An expert opinion of when the Gulf of Mexico will return to pre-spill harvest status following the BP Deepwater Horizon MC 252 oil spill

by

John W. Tunnell, Jr.
Harte Research Institute for Gulf of Mexico Studies
Texas A&M University – Corpus Christi

for

Kenneth R. Feinberg
Claims Administrator
Gulf Coast Claims Facility
Feinberg Rozen, LLP
The Willard Office Building
1455 Pennsylvania Ave., N.W.
Washington, D.C.

This expert opinion is endorsed by the Harte Research Institute for Gulf of Mexico Studies at Texas A&M University-Corpus Christi (see Endorsement on page iii of this report).

31 January 2011

Table of Contents

Endorsement

The Harte Research Institute (HRI) for Gulf of Mexico Studies at Texas A&M University-Corpus Christi has reviewed and endorses this expert opinion report. As Dr. Wes Tunnell has noted in this opinion, establishing a recovery date or time is more difficult than determining the impact from the spill itself. In fact, establishing an exact recovery time is essentially impossible. However, HRI is committed to assisting with the recovery process and understands that claimants need to be reimbursed for their losses as soon as possible. As is thoroughly explained in Dr. Tunnell's expert opinion, there are many short-term and long-term biological and ecological circumstances that can impact Gulf of Mexico fishery species, some easily detected and others not showing up for years. However, we believe that his projected recovery times are reasonable estimates at this early stage in the process.

Dr. Wes Tunnell was paid as a consultant to develop this expert opinion during the university holiday season break in December 2010. HRI did not receive any funding for their review and endorsement of this report.

Larry D. McKinney, Executive Director
Harte Research Institute for Gulf of Mexico Studies
Texas A&M University-Corpus Christi

An expert opinion of when the Gulf of Mexico will return to pre-spill harvest status following the BP Deepwater Horizon MC 252 oil spill

Background and Purpose of Report

The BP Deepwater Horizon MC 252 Spill of National Significance (DWH oil spill) became the largest accidental marine oil spill in history after releasing over 200 million gallons of oil into the Gulf of Mexico from 20 April to 15 July 2010, a period of 87 days. Because of the high environmental and economic value of the Gulf of Mexico, extensive media coverage, public outcry, and scientific concern focused attention on the Gulf for months during mid 2010.

An unprecedented response of 1000s of workers and 100s of boats and ships continued cleanup and assessment into the fall after capping the well in July. To understand the true magnitude of the response to the spill, the National Oceanic and Atmospheric Administration (NOAA) produces a monthly activity report entitled the "NRDA (Natural Resources Damage Assessment) by the Numbers" report, and on 1 December 2010 the report listed: 29,599 environmental samples collected for analysis; 37,183 NRDA laboratory analyses conducted; almost 30,000 total samples include those collected by 83 offshore research cruises, including 17,026 water samples, 3,806 sediment samples, 5,007 tissue samples, and 1,917 tarball samples; 34,768 images, and over 4,000 linear miles of shoreline surveyed.[1]

[1] National Oceanic and Atmospheric Administration [Internet]: Gulf Spill Restoration. [cited 2010 December 23]. Available from: http://www.gulfspillrestoration.noaa.gov/

Regarding the overall economics of Gulf of Mexico commercial fisheries, fishermen harvested 1.27 billion pounds of shellfish and finfish that earned $659 million in total landings revenue in 2008 (NMFS 2010a). The economic multipliers of commercial fishing range from 2X to 3X dockside value, conservatively, to 8X-10X demonstrating the significant impact all along the value chain.[2] It is not just fishermen that are impacted but also the processor, distributor, retail establishments, and restaurants.

In response to economic losses caused by the spill, the Gulf Coast Claims Facility (GCCF) opened in June 2010 "as part of an agreement between the Obama Administration and BP to assist claimants in filing claims for costs and damages incurred as a result of the oil spill stemming from the Deepwater Horizon Incident".[3] As of 13 December the GCCF had processed over 463,000 claims and paid out about $2.5 billion to over 166,000 individuals and businesses.[4]

One significant, but difficult to assess, economic sector which the Gulf Coast Claims Facility will have to deal with soon is the fishing industry of the Gulf of Mexico. NOAA Fisheries Service worked in concert with the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), and Gulf states to determine fishery closures in the northern Gulf of Mexico as a result of the DWH oil spill. This action was "a precautionary measure to ensure

[2] Center for Natural Resource Economics & Policy [Internet]: Economic Impacts of Fisheries and Coastal Habitats. [cited 2010 December 23]. Available from: http://www.cnrep.lsu.edu/pdfs/LSG%20Oil%20Spill%20FAQs.pdf
[3] Gulf Coast Claims Facility [Internet]: Deepwater Horizon. [cited 2010 December 23]. Available from: http://www.gulfcoastclaimsfacility.com/press1.php
[4] Gulf Coast Claims Facility [Internet]: Deepwater Horizon. [cited 2010 December 23]. Available from: http://www.gulfcoastclaimsfacility.com/pressB.php

public safety and (to) assure consumer confidence in Gulf seafood" (NMFS 2010b). Closures started on 2 May 2010 in the area around the well blowout and continued to expand through the middle of July, peaking at 84,101 square miles or 34.8% of the Gulf of Mexico U.S. Exclusive Economic Zone (EEZ).[5] Closures then decreased throughout the fall until 15 November when only the area around the MC252 well was closed, an area of 1,041 square miles or 0.4% of the U.S. Gulf EEZ. On 24 November an additional 4,213 square miles were added to the closure for royal red shrimp fishing only, as a result of the discovery of tar balls in some royal red shrimp trawls (NMFS 2010c).

The purpose of this report is to provide an expert opinion to the Gulf Coast Claims Facility regarding the duration of any negative biological effects of the DWH oil spill on those species commercially harvested in the Gulf of Mexico (primarily shrimp, crabs, oysters, and finfish). Because of great variability of the environment and natural populations, present-day, as well as historical, information and data, will be utilized, along with the scientific literature to give the best informed estimate of when fishery populations will be back to pre-spill conditions.

Before looking specifically at the species of concern and their recovery, it is important to understand the Gulf of Mexico ecosystem, as well as lessons learned from previous oil spills, particularly those in the Gulf of Mexico.

---

[5] National Oceanic and Atmospheric Administration [Internet]: National Marine Fisheries Service; fishery closures. [cited 2010 December 23]. Available from: http://sero.nmfs.noaa.gov/ClosureSizeandPercentCoverage.htm

The Gulf of Mexico Ecosystem

The Gulf of Mexico is the ninth largest body of water in the world, and it is economically and ecologically one of the most productive and important (Tunnell 2009). Geographically, the Gulf is located in the southeastern part of North America, and it is surrounded by three countries – the United States to the north, Mexico to the south, and the island of Cuba in the east. The Gulf is a Mediterranean-like basin connected to the Caribbean Sea via the Yucatan Strait and with the Atlantic Ocean by the Straits of Florida. The Gulf occupies a surface area of approximately 579,000 square miles, and it has a maximum depth of 12,632 feet (Darnell and Defenbaugh 1990). Although the straight-line length of the shoreline around the Gulf is about 4000 miles, when the intricacies of all the shorelines of all the estuaries, lagoons, and waterways are included, it totals over 47,000 miles (NOS/NOAA 2008).

The Gulf of Mexico is alternatively known as the American Mediterranean, America's Sea, the Energy Coast or Third Coast, and, unfortunately, the Forgotten Coast. The Gulf is a sea of contrasts, where a healthy environment and a healthy economy both coexist and contend with each other (McKinney, 2009). Perhaps a positive outcome of the DWH oil spill is the increased awareness that focused attention on the Gulf and its strong economic and environmental value to the nation.

Economically, the five U.S. states that border the Gulf of Mexico have a gross domestic product of over $2.2 trillion, and the robust economy of the Gulf region provides jobs for more than 20 million people. Much of this economic activity is linked to Gulf of Mexico natural resources, such as tourism and recreation, commercial and recreational fishing, and petroleum production and exploration (NOS/NOAA 2008). In a recent year (2006) 83% of the total US shrimp landings, 56% of the oyster landings, and 14% of the commercial fishery landings came from the Gulf of Mexico. The average number of pounds of commercial fishery landings coming from the Gulf totals 1.3 billion per year (in 2006) yielding a value of $662 million (NOS/NOAA 2008).

The oil and gas industry in the northern Gulf of Mexico is one of the most developed in the world, and it produces over 52 % of the crude oil production in the US, 54% of the natural gas production, and 47% of the crude oil refinery capacity (NOS/NOAA 2008). Over 107,000 petroleum related workers are employed in the Gulf with over $12.7 billion annual wages earned.

Biologically, the shallow waters of the northern Gulf are categorized as warm temperate and reside within the Carolinian Biogeographic Province (Briggs 1974). These are some of the most highly productive coastal waters in the world and include ecologically important habitats, such as barrier islands, tidal flats, coastal wetlands and marshes, oyster reefs, seagrass meadows, and open bay bottoms (NOS/NOAA 2008). These important habitats provide many ecological functions, such as feeding grounds, nursery grounds, nutrient sources, and structure to hide from predators. The fact that 95% of all commercially and recreationally important species depend on these estuarine and coastal habitats at some stage in their life cycle is strong evidence of their ecosystem value. The north-central Gulf of Mexico is sometimes referred to as the nation's "Fertile Crescent" due to the high productivity, plentiful nutrients, and abundance of critical nursery habitats (Moore et al. 1970, Darnell et al. 1983).

A high diversity of marine life, including over 15,400 species, exists in the Gulf of Mexico, making it one of the most biodiverse oceanic water bodies on Earth (Felder and Camp 2009). In addition to the 1000's of invertebrates, including over 2400 seashells and over 2500 crustaceans, there are over 1500 species of fishes, 5 sea turtles, nearly 400 species of birds, and 30 species of marine mammals. The Kemp's Ridley sea turtle is the most endangered in the world, but its numbers are now increasing after decades of decline and focused conservation attention. In addition to the only wild population of Whooping Cranes in the world along the Texas coast, vast numbers of colonial waterbirds nest on rookery islands along Gulf shores, and hundreds of thousands of migrating shorebirds, song birds, raptors, and waterfoul (ducks and geese) use Gulf flyways (Tunnell 2009). The most common coastal marine mammal, the bottle-nosed dolphin, has a population near 78,000 individuals in the northern Gulf of Mexico (Wursig et al. 2000).

Most Americans or visitors to the northern Gulf of Mexico have a misconception of this grand aquatic ecosystem. Their visits to Corpus Christi, Galveston, Biloxi, or Mobile often reveal brown, turbid waters in the Gulf with oil and gas platforms on the horizon and oil refineries on the mainland. However, just a short distance offshore and all the way to Mexico and Cuba, are clear and blue oceanic waters with a rich diversity of marine life and habitats.

Although Gulf waters are known to be highly productive and biodiverse, that does not mean they are without impacts and threats. Increasing population pressure and utilization of Gulf resources have caused considerable effects with a significant list of threat issues: loss of critical habitat, degradation of water quality, overfishing and poor fishing techniques, oil spills, nutrient enrichment with dead or low oxygen zones, invasive species, beach/shellfish closures, coastal development, and harmful algal blooms (Kumpf et al. 1999). Following the suggestion of the U.S. Commission on Ocean Policy (2004), the Gulf of Mexico region formed the Gulf of Mexico Alliance (GOMA) to start addressing the above environmental issues. GOMA is a partnership between the five U.S. Gulf states and two federal agencies (EPA and NOAA), and they have now produced two Action Plans to start addressing key environmental issues (GOMA 2006, 2009). Other organizations that focus primarily or exclusively on the Gulf include: Gulf States Fisheries Commission, Gulf of Mexico Fisheries Management Council, EPA Gulf of Mexico Program, NOAA Gulf Coast Service Center, Harte Research Institute for Gulf of Mexico Studies, Northern Gulf Institute, Gulf of Mexico Foundation, and the Gulf Restoration Network.

Resiliency of the Gulf of Mexico is a key issue being addressed by GOMA and Gulf scientists. Resilient coastal communities, like resilient natural populations, are those that are healthy and diverse, and able to rebound after natural or anthropogenic catastrophes. Hurricanes *Katrina* and *Rita* during 2005 severely tested both natural and human populations, and they encouraged future focus on rebuilding and restoring both. The DWH oil spill has now affected and tested some of those same natural and human populations.

In a previous large Gulf of Mexico oil spill, the Gulf of Mexico displayed resiliency, and it seemed to rebound or recover much faster than most people predicted. The Ixtoc I oil spill of 1979-80 was the world's largest accidental marine oil spill until the DWH spill, and it released 140 million gallons of oil into the Gulf over almost 10 months of time. Although small remnants of Ixtoc tar mats can still be found today at a few remote Mexican localities, the majority of Gulf species and habitats seem to have recovered. Unfortunately, there were no long-term comprehensive studies done to confirm recovery, so we cannot be certain. In addition, it is unclear today whether the Gulf of Mexico is as resilient as it was 30 years ago, due to the many and continuing environmental impacts.

