Review on the effects of exposure to spilled oils on human health

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ABSTRACT: Harmful effects of oil spills on diverse flora and fauna species have been extensively studied. Nevertheless, only a few studies have been compiled in the literature dealing with the repercussions of oil exposure on human health; most of them have focused on acute effects and psychological symptoms. The objective of this work was to gather all these studies and to analyze the possible consequences of this kind of complex exposure in the different aspects of human health. Studies found on this topic were related to the disasters of the *Exxon Valdez*, *Braer*, *Sea Empress*, *Nakhodka*, *Erika*, *Prestige* and *Tasman Spirit* oil tankers. The majority of them were cross-sectional; many did not include control groups. Acute effects were evaluated taking into account vegetative-nervous symptoms, skin and mucous irritations, and also psychological effects. Genotoxic damage and endocrine alterations were assessed only in individuals exposed to oil from *Prestige*. The results of the reviewed articles clearly support the need for biomonitoring human populations exposed to spilled oils, especially those individuals involved in the cleanup, in order to evaluate not only the possible immediate consequences for their health but also the medium- and long-term effects, and the effectiveness of the protective devices used. Copyright © 2010 John Wiley & Sons, Ltd.

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INTRODUCTION AND BACKGROUND

Since the industrial revolution took place in the eighteenth century, the use of fossil fuels, especially petroleum derivatives, has continually increased. It requires their transport from the platforms where they are extracted around the world, usually along sea routes in big tankers. The bad state of a considerable number of these, added to the fact that many are still monohull, has led to the high number of accidental spills that have occurred in recent decades.

In the last five decades approximately 38 accidents involving supertankers have taken place, affecting the coasts of different countries (International Tankers Owners Pollution Federation Limited; http://www.itopf.com/information-services/data-and-statistics/statistics/index.html#noha/). The major oil spills have occurred in western and Mediterranean Europe, as well as in North Africa; these regions have experienced 13 of the 20 major spills. In this respect and considering the high population density of these geographical areas, they have major interest from the epidemiological point of view.

The main ecosystem constituents affected by the spills are generally seaside flora and some fauna such as birds and bivalve mollusks. Nevertheless, when a big spill occurs there is usually a large group of volunteers, in general local inhabitants, who mobilize and take part in the cleanup work to minimize the impact of the spill on the natural and economic resources and recover the coastal environment as soon as possible. These individuals constitute an exposed population whose health may be potentially affected by the noxious properties of the oil.

Harmful effects of oil spills on diverse marine species, especially birds and marine invertebrates, have been extensively

studied. It is enough to type the name of any sunken oil tanker (e.g. *Exxon Valdez*, *Nakhodka*, *Erika*, *Urquiola*, *Braer*, *Sea Empress*, *Prestige*) into a bibliographic search engine (e.g. PubMed) and many studies on the impact of the spill on coastal ecosystems and the contamination and recovery are obtained. Nevertheless, there are only a few studies focused on the repercussions of oil exposure for human health. Most of them are related to acute effects and psychological symptoms. Table 1 displays a summary of the main characteristics of those oil spills for which epidemiological studies on the effects on human health have appeared in the literature.

The objective of this manuscript is to review the studies on the effects of oil exposure on human health as a result of accidents involving supertankers. Studies were classified according to the type of effect analyzed into acute toxic and psychological effects or genotoxic and endocrine effects; also a section compiling some *in vitro* works and studies on the bioaccumulation and transference of oil compounds in the food chain is included.

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Table 1. Oil spills for which epidemiological studies on the effects on human health were reported (ordered by spill size)

Ship name	Date	Location	Spill size (t)
MV Braer	5 January 1993	Southwest Shetland islands, UK	85,000
Sea Empress	15 February 1996	Milford Haven, UK	72,000
Prestige	19 November 2002	Galicia, Spain	63,000
Exxon Valdez	24 March 1989	Bligh ref, Prince William, Alaska, USA	37,000
Tasman Spirit	26 July 2003	Karachi, Pakistan	37,000
Erika	12 December 1999	South Penmarch, Brittany, France	20,000
Nakhodka	2 January 1997	Northeast Oki Island, Sea of Japan, Japan	>6,000

IN VITRO STUDIES AND STUDIES ON THE EFFECTS CAUSED BY TRANSFERENCE TO THE FOOD CHAIN

Table 2 displays a summary of the studies included in this section. All of them analyzed effects induced by oil spilled from *Erika*. Amat-Bronnert *et al*. (2007) performed an *in vitro* study in two human cell lines, one from hepatoma and another one from bronchial epithelium, treated with an *Erika* fuel extract. DNA adducts performed by ^{32}P-postlabelling method were only detected in hepatoma cells, indicating biotransformation via cytochrome P450 (CYP) 1A2 and 1B1 since the two cell lines do not possess the same metabolic system (hepatoma cells exhibit a wide spectrum of metabolic enzymes while bronchial cells do not). Moreover, western blot and densitometry quantification showed that exposure to the fuel extract induced some metabolizing enzymes such as CYP 1A2, cyclooxygenase 2 and 5-lipooxygenase; the latter two are involved in carcinogenic processes. In epithelial bronchial cells induction of leucotriene B4, a mediator of inflammation, was revealed by inmmunoassay. These results acquire special importance with regard to human health, since inhalation is one of the most representative ways of absorbing fuel compounds.

