The Environmental Consequences of War

Legal, Economic, and Scientific Perspectives

Edited by Jay E. Austin and Carl E. Bruch

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JAY E. AUSTIN AND
CARL E. BRUCH

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THE GULF WAR IMPACT ON THE TERRESTRIAL ENVIRONMENT OF KUWAIT: AN OVERVIEW

SAMIRA A. S. OMAR, ERNEST BRISKEY, RAAFAT MISAK, AND ADEL A. S. O. ASEM

Introduction

Kuwait constitutes a portion of the northwestern coastal plain of the Arabian Gulf. It covers an area of approximately 17,818 km^2, and is characterized by arid conditions, with an average annual precipitation of approximately 105 mm. Strong northwesterly winds prevail, particularly during spring and summer. The maximum wind speed is approximately 29 m/s and usually peaks in May. Summer is extremely hot, with temperatures peaking in July and August at an average of 45°C.

The population of Kuwait is 1.5 million (1995), with a maximum population density of 87 persons/km^2. Oil, natural gas, groundwater, and fisheries are the major natural resources in Kuwait. As of 1994, oil production was approximately 2.1 million barrels/day. The production of natural gas reached 7.6 billion m^3 in 1995.[1]

The terrestrial ecosystem of Kuwait is comprised of a diversity of plant and animal species. Like most Arabian Gulf countries, Kuwait's land resources are used for livestock grazing, water production, oil production, and sand and gravel quarrying, as well as for agricultural production. Traditionally, the terrestrial environment has also been used during mild seasons for wildlife hunting (mainly for birds). During hot and dry periods, the soil becomes extremely vulnerable to wind erosion, particularly when it is disturbed or becomes barren.

[1] Organization of Petroleum Exporting Countries, *Annual Statistical Bulletin* (1994).

During the Iraqi invasion and occupation of Kuwait, there occurred one of the worst man-made environmental disasters of all time.[2] Personnel carriers moved across the desert lands destroying foliage, tearing up soil surfaces, and disrupting terrestrial habitats.[3] Hundreds of kilometers of ditches were dug and thousands of makeshift shelters were constructed.[4] Vast quantities of solid, semi-solid, and liquid wastes were merely discarded, causing severe pollution in the terrestrial environment, and millions of landmines were placed throughout the country.[5] Beginning on February 17, 1991, at ten- to fifteen-minute intervals, Iraqi troops exploded most of Kuwait's oil wells, causing vast amounts of oil to spew out onto the land surface.[6] The flow of this oil followed land surface depressions and formed hundreds of "oil lakes." These lakes varied in surface dimensions and penetrated, even saturated (10–20 percent), the soil to varying depths.[7]

[2] United States General Accounting Office, Efforts to Address Health Effects of the Kuwait Oil Fires, GAO/HRD 92–50 (1992); N. Al-Awadhi, A. El-Nawawy, and R. Al-Daher, "*In-Situ* and On-Site Bioremediation of Oil-Contaminated Soil in Kuwait," proceedings of the Third World Academy of Sciences (1992); D. Al-Ajmi, "Effects of Mixing Height and Wind Speed on the Dispersion of Air Pollution in Kuwait," Harvard Conference on Kuwait Oil-Fire Impact (1991).

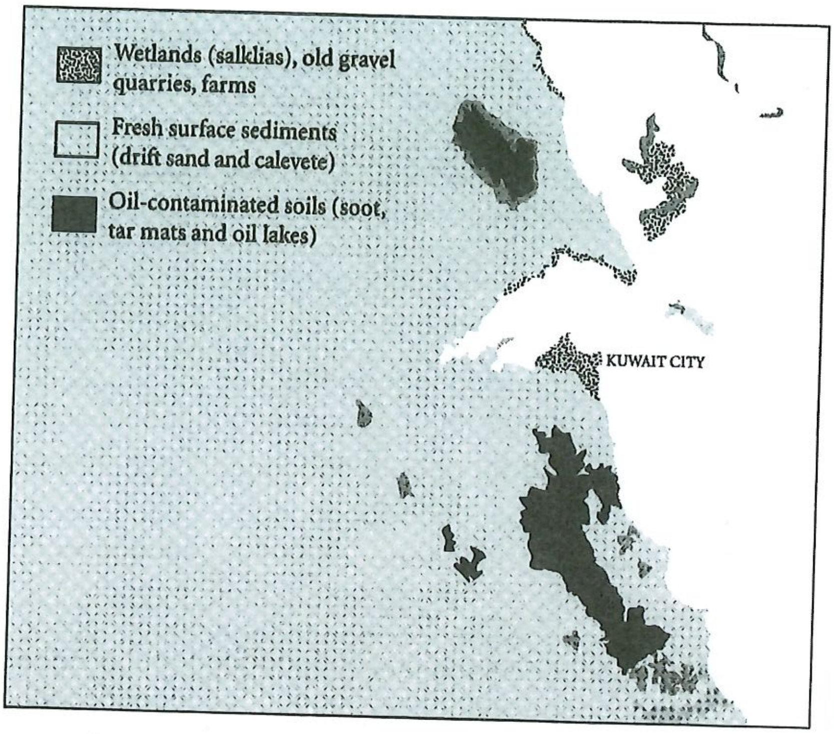
[3] Al-Houty, M. Abdal, and S. Zaman, "Preliminary Assessment of the Gulf War on Kuwait Desert Ecosystem," *J. Envtl. Sci. Health* 8 (1993), 1705–26; M. N. Alaa El-Din, A. H. Dashti, A. S. Abdu, and H. A. Nasrallah, "Environmental Impacts of Burned Oil Wells and Military Operations on Some Desert Plants and Soils of Kuwait," in *Proceedings of the International Conference on the Effects of the Iraqi Aggression on the State of Kuwait, Vol. III: Environmental and Health Effects and Remediation* (Kuwait Univ., 1996).

[4] S. Zaman and F. Alsdirawi, *Assessment of the Gulf Environmental Crisis Impacts on Kuwait's Desert Renewable Natural Resources* (Kuwait Institute for Scientific Research, 1993); D. Al-Ajmi, R. Misak, A. Al-Dousari, and A. Al-Enezi, "Impact of the Iraqi War Machinery and Ground Fortifications on the Surface Sediments and Aeolian Processes in Kuwait," in *The International Conference on the Effects of the Iraqi Aggression on the State of Kuwait.*

[5] S. A. Nawawy and K. Puskas, *Proposal: Strategic Master Plan for the Management of Solid, Semi-Solid, Liquid, and Hazardous Wastes in Kuwait* (1993); M. Al-Sudairawi, R. Misak, and R. Al-Nifaisi, "Environmental Impact Assessment of the Iraqi Strategic Mine Fields in the Southern Portion of Kuwait," in *The International Conference on the Effects of the Iraqi Aggression on the State of Kuwait*; G. Karrar, M. A. Mian, and M. N. Alsa El-Din, *A Rapid Assessment of the Impacts of the Iraqi–Kuwait Conflict on Terrestrial Ecosystems, Part Two: The State of Kuwait* (Bahrain: UNEP/ROWA, 1991); M. H. Al-Attar, "An Integrated Approach for Overcoming the Adverse Environmental Impacts Inflicted Upon Kuwait During the Iraqi Occupation," proceedings of the International Symposium on Environment, Budapest (1994).

[6] Al-Awadhi et al., "*In-Situ* and On-Site Bioremediation"; Al-Attar, "An Integrated Approach."

[7] N. Al-Awadhi, M. T. Balba, K. Puskas, R. Al-Daher, H. Tsuji, H. Cheno, K. Tsuji, M. Iwabuchi, and S. Kumamoto, "Remediation and Rehabilitation of Oil-Contaminated Lake Beds in the Kuwait Desert," *J. Aridland Studies/Special Issue of Desert Technology III* 55 (1995), 195–98.



12.1 Satellite remote sensing applications in the state of Kuwait

The oil remained in the lakes in the form of sludge and non-combusted, partially combusted, and partially weathered liquid products, all of which were vulnerable to rainstorm events on the filled playa, which caused severe runoff.[8] The oil mist and soot particle fallout from the oil-fire plumes covered vast areas of downwind terrestrial surfaces. Saltwater spray used during the fire-fighting activities following the explosions further compounded the damage to the terrestrial environment. The impacts of these activities on plants, wildlife, migratory birds, sand movement, water quality, and human security were substantial.

In sum, the military activities during the occupation and liberation of Kuwait, and through the rehabilitation period of August 1990 to July 1994, included the following:

[8] M. T. Balba, "Remediation and Rehabilitation of the Jaidan Garden," proposal to the Kuwait Institute for Scientific Research (1994).

- Transport of troops, ground entrenchment, and landmine implantation (August 2, 1990 to January 16, 1991);
- Air campaigns and ground battles (January 17 to February 26, 1991);
- Oil-well fires (January to November 1991); and
- Rehabilitation and reconstruction activities (March 1991 to July 1994).

Thus, five long-term environmental consequences of the 1990–91 Gulf War were identified: soil compaction, degradation of vegetation, surface sediment disruption, soil contamination, and groundwater pollution.[9]

This chapter summarizes the immediate and long-term impacts that the 1990–91 Gulf War has had on Kuwait's terrestrial environment. It also examines the impacts of the terrestrial environment rehabilitation efforts that were undertaken during the aftermath and recovery from the war. Finally, this chapter discusses the remedial work still in progress on the terrestrial environment, as well as the tasks yet to be undertaken.

Dimensions of the impacts on Kuwait's terrestrial environment

The invasion, occupation, and liberation warfare all seriously disrupted many aspects of Kuwait's terrestrial environment.[10] The massive releases by Iraq of Kuwaiti oil made this war particularly notorious from a terrestrial environment standpoint. The United Nations Security Council resolved that Iraq was liable for all direct environmental damage to Kuwait's natural resources.[11]

OIL POLLUTION OF SOIL

The Iraqi aggression resulted in the detonation, destruction, and ignition of 1,164 oil wells (91.8 percent of the producing wells).[12] The condition of these wells was as follows: 652 blazing, 75 gushing, and 437 completely

[9] R. F. Misak, M. Al-Sudairawi, I. Charib, A. Al-Dousari, R. Al-Nafisi, and M. Ahmed, "Environmental Impact Assessment of the Gulf War with Emphasis on Rehabilitation Activities," prepared for the International Conference on the Long-Term Effects of the Gulf War, Kuwait (Nov. 18–20, 1996).

