IMPACTS OF OIL SPILLS: ECOLOGICAL, HUMAN HEALTH AND ECONOMIC

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Abstract

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The 1979 Ixtoc I and 2010 Deepwater Horizon are the two largest accidental oil spills that have occurred in history, and both have been near United States waters. After an oil spill occurs, ecology, human health and economy are major concerns. Specifically, this thesis discusses the impacts of oil spills on microbes, marine organisms, human health and revenue.

The major focus of this research was on the oil spills near the Gulf of Mexico. Although there have been numerous oil spills in history, these two spills were chosen because they were the largest in volume and time. While spills from oil tankers are more common, both of these oil spills were caused by broken wellheads. Most of the data and analysis conducted in this research utilized information from Ixtoc I and Deepwater Horizon. However, Ixtoc I was not highly publicized and there was not sufficient data on the long term impacts of Ixtoc I in the Gulf of Mexico. Therefore, data was extracted from the 1989 Exxon Valdez oil spill.

The research methodology consisted of a review of published journal articles that provided information to address the question "What are the long term and short term effects of oil spills on ecology, human health and the economy?" Short term impacts included the creation of hypoxia closer to the surface of the ocean causing marine life to die or flee, closure of waters to fishing resulting in economic impacts on surrounding communities, and various human health symptoms such as respiratory, ocular and dermal. Many animal species at risk of being endangered before the spill were at risk of long term consequences due to an inability to return to pre-spill population sizes.

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CHAPTER 1: INTRODUCTION

I. Purpose of the Study

In its most desirable state of a free-flowing flammable liquid that can be pumped out of the ground, petroleum makes up the foundation for the United States economy. The oil is refined and separated based on boiling points to make gasoline, kerosene, and asphalt. It can be processed into pharmaceuticals, pumped into cars, utilized to create electricity or collected by governments to fight wars.

However, this vital source of energy can lead to catastrophic consequences when handled improperly or released into the ocean or land unsupervised. This thesis attempts to discuss a few ecological, human health and economic consequences when offshore crude oil is spilled and released into the fragile balance of nature. Oftentimes, newspapers sensationalize the initial impacts of the oil spill and then gradually claim that the effects of the oil spill will soon return to pre-spill conditions. Many of the impacts may follow this scenario, but a closer look at research on the effects of oil spills have shown that many of the impacts are resolved quickly while other impacts tend to linger. This thesis analyzes a few cases and attempts to determine the lasting impacts of offshore oil spills on the environment, human health and economy.

Although numerous oil spills have impacted the world, this study focuses on two oil spills in the Gulf of Mexico, the Ixtoc I oil spill (1979) and the Deepwater Horizon oil spill (2010) (DWH), and the Exxon Valdez oil spill in Alaska (1989). In addition, data from the Korea oil spill (2007), COSCO Busan oil spill (2007), Antonio Gramsci oil spill (1979) and the Tsesis oil spill (1977) are included to support the hypotheses of this research.

When an oil spill occurs, the damage may be limited and extend over a small area or be extensive and encompass a vastly large area. In all of these situations, it is important for scientists, citizens and government officials to know what to expect and what actions need to be taken when spills occur. When the Deepwater Horizon accident occurred in the Gulf of Mexico in 2010, many of the journalists and scientists suggested that if corporations and government officials had paid closer attention to past oil spill incidents, better legislation, more regulation and a faster action plan could have been determined to cap the wellhead.

The oil from offshore oil spills can spread expansively depending on the tide and the weather. Since many of the components of oil are highly volatile, oil spilled in the summer months tends to evaporate more rapidly, making the clean up process slightly more efficient and the impact possibly less severe. Because oil can easily spread, a large oil spill tends to affect a vast area. Sea birds that normally land in the water to catch fish or waddle become covered in oil that coats their feathers. Turtles frequently ingest oil. When sea otter skin becomes exposed to oil, it reduces the animal's ability to control their body temperatures which leads to pneumonia. Some microbes naturally present in the ocean can utilize many of the compounds in the oil for growth. Natural selection for these particular microbes alters the microbe population.

The fish, oysters, crab, and shrimp that normally roam the ocean and filter clean sea water consume oil at a high rate since they are unable to avoid the oil. These commercially important seafood species become unpopular and fishermen and harvesters are unable to go out to sea to fish. Therefore, many fishermen lose their jobs.