Lemiere *et al*. (2005) carried out a study to determine the potential genotoxic risk for consumers of marine food contaminated with polycyclic aromatic hydrocarbons (PAH) coming from oil spills. Mussels (*Mytilus* sp.) contaminated with *Erika* oil were collected and provided daily to rats over periods of 2 and 4 weeks. The DNA damage was measured by the single-cell gel electrophoresis (comet) assay in hepatic, bone marrow and blood cells. While no evidence of genotoxicity was observed in the peripheral blood samples, significant increases in DNA damage were observed in the liver and the bone marrow of rats ($P < 0.001$). The intensity of the DNA damage increased with the PAH contamination level of the mussels. Therefore, this study demonstrated that oil-contaminated food can cause genotoxic damage in consumers. Also, it showed that mussels, often present in the human diet especially in coastal producer regions, carry pollutants in a bioavailable form when contaminated with oil.

A similar study in rats fed with *Erika* oil-contaminated mussels (*Mytilus edulis)* was performed by Chaty *et al*. (2008). Rats were fed for 2 days and CYP 1A1 mRNA expression and ethoxyresorufin-*O*-deethylase (EROD) catalytic activity were analyzed by RT-PCR and a fluorimetric method, respectively. Results obtained showed the transient induction of CYP 1A1 mRNA and EROD activity, which reached a maximum after 12 h, returning to basal levels within 36 h.

The studies presented in this section show evidence for the bioaccumulation of oil compounds and their transference to the food chain in oil-contaminated marine food, and demonstrate the induction of DNA damage by the products generated by metabolic enzyme activity transforming many polluting agents into even more toxic intermediaries. In this regard, Bro-Rasmussen (1996) indicated that toxic chemicals at low concentrations will not immediately kill humans; however, depending on their potential to bioconcentrate when climbing the food chain, persistent chemicals may create a human hazard in the case of chronic ingestion. For this reason, *in vitro* and *in vivo* studies that consider not only bioaccumulation ability, but also the time that the pollutants stay in the organisms and the transference rate through the different links of the food chain, must be performed, and also studies on the optimal way to decontaminate oil-exposed organisms to make them safe for human consumption.

EPIDEMIOLOGICAL STUDIES ON ACUTE TOXIC AND PSYCHOLOGICAL EFFECTS, AND STUDIES ON POTENTIAL TOXICOLOGICAL RISK ASSESSMENT

A summary of the studies included in this section is shown in Table 3.

Exxon Valdez

The first oil spill for which studies on the effects on human health are collected in the literature is the one from *Exxon Valdez*. Although a variety of studies exist on the ecological impact of this spill, only a few consider the psychological, psychiatric and social effects.

Palinkas *et al*. (1992) assessed the levels of depressive symptomathology between two groups, one of indigenous people ($N = 188$) and another one of Euro-Americans ($N = 371$), all of them residents in 13 communities of Alaska (11 in the region directly exposed to the oil spill itself and two control communities). The results of these authors suggested that cultural differences played an important role in the perception of the psychological damage produced by this disaster, which was related to the cleaning work in which the people were involved and also the damage to fishing grounds, the main sustenance of these communities. The group of Euro-Americans showed a certain moderating effect of the damage in relation to familiar support; however, this factor did not significantly influence in the indigenous groups. These results emphasize the role of cultural differences in the perception of and capacity to overcome the psychological impact.

Table 2. *In vitro* studies and studies on the effects caused by transference to the food chain (in order of the chronology of the spills)

Accident –reference	Study characteristics	Methods	Results
Erika – Amat-Bronnert et al. (2007)	*In vitro* genotoxicity of an *Erika* fuel extract in human epithelial bronchial cells and human hepatoma cells	DNA adducts. CYP 1A1, 1A2, 1B1, 2C9, COX1, COX2 and 5-LOX protein expression. LT B4 and PG E2 detection	Adducts formation and induction of CYP 1A2, COX2 and 5-LOX in hepatoma cells. Formation of LT B4 in bronchial cells
Erika – Lemiere et al. (2005)	Genotoxicity associated with *Erika* oil-contaminated mussels consumption in rats fed daily for 2 and 4 weeks	Comet assay in hepatic cells, bone marrow and blood cells	Dose–effect–time relationship in hepatic and bone marrow cells. No effect in blood cells
Erika – Chaty et al. (2008)	CYP 1A1 induction associated with *Erika* oil-contaminated mussels consumption in rats fed for 2 days	CYP 1A1 mRNA expression and EROD catalytic activity in liver	CYP 1A1 mRNA and EROD activity transient induction

COX, cyclooxygenase; CYP, cytochrome P450; EROD, ethoxyresorufin-O-de-ethylase; LOX, lipooxygenase; LT, leucotriene; PG, prostaglandine.

Later, the same authors (Palinkas *et al.*, 1993) as a result of this same disaster examined the relationship between exposure and subsequent cleanup efforts and the prevalence of generalized anxiety disorder, post-traumatic stress disorder (PTSD) and depressive symptoms in 13 communities of Alaska. They performed a community survey of 599 men and women approximately 1 year after the spill. Prevalences of 20.2 and 9.4% were found for the generalized anxiety disorder and PTSD, respectively. Also, the prevalence of depression scale scores above 16 and 18 was 16.6 and 14.2%, respectively. For all the parameters analyzed, exposed individuals showed scores several times higher than unexposed individuals Women were particularly vulnerable to the effects of exposure to the oil spill and cleanup activities on the prevalence of generalized anxiety disorder (β = 0.22, $P < 0.0001$; odds ratio = 1.43, 95% CI 1.23–1.67), PTSD (β = 0.19, $P < 0.001$; odds ratio = 1.40, 95% CI = 1.15–1.69) and CES-D Scale scores of 18 and above ($\beta = 0.17$, $P < 0.001$; odds ratio = 1.35, 95% CI = 1.13–1.60). The authors suggest, on the basis of their results, improving the mental health care of disaster victims, particularly in primary care settings.