[10] A. H. Westing, "Environmental Protection from Wartime Damage: The Role of International Law," in Nils Petter Gleditsch (ed.), *Conflict and the Environment* (Dordrecht: Kluwer Academic Publishers, 1997).

[11] United Nations Security Council Resolution 687.

[12] A. Y. Al-Ghunaim, *Devastating Oil Wells as Revealed by Iraqi Documents* (Center for Research and Studies of Kuwait, 1997).

destroyed.[13] The intact wells that survived the explosions numbered 104.[14] The aggressive actions also included the destruction of oil refineries, storage depots, and power and water stations.

The blazing and gushing oil wells (over 700) spewed vast amounts of oil onto the land. It is estimated that over 60 million barrels were released, forming 246 oil lakes covering over 49 km^2.[15] Consequently, some 40 million tons of soil have been heavily contaminated with oil.[16] The general geographic distribution of the oil lakes and tar mats in the northern and southern areas of the country is shown in Figure 12.1.

Downwind plumes of oil particulates were carried mainly by the prevailing northwesterly winds, and resulted in the spreading of combusted and partially combusted oil components along a northwest–southeast line of land stretching from the oilfields, and covering approximately 100,000 hectares of land overall.[17] The contaminants spread across this terrestrial surface varied from layers of scattered soot, to areas hideously stained as if charred by fire, to areas covered by a measurable thickness (over 2 cm) of fallout material.[18] The extent of the deposits has been estimated by satellite imagery, aerial photography, and field screenplay. Overall, it has been estimated that more than 900 km^2 have been contaminated with oil.

Gas chromatographic/mass spectrophotometric analysis of soil taken from areas 500 and 1,500 meters from the oil fires revealed that concentrations of polycyclic aromatic hydrocarbons (PAHs) were higher in the more distant samples.[19] The concentration of benzofluoranthene/ benzopyrene increased threefold with distance.[20] While there has been no ground-confirmed mapping of these fallout areas, the projections of the movement of the aerial plumes have been calculated. It also has been estimated that the fires released upwards of half a million tons of aerial pollutants per day, much of which fell on the terrestrial environment before the plumes moved out to sea. The amount of oil lost due to both the fires and oil flows has been calculated as approximately 1.0–1.5 billion barrels. Table 12.1 summarizes these impacts on the terrestrial environment of Kuwait.

[13] *Ibid.* [14] *Ibid.*

[15] N. Al-Awadhi, M. Abdal, and E. J. Briskey, "Assessment of Technologies for the Remediation of Oil-Contaminated Soil Resulting from Exploded Oil Wells and Burning Oil Fires in Kuwait," proceedings of the Third World Academy of Sciences (1997); Al-Attar, "An Integrated Approach."

[16] Al-Awadhi et al., "*In-Situ* and On-Site Bioremediation."

[17] Al-Awadhi et al., "Assessment of Technologies." [18] *Ibid.*

[19] Al-Houty et al., "Preliminary Assessment of the Gulf War," 1705–26. [20] *Ibid.*

Remote sensing Landsat Thematic Mapper™ data taken from 1987 to 1995 were evaluated to show the before and after terrestrial environments downwind from the damaged wells.[21] The oil from certain oil lakes has now been drained, but both heavily saturated and lightly contaminated terrestrial soils remain. In other cases, the weathering of the oil in the lakes has shrunk the circumference of the lake, with the peripheral surface areas drying and fragmenting.[22] In many cases, sand drifts have covered the visible appearance of the accumulated oil.[23] In all cases, the heavily and lightly contaminated soils remain in the terrestrial environment. Not only has the oil in the lakes penetrated the soil to varying depths (averaging 1 m), but the addition of salty water to extinguish the fires plus the rains that have followed have washed oil pollutants downward to a recorded depth of 20 m in certain areas.[24]

The composition of the oil in the lakes varied depending on the crude composition, the degree of combustion, the surface temperature of the lake, the fallout of the partially combusted oil, and the relative amount of seawater or highly brackish water used in fighting the fires surrounding a particular lake.[25] The composition of the oil and its components has also varied over time. Volatile aromatics have been lost to the atmosphere, and the overall concentration of aromatics has increased, as have resins. Thus,

[21] A. Y. Kwarteng and D. Al-Ajmi, "Using Landsat Thematic Mapper Data to Detect and Map Vegetation Changes in Kuwait," *Int'l Archives Photogrammetry and Remote Sensing* 31 (1996), 398–405; A. Y. Kwarteng and D. Al-Ajmi, "Satellite Remote Sensing Applications in the State of Kuwait," Kuwait Institute for Scientific Research report (1997); A. Y. Kwarteng, V. Singhroy, R. Saint-Jean, and D. Al-Ajmi, "RADARSAT SAR Data Assessment of the Oil Lakes in the Greater Burgan Oil Field, Kuwait," proceedings from International Symposium on the topic (1997).

[22] J. Al-Sunaimi, unpublished data for the Kuwait Institute for Scientific Research (1992); J. Saeed, H. Al-Hashash, and K. Al-Matrouk, "Assessment of the Changes in the Chemical Components of the Crude Oil Spilled in the Kuwait Desert After Weathering for Five Years," *Envt. Int'l* 24 (1998), 141–52.

[23] A. Y. Kwarteng, "Multitemporal Remote Sensing Data Analysis of the Kuwait Oil Lakes," *Envt. Int'l* 24 (1998), 121–37.

[24] Al-Attar, "An Integrated Approach"; M. N. Viswanathan, "Rainfall Induced Transport of Crude Oil Contaminants From Unsaturated Zones," Kuwait Institute for Scientific Research report WH007K (1995).

[25] J. Al-Besharah, "The Kuwait Oil Fires and Oil Lakes – Facts and Numbers," proceedings of the International Symposium on the Environmental and Health Impact of Kuwait Oil Fires, Institute of Occupational Health, University of Birmingham (1992); T. Saeed, A. Al-Bloushi, and K. Al-Matrouk, "Study of the Chemical Composition of the Oil in the Oil Lakes and Effects of Weathering on Aromatics," Kuwait Institute for Scientific Research report VR001K (1993).

Table 12.1. *Facts and figures: the consequences of war on the terrestrial environment of Kuwait*

Type of effect	Extent of damage
Number of damaged oil wells	720
Amount of oil seepage into land[a]	60 million barrels
Amount of oil in lakes[b]	24 million barrels
Number of oil lakes[c]	246
Area covered by oil lakes[d]	49 km^2
Area covered by heavy oil mist fallout[e]	100,000 ha (1,000 km^2)
Amount of seawater or brackish water used to extinguish oil fires[f]	5,000 million gallons
Total oil contaminated areas[g]	953 km^2
Amount of heavily contaminated soil[h]	40 million tons
Aerial pollutants[i]	0.32–0.95 million m^3 per day
Oil lost due to fires and oil flows	1.0–1.5 billion barrels
Amount of oil in trenches[j]	498,447 m^3
Depth of oil in the oil trenches from the soil surface[k]	20–90 cm
Total number of bunkers, trenches, and weapon pits[l]	375,000
Amount of excavated loose sediments from large bunker[m]	1,700 m^3
Amount of excavated loose sediments from small bunker[n]	500 m^3
Number of military vehicles operating during the war[o]	About 3,500 tanks and 2,500 armored personnel carriers
Number of landmines (up to 1997)[p]	1,646,355 (1,078,705 anti-personnel and 567,650 anti-tanks)
Number of unrecovered mines in the desert[q]	33,000
Amount of recovered ordnance[r]	109,000 tons (85%)
Amount of unrecovered ordnance[s]	20,000 tons
Areas impacted from military activities[t]	about 7,500 km^2
Degree of damage to terrestrial ecosystem out of total damaged area[u]	20% intensive, 42% moderate, and 38% slight
Total surface area of Kuwait affected by 1990–91 Gulf War[v]	5,458.7 km^2 (30.6% of Kuwait)

Notes to Table 12.1

[a] Al-Awadhi et al., "*In-Situ* and On-Site Bioremediation"; Al-Attar, "An Integrated Approach."
[b] Al-Ghunaim, *Devastating Oil Wells.*
[c] *Ibid.*
[d] *Ibid.*
[e] Al-Awadhi et al., "*In-Situ* and On-Site Bioremediation."
[f] PAAC, *Environment Damage Claims Prioritization Report* (Safat, 1997).
[g] *Ibid.*
[h] Al-Awadhi et al., "*In-Situ* and On-Site Bioremediation."
[i] A. Y. Kwarteng and T. A. Bader, "Using Satellite Data to Monitor the 1991 Kuwait Oil Fires," *Arabian J. Sci. & Eng.* 18 (1993), 95–115.
[j] Al-Ajmi et al., "Oil Trenches and Environmental Destruction."
[k] *Ibid.*
[l] Al-Ajmi *et al.*, "Impact of the Iraqi War Machinery."
[m] *Ibid.*
[n] *Ibid.*
[o] *Ibid.*
[p] Ministry of Defense of Kuwait, *Periodical Mine Clearance Report* (1997).
[q] PAAC, *Environment Damage Claims Prioritization Report.*
[r] Ministry of Defense of Kuwait, *Periodical Mine Clearance Report.*
[s] *Ibid.*
[t] Al-Ajmi et al., "Impact of the Iraqi War Machinery."
[u] Al-Ajmi and Misak, "Impact of the Gulf War on the Desert Ecosystem."
[v] F. El-Baz and R. Makharita, *The Gulf War and the Environment* (1994).

the asphaltene contents have risen over time.[26] Preliminary work has also suggested that soil particles contaminated by crude oil have been bound or aggregated together, whereas soils contaminated by aerial deposits have not exhibited such trends.[27] The heavily contaminated soils have also rendered the soils hydrophobic (unable to absorb water) and anaerobic (unable to sustain oxygen-using microbes and plant roots) and thus resulted in land unsuitable for plant growth.[28] Overall, the soot and oil mist fall-out, in addition to being washed downward, may be dried or fragmented,

[26] N. Al-Matairi and W. Eid, "Utilization of Oil-Contaminated Soil for Construction Materials," in *The International Conference on the Effects of the Iraqi Aggression on the State of Kuwait*; Saeed et al., "Assessment of the Changes in the Chemical Components."
[27] Al-Houty et al., "Preliminary Assessment of the Gulf War."
[28] S. Zaman, "Impact of the Gulf War on Kuwait's Desert Flora and Soil," in proceedings of the International Conference on Desert Development, Kuwait (March 23–26, 1998); Al-Houty et al., "Preliminary Assessment of the Gulf War"; S. Zaman, "Impact of the Gulf War on Kuwait's Desert Flora and Soil," in proceedings of the International Conference on Desert Development.

potentially adding to the threat of contamination via airborne particulates, and of uptake or deposit of these particulates into plant life.[29]

The Iraqi forces constructed huge numbers of oil trenches in the southern portion of Kuwait. The amount of oil in these trenches was estimated at 3,750 m^3/km along the length of these trenches, for a total estimated amount of approximately 498,000 m^3.[30] The oil trenches have since been refilled with soil during the rehabilitation phase, although oil still exists beneath a 20–90 cm blanket of these sediments.[31] The impact of the oil trenches on deeper soils, and ultimately on groundwater, has yet to be investigated.

