

# THE GULF WAR OIL SPILL TWELVE YEARS LATER: CONSEQUENCES OF ECO-TERRORISM

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## ABSTRACT

The intentional release of an estimated 11 million barrels of oil during the 1991 Gulf War was the largest oil spill in history. An assessment of the physical, chemical, and ecological impacts of this spill shows that, 12 years later, oil residues and habitat modifications continue to have toxic effects on intertidal communities. As of 2003, there are an estimated 8 million cubic meters of oiled sediment remaining along the 803 km of impacted shoreline in Saudi Arabia. Of this volume, 45% occurs in muddy tidal flats and 23% in salt marshes and mangroves. Much of the oil in these sheltered habitats occurs as oiled crab burrows, with liquid oil remaining in the burrows to depths that exceed 50 cm. These habitats show the lowest degree of ecological recovery since the spill, with 87% of the upper intertidal zones of mangroves and marshes and 71% of muddy tidal flats having reduced species richness and a disturbed community structure. Those habitats exposed to the greatest amount of wave activity contain the smallest amount of residual oil; however, on outer sand beaches, the oil is commonly buried to depths exceeding 1 m. The factors that affect the ecological recovery of the intertidal habitats include: 1) The chemical toxicity of the oil residues; 2) the physical toxicity of heavy and hardened oil residues; 3) other physical barriers that affect seed germination of plants, settlement of larvae, and burrowing; 4) limited sources for recruitment of biota; 5) reduced hydrological functioning of tidal channels. This study shows the importance of oil removal as the first phase of habitat recovery. It also indicates the potential for large-scale damage by blatant acts of eco-terrorism.

## INTRODUCTION

The Oiled Shoreline Survey was one of several studies conducted by the Presidency of Meteorology and Environment (PME) to determine the impacts of the intentional release of an estimated 11 million barrels (Tawfiq and Olsen, 1993) (40 times the *Exxon Valdez* oil spill in Alaska) in 1991 during Iraq's illegal invasion and occupation of Kuwait on the environment and public health, with funding provided by the United Nations Compensation Commission. The study design specified by PME consisted of establishing transects at 250-meter (m) intervals along the entire coastline affected by the spill. Each transect started at the landward edge of the oil and ended at the seaward edge. Along each transect, detailed observations were recorded of the visible oiling of the sediment in trenches dug at stations established at set intervals. Figure 1 shows the transects and stations in Dawhat ad Dafi. Each red dot represents a station where oil was observed. Sediment

samples were collected at regular intervals for a wide range of chemical analyses. The transect method was augmented with the polygon method, where the boundaries of the oiled sediments possibly missed by the transects were delineated and digitized in the field.



FIGURE 1. THE DISTRIBUTION OF OILED SEDIMENTS IN DAWHAT AD DAFI TWELVE YEARS AFTER THE GULF WAR OIL SPILL. EACH RED DOT INDICATES A STATION WITH OILED SEDIMENTS. THE OILED BAND COVERS ALMOST THE ENTIRE INTERTIDAL ZONE, REACHING UP TO 2 KM.

Specially trained teams, consisting of a coastal geomorphologist, intertidal ecologist, Global Positioning System (GPS) technician, and sediment sampler, conducted the field surveys. Fieldwork began on 25 September 2002 and ended on 7 March 2003. During this time, the field teams completed 3,107 transects; dug, described, and photographed 19,515 trenches; and collected 26,158 samples for total petroleum hydrocarbon (TPH) analysis, 2,802 samples for detailed chemical characterization and finger-

printing, and 134 bivalve tissue samples. The ecological condition of the shoreline along each transect was assessed using a Rapid Environmental Assessment protocol that collected information on species richness. All of the data were collected digitally using field computers and real time differentially corrected GPS receivers.