Gill and Picou (1998) monitored the impact of *Exxon Valdez* spill on the affected populations by means of a 4-year (1989–1992) longitudinal study in which they applied a survey on social disruption and psychological stress, using random-sampling strategies, personal interviews and control communities. Data obtained revealed the chronic nature of stress. Out-migration expectations and desires increased from 1989 to 1991. Social disruption was reported by a high proportion of residents in 1989, but had declined to just over half in 1991. High levels of event-related psychological stress were found in 1989 and 1990 but they diminished in the following two years.

Finally, Palinkas *et al.* (2004) confirmed the prevalence of PTSD associated with ethnic differences. They reported high levels of social disruption one year after this disaster, in both ethnic groups (indigenous Alaskan and Euro-Americans). However, low level family support, participation in spill cleanup activities and a decline in subsistence activities were significantly associated with PTSD in indigenous Alaskan, but not in Euro-Americans.

MV Braer

Campbell *et al.* (1993) performed a cross-sectional study in which a population of individuals exposed to *MV Braer* oil spill ($N = 420$) was compared with a control group ($N = 92$), from Hillswick, 95 km north of the incident. They compiled information on demographic details, smoking and alcohol consumption, perception of health, peak expiratory flow, hematology, liver and renal function tests, and blood and urine toxicology. Their results showed that, during the first and second day after the spill, the population reported mainly headaches, irritation of the throat and itchy eyes. The authors did not find significant differences between both groups for any of the biological markers. Taking these results together, only anecdotal reports of certain acute symptoms could be confirmed.

Later, the same authors reported longer-term effects in the same populations (344 exposed individuals and 77 controls; Campbell *et al.*, 1994). Among exposed people, 7% perceived their health to be poor compared with none of the controls (χ^2 = 8.05, d.f. = 3, $P < 0.05$). Comparison of the symptoms of exposed people in the 2 weeks before with their presence immediately after the incident showed more tiredness and fever, and fewer throat, skin and eye irritations, and headaches (odds ratio = 1.86,

Table 3. Epidemiological studies on acute toxic and psychological effects, and studies on potential toxicological risk assessment (ordered by the chronology of the spills)

Accident – reference	Study characteristics	Methods	Results
Exxon Valdez – Palinkas *et al.* (1992)	Cross-sectional. Ethnic differences in stress, coping, and depressive symptoms in indigenous people (N = 188) and Euro-Americans (N = 371)	CES-D scale	Level of exposure significantly associated with CES-D scores in both groups. Indigenous people had significantly higher mean depressive symptom score. In Euro-Americans perceived family support was a moderator of effects of exposure on depressive symptoms
Exxon Valdez – Palinkas *et al.* (1993)	Cross-sectional, 1 year after the spill. Community patterns of psychiatric-disorders in exposed (N = 437) and controls (N = 162)	CES-D scale. Questions from the National Institute of Mental Health Diagnostic Interview Schedule	The exposed group showed higher prevalence of generalized anxiety disorder and CES-D scores ≥ 16 and 18. Women exposed were particularly vulnerable
Exxon Valdez – Gill and Picou (1998)	Longitudinal (4 years). Chronic community stress and social effects in residents: 1989 (N = 118) 1991 (N = 228) 1992 (N = 152) and controls: 1989 (N = 73) 1991 (N = 102) 1992 (N = 41)	Questionnaires of out-migration desires, expectations and social disruption. Psychological stress by Events Scale	Data revealed the chronic nature of stress. In residents increase in out-migration expectations and desires, and high levels of event-related psychological stress, diminishing with time, was observed
Exxon Valdez – Palinkas *et al.* (2004)	Cross-sectional, 1 year after the spill. Ethnic differences in symptoms of PTSD in indigenous people (N = 188) and Euro-Americans (N = 371)	Modified form of Version III of the DIS	High levels of social disruption were associated with PTSD in both ethnic groups. Low family support, participation in cleanup activities, and a decline in subsistence activities were significantly associated with PTSD only in indigenous people
MV Braer – Campbell *et al.* (1993)	Cross-sectional. Initial acute effects in residents (N = 420) and controls (N = 92)	Questionnaires of acute symptoms, peak expiratory flow, hematology, liver and renal function tests, blood and urine toxicology	Principal health effects arose on days 1 and 2 (headaches, itchy eyes, and throat irritation). No significant differences between exposed and controls were found for any of the biological markers. Toxicological studies did not show any exposure that are known to affect human health
MV Braer – Campbell *et al.* (1994)	Cross-sectional. Follow up after 6 months of acute effects in residents (N = 344) and controls (N = 77)	General health questionnaire. Peak expiratory flow, urine analysis, hematology, and liver and renal function tests	The mean general health questionnaire score of exposed was significantly greater than that of controls. Exposed had greater overall scores for somatic symptoms, anxiety and insomnia, but not for personal dysfunction and severe depression
MV Braer – Crum (1993)	Cross-sectional. Effect on respiratory tract in children living close to *Braer* shipwreck (N = 44 at 3 days and 56 at 9–12 days after oil spill)	Peak expiratory flow rate	Peak expiratory flow rates were within the normal range in both parts of the study, and no deterioration was seen over the study period
Sea Empress – Lyons *et al.* (1999)	Cross-sectional. Acute health and psychological effects in exposed (N = 539) and controls (N = 550)	Questionnaires of acute symptoms. HAD and SF-36 scores	Exposed showed significantly higher anxiety and depression scores, worse mental health and self-reported headache and sore eyes and throat
Sea Empress – Gallacher *et al.* (2007)	Cross-sectional. Acute symptomatology attributable to psychological exposure in exposed (N = 794) and controls (N = 791)	Questionnaires of acute toxic and non-toxic symptoms and Hospital Anxiety and Depression Scale	Perceived risk was associated with raised anxiety and non-toxicologically related symptom reporting. Toxic symptom reporting was associated with oil exposure and with raised perceived risk
Nakhodka – Morita *et al.* (1999)	Cross-sectional. Acute health problems in exposed (N = 282)	Questionnaires of acute and toxic symptoms. Personal air samplers to assess carcinogenic benzene, toluene and xylene. Urine toxicity levels	Levels of hydrocarbons in air were far below the occupational acceptable limit. The principal complaints of symptoms were low back pain, headache and symptoms of eyes and throat
Erika – Schvoerer *et al.* (2000)	Cross-sectional. Acute health effects in exposed (N = 3,669)	Questionnaires and telephone interviews on acute symptoms	The main described acute symptoms were lumbar pain, migraine, dermatitis, ocular irritation, respiratory problems and nauseas. Duration of the cleaning work was identified as risk factor