DISRUPTION OF LAND SURFACE

The soils of Kuwait are highly susceptible to erosion. The ground is usually covered by several types of recent sediments, including: aeolian, residual, playa, desert plain, slope, and coastal deposits.[32] Among these, aeolian deposits are predominant and account for 50 percent of overall surface deposits.[33]

The impact of the Gulf War on some of the fragile ecosystems of this land has been assessed, including the locations, numbers, and specifications of Iraqi fortifications, such as bunkers, trenches, ammunition storage shelters, and weapon pits.[34] The series of long trenches constructed along the southern borders were filled with oil and were to have been set on fire to deter liberation. Field reconnaissance surveys of accessible areas were

[29] Al-Ajmi, "Effects of Mixing Height and Wind Speed"; A. Hussain, Z. Baroon, S. Khalafawi, T. Al-Ati, and S. Sawaya, "Heavy Metals in Fruits and Vegetables Grown in Kuwait During the Oil Well Fires," *Arab Gulf J. Sci. Res.* (1995); S. A. Omar and J. W. Bartolome, "Nutrient Variation of Plants and Soil Impacted by Oil-Well Fires Caused by Iraqi Forces During the Gulf War," in *Proceedings of the International Conference on the Effects of the Iraqi Aggression on the State of Kuwait, Vol. III*, pp. 145–65; K. Puskas, A. El-Nawawy, N. Al-Awadhi, and R. Al-Daher, "Remediation of Land Sites Suffering Hydrocarbon Contamination," proceedings of the Second Annual Conference on Hazardous Waste Management (1995); K. Puskas, N. Al-Awadhi, F. M. Abdullah, and J. C. Joseph, "Evaluation of Passive Remediation of Oil-Contaminated Soil," final report 4601, vols. I–IV (1995); Saeed et al., "Assessment of the Changes in the Chemical Components."

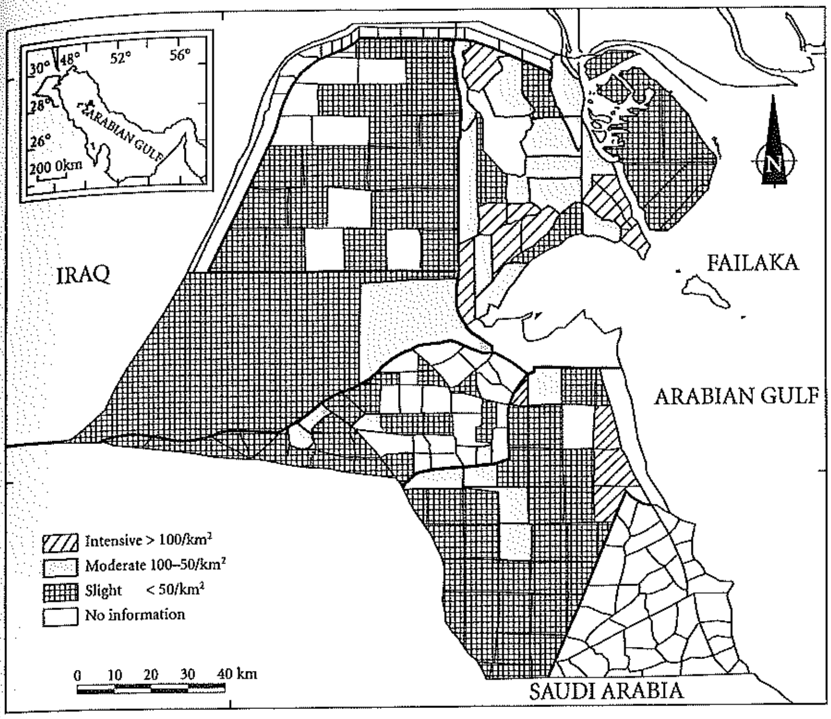
[30] D. Al-Ajmi, R. F. Misak, M. Al-Ghunaiem, and S. Mahfouz, "Oil Trenches and Environmental Destruction of Kuwait," Center for Research and Studies of Kuwait report (1997).

[31] Recent field survey conducted by the authors.

[32] F. I. Khalaf, "Desertification and Aeolian Processes in the Kuwait Desert," *J. Envts.* 16, 125–45.

[33] *Ibid.*

[34] D. Al-Ajmi and R. F. Misak, "Impact of the Gulf War on the Desert Ecosystem in Kuwait," in Eric Wathins (ed.), *The Middle Eastern Environment* (1995).



12.2 Distribution density of the total number of bunkers, trenches, and weapons pits in selected areas of Kuwait

carried out to assess the disruption of the desert surface by these military activities. Damage to the soil has accelerated erosion, as well as aeolian transportation and deposition. In sum, it was found that plant cover was destroyed, fine sediments were exposed, micro-relief was altered, soil was compacted, bedrock was fractured, vast areas of soil were contaminated, and the potential for groundwater contamination was created.

The Iraqi soldiers had established approximately 375,000 bunkers, trenches, and weapon pits. The distribution density of fortifications is presented in Figure 12.2. It has been estimated that large bunkers each yielded approximately 1,700 m^3 of excavated loose sediments, and small bunkers each yielded approximately 500 m^3.[35] Approximately 3,500 military vehicles were operating throughout Kuwait during the occupation. These vehicles were especially active in the northeastern part of the country.

[35] Al-Ajmi, "Effects of Mixing Height and Wind Speed."

Approximately 7,500 km^2 were directly impacted from this disruptive movement, which created havoc on the terrestrial ecosystems, particularly on the existence of the plant species *Haloxylon salicornicum*. Clearly, the dredging, refilling, and associated military actions have also caused major disturbances to Kuwait's soils and natural vegetation.

Al-Ajmi recently reported that the formation of sand dunes increased rapidly after the Iraqi invasion.[36] The protective layers of the soil were destroyed, exposing the underlying loose sand to the force of winds. There are now approximately 1,300 sand dunes spread throughout the Kuwaiti desert, concentrated in areas where there had been intense Gulf War activity.[37] In Wafra, for example, where disruption was extensive, moving sand has blocked irrigation canals, roads, and farm gates; destroyed produce; and covered up to 20 percent of farmland.

Taking all of the above into account, it has been estimated that the surface area of Kuwait suffered three degrees of damage: intensive (20 percent of total damaged area), moderate (42 percent of total damaged area), and slight (38 percent of total damaged area).[38]

OVERALL IMPACT ON VEGETATION, WILDLIFE, AND PROTECTED AREAS

The placement of mines, building of bunkers, fallout of oil mists, flows of oil, formation of lakes, and movement of vehicles during the war have all impacted Kuwait's vegetation. Studies have highlighted the impact of this crisis on Kuwait's desert flora, in particular. The effects are evident in vegetation structure, as well as in the chemical composition of both soil and vegetation. High levels of heavy metals were measured in plants that had been covered by oil and oil mist.

The oil lakes were also hazardous for birds and other wildlife. Upon emptying one small oil lake, the carcasses of vast numbers of birds were found, the oil having served as a trap. The desert of Kuwait harbors over 374 plant species that have enriched the habitats for both birds and

36 Al-Ajmi, "Impact of the Gulf War on the Desert Ecosystem."

37 F. El-Baz, N. Beaumont, J. Simonson, and A. Murad, "Assessment of the War Related Environmental Damage to the Desert Surface of Kuwait," prepared for the Annual Meeting of the Geological Survey of America (1993); F. El-Baz, *Kuwait Desert after Liberation* (Boston Univ. Center for Remote Sensing, 1994).

38 Al-Ajmi, "Impact of the Gulf War on the Desert Ecosystem."

12.3 Migratory bird attracted by oil lake mistaken for water

animals.[39] These unique habitats have attracted thousands of migratory birds. Over 300 different species of birds have been reported in Kuwait, of which approximately 16 percent are endemic to the country.[40] Twenty-eight species of mammals and forty species of reptiles have also been identified within Kuwait.[41]

Alsdirawi reported on the extent of the damage to this precious biodiversity: "The sludge killed the upper life forms by its toxicity and killed the deep life forms by suffocation. The oil lakes were mistaken for water bodies by migratory bird species as well as insects, both ended up tragically with corpses scattered in and around the black death."[42] (See Figure 12.3.) In 1998, in a single partially degraded oil lake, there were approximately seventeen fresh corpses of young Dhub (spiny-tailed lizard) found in the lake with hundreds of dead dung beetles and several bird corpses. Wildlife

[39] S. A. Omar, "Baseline Information on Native Plants," Kuwait Institute for Scientific Research technical report KISRI 1790 (1982); L. Boulos and M. Al-Dosari, "Checklist of the Flora of Kuwait," *J. U. Kuwait (Science)* 21, 203–18.

[40] F. Alsdirawi, "Wildlife Resources of Kuwait: Historic Trends and Conservation Potentials," PhD thesis, University of Arizona (1989). [41] *Ibid.*

[42] F. Alsdirawi, "The Negative Impact of the Iraqi Invasion on Kuwait's Protected Areas," paper presented at the Fourth World Congress on National Parks and Protected Areas (1991).

monitoring and rehabilitation measures need to be undertaken to halt further losses of fauna.

