REVIEW ARTICLE

CURRENT CONCEPTS

The Gulf Oil Spill

Bernard D. Goldstein, M.D., Howard J. Osofsky, M.D., Ph.D., and Maureen Y. Lichtveld, M.D., M.P.H.

From the Department of Environmental and Occupational Health, University of Pittsburgh Graduate School of Public Health, Pittsburgh (B.D.G.); and the Department of Psychiatry, Louisiana State University Health Sciences Center (H.J.O.); and the Department of Environmental Health Sciences, Tulane University School of Public Health and Tropical Medicine (M.Y.L.) — both in New Orleans. Address reprint requests to Dr. Goldstein at the University of Pittsburgh Graduate School of Public Health, 130 DeSoto St., A712, Pittsburgh, PA 15213, or at bdgold@pitt.edu.

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One year after the Gulf oil spill (also known as the *Deepwater Horizon* oil spill, the BP oil spill, or the Gulf of Mexico oil spill), the full magnitude of the environmental, economic, and human health effects of this major disaster remain unknown. Despite a growing literature describing the impact of oil spills on health[1-28] (Tables 1 and 2), it is difficult to respond to the many questions asked by clinicians and the public about this spill or the risk of future spills. The uncertainty is exemplified by the study of 55,000 Gulf oil spill workers by the National Institute of Environmental Health Sciences (NIEHS), which is open-ended rather than focused on a specific number of end points.[29] The uncertainty also has consequences for the economic and psychosocial well-being of Gulf Coast residents.

Potential health consequences of oil spills fall into four categories: those related to worker safety; toxicologic effects in workers, visitors, and community members; mental health effects from social and economic disruption, which are of particular concern in the Gulf; and ecosystem effects that have consequences for human health. The current literature tends to focus separately on health effects in workers and health effects in communities. However, workers who responded to the Gulf oil spill are integrated into their communities, and the ecologic, economic, and health effects of the spill are closely interconnected.

An understanding of the health consequences of the Gulf oil spill for workers and community members is built on studies of previous disasters — most notably, in the United States, the September 11, 2001, terrorist attacks on the World Trade Center (WTC) and Hurricane Katrina. WTC registries tracking tens of thousands of workers and community members at risk have been used in numerous published follow-up studies documenting mental and physical health problems.[30-33] Pertinent to the Gulf oil spill are WTC and post-Katrina studies suggesting that immigrant workers and other vulnerable populations were less likely to obtain care and more likely to have long-term health consequences than was the overall affected population.[34,35]

TOXICOLOGIC CONSEQUENCES FOR HUMAN HEALTH

Clinical and public concerns immediately after an oil spill focus on short-term chemical effects, such as respiratory and dermal irritation, headaches, eye irritation, nausea, and dizziness (Table 1). Predicting shorter- and longer-term toxicologic effects requires an in-depth understanding of exposure pathways, contaminants of concern, and vulnerable populations.

PATHWAYS OF CHEMICAL EXPOSURE

The Gulf oil spill differs significantly from previously studied oil spills in its magnitude, duration of release, source of emission (the deep sea floor), and management techniques used (dispersants and controlled burns). For the Gulf spill, all five elements of a complete exposure pathway are present: sources of contaminants, environmental media, points of exposure, routes of exposure, and the receptor population — persons working or living near the site of the spill and near the affected shoreline. Multiple sources of contaminants should be considered, from burning of chemicals to beaches coated in oil. The environmental media are complex and include the air, surface water, and soil. Multiple points of exposure further complicate the characterization of chemical exposure from the spill in the Gulf, where workers were engaged in activities close to the ruptured well, laying booms, cleaning tarballs and "mousse," and where hurricanes threaten to spread oil beyond shorelines. The predicted routes of exposure to chemicals from the oil spill are inhalation, dermal contact, ingestion of food and water, and contact with beach sand (especially by children). In the case of the Gulf oil spill, a disproportionately large underlying disease burden in the receptor population makes it particularly vulnerable to environmental and natural disasters.

CONTAMINANTS OF CONCERN

Many environmental measurements were obtained after the Gulf oil spill (see Table 3 for information sources for the public and health care providers). Crude oils contain over a thousand different hydrocarbons and, depending on the source of the oil, vary greatly in the relative amounts of individual hydrocarbons and trace metal and sulfur content. Some crude-oil components cause respiratory, hepatic, renal, endocrine, neurologic, hematologic, or other systemic effects; however, these occur only at high doses, after a threshold concentration is exceeded. In contrast, mutagenic effects theoretically can result from a single molecular DNA alteration. Regulatory prudence has led to the use of "one-hit models" for mutagenic end points, particularly cancer, in which every molecule of a carcinogen is presumed to pose a risk. The carcinogens of concern in crude oil are benzene, which is present at a concentration of 1 to 6%, and polycyclic aromatic hydrocarbons (PAHs), which are present at much lower but quite variable concentrations. Benzene and PAHs also are a result of controlled offshore combustion of crude oil.