Before moving to the next section on lessons learned from previous oils spills, it is important to discuss and understand the role of natural seepages of hydrocarbons into the Gulf of Mexico. These natural seepages are well know and widespread throughout a large area of the Gulf, and they have been occurring for millennia. The seepages are very important for two reasons: 1) the Gulf is accustomed to assimilating these slow, chronic releases of oil and Gulf waters are inoculated with natural petroleum-eating microbes in almost all habitats, and 2) it means that natural seepage oil is widespread, so scientists must be careful to note the origin of oil affecting species or habitats.

Archaeological evidence reveals Karankawa Indians on Padre Island, Texas, used beach tars or asphalt to line and seal pottery as far back as Pre-Columbian times (Campbell 1952), and early Spanish explorers used beach tars and asphalt to caulk their boats (DeGolyer (1918). The first scientific report on floating oil fields in the Gulf of Mexico explained how widespread the natural seeps are (Soley 1910), and subsequent studies have shown how consistent and continuous the seepages remain today (MacDonald 1998, Garcia 2009). Analysis of satellite imagery reveals that there are over 1000 natural seeps in a wide area of the Gulf, but they are primarily clustered in the two major oil producing areas of the northwestern Gulf of Mexico and the southern Gulf of Mexico in the Bay of Campeche (Figure 1).

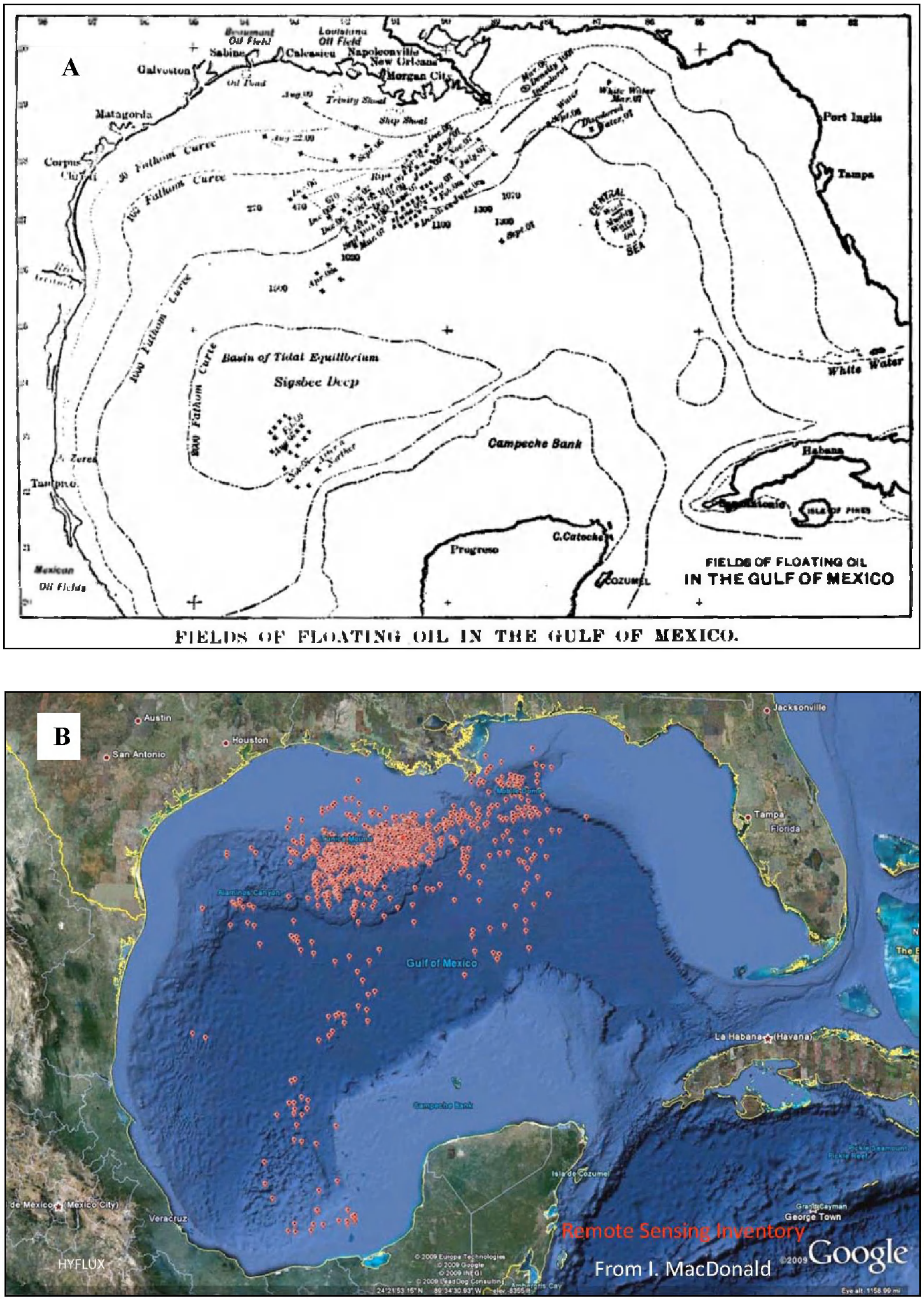

Figure 1. - Distribution of natural seeps within the Gulf of Mexico (a. Soley 1910 and b. image provided by I. MacDonald 2010).

Investigations of natural seepage sites in the northern Gulf of Mexico, beginning in the 1980s led to new discoveries of continental slope biota and unexpected new biota and habitats (Brooks et al. 1987, Kennicutt et al. 1988). After several decades of focus, these hydrocarbon seep communities of the northwestern Gulf are the best known in the world and show how these chemosynthetic communities utilize hydrocarbons to survive at the great depths where they occur (Cordes et al. 2007, 2010, Fisher et al. 2007). Recent tracking of surface sheens from seeps in the Bay of Campeche led to new discoveries of asphalt volcanism and chemosynthetic biota on the Campeche Knolls in the deep southern Gulf of Mexico (MacDonald et al. 2004). This brief overview of these hydrocarbon seep communities is simply to show the uniqueness of the Gulf of Mexico and its long term tolerance and adaptation to chronic additions of hydrocarbons over broad areas and the development of unique species and habitats in certain, select deep areas.

Oil Spills in the Marine Environment

Oil and natural gas are the dominant fuels in the U.S. economy, and they provide 62% of the nation's energy and almost 100% of transportation fuels (NRC 2003). The birth of the oil industry in the U.S. is considered to have begun with the oil discovery and subsequent blowout at Spindletop near Beaumont in coastal southeast Texas in 1901. The first well drilled in the Gulf of Mexico was located one mile offshore near Cameron, Louisiana, in 14 feet of water in 1937 (T. Priest, pers. comm.). From these slow beginnings and then with development of offshore technology, oil and gas exploration and production expanded across the continental shelf and down the slope of the northwestern Gulf of Mexico during the next seven decades. Today, about 3,500 exploration and production platforms exist in the northwestern Gulf, down from nearly

7,000 total, and including over 25,000 miles of pipeline and approximately 50,000 total wells drilled (multiple wells are drilled from most modern platforms).[6]

The wreck and spill of the tanker *Torrey Canyon* in southern England in 1967 and the blowout of a Santa Barbara, California, platform in 1969 ushered in the modern era of oil spill concern and awareness, prompting planning for oil spill response, clean up, contingency plans, and studies of major oil spills. In the U.S., Earth Day was created in 1970 because of the Santa Barbara spill, and the Clean Water Act was passed in 1972 in part because of these spills. The first oil spill training school in the U.S., the National Spill Control School (NSCS) at Texas A&M University-Corpus Christi, was developed as the first oil spill training facility in the U.S. in the mid 1970s because of these first major spills (CCSU 1978), and it remains active today. The NSCS was later named as the resource training program for the Oil Pollution Act of 1990.

The first scientific review of knowledge on the fate and effects of oil in the marine environment was carried out by leading oil spill and marine science experts for the National Research Council (NRC 1975) of the U.S. National Academy of Sciences. Because that study and compilation of knowledge were so useful with widespread distribution, it was repeated again by the NRC in 1985 and 2003 (NRC 1985, 2003) as more knowledge was gained about oil in the sea. The latter volume is the primary sourcebook in the U.S. of knowledge regarding the inputs, fates, and effects of oil in the sea today.

[6] Bureau of Ocean Energy Management, Regulation, and Enforcement [Internet]: Outer Continental Shelf Oil Production. [cited 2010 December 23]. Available from: http://www.boemre.gov/stats/OCSproduction.htm

When the *Exxon Valdez* tanker ran aground in 1989 and spilled almost 11 million gallons of oil into the pristine environment of Prince William Sound, Alaska, another new era began in dealing with oil spills in the sea. In 1990 the U.S. Oil Pollution Act was passed, and a new structure was established in the U.S. for dealing with oil spills and the payment for recovery of damaged environments and economies (Natural Resource Damage Assessment program or NRDA) by the responsible party. Until the DWH oil spill, the *Exxon Valdez* spill was the largest and most significant in U.S. history. Beyond the ecological damage, the *Exxon Valdez* disaster caused a fundamental change in the way the U.S. public viewed oil, oil transportation, and the oil industry (NRC 2003). Despite continuing heavy use of fossil fuels by society, "big oil" was suddenly seen as a necessary evil, and something that had to be feared and mistrusted. This reaction was quick and significant (NRC 2003).

The ecological consequences of oil spilled into the marine environment range from mild to severe. In any given spill the effects of an oil spill and the recovery time of the contaminated area will be influenced by many different variables (Tunnell 1978). Broadly speaking, the three main variables are: 1) the amount and type of oil spilled; 2) the environmental conditions at the time of the spill; and 3) the kind of environment(s) impacted by the spill. It is very important to note that the amount of crude oil spilled is not a sole measure of the ensuing damage (NRC 2003). This has been revealed time and time again in many spills, showing that the "dose" (the exact amount in a specific location at a particular time) of petroleum hydrocarbons into a particular habitat or on a particular species is the key element, not the total volume spilled. This, of course, is very difficult to measure over a wide area in a major spill.

Regarding environmental conditions, spilled in warmer climates will weather (naturally break down) faster than oil spilled in colder climates. Physical, chemical, and biological processes speed up the natural degradation process of spilled oil. Moderate to heavy physical energy of waves and currents tend to break up and disperse the oil, and photo-oxidation speeds up the chemical breakdown and weathering process, including evaporation at the surface. Biologically, petroleum-eating bacteria and fungi feed upon the oil and speed up its breakdown, often becoming food available for other marine organisms.

As a warm water climate example of degradation and recovery, the largest oil spill in history occurred in the Arabian Gulf (Persian Gulf to some) region when approximately 520 million gallons of crude oil was released during the Iraq-Kuwait conflict (Tawfig and Olsen 1993). Although there were severe and significant shoreline impacts to marshes and intertital habitats (Gundlach et at. 1993, Jones et al. 1996), amazingly there were no significant long-term impacts to subtidal habitats or communities, including seagrass meadows, coral patch and fringing reefs, unvegetated sandy and silty substrates, and rocky outcrops (Kenworthy et al., 1993, Richmond, 1996).

In terms of environments impacted by oil spills the Environmental Sensitivity Index (ESI) is now the standard for environmental characterization used in the U.S. and many other countries of the world. The ESI was first developed by Research Planning Institute (RPI; Michel et al. 1978) and was first applied during the Ixtoc spill in South Texas in 1979-80 (Hayes et al. 1980). Shoreline habitats are ranked according to a scale relating to sensitivity, natural persistence of oil, and ease of clean-up. The scale of 1-10 includes the least sensitive environments and easiest to clean up as

1 and the most sensitive and most difficult to clean up as 10 (1-exposed rocky shores or exposed man-made sea walls, bulk heads, and rock structures; 2-exposed rocky platforms; 3-fine-grained sand beaches; 4-course-grained sand beaches; 5-mixed sand and gravel beaches; 6-gravel beaches; 7-exposed tidal flats; 8-sheltered rocky shores or man-made sea walls, bulk heads, or rock structures; 9-sheltered tidal flats; and, 10-salt to brackish marshes and mangroves) (Gundlach and Hayes 1978). Today this scale is used to generate maps for contingency planning for oil spills and is placed in a GIS system for ease of use, broad accessibility, and updating. Specific biological resources, such as sensitive habitats and species, nesting grounds, etc., are added to the maps, along with human-use resources, such as marine sanctuaries and refuges or important cultural or historical sites. Because all U.S. shorelines have now been mapped using the ESI, it is a vital tool used by the NOAA Scientific Support Coordinator to inform the U.S. Coast Guard Federal On-Scene Coordinator during a spill.