It should be noted that seeds from annual plants are usually capable of dispersing long distances and can remain dormant for a long time, ultimately germinating with sufficient rainfall. However, perennial plants that were subjected to aerosol deposits and/or oil spills were found to contain high levels of heavy metals and need to be safeguarded from grazing by wildlife and livestock. The perennial plants that escaped from aerosol deposits dispersed seeds near the source, and thus new seedlings could not emerge due to the oil pollution. The long-term ecological consequence of this disruption on plants, both in oil-affected areas and in areas disturbed by other military actions, requires further investigation and will be influenced by mobile sand, which might cover or inhibit germination of seeds and prevent normal plant growth.[43]

At the time of the Iraqi aggression, the phenological progression of Kuwait's desert plants (that is, stages of plant growth over time) was altered by "black clouds" of oil particulates that altered temperatures and rainfall. In soot-covered sites, the survival rates of woody perennial shrubs, such as *Rhanterium epapposum* and *Haloxylon salicornicum*, were found to be almost 100 percent, but only10 percent for the perennial euphorb *Moltkiopsis ciliata*. The survival rate for perennial grasses such as *Cyperus conglomeratus* and *Stipogrostis plumosa* was only about 50 percent. The severity of impact depended on the quantity and quality of the oil pollutants. In the oil-mist-covered sites, the only species that survived was *Haloxylon salicornicum*.[44] Oil-logged sites appeared totally devoid of vegetation.

There are several protected areas established in Kuwait. These areas, including the National Park of Kuwait, are in the Jal-Az-Zor, Jahra Pond, and Doha Reserve. The areas were established in the prewar period to protect endemic and migratory wildlife species, as well as habitats of significant value. The National Park of Kuwait, which covers approximately 330 km^2, was seriously disturbed by the land-based hostilities and bombing during the war. The external fence of the park was knocked down, trenches and fox-holes were scattered all over the area, and mines were

[43] Zaman, "Impact of the Gulf War on Kuwait's Desert Flora and Soil"; A. A. Dashti, "Environmental Impacts of Burned Oil Wells and Military Operations on Some Desert Plants and Soils of Kuwait," Master's thesis prepared for the Desert and Arid Zones Sciences Program, Arabian Gulf University (1993); Omar and Bartolome, "Nutrient Variation of Plants."

[44] *Ibid.*

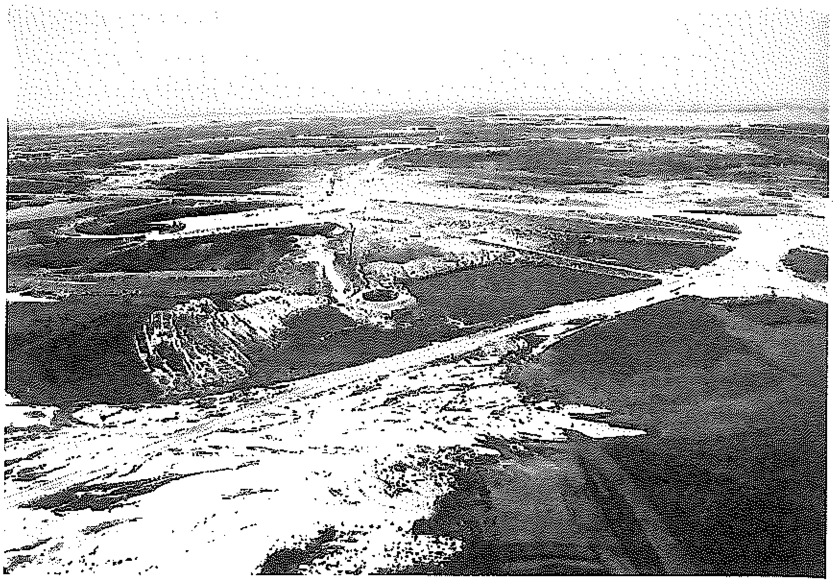
placed intermittently from the coastal front of the park to the wadis and gullies of the Jal-Az-Zor escarpment. Research enclosures established in the prewar period, such as the Sulaibiya Field Station and various range management enclosures, were also intensively damaged by Iraqi forces. The invasion of Kuwait resulted in the complete loss of results from twenty years of efforts to protect and conserve both vegetation and wildlife in Kuwait, as well as destruction of the infrastructure of field research utilities. It took the government of Kuwait seven years to rehabilitate the park area.

IMPACT ON THE HYDROLOGICAL RESOURCES

Information on the impact of oil pollution on groundwater is scarce. Researchers have indicated that groundwater pollution may result from direct infiltration of oil from oil lakes, from leaching of combusted deposits at the ground surface by rainwater, or from subsurface leakage of oil from damaged oil-well casings.[45] Preliminary assessment of groundwater revealed that the infiltration of contaminated rainwater is likely to have a lasting effect on the groundwater. PAHs also migrate in soil during rainy periods and can possibly infiltrate the groundwater aquifer (see Figure 12.4). The most vulnerable areas are Raudhatain and Umm Al-Aish, due to the proximity of the groundwater to the surface (approximately 20 m). These two areas, the main sources of fresh groundwater in Kuwait, were contaminated with products of combustion from the oil fires. Infiltrating oil from oil lakes and contaminated water used for fire fighting affected the soil in the upper horizons of unsaturated sections of these areas. With both the surface and subsurface portions of these groundwater sources contaminated, it is likely that contaminated soils will continue to leach from infiltrating rainwater for a long period of time.

Water samples analyzed from Raudhatain and Umm Al-Aish showed fluctuations in concentrations of vanadium and nickel between 1 and 833 parts per billion (ppb) during the period from January to June, and between 1 and 73 ppb during the period from July to October 1992.[46] Hydrocarbon levels fluctuated between 1 and 190 ppb during the period from January to June 1992.[47] The relatively high levels of water contamination during the period from January to June 1992 were caused by the

[45] J. Al-Sulaimi, unpublished data; Saeed et al., "Assessment of the Changes in the Chemical Components."
[46] *Ibid.* [47] *Ibid.*



12.4 Oil lakes mixed with rainwater after heavy rain showers in 1996

significant levels of contaminants in the surface and subsurface soil; the local hydrological conditions; the relatively shallow levels of intake zones of wells with respect to water table levels; and the relatively high infiltration capacities of the unsaturated zones.[48]

LANDMINES AND MILITARY DEBRIS

The Iraqi strategic minefields extended from the Arabian Gulf in the east to Wadi Al-Batin at the extreme western portion of the country.[49] It has been estimated that the mines were placed at various depths, to a linear extent of 728 km. Intensive searches had to be carried out for landmines and unexploded ordnance following the war. As an indication of the magnitude of this task, as of January 1997 the Ministry of Defense had collected a total of 1,646,355 mines.[50] The environmental effects of the ammunition left behind by the Iraqi forces, as well as of the unexploded Coalition munitions (such as cluster bombs) have not been investigated.

[48] *Ibid.*

[49] R. F. Misak, S. Mahfooz, M. Al-Ghunaim, D. Al-Ajmi, H. Malalah, and A. Muhareb, *Landmines and the Destruction of the Kuwaiti Environment* (1999). [50] *Ibid.*

12.5 Some of the military damaged vehicles stacked in designated areas in the southwest and west of Kuwait

Vast numbers of trucks, tanks, and associated damaged war machinery also had to be removed from the desert, a process that inflicted additional damage. Some of the damaged military vehicles were stacked in designated areas, particularly in the west and southwest of Kuwait. (See Figure 12.5)

Concerns also exist regarding the problem of "depleted uranium" (DU) and the risk of exposure of the population of Kuwait to radiation. The sources of DU are the anti-tank munitions used by Allied troops during the war.

FORCED NEGLECT

Significant damage to plant life resulted from "forced neglect" during the occupation, liberation, and early periods of recovery. Plants needing irrigation were not attended to during crisis periods, and many died from lack of water and nutrients. The invasion and occupation also resulted in loss of plans to enhance the visual and microclimate aspects of the country's environment, a process that had been under extensive development for almost two years.

12.6 Juaidan farm devastated by the explosion of oil wells in the Burgan oilfield

The agricultural sector was devastated during the invasion. Before the invasion, agricultural development flourished in two areas: Abdali and Wafra. The invasion forced most of the people who worked in these areas to leave the country and these sites were subsequently occupied by Iraqi troops. Wells and sources of electricity in the two areas were destroyed. The Al-Juaidan farm was completely devastated by the sabotaged oil wells in the Burgan oilfield. (See Figure 12.6.)

Rehabilitation of Kuwait's terrestrial environment

CLEARING AND REHABILITATING THE LAND

In the post-liberation period, the government of Kuwait had to accomplish the urgent task of restoring Kuwait's damaged oil production facilities. This task was carried out in two phases, namely the *Al-Awda* project (the Return) and the *Al-Tameer* project (the Reconstruction).

The Al-Awda project commenced in March 1991. Approximately 9,000 personnel were mobilized in seven months from thirty-two different countries, with the majority coming from the Philippines, Thailand, Indonesia, the United States, the United Kingdom, and Kuwait. Twenty-seven firefighting teams worked ten to fourteen hours per day, seven days per week to control the burning and gushing wells. The enormous effort was accomplished in eight months, much sooner than the two to three years initially anticipated. The last well fire was extinguished on November 6, 1991.

The Al-Tameer project was managed by the Kuwait Oil Company, with assistance from Bechtel. The project involved up-streaming crude oil; drilling and repairing wells; and refurbishing gas and oil gathering centers, booster stations, storage tanks, and export facilities. The clean-up and treatment of 300 oil lakes containing approximately 20 million barrels of weathered crude oil remains a great challenge.

Some of the oil lakes were drained and the oil pumped to gathering centers or shifted to other lakes. Some of the shallow lakes were merely covered with soil brought from elsewhere. Still others dried out as a result of weathering and were covered with sand.

Extensive efforts were undertaken by teams of professionals from seven countries to clear the land of mines and military ordnance. While this process is believed to be complete (except for the oil lake-bed areas), there are occasional accidents involving remaining landmines – most often along the border between Kuwait and Saudi Arabia. Continued surveillance is required. The trenches, bunkers, ditches, and pits have been back-filled, and debris has been removed. However, the long-term impacts of these constructions and the remediation required by them still need to be assessed in order to ensure that lasting damage is minimized.

BIOREMEDIATION OF CONTAMINATED SOIL

Numerous studies have been carried out on adaptation of techniques and technologies for remediation or bioremediation of both heavily and lightly contaminated soil. The bioremediation studies were carried out with windrows and soil piles of mixed oil-lakebed contaminated soils. The data from these studies showed that controlled, irrigated, aerated solid phase biological treatment reduced oil contamination by more than 84 percent within twelve months. It was also projected that high-ring polyaromatic compounds would remain in the desert's surface soil over a long period of time and, after extensive aging, would break into small particles and be transported by mobile sand.[51]

[51] Al-Ajmi et al., "Oil Trenches and Environmental Destruction."