Moreover, there are potential human health risks due to oil spills. Although the ecosystem and economy may be damaged from oil spills, human lives may be at stake as well. The volunteer workers cleaning up oil contaminated shores may be exposed to hazardous compounds associated with the oil via inhalation, skin absorption or possibly ingestion. Each volunteer's physical health remains a significant issue when considering the clean up process. Just as the medical community attempts to promote preventive health by focusing on prevention care, protecting oil reservoirs and preventing major oil spill disasters, seem to be the most effective methods to secure oil for future generations. This thesis attempts to analyze these situations and show that oil spills may result in irrevocable damage to the environment, human health and the economy of a country and region impaired from the effects of an oil spill despite some positive and naïve descriptions portrayed by the media.

II. Impact Qualification

Environmental disasters pose diverse and wide-ranging problems that governments, investigators, societies and individual people must cope with and solve on a daily basis. Although scientists cannot qualitatively characterize all impacts from an environmental disaster, these effects can be quantified by performance metrics. Seager proposes an array of environmental performance metrics with special consideration for oil spills.[1] First of all, when considering an assessment of oil spills, one must define the goals of the response to an environmental disaster. According to the National Oceanic and Atmospheric Administration (NOAA), the goals of the oil spill response in decreasing order are to "1. Ensure safety of human life; 2. Stabilize the situation to preclude it from worsening (e.g., source control, on-water recovery); and 3. Minimize adverse environmental and socioeconomic impacts."[2] To assess these goals in response to oil spills, metrics are used with value-based properties consisting of economic, thermodynamic, environmental, ecological, human health, and sociopolitical facets.

Of all the value based metrics, only ecological, environmental, human health and economic metrics are detailed in this thesis. Ecological metrics "attempt to estimate the effects of human intervention on natural systems in ways that are related to living things and ecosystem functions."[1] These include loss of biodiversity, number of oiled animals, number of animal death counts, and parties responsible for restoring the area to pre-spill conditions. A set of the marine animals discussed in this study are the number of sea turtles, sea otters and pelicans oiled from the spills. The dissolved oxygen condition in the water column is also analyzed to determine how the ocean's bacteria are affected by the oil spill. Different concentrations of dissolved oxygen may alter how these microorganisms utilize nutrients like phosphorus and nitrogen, and carbon dioxide. Environmental metrics are used to assess the chemical changes that occurred in the environment. Since environmental metrics are "difficult to put in an appropriate context unless they are tied to some ecological or human manifestation, such as carcinogenicity, mutagenicity or even nonhealth-based endpoints such as beach or fishery closures,"[1] they are discussed in conjunction with ecological and human health impacts. Human health impacts from oil spills usually refer to worker safety because these individuals contact the oil and inhale the chemical fumes. Then, the oil that becomes part of the food chain may affect the public if the concentration of compounds from the oil becomes high enough in seafood. However, human health impacts are difficult to quantify due to the problems associated with natural variations of sensitivities within populations, of gathering the same type of people affected by the spill. Human health metrics deal with people at risk by investigating how they may have been exposed to the oil and the intensity of the effect. Finally, economic metrics "convert nonmarket resources or effects into monetary values to allow comparison with monetary transactions or industrial accounts."[1] Information regarding lost tourism revenues, decreased property values or opportunity costs are examples of economic metrics. When oil spills occur, oftentimes it may be due to extreme environmental exploitation leading to the environment being irrevocably damaged. This thesis research focuses on marine commercial industries, and revenue for economic metrics. Although ecological, environmental, human health and economic impacts are not the only consequences from oil spills, they are the major ones that could affect the public.

In addition to the goals of NOAA's response, Seager displays that the response, recovery and restoration of the oil spill must be completed to reach maximum effective cleanup.[1] Each part contains a different aspect of the response to the oil spill: "Response includes all efforts to contain and clean up the oil. Recovery is the period after initial cleanup during which both natural and human systems begin to stabilize and recover and during which long-term effects are assessed, including natural resource damage assessment. Restoration includes all activities to restore natural and human systems to their state before the spill, including efforts to replace or offset damaged resources and effects."[1] This study attempts to assess the ecological, human health and economic issues individually to determine whether the extent of the response, recovery and restoration were effective in different situations.

Oil spills may occur in various military, economic or commercial settings, and the degrees of the spill differ in each case. There is a significant amount of oil spill data but this thesis uses studies from the Ixtoc-1 (1979), Deepwater Horizon (2010) and Exxon Valdez (1989) to study the ecological, human health and economic effects of oil spills. Other spill cases such as the Korea oil spill (2007), COSCO Busan oil spill (2007), Antonio Gramsci oil spill (1979), and the Tsesis oil spill (1977) were also studied to provide additional data to understand the extenuating impacts of oil spills.