The above complexities of oil spilled in the environment and the subsequent fate and effects clearly reveal the difficulty in assessing damages from a spill and the near impossibility in accurately predicting the environmental impact or time of recovery. As noted earlier, the effect of oil is not directly related to the amount released. It is instead a complex function of the rate of release, the nature of the released oil, and the local physical and biological ecosystem (NRC 2003). Similar encounters or habitats can respond differently over short distances, depending on the exact amount of dosage at any given time.

Marine ecosystems and their varied components fluctuate on a variety of time scales ranging from hours to millennia, and on space scales ranging from feet to that of an ocean basin (NRC

2003). Therefore, in the absence of on-going local or regional monitoring, it is very difficult to quantify the effects from an oil spill, or to establish when recovery from such a pollution event is complete. Populations in an area may be in a long-term trend upwards or downwards resulting from, for instance, large scale climatic changes or physical alterations to the habitat. So, determining recovery to a certain endpoint may be ill-conceived, if the larger scale trend is unknown or is not factored into the recovery equation or model.

Catastrophic or acute oil spills are far different than the chronic natural seepage previously mentioned above. Acute effects may be of short duration and limited impact, or they may have significant long-term effects at the population or community level depending on the many factors mentioned above. Physical fouling or suffocation from heavy oiling and varied physiological and toxicological responses may be immediate, but they may also be chronic and/or sublethal and difficult to detect, even showing up months or years later. Changes in feeding behavior or reproductive behavior could affect populations for years from re-oiling of submerged or hidden oil that was not removed. The unprecedented and unexpected crash in the herring fishery five years after the Exxon Valdez oil spill is a classic example of the unknown that can surprisingly appear years later (Peterson et al. 2003).

Sources of Oil in the Marine Environment

After years of study and review of many sources of information the National Research Council (2003) categorized all petroleum input into the sea into four categories: natural seeps, petroleum extraction, petroleum transportation, and petroleum consumption. Table 1 summarizes the

Table 1. Average, Annual Releases (1990-1999) of Petroleum by Source (best estimates in millions of gallons)(NRC 2003).

Source	Gulf of Mexico	North America	Worldwide
Natural Seeps	43.1 (82%)	49.6 (63%)	184.7 (83%)
Extraction of Petroleum (platforms, atmospheric deposition, produced waters)	0.8 (2%)	0.9 (1%)	11.7 (5%)
Transportation of Petroleum (Pipeline spills, tanker spills, operational washings, coastal facility spills, atmospheric deposition)	1.3 (2%)	2.8 (4%)	6.3 (3%)
Consumption of Petroleum (land-based, recreational, operational discharges, atmospheric deposition, jettisoned aircraft fuel)	7.1 (14%)	25.9 (33%)	20.2 (9%)
Total	52.3	79.2	222.9

average, annual releases of petroleum into the environment by source categories during 1990-1999 in gallons and percent per category for the Gulf of Mexico, North America, and Worldwide. Natural seeps dominate all three of the geographic categories. In the Gulf of Mexico during the decade of the 1990s, 82% of the input from coastal and offshore sources was from natural seeps. When only offshore sources are considered, 95% of inputs came from natural seeps (NRC 2003). This percentage would obviously be different during the next decade due to the DWH oil spill.

Lessons Learned from Previous Oil Spills

Although lessons can be learned from many previous oil spills, the most appropriate major spill for the Gulf of Mexico is the Ixtoc I spill. This platform blowout in the southern Gulf of Mexico, Bay of Campeche, 50 miles north of Ciudad del Carmen, Campeche, was very similar in many ways to the DWH oil spill, but it also had distinctive differences. The Ixtoc spill began on 3 June 1979 and ended on 23 March 1980, lasting almost 10 months and releasing about 140,000 million gallons. The burning platform sank several days after the blowout, and similar clean up strategies (burning, dispersant, booms, and skimmers), as well as containment strategies (top kill, junk shot, top hat called the sombrero, and relief wells) were utilized (Jernelov and Linden 1981). Besides extending for a much longer period of time than the DWH oil spill, the other main differences were the water depth, 170 feet for Ixtoc versus 5000 feet for DWH and the use of dispersants at great depth.

After 60 days of oil release into the southern Gulf and drifting on westward and northward moving currents, the oil reached Texas beaches and coated them with moderate to heavy oiling for over 150 miles north of the Rio Grande during August and September 1979 (ERCO 1982, Hooper 1981). The clean-up strategy in Texas was to let oil hit the outer barrier island beaches but boom off all tidal inlets to prevent oil entering the sensitive estuaries and lagoons of the South Texas coast. For the most part, this strategy worked well.

Unfortunately, as with most major spills, there were no long-term, ecosystem studies to monitor the affect of the spill in either Texas or Mexico. Short-term studies in Texas revealed impact and recovery of shorebirds (Chapman 1979, 1981) and beach biota (Tunnell et al. 1981, Kindinger

1981) after 1 and 2-3 years, respectively. Besides some minor oiling of shorelines along jettied inlets and shorelines just inside inlets, no major estuarine impacts to habitats or species were reported. Offshore, one study compared the Ixtoc oil spill and *Burmah Agate* (a tanker spill off Galveston in 1979) to the large multi-year South Texas Outer Continental Shelf study completed several years prior to both spills and found no effects related to the spills in the outer shelf area (Lewbel 1985).

In Mexico only one overview report was published by a consortium of Mexican authorities, but it had little useful information on environmental impacts of the spill (PCEESC 1980).

DWH Oil Spill and Fishery Species Recovery

The DWH oil spill released over 200 million gallons of oil into the northern Gulf of Mexico for 87 days between 20 April and 15 July 2010. Approximately 1.84 million gallons of dispersants were added to help disperse the oil and keep it from washing ashore into sensitive coastal habitats, critical fishery areas, and places of high public use. The application of over 40% of the dispersants at depth near the wellhead caused great concern among the public and many scientists. In response, the federal government launched an unprecedented effort to study the effect of the sub-surface dispersants and the plumes of micro-droplets of oil in the deep water column during the fall of 2010. A summary report on these findings was released on 17 December 2010 by the Operational Scientific Advisory Team (OSAT) of the Unified Area Command (OSAT 2010). The U.S. Coast Guard is the designated Federal On-Scene Coordinator (FOSC), and NOAA (in marine spills) is the designated Scientific Support Coordinator (SSC) to the FOSC and also leads the numerous trustees for the Natural Resource Damage Assessment (NRDA) process established in the Oil Pollution Act of 1990.

Some of the findings of the OSAT sub-surface report are important to the present report and will be used below, but a brief overview of their findings from the Executive Summary include: no liquid oil was found beyond the shoreline; no exceedences of the EPA Human Health or dispersant benchmarks were observed; less than 1% of the water samples exceeded EPA Aquatic Life benchmarks for polycyclic aromatic hydrocarbons (PAHs) but none were consistent with MC 252 oil; about 1% of sediment samples exceeded the PAH benchmarks but they were only the ones less than 2 miles from the wellhead; of the previously closed fisheries areas, 87,481 square miles have been reopened, with only 1,041 square miles around the wellhead still closed (on 24 November 2010 royal red shrimp were subsequently closed to fishing in a 4,213 square mile area near the wellhead); some drilling mud entrained with oil exists in an area near the wellhead; and, tar mats in shallow nearshore waters were identified as an area of sampling gap. A separate team has been tasked with surveying and understanding the extent of these tar mats. Toxicity testing of sediments was not available at the time of the 17 December OSAT report release, so that information will be released in a subsequent report in early 2011.

Compared to the Ixtoc I oil spill, the DWH oil spill affected a much smaller area of the Gulf (Figure 2). The DWH spill occurred during late spring and early summer when climatic conditions and sea conditions are generally calm in the northeastern Gulf near the well site, whereas the Ixtoc spill occurred from early summer to the following spring through all seasons of the year, including numerous winter fronts and several tropical storms. The DWH spill oiled a

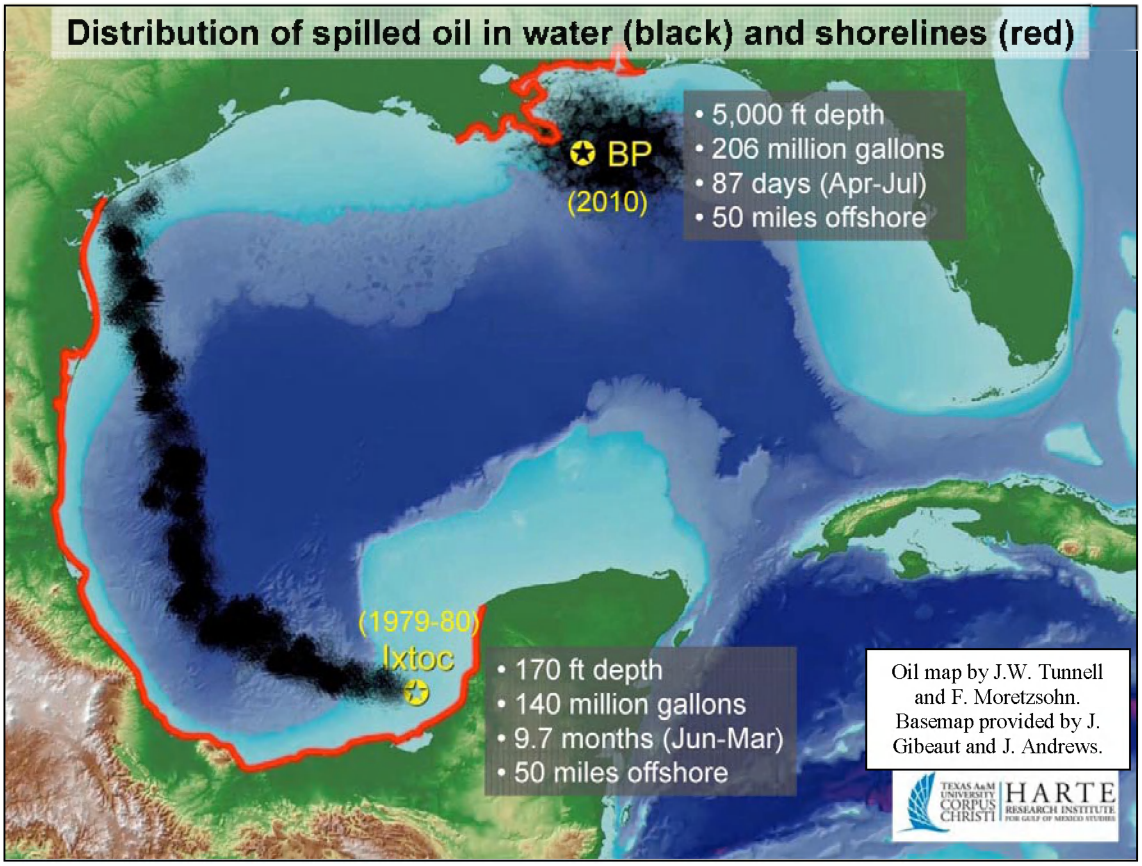

Figure 2. - Location and distribution of spilled oil and oiled shorelines caused by the BP DWH oil spill and the Ixtoc I oil spill.

shoreline area of less than 400 linear miles, and the Ixtoc spill oiled over 1500 linear miles of the entire western and southern Gulf. This oiling of an area of less than 5% of the entire Gulf during the DWH spill is significant for the recovery process, since many northern Gulf species have a much wider distribution than the affected area, and therefore the ability to help recolonize impacted areas by prolific spawners with widely dispersed planktonic eggs and larvae. Ecologically the DWH spill occurred in a very sensitive area of the Gulf, which includes the highly productive coastal wetlands and marshes of the Mississippi Delta. These salt and brackish marshes are a number 10 on the ESI scale, being sensitive to oiling and difficult to clean up. In fact, the usual clean-up strategy for marshes is to leave them alone and let natural cleaning process proceed, as any clean up activity tends to push oil deep into the sediments by clean-up crews and machinery, making recovery take much longer. In addition to these sensitive marshes, other highly productive, critical habitats in the Fertile Crescent shallow waters include oyster reefs and seagrass meadows. These highly productive and biodiverse habitats serve as feeding grounds and nursery grounds for many nearshore species. By comparison, regarding the Ixtoc oil spill, the fine-grained sand beaches of the western and southern Gulf are a number 3 on the ESI scale, so they are not as sensitive, and they can recover more quickly. These fine-grained sand beaches are found on almost continuous barrier islands and peninsulas west of the Mississippi Delta and provide natural barriers (or natural booms) for the more sensitive estuarine and lagoonal habitats inshore of them. In the northern Gulf a more open coast prevails with smaller and discontinuous barrier islands offshore, thus allowing oil to potentially reach sensitive inshore environments.