The results of other studies showed that passive remediation can aid in the rehabilitation of large surface areas, if those areas are not contaminated to a depth of more than 1 cm with deposited airborne soot and unburned oil droplets.[52] However, soils contaminated 2–50 cm in depth, as well as heavily contaminated oil lake beds, did not display any natural remediation. While limited studies have been conducted on plant biological system uptake, means of using plant life in biological clean-up and/or the implications of the uptakes in the plants regarding ultimate use have not been adequately studied and may be applicable to the long-term remediation of Kuwait's terrestrial environment.

Landsat Thematic Mapper™ imagery analyzed in 1995 indicated that a majority of the contaminated areas in Kuwait surrounding the oil lakes were gradually recovering in terms of vegetative growth. The surface cover of the oil lakes had decreased by 20 percent from 1992 to 1995.[53] This trend was a result of the decrease in volume and area of the beds caused by the recovery process, sand encroachment, and weathering of areas with shallow oil.

Oil lake beds covered by veneers of sand were not visible on satellite images and are still posing hazards to the environment, the extent and nature of which will require further investigation. As a result of weathering, the oil in most of the remaining oil lakes has thickened to a semi-solid mass. The chemical composition of weathered oil showed a decrease in aromatic compounds, an increase in resins, and an increase in concentration of PAHs. This indicates an increased hazard potential. Heavily contaminated soils may eventually erode, be re-suspended, and transported to populated areas during dust storms, causing potentially severe health hazards, such as short-term morbidity due to acute respiratory infection, and long-term predisposition for respiratory cancers. While remote sensing has been able to calculate the total areas of both heavily and lightly contaminated soils, the amount of soil requiring remediation has not been sufficiently quantified for action purposes. Various layers of soil and gatch (a hard calcareous layer) are also present throughout the contaminated areas. While a sample lakebed has been studied, much remains to be elucidated.

52 Al-Awadhi et al., "Remediation and Rehabilitation."

53 Kwarteng and Al-Ajmi, "Using Landsat"; Kwarteng and Al-Ajmi, "Satellite Remote Sensing Applications"; Kwarteng et al., "RADARSAT SAR Data Assessment."

REHABILITATION OF DESERT FLORA AND FAUNA

The impacted desert areas of Kuwait have not been sufficiently reseeded with native plants to support restoration of the animal life that populated those areas before the war. Although land has been leveled, microbial capabilities of the soil have been lost and not re-established. The plant species lost have also not been re-established. Therefore, the habitats for much of Kuwait's natural wildlife remain severely altered.

Reclamation of polluted areas still needs to take place, especially in the oil-logged areas where vegetation has been destroyed and rangeland productivity potentials have been reduced. Much of the landscape was severely damaged and will require a great deal of long-term restoration. The status of many species of wildlife and vegetation in protected areas also needs further assessment. Reintroduction of wildlife species needs to be investigated as a possible avenue of reinstituting populations of lost fauna. The biological diversity of the terrestrial environment also needs to be regularly monitored in order to develop practical and appropriate measures for its protection and management.

Terrestrial rehabilitation works yet to be undertaken

Much of the terrestrial rehabilitation yet to be undertaken can be summarized in outline form, as follows:

- Long-term impacts, particularly of soil compaction and heavy oil contamination, must be studied so that corrective actions and appropriate rehabilitation measures can be undertaken;
- Soil microbial research is needed to determine whether the microbial ecology of the soil has been affected by its oil-contaminated condition, by oil-well fires, by fallout from the resultant smoke, or by other military activities;
- The effect of radiation (from DU) on human health needs to be verified and investigated;
- The impact of suspended, contaminated soil particulates on human health needs to be assessed;
- Further studies are needed to establish the extent of native plant uptake of contaminants and possible resultant health hazards in the food chain;

- Pilot projects are necessary to assess the effectiveness of rehabilitation measures on specific areas damaged by military activities or oil pollution. Field demonstration trials need to be performed to assess appropriate technologies, and the results compared with treatment standards;
- Further work is needed to ferret out the total and long-term effects of the oil releases, the tarcrete, the open-burning, the detonation of mines and ordnance, and the impact of leaks from detonated mines and ordnance;
- Re-vegetation is needed with adapted plant species and ecotypes. Factors that will need to be addressed during this process include seed production potentials, germination requirements, and technologies to be applied. Flora mutations also need to be studied;
- Heavily contaminated soil must be remediated in order to restore terrestrial ecosystems. Large-scale rehabilitation needs to be considered;
- National parks need to be rehabilitated and wildlife species need to be reintroduced to the parks;
- Action plans are needed for rehabilitating and managing impacted rangelands, and for wildlife restoration at the national level;
- The long-term impact of oil wells and oil trenches on the terrestrial ecosystems and groundwater needs to be investigated; and
- Long-term potential for oil seepage into groundwater aquifers needs to be monitored and recorded on a regular basis.

Conclusion

The Iraqi occupation and the subsequent armed conflict devastated the terrestrial environment of Kuwait. The government of Kuwait adopted immediate measures after liberation to restore the oil sector and to clear ammunition from the desert. These two major achievements were completed very quickly. Likewise, intensive work was undertaken by scientists to assess the effect of military activities and oil pollution on the terrestrial environment. Quantitative and qualitative evaluations of the impacts of the war have been made, and the authors have been able to identify various hazardous components and their effects on both the ecology of Kuwait and on human health. There remains considerable work to be done in this area. With its 1992 signature of the Convention on Biological Diversity, Kuwait assumed responsibility for conserving and managing its biological resources, as well as rehabilitating damaged habitats. Work is needed to assess further the status of Kuwait's biological resources and to determine proper mitigation measures. The long-term impacts of pollutants on soil and microbial activities, as well as on groundwater, needs further assessment and evaluation.

The destruction of Kuwait's terrestrial resources requires attention from both planners and policymakers. The government of Kuwait, together with the private sector, could coordinate efforts to provide a National Action Programme to tackle land degradation and rehabilitation issues. Pilot projects investigating rehabilitation of war-damaged areas can provide valuable information on selection of proper technologies and costs of rehabilitation. It may be possible to develop a strategic plan for rehabilitating Kuwait's terrestrial environment.

13

WAR-RELATED DAMAGE TO THE MARINE ENVIRONMENT IN THE ROPME SEA AREA

MAHMOOD Y. ABDULRAHEEM

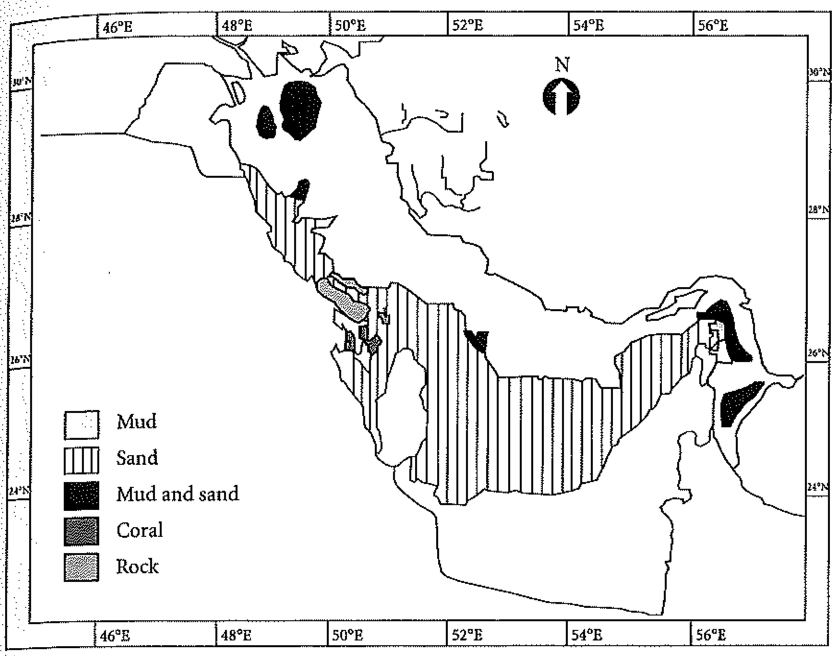
Introduction

BACKGROUND

The Arabian or Persian Gulf forms an arm of the Indian Ocean extending into the Arabian Peninsula, an area that constitutes the inner part of the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Area – the "RSA." This new term was coined to achieve unanimity in signing the 1978 Kuwait Regional Convention for Cooperation on the Protection of the Marine Environment from Pollution. The ROPME Sea Area also includes the Gulf of Oman and the Iranian and Omani waters of the Arabian Sea. This chapter uses the terms "Gulf" and "ROPME Sea Area," or "RSA," interchangeably.

The ROPME Sea Area is a relatively small, flooded valley-estuary with a surface area of 240,000 km^2. It is approximately 1,000 km in length and 200–300 km in width, narrowing to only 54 km at the Strait of Hormuz. It is generally shallow, mostly less than 60 m deep, with an average depth of 35 m, but increasing to 100 m near the Strait of Hormuz. The western part of the RSA is very shallow (less than 5 m), with tidal flats extending up to 5 km.[1] The bottom topography is generally featureless with mostly soft sediments. It is muddy in the northern and northwestern parts and sandy along the southern section, reflecting the largely biogenic origin of sediments in the area (Figure 13.1).

[1] B. B. Habashi, A. A. H. El-Gindy, and H. Karam, "Hydro-Chemical Characteristics of the Arabian Gulf after the *Umitaka-Maru* Cruise and Other Expeditions," International Symposium on the Status of the Marine Environment in the ROPME Sea Area after the 1990–1991 Gulf War, Tokyo, Japan (1995).