III. Brief Review of Ixtoc I, Deepwater Horizon, and Exxon Valdez

The Ixtoc I incident in 1979 was the largest offshore oil spill that had occurred in history until the Deepwater Horizon incident in 2010. In 1978, A Mexican company known as PEMEX started drilling in the Gulf of Mexico at a depth of approximately 50 meters; and by May of 1979, reached a depth of 3600 meters below seabed. On June 2, 1979, the drilling had reached a depth of 3615 meters below seabed. Eventually, they started to drill into mud causing a loss of circulation in the machinery. Unable to regain the circulation, the company attempted to seal the pipe using a plug, but by June 3, due to extremely high pressures, the mud ran up the pipe causing an explosion. This caused a fire near the well, causing the oil and gas to mix with the water on the sea floor. Contamination reached the surface of the sea. The final estimated total amount of oil that had burst out of the well was about 475,000 metric tons, which was the largest offshore accidental oil spill until the Deepwater Horizon incident.[3]

In 2010, the largest offshore oil spill accident occurred at a platform run by the British Petroleum company in the Gulf of Mexico. The wellhead blew out on April 20, 2010 while workers were drilling for oil at a depth of approximately 1,500 meters (5,000 feet). For three months, British Petroleum and their workers attempted to cap the wellhead but their attempts were futile. After releasing approximately 4.9 million barrels or 205.8 million gallons of crude oil, the broken wellhead was plugged and the oil leak was finally stopped on July 15, 2010.[4] Approximately 53,000 barrels gushed into the ocean each day when the wellhead was capped, but the spill rate was much higher at about 62,000 barrels per day when the wellhead initially blew out.[4]

The Exxon Valdez incident, however, occurred under an entirely different scenario. Initially, a tanker, Exxon Valdez, hit the Bligh Reef in Prince William Sound, Alaska while en route to Los Angeles, California, and spilled the oil into the sea. The vessel was actually outside of the normal shipping lanes due to ice in the area and ended up hitting the reef on March 4, 1989. This collision caused all of the oil in the tank to spill into open water. The tank released

240,500 barrels (10.9 million gallons) of the 53 million gallons of cargo it was carrying, affecting 1,100 miles of non-continuous coastline in Alaska.[5] Due to the large impact of the oil spill, the clean-up process required many volunteers and a long period of time. At the height of response, estimates indicated that more than "11,000 personnel, 1,400 vessels, and 85 aircrafts" were involved in the clean-up process.[5] For six months, volunteers and workers gathered together to manually clean oil from the shores. Efforts continued for two more years during the summer months, and only a limited amount of monitoring was conducted during the winter months due to the harsh nature of the Alaskan winters. Even today, 22 years later, state and federal agencies continue to monitor the area where the spill occurred.

Unlike the Deepwater Horizon and the Exxon Valdez incidents, the Ixtoc I oil spill was not extensively studied for years by the US federal government because it had occurred much earlier than the other oil spills. Even though Ixtoc I at that time was the largest oil spill that had ever occurred, the media did not pay particular attention to the spill. Therefore, it was not publicized as much as the Exxon Valdez and Deepwater Horizon incidents. There have only been a limited number of studies identifying the lasting impacts of the spill from the Ixtoc I incident. The following chapters address the short and long term impacts of these spills on the ecology (Chapter 2), human health (Chapter 3), and economy (Chapter 4).

CHAPTER 2: ECOLOGICAL IMPACT

The Port Aransas beach of Texas is positioned between the locations of the Ixtoc I oil spill to the southwest and the Deepwater Horizon oil spill to the northeast. Its brown and murky seawater may lead people to believe that the beaches of the Gulf of Mexico lack the commonly imagined breathtaking beauty. However, not far off from the shallow waters towards Mexico and Cuba, the waters of the Gulf of Mexico transform into a breathtaking shade of blue. In both the murky and clear blue environments, a rich marine habitat and diverse number of species dwell in the riches provided by the Gulf. When an oil spill occurs, not only is the beauty associated with these sights diminished, but the ecology of the environment is disturbed. This section of the thesis attempts to study the ecological impacts of the oil spill.