These highly productive nearshore environments are what make the northern Gulf a productive fishery area. Coastal fisheries (delineated by the 3-nautical mile state line from the shoreline for Louisiana, Mississippi, Alabama; Texas and Florida have a 9-nautical mile line) are under jurisdiction and regulation of each individual state, and offshore waters are under federal jurisdiction and regulation by the National Marine Fisheries Service (NMFS) of NOAA. The Gulf States Marine Fisheries Commission provides advisory information on coastal fisheries with representatives from each Gulf state. The Gulf of Mexico Fisheries Management Council is one of eight regional fishery management councils in the U.S. and helps advise and manage Gulf of Mexico fisheries within the EEZ of the Gulf.

In addition to the obvious and direct death of biota or habitats that can occur during an oil spill, there are many possible sublethal effects which can occur, and they can be quite insidious and are very difficult to detect or measure. These effects might include reduced reproductive capacity, or sizes of individual organisms might be smaller as a result of exposure to oil components, or a result of reduced amounts of food or habitat. The effects of oil on plankton (food for larvae of fish and invertebrates) are currently unknown, and may never be known. The effects of oil on trophic cascades and ecological interactions are also unknown (T. Shirley, pers. comm.).

The charge of this report is to provide "an expert opinion as to the duration of any negative biological effects of the Deepwater Horizon oil spill on those species commercially harvested in the Gulf (primarily shrimp, crabs, oysters, and finfish)". The first three groups will be dealt with individually below to provide a best estimate of the time to recovery of the fishery to pre-spill status, or to the duration of any negative biological effects caused by the spill. The fourth category "finfish" will be dealt with as a group, as it was not requested, nor is it perhaps even practical or necessary, to deal individually with all the many species in this category. General and relevant information about the biology of each group will be presented, as well as potential impacts from the oil spill and duration of impacts on the species and fishery. A summary statement about recovery will be given in bold for each group near the end of each discussion.

Shrimp

The major shrimp fishery species in the Gulf of Mexico include the brown, white, and pink shrimp. The Gulf of Mexico regional shrimp landings are the largest in the U.S. with over 188 million pounds or 73% of the national total in 2008. The total dockside value that year was $367 million with Louisiana landing the largest catch at 89 million pounds and a dockside value of $130.6 million, followed by Texas at 63.8 million pounds and $157.2 million, Alabama at 17 million pounds and $38.4 million, West Florida at 9.9 million pounds and $23.3 million, and Mississippi at 8.6 million pounds and $17.1 million (NMFS 2010a).

These shrimp all have a distinctive and similar life cycle with adults living and spawning in the offshore Gulf of Mexico, releasing eggs into the Gulf that go through several life stages as they migrate towards the protective estuarine nursery grounds and grow as juveniles, and then head back out to the Gulf as large juveniles or subadults. Depending on the species, each shrimp can release anywhere from 250,000 to 1 million eggs. Feeding habits of these shrimp vary by species but are often omnivorous as larvae and can be scavengers or carnivores as adults, and they serve as very important food sources for many different finfish and other marine life. Adults generally live on the bottom. Eggs when first released settle to the bottom for a short while (less than 1 day). Larvae hatch and rise to the surface, and larval stages live in the water column, often migrating up and down with daylight and dark condition. Brown and white shrimp are more common in the northern and western Gulf, and pink shrimp are more common in the eastern Gulf. Brown shrimp is usually the largest harvest, followed by white and then pink shrimp. However, since brown and white shrimp are difficult to distinguish in the field, they are often lumped together in fishery harvest statistics. Shrimp are considered an “annual crop” for harvesting purposes. Brown shrimp usually move out into the Gulf from February to April, and white shrimp move out from May through November (Patillo et al. 1997).

Unfortunately, there are few published field studies on the impact of oil spills on Gulf shrimp. However, several Mexican researchers with pre-spill data were able to document that two years after the Ixtoc oil spill, the Campeche shrimp fishery returned to pre-spill levels (Soto et al. 1981). In addition, on the South Texas continental shelf where considerable Ixtoc oil was present on the surface, there were no Ixtoc oil residues found in sediments of the shrimp grounds (Lewbel 1982), and an examination of Texas Commercial Harvest Statistics revealed no significant change in shrimp catches after the spill (Hamilton 1983).

In the case of the Arabian Gulf oil spill mentioned above, and in opposition to most subtidal habitats that did not have significant long-term impacts, shrimp stocks were severely impacted with drastic drops in spawning and total biomass (Matthews et al. 1993). Multiple causes for this collapse were attributed to such things as mass mortality of eggs, larvae, and juveniles resulting from oil exposure during the entire spawning season, emigration of adults out of the oiled area, mortality of adults, and heavy fishing of adults and juveniles. Later research, however, showed that the shrimp population rebounded to “better tan anyone could remember that it had ever been” (Jernelov 2010). A temporary shrimp closure and then new boats and equipment may have influenced these higher numbers.

Intuitively, because adult shrimp live on the bottom and spilled oil is generally on the surface, shrimp may not be directly affected. However, during the DWH oil spill, some eggs may have encountered floating oil and larval stages may have encountered dispersed oil in the water column. In addition, some important nursery habitat (coastal marshes) of shrimp was impacted by the DWH oil spill. There is also the possibility that some oil or dispersed oil attached to sediment particles near shore and sank, later forming layers of oiled sediment and clean sediment. Microbial breakdown may be enhanced by this process, unless sediment becomes anoxic (without oxygen), wherewith the degradation process would be slowed or stopped. Also, food of larvae in the water column, and of juveniles and adults on the bottom may have been reduced in quantity or contaminated with oil.

However, shrimp have annual life cycles and can live up to two years, so after a spill, or any other event that could cause a lost year class, it is reasonable to expect that shrimp would recover after just one year, or two years at the maximum, unless there is a continuation of the insult or perturbation.

Interestingly, and significantly, research scientists in the northern Gulf of Mexico off Alabama have seen increases in both biodiversity and biomass of trawled marine organisms post-spill (J. Valentine, pers. comm.). For example, an increase in abundance of four times for shrimp was recorded. These increases are likely a function of the fishery closure and removal of fishing pressure, but it also shows that shrimp are not only present but very abundant during fall 2010.

In summary, if potential impact scenarios stated above have not significantly impact 2010 shrimp populations and their life cycles, it is believed that shrimp catches for the brown, white, and pink shrimp in the northern Gulf of Mexico will likely continue along the same

harvest trends in recent years by 2011, and even more likely by 2012. Loss of Mississippi Delta nursery habitat could cause a percentage reduction in shrimp population size until marshes recover.

There is a small but distinct fishery for royal red shrimp in deep offshore waters, and as indicated by the recent closure around the wellhead (NMFS 2010c), this fishery will need further scrutiny to determine when and if it should be opened.

Crabs

Blue crab are the most economically valuable crab species for the northern Gulf of Mexico region and constitute the main crab fishery for the area. Two species of stone crabs are also harvested, but their numbers and value is not near that of the blue crab and many of them are taken incidental to the blue crab fishery. Louisiana lands the largest percentage of the harvest at 26% of the total blue crabs for the nation or 41.6 million pounds in 2008 (dockside value of $32 million). Landings and dockside value for other Gulf states for 2008 include: West Florida at 2.7 million pounds and $3.3 million; Texas at 2.6 million pounds and $2.3 million; Alabama at 1.8 million pounds and $1.5 million; and, Mississippi at 450,000 pounds and $447,000.

Because blue crab populations are essentially entirely coastal in distribution, they are managed by each state fisheries agency and the Gulf States Marine Fisheries Commission.

Blue crab are a classic example of an estuarine-dependent species, and they are considered by some to be a good indicator species of estuarine health. Mating may occur all year round in brackish areas of an estuary, while egg hatchings occurs in high salinity nearshore waters (Gillory et al. 2001). Early larval forms are generally found in nearhore-offshore waters and later larval forms migrate into the estuary, where juvenile crabs are widely distributed throughout the estuary. Adults are generally differentially distributed in an estuary with males preferring lower salinities near river inflows and females found in higher salinities towards the Gulf. Critical nursery habitats include intertidal marshes, sub-tidal seagrass beds, and unvegetated, soft sediment shorelines (Gillroy et al. 2001).

The peak reproduction period for blue crab is August-September and young crabs reach a harvestable size in the April-May timeframe. Estimated life span is 3-4 years. Blue crab are highly productive, producing 1.7 to 2.0 million eggs per hatching event (Patillo et al. 1997), and they are fast-growing and relatively short-lived. These reproductive characteristics indicate that the species can sustain high exploitation or heavy population reduction from an unnatural event and recover quite rapidly (Gillroy et al. 2001), if healthy environmental conditions exist and adjacent areas have adequate adult populations.

Although there are apparently no field studies on the impact of spilled crude oil on blue crab in the Gulf of Mexico, there is a considerable literature on lab experiments of various contaminants deleteriously affecting different life stages of blue crab from U.S. estuaries (Millikin and Williams 1984, Bookout et al. 1980, Schimmel and Wilson 1977, Bookout and Costlow 1975, to mention only a few). Regarding crude oil experimental testing in the laboratory, blue crab "juveniles were extremely tolerant to long-term petroleum aromatic hydrocarbon exposure" (Wang and Stickle 1987).

Scientists in the northern Gulf (H. Perry) reported oil droplets inside the shell of larval crabs during the DWH oil spill, but the outcome of that research is not available yet. There were no published or posted reports of blue crab die offs during the spill, even though light to medium oiling occurred in substantial areas of blue crab habitat. Some blue crab nursery habitat (coastal wetlands and marshes) was affected by the spill in the Mississippi Delta.

It is important to note that there has been a widespread multi-decadal decline in blue crab populations on the Atlantic coast and in the Gulf of Mexico. A definitive cause for this long-term and widespread decline has not been identified, but the declining trend should be considered in the Gulf impact and recovery from the DWH oil spill.

In summary, because blue crab populations do not appear to have been significantly impacted by the DWH oil spill, and because they are a highly reproductive species with widespread distribution throughout the region, it is believed that their population levels will likely continue along the same harvest trends in recent years in 2011. As noted above, some local populations may be reduced by larval impacts from the oil (or oil and dispersants) or by reduction in nursery ground coastal marshes. As indicated with shrimp, this loss of nursery habitat could cause a percentage reduction in crab population size until the marshes recover.

Oysters

The Gulf of Mexico leads the U.S. in the production of oysters, producing about 67% of the national total, including 20.6 million pounds and $60.1 million (in 2008). Louisiana leads the harvest with 12.8 million pounds and $38.8 million. Following Louisiana in harvest are: Texas at 2.7 million pounds and $8.83 million; Mississippi at 2.6 million pounds and $6.87 million; West Florida at 2.6 million pounds and $5.47 million; and, Alabama at 72,776 pounds and $243,414 (NMFS 2010a).

A recent and significant report on oyster reefs worldwide noted an 85% reduction or loss of this habitat on a global scale, and it noted that the most significant remaining oyster populations in the world exist in the Gulf of Mexico (Beck et al. 2009). This report, produced by The Nature Conservancy, sparked a widespread movement (by The Nature Conservancy and others) to enhance and restore Gulf oyster reefs in 2009 and 2010. Many new restoration projects were halted in the northern Gulf at the onset of the DWH spill.

Harvest methods for oysters include hand picking in shallows, tonging from boats, and dragging or dredging from boats. Most Gulf landings are from publicly owned oyster beds but about 30% of the harvest is from privately leased beds (Mackenzie 1989). Commercial fishery regulations for oysters vary from state to state, but all oysters harvested must be at least three inches in length according to the Gulf States Marine Fisheries Commission. Depending on location and local growth rate, oysters are harvested at about 1.5-2 years of age and live up to about six years (Galtsolf 1964).

Oysters primarily live on self perpetuating oyster reefs, but they can grow on almost any hard substrate in estuaries and nearshore waters, and therein lies their greatest vulnerability. If oil should get into the interstitial spaces of oyster reefs, then it is likely that juvenile oysters settling on oiled shell will not fare well. Also, the degradation of oil in a reef will add to the biological oxygen demand, and low dissolved oxygen could harm growth of newly settled oysters (P. Montagna, pers. comm.).

These bivalve mollusks are filter feeders and in large concentrations can filter huge quantities of water and increase water clarity. Although oysters can tolerate a wide range of salinity, their optimal range is between 12-15 parts per thousand. Depending on the amount of freshwater inflow in a particular bay, this can place reefs in upper, mid, or lower reaches. Too much freshwater will kill oysters, although they can tolerate some freshwater flooding from time to time. They do not feed or reproduce when salinities are too low for extended periods of time. Likewise, they can exist in higher salinities, but in those areas they are susceptible to numerous parasites and predators, which take a heavy toll on survivorship.