13.1 Sediment types in the RSA

The intense sunlight and shallowness of the water makes the RSA highly productive, which has encouraged the establishment of well-developed shrimp and fin-fish fisheries in the area. The bottom sediment is dominated by carbonate sands produced by decay of microbenthic organisms, which become mixed with wind-blown dust and fluvial sediments from the rivers and settle mostly in the northwestern part of the RSA. Surrounded by the arid land masses of the Arabian Peninsula and the Iranian Zagros Mountains, the area exhibits a wider range of temperature than other sub-tropical seas. Air temperatures frequently fall to 0° C in winter and reach 50° C during summer, with water temperatures fluctuating between 10° C and 39° C. However, temperatures as low as 4° C and 7° C have been reported in shallow areas of Kuwait and Qatar, respectively.[2] The dominant northwest winds blowing across the axis of the RSA influence

[2] C. R. C. Sheppard, A. R. G. Price, and C. M. Roberts, *Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments* (London: Academic Press, 1992).

surface circulation and often deposit large loads of desert dust on the sea surface. Surface circulation is generally counter-clockwise, which means that a large portion of marine pollution and debris generated in the area is likely to impact the Kuwaiti and Saudi Arabian coastal areas.

The arid climate also influences salinity, with dry, hot winds increasing evaporation rates, which range from 140 to 500 cm/yr, producing salinities that reach 60 parts per trillion (ppt). Near the Shatt Al-Arab delta, salinity drops to 36 ppt. However, it is not unusual to encounter salinities of over 100 ppt during summer in the shallow lagoons of the United Arab Emirates and Salwa Bay off Qatar, conditions that favor hypersaline eurythermal cyanophytes.[3] As the more dense seawater is driven eastwards by the northwest winds, it sinks under the incoming fresher seawater (36 ppt) through the Strait of Hormuz. The flushing time for the RSA is estimated at two to five years.[4]

It is to these harsh and extreme meteorological conditions that the marine life drifting from the Indian Ocean some 20,000 years ago had to adapt. The mostly calm and warm waters of the RSA also provided a major source of food, trade routes, and security for development of the sparse human settlements on its shorelines.

IMPACTS OF MAN

As oil and gas production reached commercial scale after World War II, the RSA witnessed an unprecedented influx of man and materials. The exponential rates of development and resulting demand for natural resources are demonstrated clearly by the fact that since the end of the sixties, all cities in the area (except in Iran and Iraq) have had to rely totally on desalination to produce potable water. Other resources – especially fisheries, mangroves, forests, coral reefs, oyster banks, and mudflats – have been subjected to intensive utilization and encroachment by development. Shrimp and finfish stocks were under severe pressure from overfishing even before the last Gulf War, and efforts to engender regional management of fisheries were progressing slowly because of the Iran–Iraq War. Releases of both treated

[3] K. E. Carpenter, F. Krupp, D. A. Jones, and U. Zajonz, *FAO Species Identification Guide for Fishery Purposes: The Living Marine Resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates* (Rome: FAO, 1997).

[4] P. G. Brewer and D. Dyrssen, "Chemical Oceanography of the Persian Gulf," *Progressive Oceanography* 14 (1985), 41–55.

and untreated sewage, as well as of industrial effluents, became a major land-based source of contamination.[5] By the end of the seventies, the oil industry in the area was producing about 60 percent of the world's crude oil exports, carried by some 10,000 tankers annually. This tanker movement, along with commercial shipping, refineries, and other heavy industry, contributes to an anthropogenic input of oil into the marine environment equivalent to more than 1 million barrels per year. It is not surprising that most monitoring programs in the area have shown that petroleum hydrocarbons are the principal marine contaminants.[6] In spite of the heavy traffic of tankers and commercial ships, the area was fortunate enough to escape major tanker collisions or groundings until the Iran–Iraq War, when the Nowruz oilfields were bombed and the Tanker War of 1980–89 took place. Unfortunately, the Iran–Iraq War was immediately followed by an even more vicious war that was especially hard on the environment.

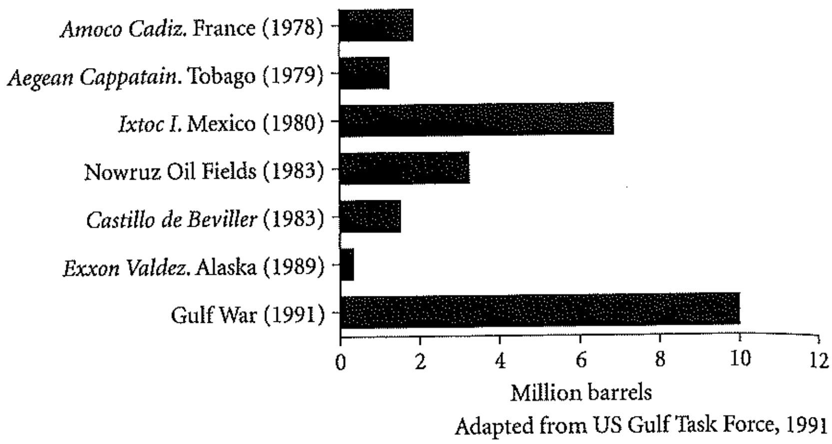
Environmental damage from the 1990–91 Gulf War

THE OIL SPILLS

The deliberate discharge of over 10 million barrels of oil from terminals, storage tanks, oil tankers, and coastal trenches in Kuwait and Iraq has resulted in the largest oil spill yet recorded (Figure 13.2). The spill is also unique in being the only spill intentionally released as part of wartime tactics. The spill moved rather rapidly along the coastal waters of Kuwait and Saudi Arabia, traveling over 600 km before being stopped by Ras Abu Ali. It should be noted that the area most affected by the spill is the most shallow and highly productive area of the RSA.

As the oil traveled rapidly south, a significant amount was lost to evaporation or landed on beaches. It has been estimated that 40 percent of the oil was lost to evaporation, 10 percent to dissolution, and about 50 percent remained afloat. Out of the 5.4 million barrels that remained afloat, 22 percent was recovered, 50 percent was stranded on beaches, and about 30 percent was unaccounted for. However, there seems to be evidence that at least some of that "lost" oil had sunk to the bottom. UNEP aerial photography off the Kuwaiti southern borders showed large patches of such

[5] Regional Organization for the Protection of the Marine Environment, "Regional Report on the State of the Marine Environment of the Region," ROPME/CM–7/PREP. 2 (1990). [6] *Ibid.*



13.2 World's major oil spills

sunken oil. Samples taken during the *Umitaka-Maru* cruise also indicated the presence of sunken oil in the 2,000 μg/g range.[7]

THE OIL-WELL-FIRE PLUMES

The impact on the marine environment of fallout from the plumes generated by over 600 burning oil wells in Kuwait may prove to be of greater significance than the oil spills. Estimates of the amount of oil that burned are as high as 500 million barrels, with the most dominant plume trajectories over Kuwait and the region. Here again, the plumes affected the same areas impacted by the oil spill.

The composition of the plume analyzed by a UK meteorology flight in March 1992 showed smoke levels of about 500 $\mu g/m^3$. Stevens et al. also have carried out analyses of suspended matter collected from ground level and by an airborne sampling system.[8] Table 13.1 summarizes the results of their analysis; the black plumes were characterized by a large number of carbon chain agglomerates.

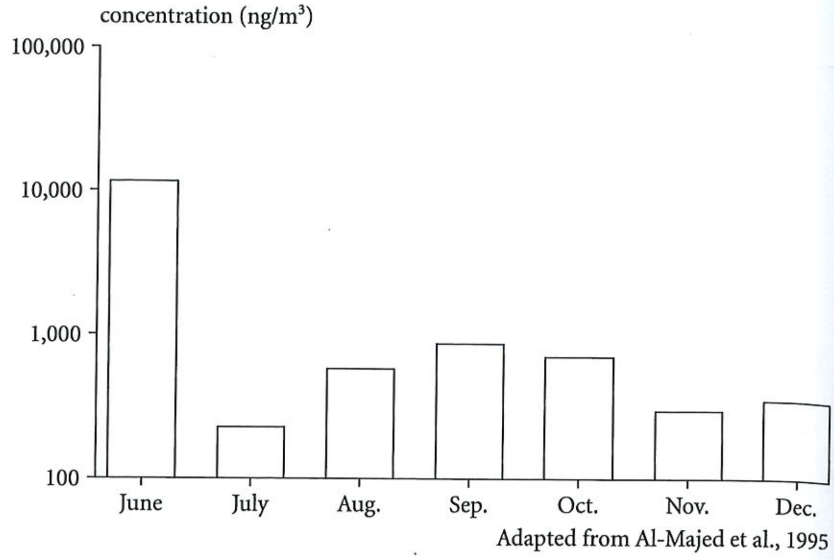
[7] N. Al-Majed, W. Rajab, and F. Al-Safar, "Levels of Pollutants in the ROPME Sea Area," International Symposium on the Status of the Marine Environment in the ROPME Sea Area after the 1990–1991 Gulf War, Tokyo, Japan (1995).

[8] R. Stevens, J. Pinto, Y. Mamane, J. Ondov, M. Abdulraheem, N. Al-Majed, M. Sadek, W. Cofer, W. Ellenson, and R. Kellogg, "Chemical and Physical Properties of Emissions from Kuwaiti Oil Fires," Fifth International Conference on Environmental Qualities and Ecosystem Stabilities, Jerusalem (1992).