Benzene is a known hematotoxicant and hematocarcinogen.[36] Evidence suggests that benzene has subtle effects on circulating blood cells in workers exposed to concentrations below the current occupational health standard,[37] as well as adverse reproductive and developmental effects.[38] Although benzene is potentially a risk to workers at sea, close to an oil source, virtually all benzene and other volatile components appear to evaporate before reaching the shore. The half-life of benzene in the environment and in the human body is measured in days, and it does not bioaccumulate. Thus, community exposures to benzene and the effects of such exposures should be relatively minimal.[9]

PAHs are much more persistent, can bioaccumulate, and potentially cause skin and lung cancer and have reproductive and developmental toxic effects.[39] The toxicologic effects of other volatile organic components of crude oil (e.g., simple aromatics and shorter aliphatic straight-chain hydrocarbons) are reasonably well characterized. All these organic components may contribute to the acute effects observed in studies of oil-spill responders but are unlikely to be present in concentrations associated with longer-term health effects. Atmospheric photochemical activity, which is common in summer, converts volatile hydrocarbons into reactive aldehydes, such as acrolein, and leads to ozone formation — both of which can cause respiratory irritation, including asthma attacks.[40,41] The toxicologic effects of other higher-molecular-weight components of crude oil have not been studied as extensively, and temperature, sunlight, and salinity alter their physicochemical characteristics (a process known as weathering), further complicating their toxicologic evaluation. A review of the many hundreds of air samples obtained by the Environmental Protection Agency (EPA) showed that no samples had concentrations of benzene or other volatile organic hydrocarbons ascribable to the Gulf oil spill that were above health-based standards. However, although the monitoring was extensive, no monitoring scheme could cover all potentially affected locales.

Much public attention has been focused on the fate and toxicity of the unprecedented release of over a million gallons of dispersant. Dispersants are surfactants that help to disperse the oil by lessening the tension of the oil–water interface. Information provided on the manufacturer's material safety data sheet for Corexit 9500, the major dispersant used in the Gulf spill, states that the surfactant consists of 10 to 30% light-

Table 1. Studies of Effects of Oil Spills on the Health and Safety of Workers and Communities.*

Reference	Study Characteristics	Methods	Results
***Sea Empress* oil spill†**			
Lyons et al.[1]	Survey of 539 exposed residents and 550 controls in communities in Wales 7 wk after spill	Residents asked about symptoms during the first 4 wk after the spill Adjustment for reporting biases	Total of 23% of exposed residents believed oil spill to have affected their health, vs. 2% of controls Significantly increased rates of headache, sore eyes, and sore throat among exposed residents were attributed to toxicologic effects of the exposure and increased anxiety and depression scores were attributed to mental health effects of the spill
***Prestige* oil spill‡**			
Suárez et al.[2]	Cross-sectional study of relation between worker activities and symptoms	Structured telephone interview of stratified sample of 265 paid workers, 266 volunteers, 133 seamen, and 135 bird cleaners, with response rate of 62.5% Univariate and multivariate analyses	Injury rate was highest among bird cleaners (19%); rates of headache and throat and respiratory tract disorders were highest among seamen (15.8% and 30.4%, respectively) On multivariate analysis, >20 days' work in highly polluted areas, vs. fewer days' work, was associated with headache (odds ratio, 2.62; 95% CI, 1.23–5.60); nausea, vomiting, and dizziness (odds ratio, 2.50; 95% CI, 1.09–5.74); and throat and respiratory problems (odds ratio, 3.74; 95% CI, 1.89–7.40) A larger number of symptoms (vs. a smaller number) was associated with a reported perception of unpleasant odors and with eating while working with oil
Carrasco et al.[3]	Cross-sectional study examining effects of providing safety and health information to response workers	Same interview and population as used by Suarez et al.[2] Odds ratios based on logistic regression	Informed workers had a higher level of PPE use than uninformed workers Lack of health information before engaging in cleanup was associated with respiratory problems (odds ratio vs. receipt of health information, 2.43; 95% CI, 1.02–5.79) and headaches (odds ratio, 3.86; 95% CI, 1.74–8.54) As compared with informed workers, uninformed workers had more nausea, vomiting, or dizziness (odds ratio, 2.25; 95% CI, 1.17–4.32), throat and respiratory problems (odds ratio, 2.30; 95% CI, 1.15–4.61), and itchy eyes (odds ratio, 2.89; 95% CI, 1.21–6.90)
Zock et al.[4]	Prevalence of respiratory tract symptoms 1–2 yr after the spill	Questionnaire given to members of fishing cooperatives (4594 men and 2186 women) Comparison of members involved and members not involved in spill response	Questionnaire response rate was 76% Prevalence of lower respiratory tract symptoms was significantly higher among exposed members than among unexposed members (odds ratio, 1.73; 95% CI, 1.54–1.94) and remained so after exclusion of participants expressing concern that they were affected by the spill (odds ratio, 1.57; 95% CI, 1.37–1.80)
***Tasman Spirit* oil spill§**			
Khurshid et al.[6]	Blood specimens obtained from 100 area residents and workers 1 month after spill No control group	Data on blood counts and liver- and renal-function tests	Some ALT elevations were found but were not evaluated further All other test results were within the normal range
Janjua et al.[7]	Acute health effects in 216 community members as compared with 83 residents living 2 km from the test community (control group A) and 101 residents living 20 km from the test community (control group B)	Household interviews Symptom score based on response to each of 48 symptoms	Mean symptom scores were 14.1 in the exposed group, 4.4 in control group A, and 3.8 in control group B The exposed group had significantly increased rates of ocular, respiratory, and skin symptoms, as well as headache, irritability, fever, and general fatigue Rates of wheezing and shortness of breath during the period of the spill were greater in the exposed group (6%) than in the control groups (1.2% and 0%)