Table 3. Continued

Accident – reference	Study characteristics	Methods	Results
Erika – Baars (2002)	Potential toxicological risk assessment for people involved in cleaning activities and for tourists	Risk characterizations on the basis of suppositions of the potential exposure during cleaning and tourist activities	The risk for the general people was limited. Increased risk for developing skin irritation and dermatitis, and very limited risk for developing skin tumors, were described for people who had been in bare-handed contact with the oil
Erika – Dor et al. (2003)	Potential toxicological risk assessment after decontamination of 36 beaches polluted by the Erika oil spill and seven control beaches	Determination of the 16 PAH selected by the US EPA in sand, water and surface of rocks. Seven scenarios of exposure for people using the beaches were contemplated, and the most conservative available toxicological values were selected for computing risks	The sand and water were slightly polluted, with values similar to those found in the control beaches. The rocky areas were still highly polluted. No lethal risk was found for a young child who had accidentally ingested a small ball of fuel. The life-long excess risks for skin cancer and for all other cancers were about 10^{-5} in scenarios including contact with the polluted rocks. The hazard quotient for teratogenic effects was very small, except in scenarios where pregnant women would walk among rocks containing high pollution levels
Prestige – Suarez et al. (2005)	Cross-sectional. Acute health problems among subjects involved in the cleanup operation after the spill ($N = 800$)	Questionnaire on exposure conditions, acute health problems, and use of protective material	Bird cleaners accounted for the highest prevalence of injuries. Working more than 20 days in highly polluted areas was associated with increased risk of injury in all workers. Toxic effects were higher among seamen. No severe disorders were identified
Prestige – Carrasco et al. (2006)	Cross-sectional. Association between health information, use of protective devices and occurrence of acute health problems in exposed ($N = 799$)	Questionnaire on exposure conditions, acute health problems, use of protective material and health-protection information received	Health-protection briefing was associated with use of protective devices and clothing. Uninformed subjects registered a significant excess risk of itchy eyes, nausea/vomiting/dizziness, headaches and throat and respiratory problems. Seamen, the most exposed group, were the worst informed and registered the highest frequency of toxicological problems
Prestige – Zock et al. (2007)	Longitudinal 12-24 months after the spill. Association between participation in cleanup work and respiratory symptoms in exposed ($N = 6780$)	Questionnaires with qualitative and quantitative information on cleanup activities and respiratory symptoms	The risk of LRTS increased with the number of exposed days, exposed hours per day, and number of activities. The excess risk of LRTS decreased when more time had elapsed since last exposure
Prestige – Carrasco et al. (2007)	Cross-sectional. Health-related quality of life and mental health in residents after 16 months ($N = 1350$) and controls ($N = 1350$)	Questionnaires of perceived social support and mental health SF-36, GHQ-28, HADS and GADS	The SF-36 showed coastal residents as having a lower likelihood of registering suboptimal values in physical functioning and bodily pain, and a higher frequency of suboptimal scores in mental health
Prestige – Sabucedo et al. (2009)	Cross-sectional. Psychological impact in subjects from 23 coastal locations from three zones according to their proximity to the location of the spill ($N = 938$).	Questionnaires on perceived involvement and social support, satisfaction with the financial aid received and social relationships. Modified version of the CRI-ADULT. Simplified version of the SCL-36	Affected subjects received a good deal of social support and were satisfied with the economic aid received. Those affected with high support and satisfaction scores were in a better situation than those with low scores, and even better than those not affected
Tasman Spirit – Janjua et al. (2006)	Cross-sectional. Acute health effects in exposed residents ($N = 216$) and controls living 2 km ($N = 83$) and 20 km ($N = 101$) far from the coastline	Questionnaires on acute health symptoms and on perception about the role of oil spill in producing ill health, and anxiousness about the effect of oil spill on health	Data showed moderate-to-strong associations between the exposed group and the symptoms. There was a trend of decreasing symptom-specific prevalence odds ratios with increase in distance from the spill site
Tasman Spirit – Khurshid et al. (2008)	Cross sectional. Health parameters of people working/living in the vicinity of an oil-polluted beach ($N = 100$)	Hydrocarbon/organic content in seawater and sand samples. Hematological and biochemical parameters. Liver and renal function tests	Seawater had no traces of hydrocarbon content. Lymphocyte and eosinophil levels were slightly increased. About 11 people had raised SGPT, but this was not significant
Tasman Spirit – Meo et al. (2008)	Cross sectional. Lung function in exposed ($N = 20$) and controls ($N = 31$)	Spirometry	Significant reduction in FVC, FEV_1, $FEF_{25-75\%}$ and MVV in exposed. Lung function parameters were improved when the subjects were withdrawn from polluted air environment

CES-D, Center for Epidemiologic Studies – Depression; CRI-ADULT, coping response inventory; DIS, diagnostic interview schedule; $FEF_{25-75\%}$, forced expiratory flow; FEV1, forced expiratory volume in first second; FVC, forced vital capacity; GADS, Goldberg anxiety and depression scale; GHQ, general health questionnaire; HADS, hospital anxiety depression scale; LRTS, low respiratory tract symptomathology; MVV, maximum voluntary ventilation; PAH, polycyclic aromatic hydrocarbons; PTSD, post-traumatic stress disorder; SGPT, serum glutamic pyruvic transaminase.