This extremely large data set was analyzed using sophisticated spatial and statistical methods to meet the following objectives of the study (Research Planning, Inc., 2003):

- Identify areas of shoreline of the Kingdom of Saudi Arabia that are still impacted by the 1991 oil spill on the surface and in the subsurface.
- Confirm through chemical sample analysis that the contaminated areas identified during the survey represent remnants of the 1991 oil spill.
- Analyze the temporal rates of natural oil removal and oil weathering by comparing data collected in 2002/2003 with surveys conducted in 1992 and 1993 (Hayes et al., 1995).
- Quantify the length, width, and depth of the oiled sediments and the overlying sediments free of visible oil.
- Evaluate the ecological health of the shoreline.
- Identify the factors that are affecting ecological recovery of oiled habitats.

**RESULTS**

**Persistence of Oil Residues**

Two different methods were used to calculate the volume of oiled sediment remaining on the shoreline of Saudi Arabia. Both methods yielded similar estimates of approximately 8 million

cubic meters of oiled sediments as of 2003. Table 1 shows the volumes of oiled sediments by oiling descriptor and habitat. Sediments described as heavily oiled as of 2002/2003 accounted for over 2,500,000 m<sup>3</sup>, nearly one-third of the total volume. Moderately oiled sediments accounted for over 3,300,000 m<sup>3</sup> or 41 percent of the total volume. Lightly oiled sediments account for nearly 2,000,000 m<sup>3</sup>, almost 25 percent of the total volume. There was a good relationship between the visual oiling descriptor and the mean TPH concentrations. Specifically, heavily oiled residue (HOR) averaged 41,000 parts per million (ppm), moderately oiled residue (MOR) averaged 20,000 ppm, and lightly oiled residue (LOR) averaged 5,500 ppm; heavily oiled burrows (HOB) averaged 13,800 ppm, moderately oiled burrows (MOB) averaged 8,200 ppm, and lightly oiled burrows (LOB) averaged 3,200 ppm. Samples of sediments described as “no visible oil” averaged 343 ppm.

Almost 45 percent of the oiled sediments are on sheltered muddy tidal flats and over 23 percent are on salt marsh habitat. About 26 percent of the oiled sediments occur on sandy tidal flats and 11 percent on sand beaches.

Polynuclear aromatic hydrocarbons (PAH) were analyzed for 2,802 sediment samples. For samples with oiled residues, the total PAH in 467 samples described as HOR averaged 126,900 nano-grams per gram (ng/g), the 902 samples described as MOR averaged 26,000 ng/g, and the 143 samples described as LOR averaged 6,200 ng/g. For samples with oiled burrows, the 166 samples described as HOB averaged 80,000 ng/g, the 296 samples described as MOB averaged 20,600 ng/g, and the 150 samples described as LOB averaged 3,580 ng/g. The 435 samples with no visible oil averaged 379 ng/g PAH.