Oysters are protandrous, starting life as males and then changing to females. This insures a large number of females in the older population, and they are highly productive, producing 15-115 million eggs in a single spawn (Galtsolf 1964). Because of the wide distribution of oysters in northern Gulf estuaries and this high productivity, there are always high numbers of oyster eggs and larval stages in the summer plankton. The limiting factor for most of these young stages is adequate hard substrate for settlement, which is rare in the soft sediment dominated region of the northern Gulf. Death of an oyster reef for whatever reason, however, can be quickly recolonized because of this natural condition of abundant eggs and larvae.

There is a significant, but old and little known, extensive study and literature on crude oil impacts to southern Louisiana oysters. Projects 9 and 23 were funded from 1947 through the early 1960s to study the impact of oil and gas activities on oysters in coastal Louisiana. Over 400 communications, including 200 reports, were filed as a result of this extensive multi-year, multi-institutional study (Texas A&M University, University of Texas, Texas Christian University, Louisiana State University, and others). Twenty eight universities received the major reports of the study, and three independent summaries were completed, with the primary one being an entire dedicated issue of the *Publications of the Institute of Marine Science* (Volume 7, 1961), published by the University of Texas, Institute of Marine Science (now Marine Science Institute). The primary paper summarizing all of the work in the dedicated issue was by Mackin and Hopkins (1961).

Years of dead or dying oysters in coastal Louisiana had been blamed on the developing and expanding oil and gas industry, so the initial question that started the projects in 1947 was "Has pollution by oil or oil well effluents, or seismographic exploration, caused mortality of oysters in Louisiana?" Years of work revealed that oysters were quite tolerant of light to medium oiling, and that a parasite new to science ("dermo", named after its first scientific name *Dermocystidium marinum,* now *Perkinsus marinus*) was the culprit killing the oysters. Another interesting revelation of the research was that oiling did kill barnacles, which are a major predator of planktonic larval oysters, and oyster numbers did increase in certain areas when barnacles died off (S. Ray, pers. com., Mackin and Hopkins 1961).

Heavy oiling is known to kill most intertidal and shallow subtidal organisms, including oysters, due to suffocation, if not by emersion in toxic components of the spilled oil. Although there were no scientific surveys or reports, fishermen along the extensive mangrove shoreline north of Campeche, Yucatan Peninsula, reported that all mangrove oysters (not the same species as the American oyster discussed herein for the northern Gulf) died because of heavy oiling from Ixtoc oil and never returned.

During the DWH oil spill varying amounts of oil reached oyster fishing areas in Louisiana, but without detailed review (day by day) of oiling maps put on GeoPlatform by the NOAA shoreline teams (SCAT teams), it would be impossible to know exact dosages of oiling in the many specific local areas. A review of these maps would likely be helpful, but it might not be definitive enough to make conclusive decisions.

One complication of the oyster survival and future harvest scenario is that many oysters were partially or totally killed by the diversion of freshwater in the Barataria Bay system to push the oil away from oyster beds (E. Melancon, pers. com.). Other oysters were likely killed by overbank flooding of the lower Mississippi River.

In summary, it is believed that oysters in most areas of the northern Gulf will likely continue along the same harvest trends in recent years in 2011. In areas where oysters died

as a result of freshwater diversion and flooding, oyster reefs should be recolonized by young oysters in 2011 (assuming there are no large scale flooding events in 2011), but they will not likely be of harvestable size until late 2012 or 2013. In areas where oyster reefs were heavily oiled, oyster reefs may not recover for 6-8, or even 10 years.

Finfish

There are over 1500 fish species known from the Gulf of Mexico (McEachran 2009). However, only a small percentage of those are taken for commercial purposes. In coastal waters most fish species are taken in the recreational fishery and managed by state fish and wildlife agencies in each state, along with overarching management by the Gulf States Marine Fisheries Commission. Many offshore species, however, utilize coastal nursery grounds as part of their life cycle, so there is an important linkage between offshore species and habitats. The commercial and recreational fishery offshore (outside state waters) is monitored and managed by the NOAA Fisheries Service and the Gulf of Mexico Fisheries Management Council. Most of the demersal (bottom living) species of fish mentioned below live on the continental shelf, not the deep Gulf.

Commercial finfish in the northern Gulf of Mexico are usually fished and monitored/managed in groupings of species. Gulf of Mexico Reef Fish is one example, and Coastal Migratory Pelagics another. There are 42 fish species within the first category including red grouper, gag grouper, tilefish, greater amberjack, and grey triggerfish, as well as some groupings which have multiple species, such as shallow water grouper and deep water grouper. Coastal Migratory Species include the two related species of king and Spanish mackerel. The reef fish group, of course, includes species that are associated with reef or reef-like hard bottoms or topographic highs on the continental shelf. The mackerels are pelagic, or open water, species.

Red snapper is one of the most valuable reef fish species in the Gulf of Mexico, and it is taken in both inshore and offshore waters. Red snapper are taken both commercially and recreationally. In 2008, commercial landings for the Gulf totaled 2.37 million pounds for a dockside value of $7.95 million. Texas led the catches in weight with 869,966 pounds valued at $2.74 million followed by West Florida with 847,884 pounds at $2.94 million, Louisiana with 589,379 pounds at $2.03 million, and Alabama with 60,391 pounds at $237,141 (no data for Mississippi) (NMFS 2010a).

Shark species are another important group, and they are distributed widely throughout the Gulf and with high abundances in the central northern Gulf of Mexico from Louisiana to Alabama. Blacktip sharks are particularly abundant in this region, and they are one of the most important commercial shark species in the Gulf (NMFS 2010a). Blacktip sharks, as well as spinner sharks, Atlantic sharpnose sharks, and bull sharks are examples of species that are found in both coastal waters and offshore.

During an oil spill, most larger or adult fish species may simply leave the area where the water is contaminated, if possible, and move elsewhere to clean water. This is one reason why no large fish kills are seen associated with crude oil spills.

The two main concerns regarding the DWH oil spill and these fish species has been: 1) the dispersed oil at depth and deepwater plumes of oil; and, 2) the exposure of floating fish eggs (characteristic of most of the above mentioned species) to oil during the spill.

Because dispersants have never been used at a great depth, the scientific community was eager to study and track the sub-surface plumes. One research group noted that the dispersed hydrocarbon plume had stimulated petroleum degrading bacteria and that the plume was degrading faster than expected at the deep, cold temperatures (Hazen et al. 2010a). Another research group noted PAH levels considered to be toxic to marine life in discrete depth layers between 3,281-4,593 feet in the region southwest of the well head out to about 8 miles (Diercks et al. 2010). A third group tracked a continuous plume of hydrocarbons more than 22 miles in length at approximately 3,609 feet and concluded that it had persisted for months without substantial degradation (Camilli et al. 2010).

The second concern regarding floating fish eggs being impacted by oil, or an oil and dispersant mixture, cannot be answered at this time without any data available. However, some of the species of concern are widely distributed in the northern Gulf, and in some cases, the entire Gulf, and since the oil only impacted less than 5% of the Gulf, the species should not see significant overall reductions in the 2010 year class.

Another important open sea nursery habitat that was affected by the spill is the sargassum community. Over 100 species of biota are known to exist within these floating masses of brown algae, and the floating community serves to shade and protect many juvenile and adult species.

Overall impact from death of the sargassum community in the well site area and associated biota is not known at this time.

Lastly, it is likely that the fishery closure that covered an area much larger than was impacted by the DWH oil spill, may lead to enhanced recovery because of reduced fishing pressure during the summer of 2010.

In summary, commercial finfish are not believed to have been significantly impacted by the DWH oil spill, except with the possibility of those in the floating fish egg stage. If the fish eggs were negatively affected for certain species, then short-term, and possible long-term consequences, are likely for those species. If recruitment classes were normal in 2010, then, the fishery will likely continue along the same harvest trends in recent years during 2011.

Conclusions

The BP Deepwater Horizon MC 252 Spill of National Significance (DWH oil spill) became the largest accidental marine oil spill in history after releasing over 200 million gallons of oil into the Gulf of Mexico from 20 April to 15 July 2010, a period of 87 days.

The Gulf of Mexico is the ninth largest body of water in the world, and it is economically and ecologically one of the most productive and important (Tunnell 2009). Commercial fisheries in the Gulf of Mexico in 2008 accounted for 1.27 billion pounds of shellfish and finfish that earned $659 million in total landings revenue (NMFS 2010a).

The DWH oil spill may have short-term or long-term environmental effects on the Gulf of Mexico ecosystem, and it may impact Gulf commercial fisheries in the near-term or long-term. Assessing recovery after a major pollution event is perhaps even more challenging and difficult than assessing the initial damage (NRC 2003), as has been reported in this present document. However, the Gulf Coast Claims Facility was set up to settle claims for individuals and businesses that lost revenue because of the spill, and the Facility needs to move as expediently as possible in settling these claims.

The purpose of this report is to give the Claims Facility a best informed estimate to allow them to proceed with their claims process as soon as possible. Realistically, the true loss to the ecosystem and fisheries may not be accurately known for years, or even decades, but the four conclusions for the four requested groups (shrimp, crabs, oysters, and finfish) is the best informed estimate that can be given at this time.

Shrimp:

In summary, if potential impact scenarios stated above have not significantly impact 2010 shrimp populations and their life cycles, it is believed that shrimp catches for the brown, white, and pink shrimp in the northern Gulf of Mexico will likely continue along the same harvest trends in recent years by 2011, and even more likely by 2012. Loss of Mississippi Delta nursery habitat could cause a percentage reduction in shrimp population size until marshes recover.

Crabs:

In summary, because blue crab populations do not appear to have been significantly impacted by the DWH oil spill, and because they are a highly reproductive species with

widespread distribution throughout the region, it is believed that their population levels will likely continue along the same harvest trends in recent years in 2011. As noted above, some local populations may be reduced by larval impacts from the oil (or oil and dispersants) or by reduction in nursery ground coastal marshes. As indicated with shrimp, this loss of nursery habitat could cause a percentage reduction in crab population size until the marshes recover.

Oysters:

In summary, it is believed that oysters in most areas of the northern Gulf will likely continue along the same harvest trends in recent years in 2011. In areas where oysters died as a result of freshwater diversion and flooding, oyster reefs should be recolonized by young oysters in 2011 (assuming there are no large scale flooding events in 2011), but they will not likely be of harvestable size until late 2012 or 2013. In areas where oyster reefs were heavily oiled, oyster reefs may not recover for 6-8, or even 10 years.

Finfish:

In summary, commercial finfish are not believed to have been significantly impacted by the DWH oil spill, except with the possibility of those in the floating fish egg stage. If the fish eggs were negatively affected for certain species, then short-term, and possible long-term consequences, are likely for those species. If recruitment classes were normal in 2010, then, the fishery will likely continue along the same harvest trends in recent years during 2011.

In conclusion, making an exact call for the time of recovery of any fishery group after a major oil spill is impossible. However, it is realized that it is very important to settle claims

with individuals and businesses on a timely basis, so the expert opinions for the four fishery groups given in this report are as reasonable as possible at this time.

Literature Cited

Beck, M.W., R.D. Brumbaugh, L. Airoldi (3 of 14 authors). 2009. Shellfish reefs at risk: a global analysis of problems and solutions. Arlington, Virginia: The Nature Conservancy.

Bookout, C.G. and J.D. Costlow. 1975. Effects of mirex on the larval developments of blue crab. *Water, Air, Soil Pollution* 4: 113-126.

Bookout, C.G., J.D. Costlow, and R. Monroe. 1980. Kepone effects on larval developments of mud-crab and blue-crab. *Water, Air, Soil Pollution* 13: 57-77.

Briggs, J.C. 1974. *Marine zoogeography*. New York: McGraw-Hill Book Company.

Brooks, J.M., M.C. Kennicutt, C.R. Fisher, S.A. Macko, K. Cole, J.J. Childress, R.R. Bidigare, and R.D. Vetter. 1987. Deep-sea hydrocarbon seep communities: evidence for energy and nutritional carbon sources. *Science* 238: 1138-1142.

Campbell, T.N. 1952. The Kent-Crane site: a shell midden on the Texas Coast. *Texas Archeological and Paleontology Society* 23: 39-77.

Camilli, R., C.M. Reddy, D.R. Yoerger, B.A.S. Van Mooy, M.V. Jakuba, J.C. Kinsey, C.P. McIntyre, S.P. Sylva, J.V. Maloney. 2010. Tracking hydrocarbon plume transport and biodegradation at Deepwater Horizon. *Science* 330: 201-204.

CCSU (Corpus Christi State University). 1977. Spill training and educational program. Corpus Christi:

CCSU (Corpus Christi State University). 1978. Spill training and educational program. Corpus Christi, Texas: National Spill Control School.

Chapman, B.R. 1979. Effects of Ixtoc I oil spill on marine bird populations along the Texas coast. Final report to NOAA and Padre Island National Seashore. Corpus Christi, TX.

Chapman, B.R. 1981. Effects of the Ixtoc I oil spill on Texas shorebird populations. Proceedings of the 1981 Oil Spill Conference, 461-465. Washington, D.C.: American Petroleum Institute.