95% CI 1.19–2.92). The mean general health questionnaire score of the exposed subjects was significantly greater than that of the controls. The high rate of non-responders among individuals selected to participate in this study was reported (59 of the 215 non-responders in the first phase of the study and 16 of the 86 non-responders in the second phase were surveyed). The main reasons for non-responding was not feeling that their health had been affected, not interested in the study or did not think the study was useful (Foster *et al.*, 1995).

Crum (1993) performed a cross-sectional study evaluating the peak expiratory flow rate in two groups of children aged 5–12 years who were resident within 5 km of the *Braer* shipwreck. The first measure was carried out three days after the accident in 44 children, and a second one in 56 children between 9 and 12 days after the oil spill. The main results showed that the children's peak expiratory flow rates were within the normal range in both parts of the study, and no deterioration was seen over the study period, even in the children known to have asthma. No significant difference was observed between the two sets of values ($P = 0.502$, Student's *t* test for paired samples).

Sea Empress

In the wake of the *Sea Empress* oil spill, Lyons *et al.* (1999) investigated the acute health effects (self-reported physical and psychological symptoms) in the residents of the vicinities of the affected area (Milford Haven, southwest Wales). They designed a retrospective cohort study that included 539 exposed and 550 controls. Results obtained, after adjustment by age, sex and smoking status, allowed the conclusion that the people living in the exposed areas presented high levels of anxiety and depression scores, worse mental health and self-reported headache (odds ratio = 2.35, 95% CI 1.56–3.55), sore eyes (odds ratio = 1.96, 95% CI 1.06–3.62) and sore throat (odds ratio = 1.70, 95% CI 1.12–2.60). These last three symptoms were expected from the known toxicological effects of oil, so the authors suggested a direct health effect in the exposed population.

On the basis that exposure to a complex emergency has a substantial psychological component, Gallacher *et al.* (2007) performed work in 794 exposed individuals and 791 controls in which anxiety, depression and symptom reporting were used as measures of the health impact. The main results indicated that perceived risk was associated with raised anxiety and non-toxicologically related symptom reporting (odds ratio = 2.28, 95% CI 1.57–3.31, $P < 0.001$), whereas physical exposure to oil was only associated with toxicologically related symptom reporting. The authors concluded that psychological exposure was a substantially more sensitive measure of health impact than physical exposure in relation to psychological outcomes.

Nakhodka

Morita *et al.* (1999), as a result of the *Nakhodka* oil spill, conducted a study in 282 people (men and women) who joined in cleanup work. Interviews on health status and determinations of several hydrocarbon metabolites in urine were carried out. Their results were similar to those from Campbell *et al.* (1993), showing that people suffered mainly from pains in the lumbar region and legs, headaches and irritation of eyes and throat. The multivariate logistic regression model was applied to clarify the risk factors of having at least one symptom with several relevant variables. Results showed that being of female gender, the number of

working days on cleanup activities, direct exposure to oil and history of hypertension and low back pain were significant risk factors for the development of symptoms ($P < 0.05$). In the urine analyses, only three individuals showed higher levels of hippuric acid (>1.0 g l^{-1}) that had returned to normality four months later. In this study the use of personal air samplers by the cleanup workers was remarkable. They allowed the determination of the concentrations of carcinogenic benzene, toluene and xylene in the environmental air, and their results showed that these levels were lower than the occupational acceptable limits (10 ppm for benzene, 100 ppm for toluene and 100 ppm for xylene). The highest concentration of suspended particles on any given day was 0.088 mg m^{-3}, also below the occupational acceptable limit (2 mg m^{-3}).

Erika

Schvoerer *et al.* (2000) presented a cross-sectional investigation on human health risk assessment as a result of the *Erika* oil spill in 3669 interviewed people, who included cleaning workers and volunteers. Their results indicated that 7.5% of the individuals experienced some type of wound and 53% some health problem (30% lumbar pain, 22% migraine, 16% dermatitis). They reported in a smaller degree ocular irritation (9%), respiratory problems (7%) and nausea (6%). The duration of the cleaning work was identified as a risk factor.

Baars (2002) evaluated the health risk for people involved in the cleaning activities after the *Erika* oil spill and also for tourists, with an emphasis on the carcinogenic properties of the oil, on the basis of the known toxicological properties of the oil components and assumptions on the levels of exposure during the performance of different activities. In assessing toxic risks the actual exposure levels were compared with limit values taken from the literature; in assessing carcinogenic risk the actual exposure levels were compared with the 1:10^4 lifetime excess risk of developing tumors. The outcome indicated that the risks for the general population were limited. For people who had been in bare-handed contact with the oil there was increased risk of developing skin irritation and dermatitis, but these effects were in general reversible, and also that of developing skin tumors, which was very limited due to the short contact time with the oil.

Dor *et al.* (2003) reported an assessment of human health risk after decontamination of beaches polluted by the *Erika* oil. They determined the 16 PAH selected by the US EPA in samples of sand, water and the surface of rocks from 36 cleaned-polluted beaches and seven control beaches, and contemplated seven possible scenarios of exposure for people using the beaches in tourist activities (children, adults and pregnant women) or working activities. The life-long excess risk for skin cancer and for all other cancers was about 10^{-5} in scenarios including contact with the polluted rocks. The authors concluded that exposure was mainly associated with polluted water among children and with contaminated rocks for adults, and that, despite uncertainties, decontaminated beaches did not entail any significant health risks and could be opened to the public.

Prestige

As a result of the disaster of the tanker *Prestige*, densely populated coastal regions of Spain (Galicia, Asturias, Cantabria and the Basque country), as well as the neighboring French coasts, with

intense activity of extraction of marine resources and tourism, were affected. Several studies were performed after this accident in order to evaluate the possible human health effects.