The Handbook of Texas Online describes the coral reefs as "'flowers'-actually, brightly colored corals and other marine animals and plants that attract both sport divers and scientists-[that] blossom in brilliant hues."[6] Naturally, the waters of the Gulf of Mexico provide many ecological resources such as "marine resources including navigation, recreation, oil and gas, commercial fisheries, oysters, and shellfish."[7] Additionally, the Aransas region in Texas provides the wintering ground for a diverse population of birds that migrate from the North while also being a wintering ground for most of the wild endangered North American whooping cranes. Not only is the Gulf home to the diverse whooping crane population, the Gulf provides a habitat to many pelicans, egrets, sea turtles, and dolphins. "Cooler water from the deep stimulates plankton growth, which attracts small fish, shrimp, and squid."[6] Evidence of the fertility in the Gulf is seen as "Louisiana contains 41% of the nation's coastal wetlands."[8] From all this richness, scientists estimate that the Gulf of Mexico may contain over "15,400 species;"[9] so it is important to understand the role of hydrocarbons on the ecosystem in the ocean, and the fate of massive tar balls that form once an oil spill occurs.

I. Natural Seepage

The natural ocean environment is exposed to crude oil through two possible sources. One is through man-made oil spills and the other is through natural seepage of oil from the seafloor. Petroleum-eating microbes in the Gulf of Mexico have naturally adapted to this type of environment for millennia. The known locations of the natural oil seeps in the Gulf of Mexico are shown in Figure 2-1. There is a significant amount of natural oil and gas naturally leaking into the interior of the Gulf of Mexico, so it would be insightful to see how the benthic communities, which are adapted to certain background levels of hydrocarbons in the water, react to a sudden and large oil spill, and how significantly they are impacted.

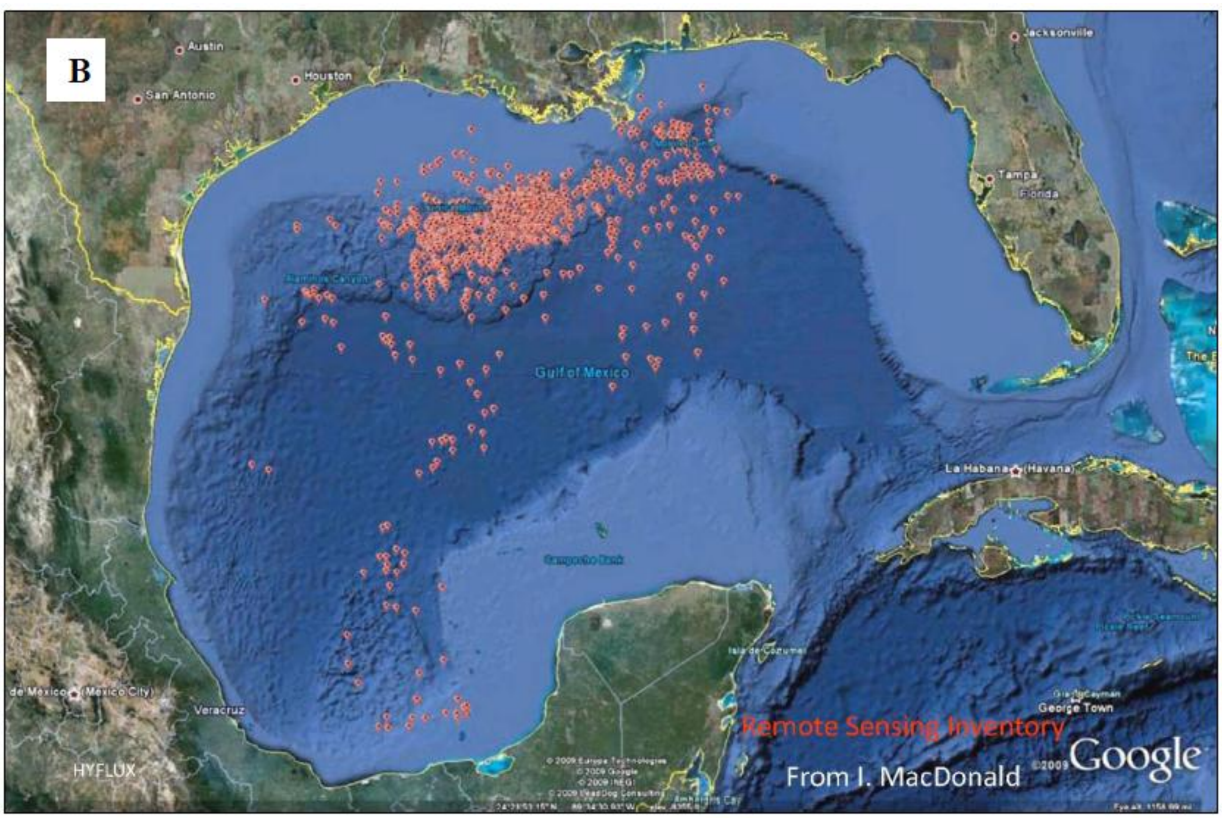

Figure 2-1: This red dots display the sources of natural seeps in the Gulf of Mexico. [9]