Meo et al.[8]	Cross-sectional and longitudinal study of lung function Soon after exposure, 20 male response workers with exposures were compared with 31 controls from the same area Exposed workers were restudied 1 yr later	Spirometry performed in nonsmokers without overt clinical abnormalities	Exposed subjects, vs. controls, had lower FVC (3.70±0.12 vs. 4.67±0.11 liters, $P<0.001$), FEV_1 (2.82±0.17 vs. 3.58±0.07 liters, $P<0.001$); $FEF_{25-75\%}$ (2.85±0.30 vs. 3.87±0.22 liters/sec, $P=0.02$), and MVV (105.85±6.72 vs .134.61±2.88 liters/min, $P=0.001$) 1 Year later, results for exposed workers were similar to results for controls
***Nakhodka* oil spill¶**			
Morita et al.[9]	Acute health problems studied in 282 cleanup workers who were residents of heavily exposed island	Home interview by public health nurses Total of 97 urine samples obtained Four workers used personal air monitors during cleanup	Lower back pain, leg pain, headaches, and eye and throat irritation were related to duration of cleanup activities At least one symptom found in 78.7% of women and 56.7% of men Highest benzene level was 1.85 ppb (for comparison, allowable 8-hr average in U.S. workplace is 1000 ppb) No increase was found in urinary indicator of benzene exposure among workers Three workers had slightly increased levels of urinary indicator of toluene exposure
MV *Braer* oil spill‖			
Campbell et al.[10]	Comparison of 420 exposed residents and 92 controls in January 1993	Structured questionnaire Tests of peak expiratory flow, results of blood tests, and levels of urinary biomarkers of exposure	Among exposed vs. control residents, there were higher incidences of headache (odds ratio, 5.75; 95% CI, 2.47–14.08), throat irritation (odds ratio, 7.03; 95% CI, 3.02–17.18), and itchy eyes (odds ratio, 6.72; 95% CI, 2.53–19.45), particularly during the first few days after exposure or when odor was present No significant differences observed in blood counts, liver- or renal-function tests, or peak respiratory flow rates Urinary toluene metabolite was detected in a larger percentage of the exposed group (34% vs. 16%, $P<0.002$)
Campbell et al.[11]	Follow-up of January 1993 study in June 1993, involving 344 of the 420 exposed residents and 77 of the 92 controls in the earlier study, to evaluate later effects	Same as for Campbell et al.[10]	More exposed residents than controls reported poor health ($P<0.05$) or deteriorating health ($P<0.001$) and breathlessness on exertion (odds ratio, 4.81; 95% CI, 1.09–29.92) Exposed residents had a lower rate of throat and eye irritation and headaches than immediately after the spill No pertinent differences between exposed subjects and controls were found in levels of biologic markers
Crum[12]	Comparison of PEF levels on day 3 and days 9–12 after the oil spill in 44 children living within 5 km of the spill FEV and FVC tested on days 9–12	Use of Mini-Wright flow meter and pocket spirometer	No significant difference in PEF levels was found between day 3, when a strong odor was present, and days 9–12 ($P=0.50$) FEV and FVC values were all within normal limits No adverse effects were observed in 6 children with asthma
Erika* oil spill*			
Dor et al.[13]	Cancer-risk analysis based on measurement of PAHs on beaches and in water 4 months after spill and modeling of atmospheric levels of volatile PAHs	PAH exposure levels based on 5 exposure scenarios, including accidental ingestion by a small child of a 1-g ball of fuel and an adult working at the beach for 2 months	PAH residues were greatest on rocky soil The highest estimated cancer risk was in the range of 10^{-5} per lifetime

Table 1. (Continued.)

Reference	Study Characteristics	Methods	Results
Baars[14]	Analysis of risk among response workers and tourists	PAH and benzene exposure levels based on extrapolation from measured values	Risk of acute eye irritation and dermatitis was limited to those with skin exposure from cleaning oil-contaminated birds Long-term cancer risks were reported to be generally negligible
Schvoerer et al.[15]	Cross-sectional study of acute health symptoms in 1465 professionals and volunteers involved in cleanup	Postal questionnaire Telephone follow-up of nonrespondents	Back pain was reported in 30%, skin irritation in 16%, and eye irritation in 9% of participants Women were at higher risk for acute health effects Among volunteers, lack of safety information was associated with increased risks of skin irritation (odds ratio, 1.83; 95% CI, 1.21–2.77), musculoskeletal problems (odds ratio, 2.36; 95% CI, 1.30–4.30), and back pain (odds ratio, 1.45; 95% CI, 1.07–1.96)

* ALT denotes alanine aminotransferase, CI confidence interval, $FEF_{25-75\%}$ forced expiratory flow from 25% to 75% of vital capacity, FEV forced expiratory volume, FEV_1 FEV at 1 second, FVC forced vital capacity, MVV maximal voluntary ventilation, PAH polycyclic aromatic hydrocarbon, and PPE personal protective equipment.

† The *Sea Empress* oil spill occurred off Pembrokeshire, Wales, in February 1996. The vessel hit mid-channel rocks and rapidly spilled 73,000 tons of crude oil near a highly populated area, with strong odors detectable in the area.

‡ The *Prestige* oil spill occurred off northwestern Spain in November 2002. Approximately 63,000 tons of oil were released, rapidly at first and more slowly over a period of months. More than 100,000 people were involved in the response.

§ The *Tasman Spirit* oil spill occurred off Karachi, Pakistan, in July 2003. The tanker contained 68,000 tons of crude oil, an estimated 28,000 tons of which came ashore; 11,000 tons evaporated, producing a pungent odor. Volatile organic compounds in nearby areas were at concentrations of 44 to 179 ppm for at least 15 to 20 days.

¶ The *Nakhodka* oil spill occurred in January 1997 off the west coast of Honshu, Japan, with 6000 tons of oil spilled.

‖ The *MV Braer* oil spill occurred off Shetland, Scotland, in January 1993, releasing 85,000 tons of crude oil over a 6-day period. Management included aerial spraying of dispersants.