**TABLE 1. The volumes and average thickness of oiled sediments by habitat and oiling descriptor.**

Habitat Type	AP		CR		HOB		MOB		LOB		HOR		MOR		LOR		SR		TB		Vol. Oiled Vol. (m <sup>3</sup> )	No Vis. Oil Interbedded (m <sup>3</sup> )	No Vis. Oil Overburden (m <sup>3</sup> )	Avg. Overburden Thickness (cm)	Grand Total Vol. (m <sup>3</sup> )
	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)	Sum Vol (m <sup>3</sup> )	Avg. Thickness (cm)					
Exposed outer sand beaches	20,258	12	585	13	145	6	136	4	157	10	60,308	20	79,037	15	31,444	16	92	1	54,920	22	247,622	9,327	232,283	20.3	489,331
Exposed sandy tidal flats	5,082	6	136	1	1,916	10	2,292	7	2,524	7	22,792	13	25,713	7	32,768	11			2,456	11	85,690	260	23,239	3.1	119,180
Moderately exposed sand beaches	18,885	5	4,464	7	64,158	20	63,348	15	26,673	12	180,611	15	182,002	9	54,560	8	334	2	66,693	18	632,229	6,832	268,919	7.1	908,080
Mangroves					26,849	30	37,252	12	13,798	10	86	10	2,683	8							88,649		4,162	1.1	84,811
Man-made structures	913	4					302	10			975	14	273	5	1,703	19	21	1	1,726	26	5,914		2,298	6.2	8,211
Moderately exposed sandy/muddy tidal flats	10,576	4	2,983	1	260,441	17	424,336	11	236,847	9	164,442	8	283,543	5	96,144	3	443	1	25,499	9	1,504,867	7,940	255,380	2.3	1,768,197
Rocky shores	609	2	4	1	525	16	1,884	6			157	2	529	2	337	2	537	1	9	1	4,547	69	134	0.2	4,749
Sabkhas			2,047	2	7,491	18	3,392	11	4,371	19	19,756	6	33,299	4	22,116	3	26	0			98,857	1,441	5,021	0.3	101,318
Salt marshes	4,599	7	686	1	582,771	22	621,941	14	373,824	11	25,466	8	121,478	4	69,939	4	4	0	3,173	6	1,803,541	4,851	81,736	0.8	1,889,227
Muddy tidal flats	8,104	4	2,626	1	901,660	18	1,001,221	13	701,153	10	224,385	7	439,694	5	521,431	3	17	1	19,928	6	3,620,196	15,725	373,983	1.6	4,011,903
<b>All Habitats</b>	<b>70,316</b>		<b>13,111</b>		<b>1,845,957</b>		<b>2,156,103</b>		<b>1,359,428</b>		<b>668,979</b>		<b>1,172,211</b>		<b>630,418</b>		<b>1,473</b>		<b>174,401</b>		<b>8,092,482</b>	<b>46,343</b>	<b>1,246,264</b>		<b>9,385,088</b>

The extent of oiling by habitat was related, in part, to the degree of exposure to wave and tidal current action. Exposed shorelines had the lowest percentage of habitat oiled; 13 percent of the exposed rocky shores and 50 percent of the exposed outer sand beaches retained visible oil 12 years after the spill. On the sand beaches, oil was commonly deeply buried (up to 1 m). Although surficial asphalt pavements (AP in Table 1) of 1991 oil were common, they comprised less than 1 percent of the oil residues. Moderately exposed shorelines had more oil: 59 percent of the moderately exposed sand beaches and 64 percent of the moderately exposed sandy and muddy sand tidal flats retained visible oil. Sheltered shorelines retained the most oil: 85 percent of the sheltered muddy tidal flats and 65 percent of the salt marshes retained visible oil.

In summary, the oil from the 1991 oil spill has persisted along most of the Saudi Arabian shoreline between the Kuwaiti border and Abu Ali Island. There has been limited removal by natural processes in the twelve years since the spill, and only in the areas of highest exposure to wave action and the lowest initial oil loading. In the northern area, from the Kuwaiti border to about Safaniya, many of the exposed outer sand beaches have little to no visible oil remaining. Most moderately exposed and sheltered habitats in this northern area remain oiled. Along the exposed shoreline between Manifa and Ras az Zawr, where it was expected that the oil would be removed by natural processes, the oil was deeply buried in the sand beaches. Once inside the moderately exposed and sheltered bays of Dawhats al Musallamiyah and ad Dafi (Figure 1), the oiling along the shoreline was essentially continuous, often very wide (up to 2 km), and had the heaviest oiling degree of any area.

### Fingerprinting of Oil Residues

The major conclusions of the fingerprinting analyses were:

- The pre-spill levels of petroleum hydrocarbons in intertidal sediments were consistent with regional background levels and orders of magnitude lower than post-1991 levels.
- Petroleum activities in the area contribute negligible amounts of hydrocarbons to the shoreline sediments relative to the 1991 oil spill.
- The source of oil residues that still contaminate the Saudi Arabian shoreline between the Kuwaiti border and Abu Ali Island is dominated by the 1991 oil spill.

### Ecological Condition of Oiled Habitats

The results of the Rapid Environmental Assessment to assess the ecological conditions are summarized in Table 2. The terms “recovering/disturbed” and “nonrecovering” are used to summarize the ecological condition, and these are defined below.