Cordes, E.E., S. Hourdez, and H.H. Roberts. 2010. Unusual habitats and organisms associated with the cold seeps of the Gulf of Mexico. In *The Vent and Seep Biota*, ed. S. Kiel, 315-332. *Topics in Geobiology.*

Cordes, E.E., S.L. Carney, S. Hourdez, R.S. Carney, J.M. Brooks, and C.R. Fisher. 2007. Cold seeps of the deep Gulf of Mexico: community structure and biogeographic comparisons to Atlantic equatorial belt seep communities. *Deep Sea Research Part I* 54: 637-653. Corpus Christi State University.

Darnell, R.M., J.A. Kleypas, and R.E. Defenbaugh. 1983. Northwestern Gulf shelf bio-atlas. Minerals Management Service Report 82-04.

Darnell, R.M. and R.E. Defenbaugh. 1990. Gulf of Mexico: Environmental overview and history of environmental research. *American Zoologist* 30: 3-6.

DeGolyer, E. 1918. The geology of Cuban petroleum deposits. *American Association of Petroleum Geologists Bulletin* 2: 133-167.

Diercks, A.R., R.C. Highsmith, V.L. Asper (3 of 12 authors). 2010. Characterization of subsurface polycyclic aromatic hydrocarbons at the Deepwater Horizon site. *Geophysical Research Letters* 37: 1-6.

ERCO (Energy Resources Co., Inc.). 1982. Ixtoc oil spill assessment. Final report-Executive summary. Report prepared for the Bureau of Land Management, AA851-CTO-71. Cambridge, MA.

Felder, D.L. and D.K. Camp. 2009. *Gulf of Mexico: origin, waters, and biota-Volume I, Biota.* College Station, Texas: Texas A&M University Press.
Fisher, C.R., H.H. Roberts, E.E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20: 118-129.
Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* (Gmelin). *Fisheries Bulletin,* U.S. 64: 1-480.
Garcia, O.G. 2009. Spatial and temporal analysis of oil slicks in the Gulf of Mexico based on remote sensing. PhD Dissertation, Texas A&M University-Corpus Christi.
GOMA (Gulf of Mexico Alliance). 2006. *Governors' action plan.*
GOMA (Gulf of Mexico Alliance). 2009. *Governors' action plan II.*
Guillory, V., H. Perry, P. Steele, T. Wagner (3 of 12 authors). 2001. The blue crab fishery of the Gulf of Mexico, United States: A regional management plan. Ocean Springs: Gulf States Marine Fisheries Commission.
Gundlach, E.R. and M.O. Hayes. 1978. Vulnerability of coastal environments to oil spill impacts. *Marine Technology Society Journal* 12(4): 18-27.
Gundlach, E.R., J.C. McCain and Y. Fadlallah. 1993. Distribution of oil along the Saudi Arabian coastline (May/June 1991) as a result of the Gulf War oil spills. Marine Pollution Bulletin 27: 93-96.
Hamilton, C.L. 1983. Texas commercial harvest statistics 1977-1982. Austin: Texas Parks & Wildlife Department, Coastal Fisheries Branch.
Hayes, M.O., D.D. Domeracki, C.D. Getter, T.W. Kana, and G. I. Scott. 1980. Sensitivity of coastal environments to spilled oil, South Texas coast (Rio Grande to Aransas Pass). Prepared by Research Planning Institute, Inc., for NOAA's Office of Marine Pollution Assessment, RPI/R/80/4/11-12, Boulder, CO.
Hazen, T.C., E.A. Dubinsky, T.Z. DeSantis (3 of 32 authors). 2010. Deep-sea oil plume enriches indigenous oil degrading bacteria. *Science* 330: 204-208.
Hooper, C.H. (ed.). 1981. The Ixtoc I oil spill: The federal scientific response. NOAA Hazardous Material Response Project. Boulder, CO.
Jernelöv, A. and O. Lindén. 1981. Ixtoc I: a case study of the world's largest oil spill. *Ambio* 10(6): 299-306.
Jernelöv, A. 2010. The threats from oil spills: Now, then, and in the future. *Ambio* 39:353-366.
Jones, D.A., I. Watt, J. Plaza, T.D. Woodhouse, and M. Al-Sanei. 1996. Natural recovery of the intertidal biota within the Jubail Mainre Wildlife Sanctuary after the 1991 Gulf War oil spill. In A marine wildlife sanctuary for the Arabian Gulf: Environmental research and conservation following the 1991 Gulf War oil spill. National Commission for Wildlife Conservation and Development, eds F. Krupp, A.H. Abuzinada, and I.A. Nader, 138-158. Riyadh, Saudi Arabia: Kingdom of Saudi Arabia, and Frankfurt Germany: Senchenberg Research Institute.
Kennicutt, M.C., J.M. Brooks, R.R. Bidigare, and G.J. Denoux. 1988. Gulf of Mexico hydrocarbon seep communities I. Regional distribution of hydrocarbon seepage and associated fauna. *Deep Sea Research A* 35: 1639-1651.
Kenworthy, W.J., M.J. Durako, S.M.R. Fatemy, H. Valavi, and G.W. Thayer. 1993. Ecology of seagrasses in northeastern Saudi Arabia one year after the Gulf War oil spill. Marine Pollution Bulletin 27:213-222.

Kindinger, M.E. 1981. Impacts of the Ixtoc I oil spill on the community structure of the intertidal and subtidal infauna along South Texas beaches. M.S. Thesis, Division of Biology, Corpus Christi State University. Corpus Christi, TX.

Kumpf, H., K. Steidinger, and K. Sherman. 1999. *The Gulf of Mexico Large Marine Ecosystem: assessment, sustainability, and management*. Malden, Massachusetts: Blackwell Science, Inc.

Lewbel, G.S. 1985. Strengths and weaknesses of damage assessment programs: the Ixtoc-I and *Burmah Agate* oil spills, and the benthic macroinfauna of the Texas continental shelf. *The Texas Journal of Science* 37(4): 269-310.

MacDonald, I.R., G. Bohrmann, E. Escobar (3 of 18 authors). 2004. Asphalt volcanism and chemosynthetic life in the Campeche Knolls, Gulf of Mexico. *Science* 304: 999-1002.

MacDonald, I.R. 1998. Natural oil spills. *Scientific American* November Issue 30-35.

MacKenzie, C.L., Jr. 1989. A guide for enhancing estuarine molluscan shellfisheries. *Marine Fisheries Review* 51(3): 1-47.

Mackin, J.G. and S.H. Hopkins. 1961. Studies on oyster mortality in relation to natural environments and to oil fields in Louisiana. *Publications of the Institute of Marine Science* 7: 1-131.

Matthews, C.P., S. Kedidi, N.I. Fita, A. Al-Yahya, and K. Al-Rasheed. 1993. Preliminar assessment of the effects of the 1991 Gulf War on Saudi Arabian prawn stocks. Marine Pollution Bulletin 27: 251-271.

McEachran, J.D. 2009. Chapter 75 – Fishes (Vertebrata: Pisces) of the Gulf of Mexico. In *Gulf of Mexico – origin, waters, and biota: Volume 1, Biota* eds. Felder, D.L. and D.A. Camp, 1223-1316, College Station: Texas A&M University Press.

McKinney, L. 2009. HRI News - Director's corner: Why the Gulf of Mexico? Summer 2009 Newsletter: Harte Research Institute for Gulf of Mexico Studies.

Michel, J. M.O. Hayes, and P.J. Brown. 1978. Application of an oil spill vulnerability index to the shoreline of lower Cook Inlet, Alaska. *Environmental Geology* 2(2): 107-117.

Millikin, M.R. and A.B. Williams. 1984. Synopsis of biological data on the blue crab, *Callinectes sapidus*. FAO Fish. Synop. No. 138, NOAA Tech. Rep. NMFS 1.

Moore, D., H.A. Brusher, and L. Trent. 1970. Relative abundance, seasonal distribution, and species composition of demersal fishes off Louisiana and Texas, 1962-1964. Contributions to Marine Science 15: 45-70.

NMFS (National Marine Fisheries Service). 2010a. Fish stocks in the Gulf of Mexico. Fact Sheet (April 2010, Southeast Regional Office).

NMFS (National Marine Fisheries Service). 2010b. Information about the federal fishing closure in oil-affected portions of the Gulf of Mexico. *Southeast Fishery Bulletin* FB10-063 (12 July 2010).

NMFS (National Marine Fisheries Service). 2010c. BP oil spill: NOAA closes federal water to royal red shrimp fishing. *Southeast Fishery Bulletin* FB10-102 (24 November 2010).

NOS (National Ocean Service), NOAA. 2008. Gulf of Mexico at a glance. Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

NRC (National Research Council). 1975. Petroleum in the marine environment. Washington, D.C.: National Academy Press.

NRC (National Research Council). 1985. Oil in the sea: inputs, fates, and effects. Washington, D.C.; National Academy Press.

NRC (National Research Council). 2003. Oil in the sea III: inputs, fates, and effects. Washington, D.C.: National Academy Press.
OSAT (Operational Science Advisory Team). 2010. Summary report for sub-sea and sub-surface oil and dispersant detection: sampling and monitoring. New Orleans, LA.
Pattillo, M.E., T.E. Czapla, D.M. Nelson, and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division. Silver Spring, MD.
PCEESC (Programa Coordinado de Estudios Ecologicos en la Sonda de Campeche). 1980. Informe de los trabajos realizados para el control del pozo Ixtoc I, el combate del derrame de petroleo y determinacion de sus efectos sobre el ambiente marino. Mexico: Instituto Mexicano del Petroleo.
Peterson, C.H., S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey, and D.B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez Oil Spill. *Science* 302:2082-2086.
Richmond, M.D. 1996. Status of subtidal biotopes of the Jubail Mainre Wildlife Sanctuary with special reference to soft-substrata communities. In A marine wildlife sanctuary for the Arabian Gulf: Environmental research and conservation following the 1991 Gulf War oil spill. National Commission for Wildlife Conservation and Development, eds. F. Krupp, A.H. Abuzinada, and I.A. Nader, 159-176. Riyadh, Saudi Arabia: Kingdom of Saudi Arabia, and Frankfurt, Germany: Senchenberg Research Institute.
Schimmel, S.C. and A.J. Wilson. 1977. Acute toxicity of Kepone to four estuarine animals. *Chesapeake Science* 18: 224-227.
Soley, J.C. 1910. The oil fields of the Gulf of Mexico, their geological place. *Scientific American Supplements.*
Soto, L.A., A. Gracia and A. V. Botello. 1981. Study of the penaeid shrimp population in relation to petroleum hydrocarbons in Campeche Bank. Proceedings of the 33th Annual Session, 81-100. University of Miami: Gulf and Caribbean Fisheries Institute.
Tawfig, N.I. and D.A. Olsen. 1993. Saudi Arabia's response to the 1991 Gulf oil spill. Marine Pollution Bulletin 27: 333-345.
Tunnell, J.W., Jr. 1978. Oil spills in the environment. In *Spill training and educational program*, CCSU, H 1-8. Corpus Christi, Texas: National Spill Control School.
Tunnell, J.W., Jr. 2009. Gulf of Mexico. In *Ocean: An illustrated atlas*, ed. S.A. Earle and L.K. Glover, 136-137. Washington, D.C.: National Geographic Society.
Tunnell, J.W., Jr., Q.R. Dokken, M.E. Kindinger, and L.C. Thebeau. 1981. Effects of the Ixtoc I oil spill on the intertidal and subtidal infaunal populations along lower Texas coast barrier island beaches. Proceedings of the 1981 Oil Spill Conference, 467-475. Washington, D.C.: American Petroleum Institute.
U.S. Commission on Ocean Policy. 2004. An ocean blueprint for the 21st century. Washington, D.C.: U.S. Commission on Ocean Policy.
Wang, S.Y. and W.B. Stickle. 1987. Bioenergetics, growth and molting of the blue crab, *Callinectes sapidus*, exposed to the water-soluble fraction of south Louisiana Crude Oil. In *Pollution physiology of estuarine organisms*, ed. W.B. Vernberg, A. Calabrese, F.P. Thurberg, and F.J. Vernberg. South Carolina: University of South Carolina Press.
Wursig, B., T.A. Jefferson, and D.J. Schmidly. 2000. *The marine mammals of the Gulf of Mexico.* College Station, Texas: Texas A&M University Press.

Appendix I

About the Author

Dr. John W. (Wes) Tunnell, Jr. is Associate Director of Harte Research Institute for Gulf of Mexico Studies, Professor of Biology, Fulbright Scholar, and Regent's Professor at Texas A&M University-Corpus Christi (TAMU-CC). After studies in Colorado, he received his B.S. (1967) and M.S. (1969) degrees in Biology from Texas A&I University (now Texas A&M University-Kingsville), and after studies in California and Florida, his Ph.D. in Biology (1974) from Texas A&M University. He started his career at Texas A&I University at Corpus Christi (now TAMU-CC) in 1974. At TAMU-CC Dr. Tunnell was founder and Director of the Center for Coastal Studies (1984-2009), creator of the co-location concept of state and federal natural resource agencies on campus (1980s-90s), developer of the Natural Resources Center (1996), and he assisted in the development of the Harte Research Institute (2001) and its building (2005).