** The *Erika* oil spill occurred off Brittany, France, in December 1999. A total of 28,000 tons of heavy fuel oil were spilled, affecting approximately 500 km of shoreline.

weight petroleum distillate, 1 to 5% propylene glycol, and 10 to 30% proprietary organic sulfonic acid salt. Some aquatic safety information about Corexit 9500 had been obtained previously by the manufacturer. After the spill, additional studies were rapidly performed by the EPA, which publicly identified the proprietary salt as dioctyl sodium sulfosuccinate, a commonly used stool softener. Secrecy about this generic drug appeared to contribute to public concern, despite the fact that the exposure of humans through use of the dispersant was trivial as compared with the usual prescribed doses. Another dispersant used early in the spill contained 2-butoxyethanol, which is known to cause hemolytic anemia and hepatic angiosarcoma in rodents but not in humans.[42]

There is little evidence that exposure to the trace quantities of metals (including arsenic, boron, chromium, lead, and nickel) present in crude oil are of immediate toxicologic concern, although a statistical association of metals with endocrine and genotoxic effects after an oil spill was reported.[43] As of October 2010, water monitoring by the EPA for PAHs and benzene was negative, and air monitoring has not detected any volatile components of crude oil except for trace levels of naphthalene. PAHs were found in sediment.[44]

EXPOSED POPULATIONS

Workers with Chemical Exposures

According to a National Institute for Occupational Safety and Health (NIOSH) roster, the number of workers responding to the Gulf oil spill totaled 52,000 as of August 2010.[45] The degree to which workers are exposed to contaminants depends not only on job assignment and duration of exposure but also on the extent of worker training and the use of personal protective equipment.[3,46,47] During the active cleanup phase, NIOSH conducted a series of Health Hazard Evaluations, and a variety of symptoms in workers were reported (Table 4).[48] (For other symptoms, see Table 1 and a recent review by Aguilera and colleagues.[47]) Chemical-induced symptoms in cleanup workers commonly include upper respiratory tract illnesses, throat and eye irritation, headaches, dizziness, nausea, and vomiting.[2,3,9,15,16] Louisiana reported 415 self-identified health problems believed to be related to the Gulf oil spill, including symptoms of heat exposure in 169 of 329 workers, as well as 18 short hospitalizations. No increase was noted in the rate of upper respiratory illness or asthma as compared with the rates in the 3 previous years.[49]

Rapid mobilization of workers — such as occurred after the Gulf oil spill — is associated with lower rates of discovery of or communication about preexisting health conditions, including hepatic and renal disease and pregnancy, that may put workers at increased risk. Four deaths due to heart attack or stroke were reported among cleanup workers involved with the *Nakhodka* oil spill off Japan.[9]

There have been few studies of longer-term health consequences. Persistent abnormalities of pulmonary function have been reported, with improvement occurring over time[50] (Table 1). After the *Prestige* oil spill off Spain, bronchial hyperresponsiveness (measured by means of methacholine challenge) was reported, as were increased levels of 8-isoprostane and vascular endothelial growth factor in exhaled breath from fishermen who did not smoke.[4,5,47] Acute and persistent genotoxic effects (represented by sister-chromatid exchange and the results of the micronucleus assay and comet assay [single-cell gel-electrophoresis assay]) were also reported in heavily exposed cleanup workers in the *Prestige* oil spill.[47,51,52] However, genotoxic effects were not observed after the *MV Braer* oil spill off Scotland.[53] Other reported longer-term physiological data include changes in prolactin and cortisol levels in cleanup workers, suggesting endocrine effects, but biologic monitoring did not reveal hepatic, renal, or other systemic effects.[43,47] Risk assessments after the *Erika* oil spill off France suggested a low risk of cancer among workers and persons visiting decontaminated beaches.[13,14]

Community Members with Chemical Exposures

Gulf Coast populations affected by the oil spill include communities with a history of disparities in health (as compared with other regions of the United States), environmental-justice concerns, recurrent impacts of natural disasters, and poor health metrics. Among the 50 states, Louisiana ranks 44th to 49th (depending on the metric used, with 1st being best) in the overall health of residents; rates of infant death, death from cancer, premature death, death from cardiovascular causes, high-school graduation, children living in poverty, health insurance coverage, and violent crime.[54]

Affected communities in Mississippi and Alabama also tend to have poor health indexes. Children are at particular risk for effects from environmental exposures. As compared with adults, they breathe in more air per unit of body mass, their bodies detoxify many chemicals less effectively, and they explore more adventurously. Hurricane Katrina showed that their risks are diverse and severe.[35]

However, evidence is lacking regarding the effect of oil spills on the risk of asthma or impaired respiratory function in children.[12] Concomitant indoor air exposures may pose an additional risk for children with asthma.[55] There is inadequate information about the potential reproductive and developmental effects of crude-oil components, particularly the higher-molecular-weight compounds reaching the shore. Pregnant women should particularly avoid dermal contact with oil and should avoid areas with visible oil contamination or odors. Residents should balance the risks of exposure with the risks of moving to new surroundings. Factors related to an increased risk of cancer are disproportionately high in immigrant communities on the Gulf Coast.[56]

WORKER SAFETY

Eleven workers died immediately after the explosion causing the Gulf oil spill, and more than 30 workers were seriously injured. For the more than 50,000 response workers, safety issues were of paramount concern. As a result of the WTC experience, much attention was paid to training the Gulf spill response workers, particularly regarding heat stress and the use of personal protective equipment appropriate for minimizing exposure to chemicals. The extent of overall compliance is not yet known. Also unclear is the number of workers who underwent necessary medical screening to detect preexisting health conditions.[3,44,46] In the cleanup effort after Hurricane Katrina, Latino day laborers were reported to be occupationally vulnerable owing to suspended workplace regulations and limited ability to understand workplace safety messages (because of limited knowledge of the English language).[57] Injuries and back problems have been commonly reported among response workers after oil spills.[2]

Vulnerability to heat stress, a major risk factor in the hot summer months in the Gulf, was compounded by the necessity of using personal protective equipment. Inexperienced volunteers are particularly prone to heatstroke and exhaus-

Table 2. Studies of Effects of Oil Spills on Mental Health of Workers and Communities.*

