured in seafood collected in federal waters from April 28, 2010 through March 31, 2011 that were tested for reopening, as well as subsets for baseline and surveillance reopened samples. The levels of concern for each PAH are shown as solid diamonds for fish and solid squares for shrimp. Seafood PAH concentrations are shown in three columnar groupings above each abbreviated PAH, with levels for baseline, reopening, and surveillance reopened samples presented in left, center, and right columns, respectively. (Inset) (Left) Circles and triangles indicate samples where the concentrations are below the limit of detection (LOD) of the sensitive gas chromatography/mass spectrometer (GC/MS) instrumentation used; (Right) circles and triangles indicate samples where the levels are above the GC/MS LOD. Abbreviations: BAA, benz(a)anthracene; BAP, benzo(a)pyrene; BBF, benzo(b)fluoranthene; BKF, benzo(k)fluoranthene (coelutes with benzo(i)fluoranthene); CHR, chrysene (coelutes with triphenylene); DBA, dibenz(a,c)anthracene + dibenz(a,h)anthracene; IDP, indeno(1,2,3-cd)pyrene.

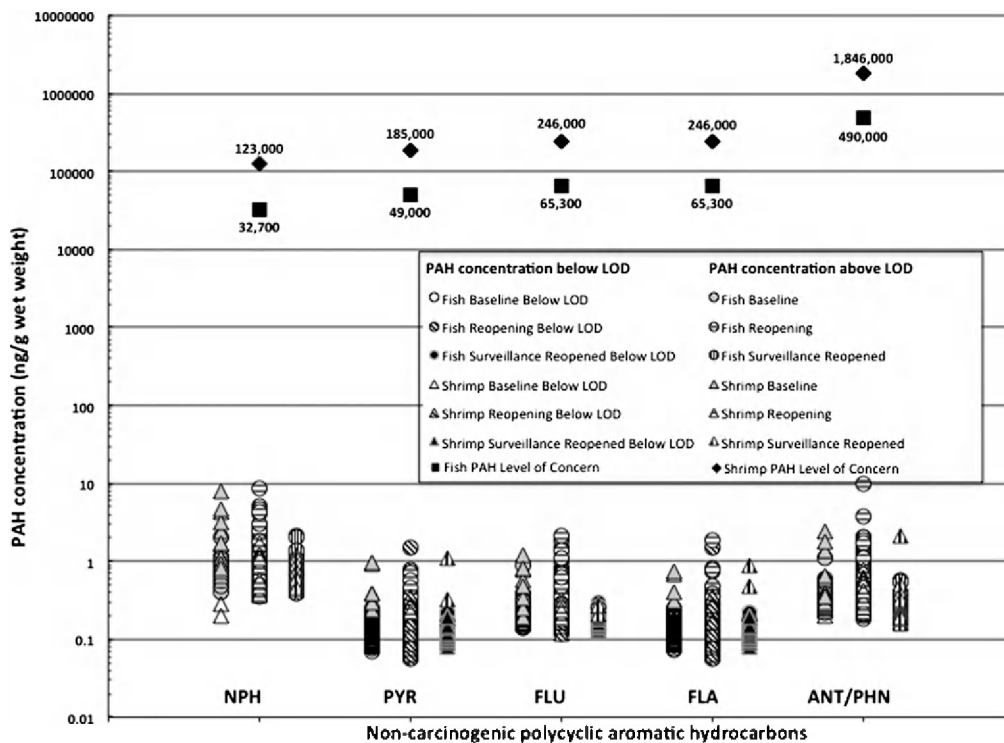


Fig. 4. Concentrations of non-carcinogenic polycyclic aromatic hydrocarbons (PAHs) measured in seafood samples collected in federal waters from April 28, 2010 through March 31, 2011 that were tested for reopening, as well as subsets for baseline and surveillance reopened samples. The levels of concern for each PAH are shown as solid diamonds for fish and solid squares for shrimp. Seafood PAH concentrations are shown in three columnar groupings above each abbreviated PAH, with levels for baseline, reopening, and surveillance reopened samples presented in left, center and right columns, respectively. (Inset) (Left) Circles and triangles indicate samples where the concentrations are below the limit of detection (LOD) of the sensitive gas chromatography/mass spectrometer (GC/MS) instrumentation used; (Right) circles and triangles indicate samples where the levels are above the GC/MS LOD. Abbreviations: ANT/PHN, anthracene + phenanthrene; FLA, fluoranthene; FLU, fluorene; NPH, naphthalene; PYR, pyrene.