Dr. Tunnell is a marine biologist/ecologist focusing primarily on coastal and coral reef ecosystems. He has extensive expertise working on coastal ecology in Texas and coral reef ecology in Mexico, but he has also studied reefs in the Bahamas, Persian Gulf, Great Barrier Reef, Panama, Honduras, Netherland Antilles, Palau, French Polynesia, Indonesia, and Okinawa. In addition, Dr. Tunnell has studied and published on vertebrate fossils from the seabed, sponges, brachiopods, mollusks (in particular), colonial seabirds, oil spill impacts, and Gulf of Mexico biodiversity.

Regarding his oil spill work, Dr. Tunnell:

1) helped develop the National Spill Control School (NSCS) at TAMU-CC during the mid 1970s, particularly in the biological and environmental impacts area;

2) wrote the "Oil Spills in the Environment" chapter for the NSCS training manual/book and taught that subject in training classes at TAMU-CC for almost 20 years;

3) became the Local Scientific Advisor for NOAA in Corpus Christi, Texas, during the Ixtoc I oil spill;

4) assisted Dr. Miles Hayes and Research Planning Institute (now Research Planning, Inc.) sample South Texas during Ixtoc oil spill and apply the Environmental Sensitivity Index mapping;

5) studied the impact of the Ixtoc oil spill on South Texas beaches with NOAA funding; published one paper on this work and directed one MS student thesis on this work;

6) presented four papers on Texas and Mexico impacts of Ixtoc oil spill at two separate conferences in Mexico, but the proceedings were never published;

7) tracked Ixtoc oil spill on southern Gulf of Mexico coral reefs, sandy beaches and rocky shores during July and August of 1980; continued some tracking for the following 30 years;

8) studied the impact of oil spills and deballasting on the coral reefs, sandy shores, and benthos of the Arabian Gulf in Abu Dhabi, United Arab Emirates, with Hazelton Environmental Sciences in 1979;

9) prepared a report for the Mobile District US Army Corps of Engineers on an impact assessment of the fate and effects of brine discharges from oil wells in Tallahala Creek Lake, Mississippi, in 1981;

10) worked with numerous oil companies in the 1980s to develop plans of operation in Padre Island National Seashore to keep them from causing environmental damage to sensitive habitats;

11) trained Kuwait government workers in Kuwait on oil spill contingency planning, clean-up, and response with the NSCS in 1984;

12) studied the environmental impact and recovery of the Exxon Pipeline oil spill and burn site in upper Copano Bay marshes from 1992-95; published several papers and reports related to this work;

13) worked with O'Brien Oil Pollution Services as an advisor to resource agencies on the *Berge Banker* oil spill affects on southern Matagorda Island in 1995;

14) worked with O'Brien Oil Pollution Services on two oil spill training excercises;

15) studied the impact of the *Berge Banker* spill on Padre Island National Seashore beaches;

16) worked with numerous media outlets giving expert opinion on the BP Deepwater Horizon oil spill and its comparison to the Ixtoc I oil spill 30 years earlier, including some trips to Mexico to see old remnant Ixtoc tar sites (New York Times, Washington Post, Time Magazine, National Geographic, Nature, ABC World News, CNN International, and many more);

17) lead a peer review panel (independent evaluation) of research proposals on the BP Deepwater Horizon oil spill for the Alabama Marine Environmental Science Consortium and Dauphin Island Sea Lab for $5 million in BP Gulf Research Initiative funding in October 2010;

18) was keynote speaker at two symposia in Finland, speaking on "Gulf of Mexico Oil Spills: Historically and Spatially", in November 2010;

19) was keynote speaker at Alabama-Mississippi Bays and Bayous Symposium, speaking on "Gulf of Mexico Oil Spills: Historical and Spatial Perspectives", in December 2010;

20) lead a peer review panel (independent evaluation) of research proposals on the BP Deepwater Horizon oil spill for the Northern Gulf Institute in Mississippi for $4 million of BP Gulf Research Initiative funding in January 2011; and,

21) was a panelist during "Oil Day" for the National Council for Science and the Environment Annual Conference on "Our Changing Oceans" at the Reagan Center in Washington, DC on 19 January 2011.

Dr. Tunnell has received numerous awards, most notably a Fulbright Scholar Award to Yucatan, Mexico (1985-86), Regent's Professor Award (1998), TAMU-CC Alumni Distinguished Professor Award (2003), Gulf Guardian Award, Bi-National Category (2006, 2008) and the TAMU-CC Excellence in Scholarly Activity Award (2006-07). He has published over 75 peer-reviewed manuscripts and book chapters and over 60 technical reports, 5 books, and received approximately 150 research grants and contracts. He has advised or co-advised 55 M.S. students, 4 Ph.D. students, and 4 post doctoral research associates.

Dr. Tunnell has also been very involved with community and professional service, serving on many advisory councils and boards, as well as belonging to numerous societies. Currently, he belongs to 10 professional organizations/societies, serves on 13 regional, national, and international advisory boards, and is Past-President of the Southern Association of Marine Labs. Dr. Tunnell is also editor of two book-series, one newsletter, and one Gulf of Mexico database website (www.gulfbase.org). More information can be found on Wes Tunnell at http://www.harteresearchinstitute.org/dr-wes-tunnell.

Appendix II

Literature Reviewed

AIBS (The American Institute of Biological Sciences). 1976. Sources, effects & sinks of hydrocarbons in the aquatic environment. Proceedings of the Symposium. Washington, D.C.: American University.

Alexander, S.K. and J.W. Webb, Jr. 1987. Relationship of *Spartina alterniflora* growth to sediment oil content following an oil spill. In *Proceedings: 1987 Oil Spill Conference,* 445-449. *American Petroleum Institute.*

Amos, A.F., S.C. Rabalais, and R.S. Scalan. 1983. Oil-filled *Callianassa* burrows on a Texas barrier island beach. *Journal of Sedimentary Petrology* 53(2): 412-416.

Amos, A.F. 1984. Persistence of Ixtoc-I oil along the South Texas coast. Proceedings, 4th Ann. Gulf of Mexico Inform. Trans. Mtg., USDI/MMS, OCS Rep. MMS-0026:206-210.

Anderson, J.W. 1979. An assessment of knowledge concerning the fate and effects of petroleum hydrocarbons in the marine environment. In *Marine Pollution: Functional Responses.* Academic Press, eds.W.B. Vernberg, F.J. Vernberg, A. Calabrese and F.P. Thurberg, 3-22.

Anderson, S., P. Boehm, D. Fiest, R. Howard, C. Lewbel, D. Pilson, and A. Wait. 1982. Ixtoc oil spill assessment. Final report for the U.S. Department of Interior, Bureau of Land Management, AA851-CTO-71. New Orleans, LA.

Anonymous. 1979. A contingency plan for protection of whooping cranes during a major spill in the Gulf of Mexico. 19 pp. + appendix. (typed document, no publisher listed).

Armstrong, H.W., K. Fucik, J.W. Anderson, and J.M. Neff. 1979. Effects of oilfield brine effluent on sediments and benthic organisms in Trinity Bay, Texas. *Marine Environmental Research* 2: 55-69.

Atlas, R.M. and C.E. Cerniglia. 1995. Bioremediation of petroleum pollutants. *BioScience* 45: 332-338.

Atwood, D.K., F.J. Burton, J.E. Corredor, G.R. Harvey, A.J. Matajimenez, A. Vasquezbotello, and B.A. Wade. 1987b. Petroleum pollution in the Caribbean. *Oceanus* 30: 28-32.

Baca, B.J., T. M. Schmidt, and J.W. Tunnell. 1982. Ixtoc oil in seagrass beds surrounding Isla de Media. Simposio Internacional Ixtoc I, Mexico City. 2-5 June 1982. (presented at oil spill symposium in Mexico City; proceedings never published).

Bak, R.P.M. 1987. Effects of chronic oil pollution on a Caribbean reef. *Marine Pollution Bulletin* 18: 534-539.

Baker, J.M. 1983. Impact of oil pollution on living resources. *The Environmentalist* 3(4): 1-48.

Baker, J.M., L.M. Guzman, P.D. Bartlett, D.I. Little, and C.M. Wilson. 1993. Long-term fate and effects of untreated thick oil deposits on salt marshes. Proceedings 1993 Oil Spill Conference., Washington, D.C., 395-399. *American Petroleum Institute.*

Boehm, P. and D. Fiest. 1982. Subsurface distributions of petroleum from an offshore well blowout. The IXTOC Blowout, Bay of Campeche. *Environmental Science and Technology* 16(2): 67-74.

Brooks, J.M., C. Fisher, H. Roberts, B. Bernard, I. MacDonald, R. Carney, S. Joye, E. Cordes, G. Wolff, and E. Goehring. 2009. Investigations of chemosynthetic communities on the lower continental slope of the Gulf of Mexico. New Orleans: Minerals Management Service.

Burns, K.A. and J.M. Teal. 1979. The west Falmouth oil spill, hydrocarbons in the salt marsh ecosystem. *Estuarine, Coastal and Shelf Science* 8: 349-360.
Burns, K.A. and A.H. Knap. 1988. The Bahia Las Minas Oil Spill: Hydrocarbon uptake by reef building corals. *Marine Pollution Bulletin* 20(8): 391-398.
Carr, R.S., D.C. Chapman, B.J. Presley, J.M. Biedenbach, L. Robertson, P. Boothe, R. Kilada, T. Wade and P. Montagna. 1996. Sediment porewater toxicity assessment studies in the vicinity of offshore oil and gas production platforms in the Gulf of Mexico. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 2618-1628.
Caudle, C. 1995. Impact assessment of produced water discharges to Nueces Bay—August 1993. Publ. No. AS-49/SR, Texas Natural Resources Conservation Commission. Austin, TX.
Casey, R., A. Amos, J. Anderson, R. Koehler, R. Schwarzer, and J. Sloan. 1980. A preliminary report on the microplankton and microbenthon responses to the 1979 Gulf of Mexico oil spills (Ixtoc I and Burmah Agate), with comments on avenues of oil to the sediments and the fate of oil in the column and bottom. *Transactions-Gulf Coast Association of Geological Societies* XXX: 273-281.
Chapman, B.R. 1984. Seasonal abundance and habitat-use patterns of coastal bird populations on Padre and Mustang Island barrier beaches (following the Ixtoc I oil spill). Report prepared for the U.S. Fish and Wildlife Service, FWS/OBS-83/31.
Chassé, C. 1978. The ecological impact on and near shores by the AMOCO CADIZ oil spill. *Marine Pollution Bulletin* 9(11): 298-301.
Cubias-Castro, B. 1980. Estudio para determinar el efecto del derrarme de petroleo proveniente del Pozo Ixtoc No. 1 y de las aplicacion del dispersante COREXIT en plancton, camaron (juvenil) y ostion efectuado en Cd. del Carmen, Campeche. Congresso sobre Problemas Ambientales de Mexico Resumenes. Intituto Politecnico Nacional. 8-12 December 1980. Mexico City. p. 46. (Abstract; proceedings never published).
Dinnel, S. and T.W. Kana. 1980. Continuing oceanographic surveys of South Texas tidal inlets for contingency planning. March 1980. Progress report to NOAA/MESA Program Office, RPI/R/80/4/25-16. Boulder, CO.
Farrington, J.W. 1981. NOAA Ship Researcher/Contract Vessel Pierce Cruise to Ixtoc-1 Oil Spill: Overview and Integrative Data Assessment and Interpretation. Report prepared for the Office of Marine Pollution Assessment, NOAA, NA80RAC0017.
Fischel, M., W. Grip, and I.A. Mendelssohn. 1989. Study to determine the recovery of a Louisiana marsh from an oil spill. In *Proceedings 1989 Oil Spill Conference*, Washington, D.C., 383-387. *American Petroleum Institute.*
García-Cuéllar, J.A. 2006. Análisis del impacto de la industria petrolera en el ecosistema y su relación con las pesquerías de la sonda de Campeche, México. Doctor en Ciencias en el uso, manejo y preservación de los recursos naturales, orientación en ecología, Centro de Investigaciones Biológicas del Noroeste.
García-Cuéllar, J.A., F. Arreguín-Sánchez, S. Hernández Vázquez, and D.B. Lluch-Cota. 2004. Impacto ecológico de la industria petrolera en la sonda de Campeche, México, tras tres décadas de actividad: una revisión. *Interciencia* 29(6): 311-319.
Garmon, L. 1980. Autopsy of an oil spill. *Science News* 118(17): 267-270.
Getter, C.D., L.C. Thebeau, and G.I. Scott. 1980. Chapter 6: Results of ecological monitoring at the Ixtoc I oil spill. Report prepared for NOAA's Office of Marine Pollution Assessment, RPI/R/80/7/30-20. Boulder, CO.