Suarez *et al.* (2005) evaluated the conditions of exposure and the acute health effects in individuals who participated in the cleanup works in the regions of Asturias and Cantabria (Spain), and the association between these and the type of work. Four hundred individuals from each region were interviewed. Collected data included information on the work performed, use of protection devices and acute symptoms. Bird cleaners accounted for the highest prevalence of lesions (19%, $P < 0.001$), including neurovegetative disorders (11.2%, $P = 0.169$) and low back pain (3.1%, $P = 0.281$). Working periods longer than 20 days in highly polluted areas were associated with increased risk of injury in all workers. A specific analysis restricted to seamen only found a strong and significant association with having worked for more than 3 days (odds ratio = 14.30 and 11.02 for categories of 3–20 days and over 20 days, respectively) and having torn or not worn the protective suit (odds ratio = 1.20 and 7.79, respectively), but no severe disorders were identified among individuals analyzed.

The same authors reported another study examining the association between use of protective devices, frequency of acute health problems and health-protection information received by 799 exposed individuals, classified according to the tasks performed (Carrasco *et al.*, 2006). These authors observed a significant excess risk of itchy eyes (odds ratio = 2.89; 95% CI 1.21–6.90), nausea/vomiting/dizziness (odds ratio = 2.25; 95% CI 1.17–4.32) and throat and respiratory problems (odds ratio = 2.30; 95% CI 1.15–4.61) among uninformed subjects. Furthermore, there was a noteworthy significant excess risk of headaches (odds ratio = 3.86; 95% CI 1.74–8.54) and respiratory problems (odds ratio = 2.43; 95% CI 1.02–5.79) among uninformed paid workers. Seamen, the group most exposed to the spilled oil, were the worst informed and registered the highest frequency of toxicological problems. Therefore, the authors confirmed the results obtained in their previous study and found a significant association between proper health-protection briefing and use of protective devices and lower frequency of health problems.

Zock *et al.* (2007) evaluated the prevalence of lower respiratory tract symptoms (LRTS) more than a year after *Prestige* accident in 6780 fishermen who had participated in the cleanup labors (response rate 76%), through questionnaires that included qualitative and quantitative information. Their results showed that LRTS was more prevalent in cleanup workers (odds ratio = 1.73; 95% CI 1.54–1.94), and that the risk of LRTS increased in relation to the number of exposed days, exposed hours per day and number of activities carried out (linear trend, $P < 0.0001$). The excess risk of LRTS decreased with elapsed time since last exposure (odds ratio = 2.33, 1.69 and 1.24 for less than 14 months, 14–20 months, and more than 20 months, respectively), although it was still significant when more than 20 months had elapsed.

Carrasco *et al.* (2007) performed a new study on the effects of the *Prestige* oil spill on health-related quality of life (HRQoL) and mental health in the affected population, approximately 18 months after this disaster, using several questionnaires. The main results showed coastal residents as having a lower likelihood of registering suboptimal HRQoL values in physical functioning (odds ratio = 0.69; 95% CI 0.54–0.89) and bodily pain (odds ratio = 0.74; 95% CI 0.62–0.91), and a higher frequency of suboptimal scores in mental health (odds ratio = 1.28; 95% CI 1.02–1.58). The authors concluded that, almost one and a half years after the accident, worse HRQoL and mental health levels were

not in evidence among subjects exposed to the spilled oil. Nevertheless, a slight impact on the mental health of residents in the affected areas was suggested by some of the scales applied.

Similar results were obtained by Sabucedo *et al.* (2009), who evaluated the psychological impact of *Prestige* oil spill. They carried out a descriptive study that involved 938 men and women from 23 localities throughout the Galician coast. Half of them were fishermen or workers related to the extraction of fishing resources, and the other half were not linked to these activities. Questionnaires on different psychological and psychosocial factors were filled in at the time of the accident and one year after. The results showed that the affected subjects had received a good deal of social support and were satisfied with the economic aid received. In addition, affected individuals with high support and satisfaction scores were currently in a better situation than those affected with low scores, and even better than those not affected.

Tasman Spirit

Janjua *et al.* (2006), following the *Tasman Spirit* shipwreck, conducted a study which included an exposed group composed of adults of both genders living on the affected coastline ($N = 216$) and two control groups living 2 km ($N = 83$) and 20 km ($N = 101$), respectively, away from the indicated area. Surveys on acute symptoms related to eyes, respiratory tract, skin and nervous system, as well as consultations of allergies, tobacco consumption and perceptions on the effect on their health and anxiety about their health effects were performed. Their results showed moderate-to-strong associations (prevalence odds ratios ranging from 2.3 to 37.0) between the exposed group and the symptoms, which decreased with the distance from the spill site, and multiple linear regression model revealed strong relationship of exposure status with the symptoms score ($\beta = 8.24$, 95% CI 6.37–10.12).

Khurshid *et al.* (2008) presented a short-term study in people who were working or living in the vicinity of Karachi beach. Hematological and biochemical parameters were determined, and liver and renal function tests were carried out. They also took seawater and sand samples and analyzed them for hydrocarbon/organic contents. The results only showed slight rises in the levels of lymphocytes and eosinophiles. The authors recommended performing follow-up studies after oil spills taking samples every 3 months for 3–5 years, noting respiratory disorders and any changes in the skin.

Finally, Meo *et al.* (2008) assessed, by means of spirometry, lung function and followed up the progression after one year in 20 subjects exposed to this oil spill and 31 controls. Subjects exposed to polluted air had significant reductions in lung function compared with their matched controls (P ranging from 0.001 to 0.02 for the different lung function parameters). The reported impairment was reversible and lung function parameters were improved when the subjects were withdrawn from the polluted air environment.