commercial and recreational seafood species (including near-shore, reef, and pelagic species) and primary harvesting areas were identified to target sampling in federal waters. The criteria established in the protocol (4) specified the minimum numbers of samples required to be tested for sensory testing and chemical analyses for an area to be considered for reopening. Details on seafood sampling for reopening oil-impacted areas are publicly available online at <http://www.fda.gov/Food/ucm217601.htm> and information on fishery closure boundaries in federal waters can be found at <http://sero.nmfs.noaa.gov/ClosureInformation.htm>. In addition, oversampling was recommended so that a portion of each sample could be archived for future studies. Information on seafood sampling, including gear used, species collected, number of individuals sampled, and time and location of collection, was recorded with chain of custody protocols and transferred to a database for access by end users (e.g., federal managers).

Discussions among representatives from responding federal agencies (e.g., NOAA, FDA, and EPA) and the affected Gulf states led to identification of the appropriate compounds to target in analyzing seafood. PAHs were selected as oil-related chemicals of concern due to their toxic and carcinogenic properties as well as their ability to persist in the environment (5). One unusual aspect of the DWH oil spill was the extensive use of dispersant (e.g., Corexit 9500 and Corexit 9527) that was applied onto surface waters as well as applied directly to the waters near the wellhead. DOSS was selected as the best target component of the Corexit dispersant due to its bioactivity, extremely low volatility, and potential to persist in the environment longer than other dispersant components.

Initially, a detailed GC/MS method was used to determine levels of PAHs in seafood but it became apparent soon after testing began that a more rapid method was needed to increase the capacity of the seafood safety program. As a result, a method to rapidly measure PAHs in seafood was developed and validated by the FDA as part of the response to the DWH spill. Because the PAH screening method was much more rapid than the comprehensive GC/MS method, larger numbers of samples were analyzed in less time; however, the GC/MS method remained the standard for measuring PAH levels (including

alkylated homologs) in seafood and was also used to confirm PAH screening results.

Published research on the persistence of dispersant chemicals in the environment and their toxicity suggested that potential contamination of seafood would pose a low risk to consumers (see ref. 14 for references). However, public concern about dispersant use led to a collaborative effort between the FDA and the NOAA to develop and validate a rapid, sensitive chemical method for measuring DOSS from the dispersant in a wide array of edible seafood. A description of the chemical method can be found at the Web site <http://www.fda.gov/downloads/ScienceResearch/FieldScience/UCM231510.pdf>, and results of dispersant testing of seafood collected in federal waters as part of the reopening can be obtained at the Web site <http://sero.nmfs.noaa.gov/PreviousReopenings.htm>. Once the DOSS method was developed and validated, up to 50% of seafood samples previously analyzed for PAHs by GC/MS were subsequently analyzed for DOSS and all subsequent samples for reopening were analyzed for DOSS.

Analyses for spill-related contaminants proceeded in a timely manner, especially considering the large number of samples tested and the nearly 90,000 square miles of federal waters of the Gulf of Mexico that were closed. For example, sensory results were available within 4 h of sample analysis and the chemical data for a sample batch containing 14 field samples were quality assured and finalized within 48 h (LC-FLD PAH results) to 96 h (GC/MS PAH results) postreceipt.