*Recovering/disturbed* habitats are defined as those that have recovering species richness and may have a disturbed species assemblage. These habitats have a species richness that is equal to or greater than the threshold for that habitat and zone combination. The thresholds were developed from comparison transects that were not oiled by the 1991 oil spill. Reaching the species threshold is the first step of recovery. Though species richness may be equal to or greater than the set threshold for a given habitat and zone combination, this is not an indication that the species assemblage has returned to baseline conditions for that habitat and zone combination. Indeed, the species assemblage in most of the recovering transects is different than the comparison transects, indicating a disturbed or damaged community structure. The existing community structure is still undergoing succession and is significantly influenced by opportunistic species that have modified its structure. Another factor, which may be contributing to the disturbed assemblage, is a modification in the habitat structure. Two

possible successional paths or recovery trajectories are possible for these recovering but disturbed species assemblages:

- 1) Continued fluctuations in species composition until the competitively superior species eventually become dominant and the community returns to its normal characteristic composition. This recovery path is followed when there are no continuing effects from oil toxicity or physical changes to the substrate. The successional path will be a function of the species life histories and occurrence of other stressors (e.g., extreme temperature or salinity events).
- 2) Continued presence of a disturbed or damaged assemblage that may never fully recover or take a very long time to recover because of continued oil toxicity or physical modifications to the habitat structure that maintains a disturbed species assemblage. High oil residues continue to have toxic effects in many areas. However, habitat structure has also been significantly modified in the oil-impacted areas. On rocky shores, algal mats have expanded and trapped sediments, thus allowing the colonization by species that feed on the algal mats and occupy the sediment substrate, as well as those that prey on these introduced species. Normal rocky shore species are excluded from these areas. On salt marshes and tidal flats, asphalt pavements have provided hard substrates for colonization by opportunistic species and excluded these areas for use by characteristic infauna, plants, and sediment grazers (Figure 2). On tidal flats, the much-expanded algal mats have formed a thick cover on the surface that prevents use by burrowers (Figure 3). Under these conditions, the species composition may never become similar to unoiled areas.

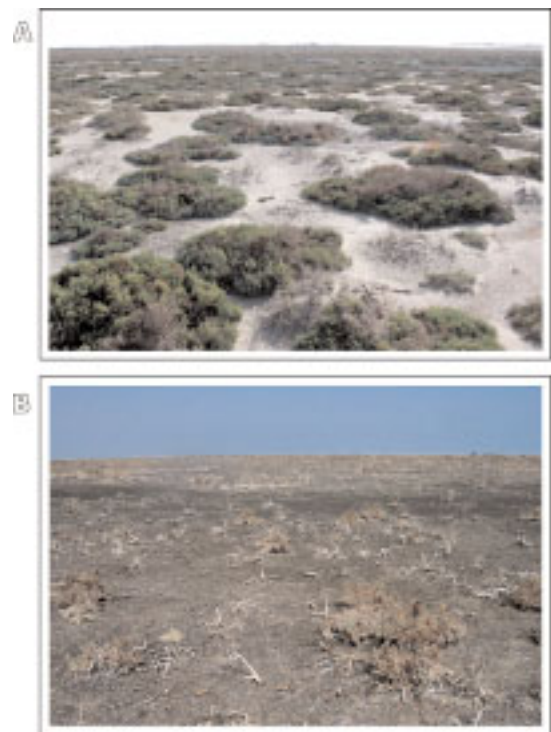


FIGURE 2. A. HEALTHY MARSH HABITAT. B. HEAVILY OILED MARSH HABITAT WITH THE DEAD WOODY STEMS INDICATING THE DENSITY OF VEGETATION PRIOR TO THE 1991 OIL SPILL. THERE ARE ONLY A FEW LIVE PLANTS TWELVE YEARS AFTER THE SPILL.