In summary, studies performed after *Exxon Valdez* spill only accounted for psychological effects in the exposed populations. For all the other accidents, there are also studies on acute toxic effects, and moreover, for the *Erika* oil spill there are two works on potential toxicological risk assessment, both concluding that exposure to pollutants contained in the oil during common activities did not entail any significant health risk. Data obtained in most of these studies indicated that technological disasters that involve oil spills have acute physical consequences

that diminish with time and are mainly reversible, and psychological consequences and continuing disruptive and stress-provoking consequences for resident communities. The results also suggested that conflicting definitions of long-term effects and recovery of the natural environment contributed to community stress.

EPIDEMIOLOGICAL STUDIES ON GENOTOXICITY AND ENDOCRINE TOXICITY

Table 4 displays a summary of the main characteristics of these studies.

Braer

Cole *et al.* (1997) evaluated the possible genotoxicity as a consequence of the *Braer* tanker oil spill. They used blood samples to assess the primary damage in the DNA (DNA adducts in the mononuclear cell fraction by a modified ^{32}P-postlabeling method and mutations at the hprt locus in T lymphocytes). These authors did not obtain any evidence of genotoxicity for either end point, but they proposed several issues to be taken into account in the design of biomonitoring studies after oil spills.

Prestige

Laffon *et al.* (2006) conducted a study to determine the possible genotoxic damage associated with the exposure to *Prestige* oil, in 34 volunteers, who worked in autopsies and cleaning of oil-contaminated birds, and 35 controls. Environmental concentrations of volatile organic compounds (VOC) in the working room were determined. Genotoxicity was evaluated by means of micronucleus (MN) test and comet assay, and the possible influence of several DNA repair genetic polymorphisms was also analyzed. Their results showed significantly higher DNA damage ($P < 0.01$), but not cytogenetic damage, in relation to the exposure time ($r = 0.376$, $P < 0.05$), and also certain exposure–genotype interactions.

Pérez-Cadahía and colleagues performed a study with the objective of evaluating the genotoxicity and endocrine toxicity related to exposure to *Prestige* oil during the different cleaning labors. Exposed individuals were classified into three groups: manual volunteers, hired manual workers and hired workers using high-pressure water machines. The environmental exposure levels of VOC were determined, and different biological parameters were measured. Their results were published in different papers. In an initial stage (Pérez-Cadahía *et al.*, 2006, 2007), a relatively small population (68 total exposed vs 42 controls) was analyzed. The data obtained indicated that the highest levels of VOC were observed in the volunteer environment and that exposure to *Prestige* oil induced genotoxic damage (tests applied: sister chromatid exchanges (SCE), MN test and comet assay), the comet assay being the most sensitive test to detect it, and alterations in hormonal status (prolactin and cortisol plasma concentrations, significant decreases with $P < 0.01$). Also, gender, age and tobacco smoking influenced the levels of genetic damage, while the effect of using protective devices (clothes and mask) was less noticeable than expected.

Later, they enlarged the study with the aim of checking the validity of their previous data, including 180 exposed subjects

and 60 controls. Their results showed significant increases in the levels of blood heavy metals (aluminum, nickel and lead) and DNA damage, and alterations in the endocrine status of the exposed populations (significantly higher prolactin plasma concentrations, $P < 0.01$; Pérez-Cadahía *et al.*, 2008a). They also found general increases in MN frequency and decreases in the proliferation index in the individuals with longer times of exposure (Pérez-Cadahía *et al.*, 2008b). Moreover, significant influence of several genetic polymorphisms in metabolizing enzymes and DNA repair proteins was observed. In addition, their previous results showing the absence of effect of using protective devices were confirmed.

Finally, the same authors (Pérez-Cadahía *et al.*, 2008c) investigated the relationship between blood levels of heavy metals and genotoxic or endocrine parameters in the individuals exposed to *Prestige* oil. Cortisol plasma concentration appeared to be the most sensitive parameter to the effects of metal exposure, since it was significantly influenced by blood concentrations of aluminum, nickel (both inversely) and cadmium (positively), and jointly by aluminum and nickel. On this basis, the authors suggested plasma levels of cortisol as a potentially relevant biomarker to assess the effects of exposure to heavy metals.

Taking into account the known genotoxic, cancer-provoking and endocrine disrupting properties of many compounds contained in the spilled oils, it seems surprising that only for two oil spills (*Braer* and *Prestige*) are there studies contemplating these consequences for human health in exposed individuals. The results obtained in most of these studies provide evidence of genotoxicity and alterations in the hormonal status related to the exposure. The only work with negative results (Cole *et al.*, 1997) comprised a relatively small population (26 exposed vs 9 controls), and nothing is specified on the participation of the exposed individuals in the cleanup tasks; only their status as residents in the polluted area is mentioned. It seems probable that direct participation in the cleanup work involved a higher exposure to the oil toxic compounds than that experienced by zone inhabitants who did not participate in the cleaning.

CONCLUSIONS

Until now there have been 38 large oil spills, but only for seven of them have studies on the repercussions of the exposure to spilled oils on human health been performed. Most of these investigations correspond to cross-sectional epidemiological studies that analyze acute physical effects or psychological consequences in the affected people. Some of them do not include a matched control population, which makes the information provided confusing and difficult to interpret. A smaller number of studies are *in vitro* or *in vivo* approaches aiming to investigate the effects at the cellular level and the ability of the oil compounds to be transferred into the food chain and induce damage in consumers; others are focused on biological markers indicative of genotoxicity and/or endocrine toxicity.