It has been well established in the scientific literature that all teleost fish (modern bony fishes, e.g., grouper, snapper, and tuna) have a well-developed capacity to metabolize and eliminate PAHs and other oil constituents such as aliphatic hydrocarbons (15). Because of this efficient metabolism, there is a very low potential for PAHs to accumulate in muscle and consequently a low potential for transfer of PAHs up the food chain to human consumers. However, efficient PAH metabolism by species other than teleosts is not universal (3). For example, bivalves (e.g., oysters and clams) have a lower capacity to metabolize PAHs, whereas crustaceans such as shrimp have an intermediate metabolic capacity. In the current study, concentrations of individual PAHs measured in seafood collected in federal waters were, in many cases, below the limit of

quantitation or, when detected, were at least two orders of magnitude lower than the FDA LOC for the particular compound (Figs. 3 and 4). Although scientists were confident that high levels of PAHs would not be found in edible seafood tissues, it was necessary to test seafood to assure the public of its safety. Without an extensive, real-time sampling and analysis protocol, there would be little to no ability to convince the public that Gulf seafood was safe to eat following this major oil spill.

The PAH concentrations determined by various federal and state agencies to be of concern for human health were based on a projected daily level of consumption (grams per day of finfish, mollusks, crabs, and shrimp) and an acceptable risk (e.g., 1:100,000 risk for cancer) for 5 y (*SI Text, Cancer risk*). For the LOC calculations, to ensure a health protective approach (in addition to using cancer and noncancer values that are designed to be conservative values), the FDA used the 90th percentile of the national consumption data reported in the National Health and Nutrition Examination Survey for fish, shrimp, and shellfish for calculating risk and then adjusted the 90% meal size to account for the number of meals eaten by a 90th percentile consumer to ensure protection for low- through high-level consumers. Nevertheless, some concerns were raised with regard to the seafood consumption rates used by the FDA to calculate the PAH LOCs for the DWH seafood assessment (16). For example, a 2010 Natural Resources Defense Council survey of 547 people living in Louisiana, Alabama, Mississippi, and Florida showed that the average shrimp median daily consumption rate among residents was 3.6 times higher (48 g/d) than the FDA estimated shrimp consumption rate of 13 g/d (17). On the basis of the information collected on PAH levels in various seafood species from the Gulf, risk assessors can calculate the seafood consumption rates that are allowable without being a health concern for Gulf seafood. The Louisiana Department of Wildlife and Fisheries and the Louisiana Department of Health and Hospitals determined that the average consumer could eat ~63 pounds of peeled shrimp, 5 pounds of oyster meat, or 9 pounds of finfish every day for 5 y and have minimal risk of health effects (18). The concentrations of PAHs measured in Gulf seafood were very low or were below the levels of quantitation, and thus these

compounds did not appear to pose a health risk, even when higher consumption values are applied to the risk model.

In summary, scientists and regulators from federal and state agencies worked together to develop a seafood sampling plan and analytical protocols to determine whether seafood was safe to eat and acceptable for sale in the marketplace in response to the 2010 DWH oil spill. Approved methods for sensory testing and chemical analyses were used to detect PAHs and the dispersant component DOSS in >8,000 seafood specimens collected in federal waters of the Gulf. Overall, a low percentage (0.16%) of these samples failed sensory testing, which was expected as sampling of an area commenced only when the risk of oil being present was negligible. We also found that the concentrations of individual PAHs and the dispersant component DOSS measured in Gulf seafood were below the limits of quantitation or, when detected, were at least two orders of magnitude lower than the FDA LOC for each compound. Once an area closed to fishing was free of visibly floating oil and all sensory and chemical results for the seafood species within an area met the criteria for reopening, that area was eligible to be reopened. Since July 2010, ~88,500 square miles of federal waters have been reopened, with the area nearest the wellhead being reopened nearly 1 y (April 2011) after the spill began. As of November 9, 2011, a few areas off the Louisiana coast (Barataria Bay and the Delta region), however, remain closed because of residual oil and because the species at risk for exposure, such as oysters, have low metabolic capacity and a higher risk of accumulation of PAHs.

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