Reference	Study Characteristics	Methods	Results
***Exxon Valdez* oil spill†**			
Palinkas et al.[17]	Cross-sectional study, conducted 1 yr after spill, of community patterns of psychiatric disorders in 437 exposed workers and 162 controls	Survey of 599 households in 13 communities CES-D score NIMH Diagnostic Interview Schedule	Most-exposed group was more likely than controls to have generalized anxiety disorder (odds ratio, 3.73; 95% CI, 1.99–6.97), PTSD (odds ratio, 2.63; 95% CI, 1.22–5.66), and depression (defined as CES-D score ≥18; odds ratio, 2.13; 95% CI, 1.01–4.50) Women were significantly more vulnerable than men regarding all three measures Native Americans and younger men had more evidence of depression than other subgroups
Palinkas et al.[18]	Cross-sectional study of levels of depression among 188 Alaskan Natives and 371 Americans of European descent	Same as for Palinkas et al.[17]	Exposure significantly associated with CES-D scores in both Alaskan Natives (P<0.05) and Euro-Americans (P<0.01) Effect on Alaskan Natives associated with loss of subsistence lifestyle
Gill and Picou[19]	Longitudinal study over 4 yr of stress in affected community (Cordova, AK) vs. control community (Petersburg, AK) Sample sizes as follows: Cordova — 118 in 1989, 228 in 1991, and 41 in 1992 Petersburg — 73 in 1989, 102 in 1991, and 41 in 1992	Desire or expectation to migrate out of the area Social disruption Score on Impact of Events Scale (of psychological stress)	Event-related psychological stress diminished with time, although 3 yr after the spill, 50% of Cordova residents still were classified as having a high level of social disruption and were more likely than controls to have a desire or expectation to migrate (32% vs. 15% and 44% vs. 23%, respectively; P<0.01 for both comparisons)
Palinkas et al.[20]	Cross-sectional study 1 yr after spill of PTSD symptoms in 188 indigenous people and 371 Euro-Americans	Factor analysis of Diagnostic Interview Schedule scores	Prevalence of PTSD was similar in the two groups Social disruption was associated with PTSD in both groups but symptoms were dissimilar Low degree of family support, participation in cleanup activities, and decline in subsistence activities were significantly associated with PTSD in indigenous people only
Picou et al.[21]	Longitudinal study of residents of exposed community (Cordova, AK): 223 residents in 1991, 154 in 1992, and 96 in 2000	Intrusive stress factors	In 2000, >95% of respondents reported that the community had not recovered Litigant status predicted the degree of spill-related stress
***Sea Empress* oil spill‡**			
Lyons et al.[1]	Cross-sectional study of 4-wk period after spill, involving 539 residents of exposed community and 550 residents of control community	Postal questionnaire Score on Hospital Anxiety and Depression Scale SF-36 mental health score	Residence in exposed community was associated with higher anxiety scores (P=0.04) and depression scores (P=0.049) and lower SF-36 mental health scores (P=0.002) Exposed residents were more likely than controls to consult a general practitioner (odds ratio, 2.34; 95% CI, 1.47–3.72) Residents with higher anxiety scores had more physical symptoms
Gallacher et al.[22]	Cross-sectional study of 74-wk period after spill, focused on acute psychological symptoms attributable to exposure vs. perception of exposure in 539 exposed residents of four exposed coastal towns and 550 controls in two control coastal towns	Postal questionnaire Score on Hospital Anxiety and Depression Scale	Response rate was 69% Perception of exposure was more highly associated than proximity to spill with reporting of toxicity symptoms and nontoxicity (psychological) symptoms Perceived health and financial risks were associated with anxiety and depression Perceived environmental risk was associated with anxiety

***Prestige* oil spill§**			
Carrasco et al.[23]	Cross-sectional study of 16-mo period after spill, focused on health-related quality of life and mental health among 1350 coastal residents vs. 1350 controls residing inland	Scores on social support and mental health questionnaires: SF-36, General Health Questionnaire, Hospital Anxiety and Depression Scale, and Goldberg Anxiety and Depression Scale	Overall mental health scores did not differ significantly between coastal residents and controls Coastal residents had a higher frequency of suboptimal mental health scores than controls (odds ratio, 1.28; 95% CI, 1.02–1.58) SF-36 physical-functioning score increased with level of exposure ($P<0.001$)
Sabucedo Camselle et al.[24]	Cross-sectional study, conducted 1 yr after spill, of psychological effect on 938 residents with proximity to spill and effect of community support and financial aid	Perceived involvement, social support, satisfaction with economic aid received, and mental health questionnaire (SCL-36)	Overall, no relevant clinical symptoms were found among residents Affected residents reported receipt of great social support and high satisfaction with economic aid Affected residents with great social support, high satisfaction with economic aid, or evasive coping strategies had better mental health scores than other affected residents and than controls
Sabucedo et al.[25]	Cross-sectional study, conducted 1 yr after spill, of psychological effect on 938 residents with proximity to spill, compared across three zones of proximity	Questionnaire administered by psychologists Score on Exposure Status Scale Score on mental health questionnaire (SCL-36) Perception of health and functional capacity (SF-36)	Several symptoms differed across zones: somatization ($P=0.007$), anxiety ($P=0.03$), obsessive–compulsive disorder ($P=0.03$), and hostility ($P=0.001$) Residents closer to spill had lower perception of physical health and functional capacity Fishermen had more somatization than nonfishermen Women were more affected than men
Gulf oil spill¶			
Abramson et al.[26]	Study of mental health effects of oil spill on 518 children, based on parental reports	Asked whether child had any emotional or behavioral problems that were not present before the oil spill	Preliminary findings were that 19.2% of parents reported that a child had some mental health effects due to the oil spill Parents were twice as likely to report mental health symptoms in exposed children as in nonexposed children
Witters[27]	Cross-sectional survey from January 2–August 6 2598 Participants on the Gulf Coast: 1539 before spill and 1239 after spill 30,657 Participants from inland counties of Gulf Coast states: 15,356 before spill and 15,001 after spill	Score on Emotional Health Index, with specific question about whether participant ever received clinical diagnosis of depression	Rate of "yes" response to depression question increased among Gulf Coast participants from 15.6% before spill to 19.6% after spill but was relatively unchanged among inland participants Slightly worse scores on Emotional Health Index were also recorded among Gulf Coast participants after the spill, as well as increases in stress, worry, and sadness

* CES-D denotes Center for Epidemiological Studies Depression Scale, NIMH National Institute of Mental Health, PTSD post-traumatic stress disorder, SCL-36 Symptom Checklist-36, and SF-36 the Medical Outcomes Study 36-Item Short-Form Health Survey.