On the occasion of the *Prestige* oil spill, Porta and Castaño-Vinyals (2003) recommended performing epidemiological studies of exposure to the spilled oil on the medium- and long-term impact on human health. In addition to a first transversal stage, they recommend the monitoring of the exposed populations in a second longitudinal stage. This would allow (i) determination of whether the biomarkers of internal dose, of biologically effective dose and of early biological response

Table 4. Epidemiological studies on genotoxicity and endocrine toxicity (ordered by the chronology of the spills)

Accident – reference	Study characteristics	Methods	Results
Braer – Cole *et al.* (1997)	Longitudinal. Genotoxicity in residents (N = 26) and controls (N = 9) at 3 sampling times (10 days, 10 weeks and 1 year after the accident)	DNA adducts in the mononuclear cell fraction and frequency of hprt mutations in T lymphocytes	No evidence of genotoxicity was obtained for either end point
Prestige – Laffon *et al.* (2006)	Cross-sectional. Genotoxicity in individuals performing autopsies and cleaning of oil-contaminated birds (N = 34) and controls (N = 35)	Environmental VOC. Comet assay and MN test. DNA repair genetic polymorphisms (XRCC1, XRCC3, APE1)	Significant increase in the comet assay, but not in the MN test, related to the time of exposure. Exposed individuals carrying XRCC1-399Gln or APE1-148Glu alleles showed increased DNA damage
Prestige – Pérez-Cadahía *et al.* (2006)	Cross-sectional. Genotoxicity in volunteers and hired workers participating in the cleanup (N = 68) and controls (N = 42)	Environmental VOC. Comet assay, SCE, MN test	Highest VOC levels in the volunteer's environment. Significant increase in the comet assay in exposed individuals. Influence of sex, age and tobacco smoking on the genotoxicity variables. No effect of using protective mask during cleanup labors
Prestige – Pérez-Cadahía *et al.* (2007)	Cross-sectional. Genotoxicity and endocrine alterations in volunteers and hired workers participating in the cleanup (N = 68) and controls (N = 42)	Environmental VOC. Heavy metals in blood (Al, Cd, Ni, Pb, Zn). SCE. Prolactin and cortisol. Metabolic genetic polymorphisms (GSTM1, GSTT1, GSTP1)	Highest VOC levels in the volunteer's environment. Significant increase in the levels of Al, Ni and Pb, and decrease of Zn, in exposed individuals. Significant increase in SCE rate in exposed, influenced by age, sex, smoking and GSTM1 polymorphism. Significant decrease in prolactin and cortisol levels in exposed subjects
Prestige – Pérez-Cadahía *et al.* (2008a)	Cross-sectional. Genotoxicity and endocrine alterations in volunteers and hired workers participating in the cleanup (N = 180) and controls (N = 60)	Heavy metals in blood (Al, Cd, Ni, Pb, Zn). Comet assay. Prolactin and cortisol. Metabolic genetic polymorphisms (CYP 1A1, EPHX1, GSTM1, GSTT1, GSTP1)	Significant increase in the levels of Al, Ni and Pb, and decrease of Zn, in exposed individuals. Significant increase in comet assay and decrease in cortisol levels in exposed individuals. Higher DNA damage was related to CYP 1A1 and EPHX1 variant alleles, and lower DNA damage to GSTM1 and GSTT1 null genotypes
Prestige – Pérez-Cadahía *et al.* (2008b)	Cross-sectional. Genotoxicity in volunteers and hired workers participating in the cleanup (N = 159) and controls (N = 60)	MN test. Metabolic genetic polymorphisms (CYP 1A1, CYP 1B1, EPHX1, GSTM1, GSTT1, GSTP1). DNA repair genetic polymorphisms (XRCC1, XRCC3, XPD)	General increases in MN frequency and decreases in the proliferation index were observed in individuals with longer time of exposure. All the polymorphisms analyzed, excepting for CYP 1B1 and XRCC1, influenced cytogenetic damage levels
Prestige – Pérez-Cadahía *et al.* (2008c)	Cross-sectional. Relationship between blood concentrations of heavy metals and cytogenetic and endocrine parameters in exposed by means of univariate statistics (general linear model) (N = 179).	Heavy metals in blood (Al, Cd, Ni, Pb, Zn). Comet assay, SCE, MN test. Prolactin and cortisol	Pb was related to the comet assay. Cortisol plasma concentration was influenced by Al and Ni inversely and by Cd positively. In women there was a strong association between Cd and prolactin levels

MN, micronucleus test; SCE, sister chromatid exchanges; VOC, volatile organic compounds.

remain stable with time or undergo variations; (ii) determination of certain factors influencing the mentioned biomarkers; and (iii) analysis of the levels of biomarkers or any other factor associated with the appearance of a particular illness, subclinical effects or interesting alterations (physiological, genotoxic, etc.).

Some studies compare the evaluated or estimated exposure levels with occupational acceptable exposure limits, or use these limits to calculate the potential toxicological risk. Nevertheless, this comparison is not entirely correct, since the occupational limits are usually defined for exposures of 8 h/day during a whole working life, i.e. considering a chronic exposure. Exposure to spilled oils takes place over several days or some months at the most, involving time periods much shorter than occupational exposures.

In summary, most of the studies collected in this review provide evidence on the relationship between exposure to spilled oils and the appearance of acute physical, psychological, genotoxic and endocrine effects in the exposed individuals. Considering the relatively high frequency of this kind of environmental disaster, it seems necessary to establish detailed intervention protocols that include some mechanisms to detect and control the possible harmful health effects that exposure can induce, including performing the immediate collection of biological samples from the beginning of the cleanup work, in order to establish the levels of individual internal exposure effects at the acute and chronic level, especially those related to genotoxicity. This will permit not only determination of the risk that exposure may involve, but also evaluation of whether protective devices used by the individuals in each case adequately fulfilled their function, or on the contrary they did not exert the required protection and therefore require to revision of material characteristics and improved briefing sessions on their correct use.

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