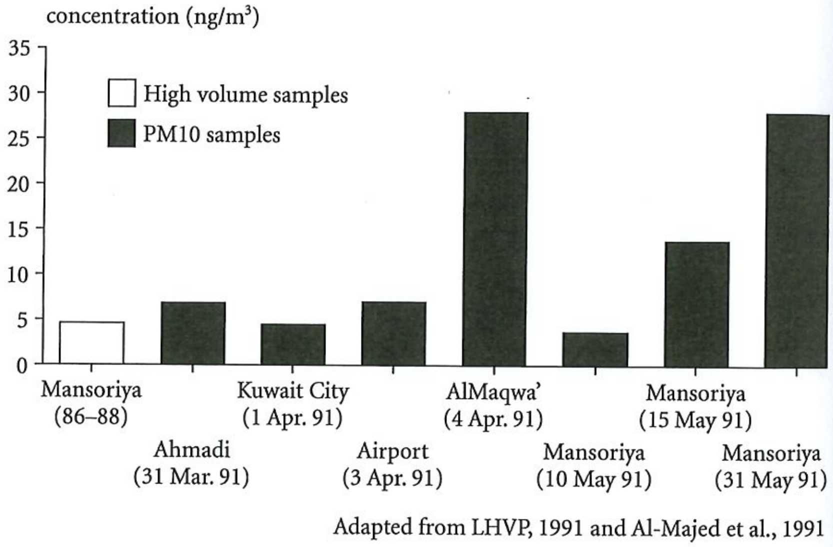
Table 13.1. *Concentrations of selected compounds (g/m³) of oil-well-fire plumes in Kuwait, 1991*

Compounds	Black plume Aug. 2, 1991	Black plume Aug. 3, 1991	Black plume Aug. 5, 1991	Mixed plume Aug. 6, 1991	White plume Aug. 7, 1991	Mixed plume Aug. 8, 1991
Na	NDB	6.0 ± 2.9	NDB	3.2 ± 0.6	905 ± 45	6.4 ± 0.6
Al	3.7 ± 3.2	3.5 ± 1.8	8.9 ± 1.3	3.7 ± 0.2	1.9 ± 1.7	3.7 ± 0.52
S	3.0 ± 1.5	18.9 ± 1.7	2.9 ± 0.5	3.9 ± 0.3	95 ± 7	3.2 ± 0.3
Cl	2.2 ± 1.1	7.1 ± 0.9	NDB	5.0 ± 0.3	1,820 ± 92	9.2 ± 0.5
SO_4	9.3	56	8.7	12	285	9.6
SO_2	133	169	12	49	319	26
Mass	755	955	493	167	4,356	22
Volatile carbon	152	183	NM	37	105	NM
Elemental carbon	142	443	NM	22	22	NM

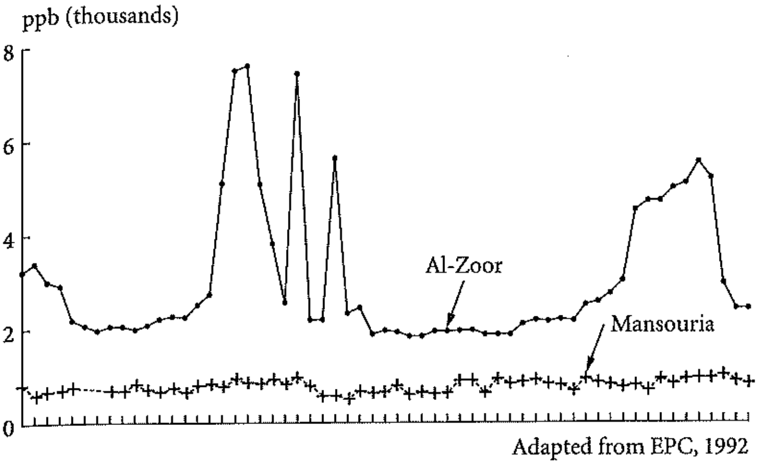
NDB: Non-detected above filter blank.
NM: Not measured.
Adapted from Steven et al., 1992.



13.3a Levels of PHCs (ng/m^3) in PM10 samples collected from Riqqa, Kuwait, 1991



13.3b Benzo(a)pyrene levels (ng/m^3) in particulate matter before and after the Gulf War



13.4 Total hydrocarbons measured simultaneously in Mansouria and Al-Zoor, August 3–4, 1991

To develop a better understanding of what was being deposited in the marine environment, fluctuations in the levels of petroleum hydrocarbons (PHCs) in daily samples of particulate matter collected at Riqqa, south of Kuwait City, and closer to the burning oil fields, were compared with satellite images taken in the same period. High PHC levels detected on land appear to coincide with the behavior of the plume, as shown in Figure 13.3a; levels of Benzo(a)pyrene measured at ground level and associated with the plume are shown in Figure 13.3b. Consistency of the levels of PHCs with the plume behavior was also evident from the comparison of levels of PHCs monitored simultaneously at the Mansouria station with those monitored by the German Air Quality Mobile Laboratory placed at the Al-Zoor Port, as shown in Figure 13.4.

Distribution of oil and oil-burn products in the marine environment

The marine environment in the RSA has one of the world's highest rates of chronic releases of petroleum hydrocarbons from anthropogenic sources and, to a much lesser degree, from natural seepage.[9] Baseline surveys and environmental monitoring programs have not been maintained historically, so comparison between pre- and postwar levels of contaminants in the marine environment is not possible. ROPME's eighteen-month marine

[9] Regional Organization for the Protection of the Marine Environment, "Regional Report."

environment monitoring program was initiated in 1982, when almost all of the member states carried out an assessment of the natural characteristics and contaminant levels in their coastal areas. However, the program could not be maintained for all member states; the war between Iran and Iraq was a major obstacle in obtaining data from the northwest part of the RSA. The limited baseline data collected were used as an indication of the extent of the major sources of contamination. This data also provided insight into the types and magnitude of marine contaminants.[10]

Thus far, coastal surveys, national monitoring activities, and two open-sea cruises, the *Mt. Mitchell* (1992) and the *Umitaka-Maru* (1993–94), represent the extent of the efforts undertaken to assess the impacts of war on the marine environment of the RSA. Efforts to develop a sustainable follow-up program with the goal of more completely understanding the fate of oil and oil-burn products in the marine environment, as well as the subsequent rates of recovery, have had limited success.

Figure 13.5 summarizes the results of petroleum hydrocarbon analysis in marine sediments before and after the war. Baseline data from the Kuwait Environment Protection Department (EPD), now part of the Environment Protection Authority (EPA), suggests that a fivefold increase over 1986 PHC levels occurred in 1991, dropping to less than half that value by 1995.[11] Data by Fowler et al. indicate high levels of PHCs in sediments of Ras Abu Ali in Saudi Arabia, decreasing with distance towards the Strait of Hormuz.[12] Moreover, PHC levels of over 2,000 μg/g were reported off the Saudi waters, suggesting the presence of sunken oil. The breakdown of PHCs into aliphatic and aromatic compounds is shown in Figure 13.6. Maximum concentrations of PHCs were seen off Saudi Arabia, decreasing along the coast towards the Strait of Hormuz.[13]

In their study of sediment toxicity to amphipods, Randolph et al. have shown high mortality rates associated with PHC concentrations of 1,000 μg/g or higher in dry sediment.[14] Of the eleven sites sampled in Saudi

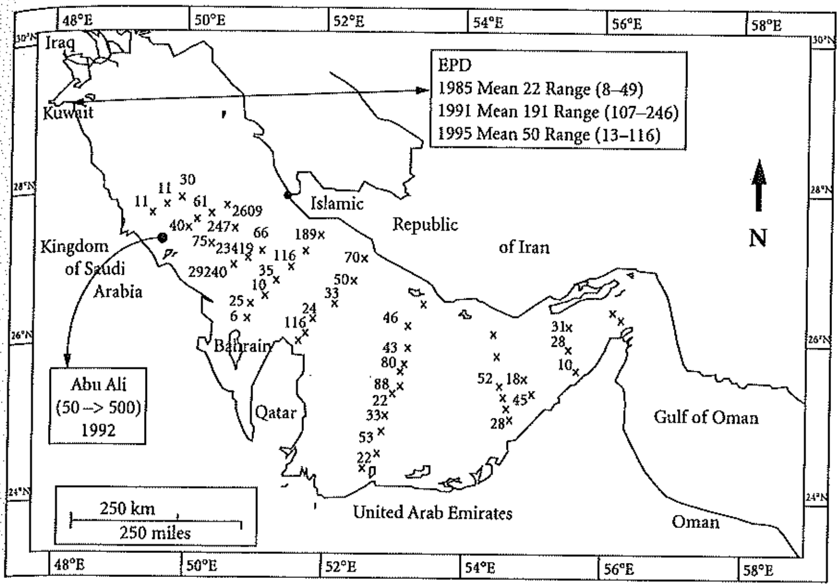
[10] *Ibid.*

[11] Environment Protection Department, Annual Report 1985; Annual Report 1991–1992; Annual Report 1995.

[12] S. Fowler, J. Readman, B. Oregioni, J. Villeneuve, and K. McKay, "Petroleum Hydrocarbons and Trace Metals in Nearshore Gulf Sediments and Biota Before and After the 1991 War: An Assessment of Temporal and Spatial Trends," *Marine Pollution Bull.* 27 (1993), 171–82.

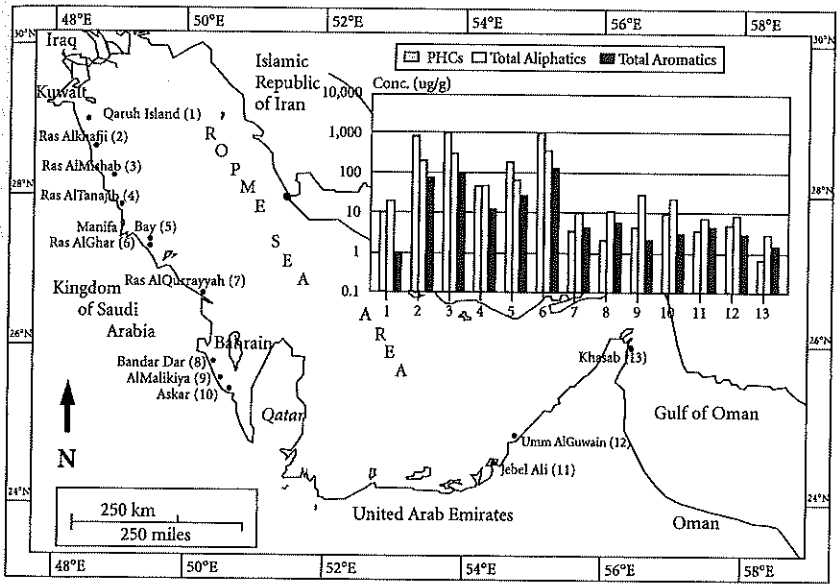
[13] *Ibid.*

[14] R. C. Randolph, J. Hardy, S. Fowler, A. R. G. Price, and W. Pearson, "Toxicity and Persistence of Nearshore Sediment Contamination Following the 1991 Gulf War," study submitted to *Env't Int'l* (1996).