† The *Exxon Valdez* oil spill occurred in Prince William Sound, Alaska, in March 1989, spilling 40,000 to 120,000 tons of crude oil.

‡ The *Sea Empress* oil spill occurred off Pembrokeshire, Wales, in February 1996. The vessel hit mid-channel rocks and rapidly spilled 73,000 tons of crude oil near a highly populated area, with strong odors detectable in the area.

§ The *Prestige* oil spill occurred off northwestern Spain in November 2002. Approximately 63,000 tons of oil were released, rapidly at first and more slowly over a period of months. More than 100,000 people were involved in the response.

¶ The Gulf oil spill occurred in the Gulf of Mexico, off Louisiana, in April 2010. An explosion on the *Deepwater Horizon* mobile offshore drilling unit killed 11 workers and resulted in the release of 70,000 tons of crude oil, mostly from the sea floor.[28]

Table 3. Resources for Information about the Gulf Oil Spill.*

Organization	URL	Information Provided
Centers for Disease Control and Prevention	www.bt.cdc.gov/gulfoilspill2010	Information about public health issues, hazardous substances, studies of previous oil spills; information for specific groups, including coastal residents, health professionals, response workers, pregnant women, and parents; and information about workplace safety and health topics and health surveillance (including the national poison data system, and state surveillance)
Environmental Protection Agency	www.epa.gov/bpspill/index.html	Data on air quality, water, and sediment; waste-management information; data on toxicity testing; and dispersant information
Food and Drug Administration	www.fda.gov/Food/ucm210970.htm	Information about seafood safety, reopening of closed waters, and assessment of the effects of the oil spill through monitoring and surveillance
National Institute of Environmental Health Sciences	http://tools.niehs.nih.gov/wetp/index.cfm?id=2495	Information about safety and training of oil spill response workers
FoodSafety.gov, Department of Health and Human Services	www.foodsafety.gov/keep/types/seafood/index.html	Information about seafood safety and closures of federal fisheries
National Oceanic and Atmospheric Administration	http://response.restoration.noaa.gov/dwh.php?entry_id=809	Forecasts of oil spill trajectories and marine conditions and weather at the spill site, information about closures of federal fisheries, and other information
RestoreTheGulf.gov (the official federal portal for response to and recovery from the Gulf oil spill)	www.restorethegulf.gov/health_and_safety.shtm	Health and safety resources for coastal residents, workers, volunteers, and health professionals, and beach, boating, and seafood safety information
The White House	www.whitehouse.gov/deepwater-bp-oil-spill	Federal response resources and information on air, food, and water safety
Louisiana Department of Health and Hospitals	www.dhh.louisiana.gov/offices/?ID=378	Information about surveillance of exposures and reported effects, seafood safety, fisheries closures, and mapping
Department of Wildlife and Fisheries, State of Louisiana	www.wlf.louisiana.gov/oilspill	Information about closures of recreational and commercial fishing areas and oyster beds
Alabama Department of Public Health	www.adph.org/riskcommunication/Default.asp?id=4362	Information for health care providers, information about beach conditions, and surveillance information from coastal area emergency departments, urgent care facilities, and community health centers
Mississippi State Department of Health	http://msdh.ms.gov/msdhsite/_static/23,0,346.html	Information and recommendations about safety of air, water, fish consumption, and beaches
Florida Department of Environmental Protection	www.dep.state.fl.us/deepwaterhorizon	Information about affected areas
OSHA and NIOSH	www.osha.gov/oilspills/index.html, www.cdc.gov/niosh/topics/oilspillresponse/data.html	Joint NIOSH–OSHA interim guidance, NIOSH Injury and Illness Reports, BP *Deepwater Horizon* recordable injury and illness data, information about exposure to toxic chemicals, and Health Hazard Evaluations of worker exposures and work-related injuries and illnesses among oil spill response workers

Department of Health and Human Services	www.hhs.gov/gulfoilspill/index.html	Mental health information; health information for coastal residents, response workers, and health professionals; and state and local health-related resources
American Academy of Pediatrics	www.aap.org/disasters/oil-spill.cfm	Resources, tips, and information for parents and caregivers to protect children from oil exposure
Substance Abuse and Mental Health Services Administration	www.samhsa.gov/Disaster/traumaticevents.aspx	Tips for dealing with the Gulf oil spill for parents and teachers, the general public, and emergency response workers
National Library of Medicine, National Institutes of Health	http://sis.nlm.nih.gov/dimrc/oilspills.html	Health information, resources for coping with disasters and stress, occupational health information, information about seafood and fisheries contamination, and other information
American Psychiatric Association	www.psych.org/Resources/DisasterPsychiatry/Current-Disasters/Oil-Spill.aspx	Recommendations about mental health issues
Pediatric Environmental Health Specialty Units	www.aoec.org/PEHSU/documents/gulf_spill_7-1-2010.pdf	Advice for protecting children from the Gulf oil spill

* Seafood sampling and monitoring and environmental sampling were coordinated across the states affected by the Gulf oil spill. NIOSH denotes National Institute for Occupational Safety and Health, OSHA Occupational Safety and Health Administration, and URL uniform resource locator.

tion, and workers with heat stress are at increased risk for acute injury.[58] The thermoregulatory role of the central nervous system may be affected by drugs commonly taken for mental health purposes, such as phenothiazines.[59] Physicians should consider whether pharmaceutical agents affecting salt and water balance, such as diuretics, will affect normal thermoregulatory responses.