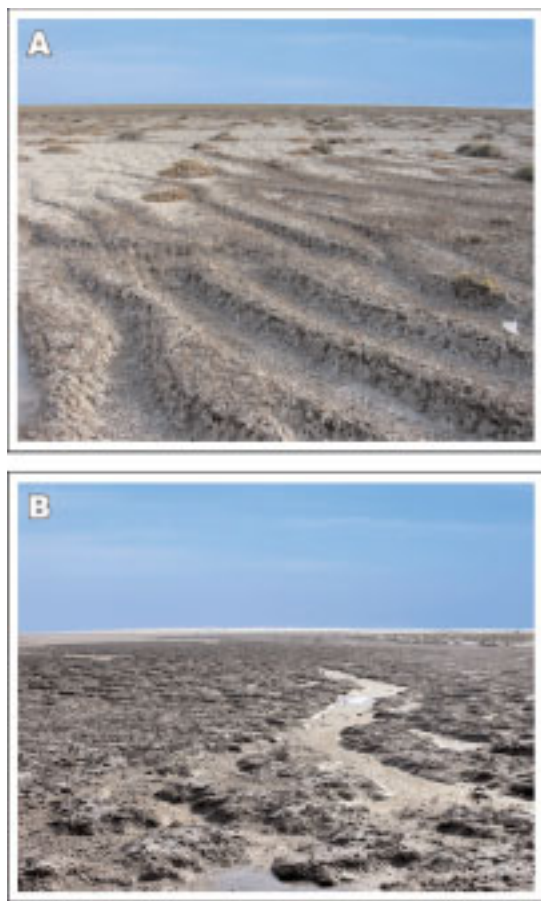


FIGURE 3. A. HEALTHY TIDAL CHANNEL IN A LOW-MARSH UNOILED AREA ON ABU ALI ISLAND (DECEMBER 2002). B. TIDAL CHANNEL IN A HEAVILY IMPACTED MARSH NEAR MANIFA (DECEMBER 2002) WHERE THE TIDAL CHANNEL IS CLOGGED WITH SEDIMENT AND ALGAL MAT, REDUCING ITS HYDROLOGICAL AND ECOLOGICAL FUNCTIONING.

*Nonrecovering* habitats are those that have a species richness that is below the threshold. In these habitats, the shift (or disturbance) in community structure and species assemblage and composition also were observed.

The species assemblage at the recovering/disturbed transects included opportunistic species that are not characteristic of the comparison transects. Also, data from 30 transects in the impacted area, where the epifaunal density and diversity and halophyte coverage were quantified and compared to similar data from comparison transects, showed that the impacted transects on moderately exposed sandy tidal flats, muddy sand tidal flats, and salt marshes had significantly lower epifaunal density and diversity and halophyte coverage.

Mangroves and salt marshes have the lowest level of recovery twelve years after the 1991 oil spill, with 89 percent and 87 percent, respectively, of the upper shore transects ranked as non-recovering. Figure 2 compares the condition of heavily oiled versus unoiled marshes. It was determined that there were 7.74 km<sup>2</sup> of heavily oiled marsh that showed little recovery and 5.7 km<sup>2</sup> of oiled marsh with partial recovery. The sheltered muddy tidal flats also showed low recovery, with 71 percent of the transects ranked as nonrecovering. Even the recovering/ disturbed muddy tidal flats had reduced frequency of characteristic species and

increased frequency of opportunistic species. It is clear that these habitats have not fully recovered.

The more exposed habitats showed better recovery as indicated by species richness. For example, exposed rocky shores had the highest number of recovering/disturbed transects, with 81 percent for the supralittoral zone and 69 percent for the upper shore zone. On exposed outer sand beaches, 62 percent of the supralittoral zone and 72 percent of the upper shore zone were classified as recovering/disturbed.