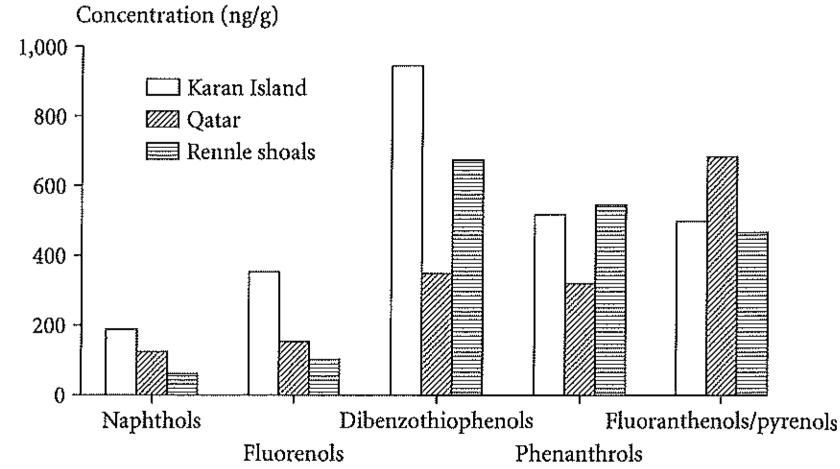
Adapted from EPD (1985, 1991, 1995), Fowler et al. (1992), and Al-Majed et al. (1995)

13.5 Distribution of PHCs in sediments before and after the Gulf War



Adapted from Fowler et al., 1992

13.6 Distribution of PHCs (μg/g) in sediments after the Gulf War, showing breakdown into aliphatic and aromatic compounds



Adapted from Krahn et al., 1993

13.7 Levels of metabolites of aromatic compounds (ng/g wet wt.) in bile samples of *Lethrinus kallopterus* species, RSA, 1992

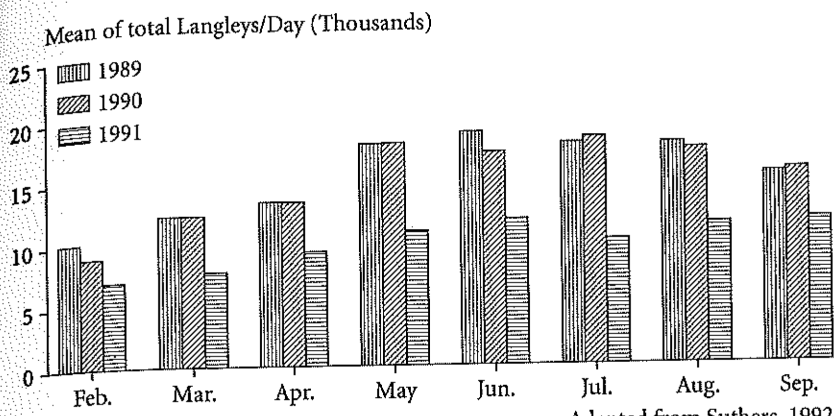
Arabia, five proved to be toxic by this definition. The data suggest that as the soluble components of oil and the weathering products become available in the water column, toxicity increases. Being lighter than water, these products tend to accumulate in the surface microlayer. About half of the samples of the coastal surface microlayers that were done by Hardy et al. and used in bioassay tests, were shown to be toxic to echinoderm larvae.[15] Around the same time, analysis of metabolites of aromatic hydrocarbons in fish bile carried out on board the *Mt. Mitchell* identified elevated levels of naphthols, fluororentols, and phenanthrols, as well as of their parent compounds, in sediments collected in the area.[16] The same data showed that the level of dibenzothiophenols had reached over 900 μg/g.

Data on the toxicity of the surface microlayer and sediments in the RSA have led to a widespread discussion of the war's impacts on fisheries. In a preliminary assessment of the impacts, it was estimated that the shrimp populations have collapsed to about 10 percent of their prewar levels.[17]

[15] J. Hardy, S. Fowler, A. Price, J. Readman, B. Oregioni, E. Crecelius, and W. Gardiner, "Environmental Assessment of Sea Surface Contamination in the Gulf," UNESCO/IUCN Report (1993).

[16] M. Krahn, G. Ylitalo, J. Buzitis, J. Bolton, C. Wigren, S. Chan, and U. Varanasi, "Survey of Oil Contamination in Marine Fish and Sediments following the ROPME Sea Oil Spill," *Mt. Mitchell Workshop* (1993).

[17] International Union for the Conservation of Nature, *IUCN's Response to the 1990–91 Gulf War* (1992).



Adapted from Suthers, 1992

13.8 Impacts of oil well fires on solar radiation in RSA

Support for this conclusion comes from another study, in which fieldwork showed a decrease in penaeid egg and larval abundance at Ras Tanura in 1992, compared with the years 1975–78.[18] At Safaniya, a decrease of both zooplankton and penaeid egg and larval abundance was also apparent in 1992, compared with the data available from the 1970s.[19] In Kuwait, Siddiqui and Al-Mubarak have analyzed shrimp-landing statistics before and after the war. Their results indicate a large fluctuation in the landings and catch effort over the past few years, and a declining trend in landings may be inferred.[20]

In the absence of reliable regional data, and given the stress on the stocks by overfishing and encroachment on spawning areas, it is difficult to draw a clear picture. Nevertheless, given the indicators of elevated toxicity of sediments and the sea surface microlayer, the decline in abundance, the presence of oil on beaches and at the bottom in the intertidal zone, the reduction of incidence of light (shown in Figure 13.8), and the sea temperature regime, it is not unreasonable to assume that the fisheries of the area have suffered severe impacts. Only long-term monitoring, along with intensive fishery management procedures to halt overfishing and

18 A. R. G. Price, C. P. Mathews, R. W. Ingle, and K. Al-Rasheeid, "Abundance of Zooplankton and Penaeid Shrimp Larvae in the Western Gulf: Analysis of Pre-War (1991) and Post-War Data," *Marine Pollution Bull.* 27 (1993), 273–78.

19 *Ibid.*

20 M. S. Siddiqui and A. Khalid Al-Mubarak, "The Post-Gulf War Shrimp Fishery Management in the Territorial Waters of Kuwait," *Env't Int'l* 24 (1998), 105–8.

encroachment on habitats and pollution, will aid this major natural resource in recovering.

Long-term impacts of the war on the marine environment

IMPACTS ON SEAWATER QUALITY

As stated earlier, most of the countries in the region rely on desalination of seawater for the production of potable water. The Gulf Cooperation Council countries produce a total of about 2 billion m^3/yr of potable water by desalination.[21] The presence of petroleum hydrocarbons and chlorine at the seawater intakes of desalination plants could produce halogenated organics, mostly as bromoform, in the volatile fraction.[22]

LONG-TERM IMPACTS OF EXPOSURE OF MARINE ORGANISMS TO AROMATIC HYDROCARBONS

Aromatic hydrocarbons represent the principal component of the soluble fraction of oil that could have detrimental long-term effects, including genetic changes, on marine organisms. This could be especially critical for larvae, which spend most of their lives in the planktonic phase, close to the sea surface where these products are likely to accumulate.[23] Thus, the rapid rates of weathering of oil in the RSA may not actually be desirable. Increased rates of weathering result in greater amounts of soluble weathering products becoming available at the surface microlayer, thus increasing the toxicity to marine organisms. The implications of such a scenario, if proven to be true, could spell a disastrous future for fisheries in the RSA if sunken oil is not removed and the chronic sources of oil pollution are not abated.

Lessons learned from the war and recommendations

The massive oil spills and deposition of oil-burn products impacted the shallowest, most highly productive, and previously stressed part of

[21] W. Al-Zubari, presentation at the Seventh Regional Meeting of Arab IHP Committees, Rabat, Morocco (1997).
[22] M. Y. Abdulraheem, unpublished experimental data (1994).
[23] J. Hardy et al., "Sea Surface Contamination."

the marine environment of the RSA. Recovery of the coastal lagoons and mangroves in Kuwait and Saudi Arabia can only be enhanced by greater protection efforts. Recovery of the fisheries will also require greater efforts in management, including stricter control of fishing in the area – a process that would require addressing the economic and social impacts on the fishing industry.

Recovery of the marine environment may be further enhanced by incorporating the provisions of the Kuwait Regional Convention and its Protocols into the national legislation of member states. The 1990 Protocol for the Protection of the Marine Environment against Pollution from Land-Based Sources, the 1989 Protocol Concerning Marine Pollution Resulting from Exploration and Exploitation of the Continental Shelf, and the 1998 Tehran Protocol on the Control of Marine Transboundary Movements and Disposal of Hazardous Wastes and Other Wastes all contain provisions to reduce further abuse of the marine environment. Adopting the preventive approach to oil pollution advocated by the 1978 Protocol Concerning Regional Cooperation in Combating Pollution by Oil and other Harmful Substances in Cases of Emergency, including placing a ban on substandard tankers and establishing a regional scheme of reception facilities for oily wastes and other wastes, and adopting a Memorandum of Understanding on Port State Control and Ratification of MARPOL, would enable member states to declare the area as a "Special Area" in which release of ballast waters and other wastes could be prohibited.

Important as they are, the positive impacts of the efforts outlined above may still be rendered ineffective if the land-use patterns of landfilling, dredging, and alteration of coastal morphology continues. A major activity that has devastating effects on fisheries and the ecology of the area is the drainage of the Iraqi marshes. The Iraqi regime, driven by political and military objectives, has reduced the Iraqi marshes (an estimated area of about 0.5 million hectares), to water channels that deliver river water, with all its sediment loads, agrochemicals, sewage, and industrial wastes, directly into the RSA.[24] This action has deprived the area of a giant "kidney" that previously acted as a self-sustaining waste treatment facility, and it is likely to affect the spawning grounds of shrimp and migratory fish at the Shatt Al-Arab delta and Kuwait Bay. This area has been transformed from a

[24] E. Maltby, *The Amar Appeal: An Environmental and Ecological Study of the Marshlands of Mesopotamia* (1994).

paradise for migratory birds of Europe and a major source of fisheries into an arid, barren land.

Finally, there is a need to transform our knowledge of the impacts of war on the marine environment of the RSA into actions that would make future generations see us in a better light. These include international support and cooperation in assessment of the long-term impacts and recovery rates, as well as in rehabilitation efforts. Such efforts would provide a better understanding of the fate and effects of petroleum hydrocarbons on the marine ecosystems and populations of arid sub-tropical seas. It is obvious that the cost and expertise of such endeavors are too heavy a burden to be borne by the ROPME region alone. The United Nations system needs to develop a mechanism by which countries that are victims of such environmental damage could utilize funds made available by the responsible party, or from a fund to be replenished by the responsible party in accordance with UN Security Council decisions. Experience gained from the establishment of oil industry funds in covering the costs of combating oil spills and compensating claims for economic and environmental damages should be used as examples by the international court systems to enhance their response to the environmental impacts of war on the marine environment.