MENTAL HEALTH CONSEQUENCES

Mental health symptoms are commonly reported by response workers and community members after oil disasters[1,2,7,10,15,16,47] (see Table 2 for an overview). Calls to mental health and domestic violence hotlines in the Gulf area have increased since the oil spill, in keeping with reports of increased domestic violence, mental illness, and substance abuse after other disasters.[60] However, the relevant literature is limited by variations in the rigor of assessments of stressors and postdisaster mental health symptoms; the lack of predisaster baseline data and validated measures; cross-sectional designs; and the loss of data on contributing variables because of delays in study initiation.[61,62] Masten and Osofsky[63] and Pfefferbaum and North[64] questioned the reliability of assessments of mental health consequences in children and adolescents based on surrogate data from parents. Galea and colleagues[65] discuss difficulties in defining, finding, and sampling populations; and Raphael[66] describes the challenges of comparing studies that used different measures of exposure, study populations, and research designs. As Ginzburg and Solomon[67] comment, one size does not fit all in disaster research. For local clinicians, studies describing the effects of Hurricane Katrina and of other oil releases requiring cleanup of affected ecosystems are relevant to an understanding of the probable mental health responses to the Gulf oil spill.

Many communities affected by the Gulf oil spill were still recovering from Hurricane Katrina at the time of the spill, which increased the complexity of the response.[60] Recovery, although progressing, is still incomplete, with some persistent or easily triggered mental health symptoms. After Hurricane Katrina, Kessler and colleagues[68] reported increases in the frequency and severity of mental health symptoms but a concomitant decrease in the use of mental health

Table 4. Results of a Health Symptom Survey Performed in the Spring or Summer of 2010 by the National Institute of Occupational Safety and Health, According to Worker Activity.*

Symptom	Wildlife Cleaning (N=54)	Oil Skimming (N=190)	Work on Motorized Vessels (N=123)	Attendance at Coast Guard Meeting (N=74)	Activities Not Involving Exposure (N=103)
			number (percent)		
Injuries					
Scrapes or cuts	36 (67)	15 (8)	12 (10)	7 (9)	11 (11)
Burns from fire	0	0	1 (1)	0	1 (1)
Chemical burns	1 (2)	0	2 (2)	1 (1)	0
Bad sunburn	0	5 (3)	4 (3)	8 (11)	8 (8)
Constitutional symptoms					
Headaches	19 (35)	24 (13)	33 (27)	15 (20)	5 (5)
Faintness, dizziness, fatigue or exhaustion, or weakness	19 (35)	10 (5)	22 (18)	9 (12)	13 (13)
Eye and upper respiratory symptoms					
Itchy eyes	7 (13)	5 (3)	20 (16)	9 (12)	5 (5)
Nose irritation, sinus problem, or sore throat	15 (28)	21 (11)	24 (20)	13 (18)	16 (16)
Metallic taste	0	1 (<1)	2 (2)	1 (1)	0
Lower respiratory symptoms					
Coughing	5 (9)	12 (6)	13 (11)	12 (16)	8 (8)
Trouble breathing, shortness of breath, chest tightness, or wheezing	2 (4)	4 (2)	7 (6)	3 (4)	4 (4)
Cardiovascular symptoms					
Fast heartbeat	1 (2)	0	1 (1)	1 (1)	1 (1)
Chest pressure	0	1 (<1)	2 (2)	0	0
Gastrointestinal symptoms					
Nausea or vomiting	5 (9)	6 (3)	7 (6)	3 (4)	3 (3)
Stomach cramps or diarrhea	3 (6)	7 (4)	9 (7)	8 (11)	7 (7)
Skin symptoms: itchy skin, red skin, or rash	25 (46)	5 (3)	15 (12)	9 (12)	8 (8)
Musculoskeletal symptoms: hand, shoulder, or back pain	21 (39)	5 (3)	13 (11)	6 (8)	6 (6)
Psychosocial symptoms: feeling worried or stressed, pressured, depressed, hopeless, or short-tempered, or having frequent changes in mood	13 (24)	11 (6)	32 (26)	6 (8)	7 (7)
Heat-stress symptoms					
Any	41 (76)	30 (16)	44 (36)	21 (28)	21 (20)
Four or more of heat-stress class of symptoms	6 (11)	3 (2)	5 (4)	1 (1)	3 (3)

* Data are from the National Institute for Occupational Safety and Health.[48] The category of wildlife cleaning includes wildlife cleaning and rehabilitation workers surveyed in June and July 2010 from Theodore, Alabama; Pensacola, Florida; Fort Jackson and Grand Isle, Louisiana; and Gulfport, Mississippi. The category of oil skimming includes shrimp-boat captains, deckhands, and contract laborers working to skim oil who were housed on "Floating City #1" near Venice, Louisiana, and were surveyed from June 19 through 23, 2010. The category of motorized vessels includes workers on vessels throughout the Gulf of Mexico, within a 3-mile (nearly 5-km) radius of the explosion site, who were involved in applying and monitoring dispersant from vessels to the water, transporting workers to oil rigs, and conducting oil burns in situ. The category of Coast Guard meeting attendance included Coast Guard personnel and offshore response workers at a meeting held in Venice, Louisiana, who were surveyed on June, 18, 2010. The control category of activities not involving exposure included workers recruited at the Venice Field Operation Branch and Venice Commanders' Camp, Louisiana, who reported having no exposures to oil, dispersants, cleaners, or other chemicals and who had not worked on a boat.