Grose, P., F. Everdale, and L. Katz. 1983. Predicting the surface transport of oil pollutants in the Gulf of Mexico. *Marine Pollution Bulletin* 14(10): 372-377.
Gundlach, E.R., P.D. Boehm, M. Marchand, R. Atlas, D.M. Ward, and D.A. Wolfe. 1983. The fate of *Amoco Cadiz* oil. *Science* 221(4606): 122-129.
Guzmán del Proés, S.A., E.A. Chávez, F.M. Alatriste, S. de la Campa, G. de la Cruz, L. Gómez, R. Guadarrama, A. Guerra, S. Mille, and D. Torruco. 1986. The impact of the Ixtoc-1 oil spill on zooplankton. *Journal of Plankton Research* 8(3): 557-581.
Hall, R.J., A.A. Belisle, and L. Sileo. 1983. Residues of petroleum hydrocarbons in tissues of sea turtles exposed to the Ixtoc I oil spill. *Journal of Wildlife Diseases* 19(2): 106-109.
Hardegree, B., D.W. Hicks, and J.W. Tunnell, Jr. 1996. Evaluation of burning as an oil spill cleanup technique in a high marsh community along the South Texas coast. Proceed. Gulf of México and Caribbean Oil Spills in Coastal Ecosystem: Assessing Effects, Natural Recovery, and Progress in Remediation Research, 195-212. New Orleans, LA.
Hildebrand, H.H. and G. Gunter. 1954. A report on the deposition of petroleum tars and asphalts on the beaches of the northern Gulf of Mexico, with notes on the beach conditions and the associated biota. Port Aransas, Texas: University of Texas Institute of Marine Science.
Hill, G. 1979. Ixtoc's Oil has a Silver Lining. *Audubon* 81(6): 150-159.
Holt, S., S. Rabalais, N. Rabalais, S. Cornelius, and J. S. Holland. 1978. Effects of an oil spill on slat marshes at Harbor island, Texas: I: Biology. In *Proceedings of Conference on Assessment of Ecological Impacts of Oil Spills*, Washington, D.C., 344-352. *American Institute of Biological Sciences.*
Hyde, L.J., K. Withers, and J.W. Tunnell, Jr. 1998. Coastal high marsh oil spill clean-up by burning: five-year evaluation. Center for Coastal Studies Technical Report No. TAMU-CC-9811-CCS. Texas A&M University-Corpus Christi. Corpus Christi, TX.
Kalke, R.D., T.A. Duke, and R.W. Flint. 1982. Weathered Ixtoc I oil effects on estuarine benthos. *Estuarine, Coastal and Shelf Sciences* 15: 75-84.
Keller B.D. and J.B.C. Jackson. 1993. Long-term assessment of the oil spill at Bahia Las Minas, Pamana Synthesis Report. Volume I: Executive Summary and Volume II, Technical Report. Minerals Management Service, Gulf Of Mexico OCS Region, OCS Study MMS 93-0048.
Kiesling, R.W., S.K. Alexander, and J.W. Webb. 1988. Evaluation of alternative oil spill cleanup techniques in a *Spartina alterniflora* salt marsh. *Environmental Pollution* 55: 221-238.
Lizarraga-Partida, M.L., J. Munoz-Rubio, J. Porras-Aguirre, F.B. Izquierdo-Vicuna, and I. Wongchang. 1984. Taxonomy and distribution of hydrocarbonoclastic bacteria from the Ixtoc-I area. 2. *Colloque International de Bacteriologie Marine*, 1-5. Brest (France).
MacDonald, I.R. 1998. Natural oil spills. *Scientific American* 279: 56-61.
MacDonald, I.R., J.F. Reilly, Jr., W.E. Best, R. Venkataramaiah, R. Sassen, N.S. Guinasso, Jr., and J. Amos. 1996. Remote sensing inventory of active oil seeps and chemosynthetic communities in the northern Gulf of Mexico. Hydrocarbon Migration and its Near-surface Expression, eds. D. Schumacher and M.A. Abrams. *American Association of Petroleum Geologists Memoir* 66: 27-37.
MacDonald, I.R., N.L. Guinasso, Jr., S.G. Ackleson, J.F. Amos, R. Duckworth, R. Sassen, and J.M. Brooks. 1993. Natural oil slicks in the Gulf of Mexico visible from space. *Journal of Geophysical Research* 98(C9): 16,351-16,364.

Mackin, J.G. 1971. A study of the effect of oilfield brine effluents on benthic communities in Texas estuaries. Texas A&M Research Foundation, Project 735. Texas A&M University, College Station, TX.

McCauley, C.A. and R.C. Harrel. 1981. Effects of oil spill cleanup techniques on a salt marsh. Proceedings, 1981 Oil Spill Conference, Washington, D. C, 401-407. *American Petroleum Institute.*

Mendelssohn, A.A., M.W. Hester, C. Sasser, and M. Fischel. 1990. The effect of a Louisiana crude oil discharge from a pipeline break on the vegetation of a Southeast Louisiana brackish marsh. *Oil and Chemical Pollution* 7: 1-15.

Mitchell, R., I.R. MacDonald, and K.A. Kvenvolden. 1999. Estimation of total hydrocarbon seepage into the Gulf of Mexico based on satellite remote sensing images. *Transactions, American Geophysical Union* 80(49): Ocean Sciences Meeting Supplement, OS242.

Montagna, P.A., and D.E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 2567-2588.

Muir, J.M. 1936. Geology of the Tampico region, Mexico. Houston, Texas: Stephen F. Austin State University.

NOAA (National Oceanic and Atmospheric Administration) and USEPA (United States Environmental Protection Agency). 1978. The AMOCO Cadiz oil spill: A preliminary scientific report. Washington, D.C.: NOAA.

NOAA (National Oceanic and Atmospheric Administration) and USEPA (United States Environmental Protection Agency). 1979. Ixtoc-I oil spill damage assessment program. A cooperative federal and state program.

NRC (National Research Council). 2005. Oil spill dispersants: Efficacy and effects. Washington, D.C.: National Academy Press.

Payne, J.R, G.D. McNabb. 1984. Weathering of petroleum in the marine environment. *Marine Technology Society Journal* 18(3): 24-42.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology Annual Review* 16: 229-311.

Programa Coordinado de Estudios Ecológicos en la Sonda de Campeche. 1980. Informe de los trabajos realizados para el control del pozo Ixtoc I, el combate del derrame de petróleo y determinación de sus efectos sobre el ambiente marino. *Instituto Mexicano del Petroleo.*

Rabalais, S.C., C.R. Arnold, and N.S. Wohlschlag. 1981. The effects of Ixtoc I oil on the eggs and larvae of red drum (*Scianops ocellata*). *Texas Journal of Science* XXXIII(1): 33-38.

Restrepo, C.E., F.C. Lamphear, C.A. Gunn, R.B. Ditton, J.P. Nichols, and L.S. Restrepo. 1982. Ixtoc I oil spill economic impact study. Report prepared for the Bureau of Land Management, AA-851-CTO-65. New Orleans, LA.

Sanders, H.L. 1978. Florida oil spill impact on the Buzzard's Bay benthic fauna, West Falmouth. *Journal of Fisheries Research Board of Canada* 35: 717-730.

Sanders, H.L. 1981. Environmental effects of oil in the marine environment. In *Safety and Offshore Oil: Background Papers of the Committee on Assessment of Safety of OCS Activities*, Washington, D.C., 117-146. *National Research Council, National Academy Press.*

Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: Long-term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. *Journal of Marine Research* 38: 265-380.

Straughan, D. and B.C. Abbott. 1971. The Santa Barbara oil spill: ecological changes and natural oil leaks. In *Water Pollution by Oil*, ed. P. Hepple, 257-262. *Institute of Petroleum*.

Surtevant, P. 1979. A survey of tar accumulation remaining on Texas beaches: Rio Grande river to Aransas Pass. Report to NOAA Damage Assessment Team, Corpus Christi, TX. (typed document, no publisher listed).

Texas House of Representatives Committee on Environmental Affairs. 1980. Report on the Ixtoc I Oil Spill.

Tunnell, J.W. 1978. Impact assessment of oil production at Tallahala Dam and Lake, Mississippi. Technical report to U.S. Army Corps of Engineers Mobile District. Contract No. DAC WO1-78-C-0211.

Tunnell, J.W. and Q.R. Dokken. 1979. Environmental directory of scientists, facilities, and projects along the central and south Texas coast. Report submitted to NOAA/OMPA, damage Assessment Prog., IXTOC I Oil Spill, Cont. No. NA 79RC00136.

Tunnell, J.W., Jr. and B.R. Chapman. 1980. Environmental effects of Ixtoc I oil spill on South Texas barrier island beaches. Congresso sobre Problemas Ambientales de Mexico Resumenes. Instituto Politecnico Nacional. 8-12 December 1980. Mexico City. (presented and submitted; proceedings never published).

Tunnell, J.W., Jr. and Q.R. Dokken. 1980. Observations on Ixtoc I oil impact of southwestern Gulf of Mexico coral reefs. Congresso sobre Problemas Ambientales de Mexico Resumenes. Instituto Politecnico Nacional. 8-12 December 1980. Mexico City. (presented and submitted; proceedings never published).

Tunnell, J.W. 1981. Impact assessment of the fate and effect of a brine spill into a freshwater environment (Tallahala Creek Lake, Mississippi). Technical Report to U.S. Army Corps of Engineers, Mobile District. Contract No. DACW01-81-M-9931.

Tunnell, J.W., Jr., B.R. Chapman, M.E. Kindinger, and Q.R. Dokken. 1982. Environmental impact of Ixtoc I oil spill on South Texas sandy beaches: Infauna and shorebirds. Simposio Internacional Ixtoc I, Mexico City. 2-5 June 1982. (presented and submitted; proceedings never published).

Tunnell, J.W. 1984. Oil spills in the environment. In *Workshop on oil spill prevention and control in the coastal and territorial water of Kuwait*, 27-30 May 1984. Environmental Protection Council of Kuwait and National Spill Control School, Corpus Christi State University, F-1 - F-20.

Tunnell, J.W., Jr., D.W. Hicks, and B. Hardegree. 1994. Environmental impact and recovery of the Exxon pipeline oil spill and burn site, Upper Copano Bay, Texas: year one. Center for Coastal Studies Technical Report No. TAMU-CC-9402-CCS. Texas A&M University-Corpus Christi. Corpus Christi, TX.

Tunnell, J.W., Jr., B. Hardegree, and D.W. Hicks. 1995. Environmental impact and recovery of a high marsh pipeline oil spill and burn site, upper Copano Bay, Texas. Proceedings, 1995 Oil Spill Conference, 133-138. Long Beach, CA.

Tunnell, J.W., Jr., B. Hardegree, K. Withers, and D.W. Hicks. 1995. Environmental impact and recovery of the Exxon pipeline oil spill and burn site, upper Copano Bay, Texas: year two. Center for Coastal Studies Technical Report No. TAMU-CC-9501-CCS. Texas A&M University-Corpus Christi. Corpus Christi, TX.

Tunnell, J.W., K. Withers, and B. Hardegree. 1997. Environmental impact and recovery of the Exxon Pipeline oil spill and burn site, upper Copano Bay Texas: Final Report. Center for Coastal Studies Technical Report No. TAMU-CC-9703-CCS. Texas A&M University-Corpus Christi. Corpus Christi, TX.

Webb, J.W., S.K. Alexander, and J.K. Winters. 1985. Effects of autumn application of oil on *Spartina alterniflora* in a Texas salt marsh. *Environmental Pollution* (A)38: 321-337.

Webb, J.W. 1996. Effects of oil on salt marshes. In Symposium Proceedings: Gulf of Mexico and Caribbean Oil Spills in Coastal Ecosystems: Assessing Effects, Natural Recovery, and Progress in Remediation Research, eds. C.E. Proffitt and P.F. Roscigno, 55-64, OCS Study MMS 95-0063. Dept. of the Interior, Minerals Management Service. New Orleans, LA.

Withers, K., D. Rocha, S. Alvarado, and J.W. Tunnell. 1995. Benthic invertebrate abundance and community structure in Gulf beach habitats on Padre Island National Seashore, Texas following the M/T *Berge Banker* oil spill. Report to Beak Consultants and Eastham, Watson, Dale, and Foney, L.L.P., Center for Coastal Studies, Texas A&M University-Corpus Christi. Corpus Christi, TX.

Woody, J. 1979. Contingency plan-protection of Fall migrating peregrines Campeche oil well blowout. 7 pp. (typed document, no publisher listed).