## FACTORS AFFECTING RECOVERY

There are many factors that affect the ecological recovery of the intertidal habitats that were oiled as a result of the 1991 oil spill. These factors include:

*The chemical toxicity of the oil residues.* Although the residual oil was characterized as moderately to extremely weathered, the levels of PAH in the intertidal sediments in 60 percent of the samples of sediments with visible oil exceeded 4,022 ng/g, which is the Effects Range-Low (ERL) of Long et al. (1995) and thus are likely to have impacts to sensitive species. For HOR sediments, 91 percent of the samples exceed the ERL. In 29 percent of the samples of sediments, the PAH levels exceeded 44,792 ng/g, which is the Effects Range-Medium (ERM) and thus are likely to affect a broad range of species. The sediments with the most potential toxicity are those that are the least weathered, which are located in the muddy sediments of the salt marshes and sheltered tidal flats.

*The physical toxicity of heavy and hardened oil residues.* Heavy accumulations of weathered oil residues on the surface can slow the recovery of intertidal communities even when the oil is no longer chemically toxic. Thick and hardened residues modify, prevent, or slow many ecological processes, including the moisture content and flushing of underlying sediments, nutrient cycling, oxygen exchange, seed germination, settlement of larvae, feeding of intertidal grazers, and burrowing by crabs.

*Other physical barriers that affect seed germination of plants, settlement of larvae, and burrowing.* On moderately exposed sandy and muddy tidal flats, the stations on the comparison (un-oiled) transects have 0 percent algal mat versus 21 percent of the stations on transects in the impacted areas. On sheltered muddy tidal flats, comparison stations have 6 percent algal mat versus 37 percent in oiled stations. On salt marshes, comparison stations have 8 percent algal mat versus 41 percent in oiled stations. Thus, in oiled areas, the algal mat has expanded significantly. It is believed that this expansion of thick algal mats plays a significant role in the delay of recovery on tidal flats and salt marshes.

*Limited sources for recruitment of biota.* When large, contiguous stretches of habitat are so heavily impacted, recovery may be delayed because of limited sources of seeds and larvae for recruitment. This factor is particularly important for species that do not have pelagic eggs or larvae that can drift in from other areas.

*Hydrological functioning of tidal channels.* Many of the tidal channels in the heavily oiled tidal flats and salt marshes are clogged with a thick algal mat that reduces the tidal flow volume (Figure 3). There are no active crab burrows in these channel banks. The tidal channels are not functioning as they would without the effects of the oil and the presence of thick algal mats. Tidal channels are extremely important to the functioning of tidal flats and salt marshes, and they are a key to habitat recovery. Seeds float in via the channels and successfully root along the channel banks where the water quality is highest and the soils better flushed. This pattern of recovery for salt marshes and mangroves is proceeding at a very slow rate.

This study shows the importance of oil removal as the first phase of habitat recovery. It also indicates the potential for large-scale damage by blatant acts of eco-terrorism.

**TABLE 2. Summary of the biological data on the recovery status (as per the definition of recovering/disturbed and nonrecovering in the text) of transects by habitat and zone in the oil-impacted areas. Note that there can be multiple habitats per zone in a transect, so the totals for each zone exceed the number of transects.**

	Supralittoral (SL)			Upper Shore (US)		
	Total Oil-Impacted	Recovering/ Disturbed* (%)	Nonrecovering (%)	Total Oil-Impacted	Recovering/ Disturbed* (%)	Nonrecovering (%)
Exposed outer sand beaches	536	62.1	37.9	181	71.8	28.2
Moderately exposed sand beaches	1,532	35.9	64.1	65	76.9	23.1
Exposed rocky shores	123	81.3	18.7	204	69.1	30.9
Moderately exposed rocky shore	228	68.9	31.1	428	32.2	67.8
Sheltered rocky shores	105	85.7	14.3	158	42.4	57.6
Exposed and moderately exposed sandy tidal flats	-	-	-	1,362	59.0	41.0
Sheltered muddy tidal flats	-	-	-	566	28.8	71.2
Salt marsh on sand	264	30.7	69.3	98	40.8	59.2
Salt marsh on mud	444	10.8	89.2	337	12.8	87.2
Mangroves	23	56.5	43.5	47	10.6	89.4

\* See definition in the text.

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