services and in the rate of prescribed medications. Needs assessments by the Centers for Disease Control and Prevention after Hurricane Katrina showed that 50% of adults still living in New Orleans had psychological distress. Surveys of first responders showed persistently elevated rates of post-traumatic stress disorder (PTSD), depression, alcohol abuse, and conflict between domestic partners. In another study[69] involving a culturally modified National Child Traumatic Stress Network Hurricane Assessment and Referral Tool between 2005 and 2010, researchers evaluated 25,000 students returning to schools in New Orleans, St. Bernard, and Plaquemines Parishes. Forty-eight percent were considered to have mental health symptoms in 2005–2006. Despite subsequent improvement, the rate of mental health symptoms remained higher than expected on the basis of studies after other disasters. In 2009–2010, before the Gulf oil spill, 30% of the students continued to be classified as having mental health symptoms, suggesting that a complex or repeated trauma increases vulnerability to mental health conditions.

Psychosocial concerns are particularly pertinent in culturally diverse populations. Vu and colleagues had interviewed a group of working-age Vietnamese residents of New Orleans before Hurricane Katrina and then re-interviewed them 1 year afterward.[70] Although many problems in the immediate aftermath of the hurricane had been resolved, others — including lack of access to care and information — remained. When free health services were suspended, the temporary reduction in the rate of health disparities among races and ethnic groups disappeared.[71] In this same population, 21% and 5% of residents met the criteria for partial and complete PTSD, respectively. Symptoms were most common among residents with a low degree of acculturation and a high degree of exposure to floods, combined with prolonged stays in emigration transition camps.[72]

The *Exxon Valdez* oil spill in Alaska is of particular relevance to the Gulf oil spill. Like the Gulf spill, the *Valdez* spill resulted in environmental disruption, exposure to toxic chemicals, loss of employment, and impacts on traditional cultures. Studies revealed that depression, generalized anxiety disorder, PTSD, interpersonal violence, and a variety of other socially disruptive behaviors were more common among close-knit Alaskan natives than in other residential groups.[17,18,21] Problems in children included fear of being left alone and poor school performance.

Neurotoxic effects of crude oil have been differentiated from those attributable to the mental health consequences of oil spills.[22] Many of the symptoms of direct neurotoxicity of volatile hydrocarbons, such as headache, nausea, weakness, and lassitude, are nonspecific and may be associated with depression or other mental health problems or with heat stress. On the basis of air-monitoring data, it is highly unlikely that exposures from the Gulf oil spill reached the level required to cause more specific neurotoxic symptoms from volatile hydrocarbons, such as convulsions and coma, or from *n*-hexane, such as peripheral neuropathy.

ECOSYSTEM EFFECTS WITH CONSEQUENCES FOR HUMAN HEALTH

The Gulf oil spill represents a national seafood-safety issue. Government agencies have monitored seafood, including fish, shrimp and crabs, and have restricted areas of seafood harvesting (Table 3). Pressure remains regarding seafood harvesting and drilling restrictions. Individual people may be continuing to harvest seafood.

Studies in cell systems and laboratory animals after the *Erika* and *Prestige* oil spills suggest that bioaccumulation and biomagnification of crude-oil components, particularly PAHs, can occur in seafood.[47,73] Uncertainty exists about the roles of oil and dispersants in the complex Gulf ecosystem, but they potentially affect algal blooms and the production of harmful toxins, such as brevetoxin. The coating of marine rocks with oil interferes with arsenic absorption and may increase arsenic levels in seafood.[74]

CONCLUSIONS AND IMPLICATIONS FOR THE FUTURE

Increasing global demand for energy will inexorably lead to exploitation of oil sources that are challenging to access and thus have a high risk of oil release. Major oil spills from megatankers in crowded sea lanes are also likely. The Gulf oil spill, a multistate disaster affecting workers and communities, highlights the linked vulnerability of ecosystems and humans to environmental changes. The interdependence of symptoms and preexisting clinical conditions, toxicologic effects, and ecologic and economic concerns requires holistic, transdisciplinary clinical, mental health, and public health studies and interventions.

After the Gulf oil spill, many studies were begun quickly to assess the ecologic effects. Unfortunately, the NIEHS study of response workers was not funded until at least 6 months after the beginning of the disaster. This delay challenges the ability of response workers to recall their exposures. It also limits the use of biologic markers of exposure; some of these markers (e.g., hemoglobin and albumin adducts derived from benzene) are unlikely to persist over time, and others (e.g., PAH metabolites) are likely to be confounded by other types of exposures. In addition to exposure misclassification, major research challenges include recruitment of participants and appropriate control groups, and these challenges may be exacerbated by litigation, such as that which occurred after the *Exxon Valdez* oil spill. Concerns about confidentiality and compatibility of federal and state databases may prevent their linkage, further hindering study comparisons (Table 3). The NIEHS scientists also need to link with local researchers who have baseline information on Gulf residents (from post–Hurricane Katrina studies) and with local physicians who can report to public health authorities cases that raise clinical suspicion of an association with the oil spill.

In two Institute of Medicine workshops about assessing the health effects of the Gulf oil spill, the focus of the participants has been on addressing uncertainties by characterizing contaminant mixtures in all environmental media, detecting exposure sources, focusing on vulnerable populations, disseminating information effectively and in a timely manner, and working closely with local leaders, communities, and academic programs to assess and protect public health.[75,76] Several initiatives are urgently needed, before similar disasters occur in the future: rapid development and implementation of protocols for baseline clinical evaluations, including respiratory function; biospecimen banking; short- and longer-term medical surveillance and monitoring of workers; and development of psychosocial interventions. In addition to research, clinical referral networks addressing immediate physical and mental health symptoms and untreated existing health conditions such as asthma and hypertension are critical, especially for vulnerable populations.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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