Although the distribution of the natural seeps in the Gulf of Mexico may be extensive, the rate of natural seepage is relatively low. When oil is "thicker than four microns in the water, which might result from a shipping accident, fresh oil forms an obvious covering, [which is] reddish brown to tan in color."[10] However, natural oil seepage forms oil layers with a thickness, "which range from less than 0.01 to one micron [and] may be only a few tens of molecules thick."[10] One surprising fact is that "natural leakage has extracted at least as much oil and gas from buried reservoirs as the petroleum industry has. But even though the total quantities may be roughly equivalent, the rates are not."[10] A major difference of oil in the ocean between oil spills and natural seepage is the thickness. The thicker the oil becomes, the more concentrated and potentially toxic it may be. In nature, the seepage spreads throughout a large area, but the oil from an oil spill is concentrated in a small area of the ocean.

To put the quantity of oil released to the ocean from natural sources in perspective, it is useful to relate the time that it takes for a natural release to produce an amount of oil equivalent to a major oil spill. The amount of time it will take for the natural sources of oil to release oil equivalent to the volume of oil released during the Ixtoc I oil spill is equivalent to approximately 131 years. Similarly, it would take 213 years for natural oil sources to produce as much as oil as was released in the Deepwater Horizon oil spill.[10] This comparison highlights the fact that the natural rate of seepage is significantly slower and represents a rate that the ecosystem has naturally adapted. Thus, an oil spill can be devastating to the local ecological system or habitats exposed to the massive oil spill. The advocates who claim that the ecological impacts of an oil spill are not as harsh as expected should consider these differences while attempting to understand the consequences an oil spill; and determine if the natural conditions of the marine environment recover after an oil spill has been cleaned up.

II. Microbiological Degradation

Oil spilled in warmer climates generally disappears at a faster rate than oil spilled in colder climates due to higher evaporation. However, not all spilled oil is removed by surface evaporation. A significant portion is cleaned up by humans, and other masses are metabolized by bacteria and eventually incorporated into the food web.

Microbes are characterized as very small free-living organisms visible only under the microscope. Microbes can be prokaryotes or eukaryotes descending either from the domains Bacteria or Archaea. Although the microbes may be minute in size relative to other living organisms on Earth, their collective total mass is staggering due to their ubiquitous nature. It is estimated that there can be approximately 1 million bacteria per mL of water, which would correlate to about 10^{29} cells total in all the world's oceans.[11] Each microbe species has an optimal environment, but there are many different species, so different types of bacteria can grow optimally in different conditions. For example, some grow in very high or low temperatures or even very acidic or basic conditions. Due to their diverse nature, many of them are able to obtain metabolic energy through very different mechanisms. Many microbes are photosynthetic, having the ability to utilize the sun's energy to harvest energy, while others have evolved to utilize energy from the chemical bonds of inorganic compounds such as molecular hydrogen, reduced iron, nitrite, methane and sulfide.[11] In order to grow, all microbes require "nutrition (intermittent availability of food), occupancy (the need to remain in a certain habitat), and resistance to damaging agents."[11] Most of the microbes studied in this thesis typically occupy various parts of the ocean ranging from the surface to deep depths. The focus of this section is to understand the effectiveness of bioremediation and impacts of microbial respiration on oxygen levels after oil spills have occurred.

Pollution occurs everywhere and everyday, but when oil is dumped into rivers, lakes, and oceans, the severity increases in magnitude. Researchers have tried to understand how microbes react to the overload of crude oil resulting from anthropogenic releases.

In a study led by Geiselbrecht analyzing degradation of oil in the Gulf, researchers gathered phenanthrene and naphthalene-degrading bacteria in the Gulf of Mexico. Her research showed that of the samples of bacteria collected, a total of 23 strains were able to degrade polycyclic aromatic hydrocarbons (PAHs). She then separated the strains based on whether they were offshore or nearshore samples. It was important to differentiate between the two locations because the offshore samples could "assess the effects of long-term oil and gas exploration and development on marine organisms."[12] To identify the ancestry of the collected strains, Geiselbrecht and her team ran partial 16S rDNA sequencing along with a phylogenetic analysis. The results showed that "all 23 isolates were very closely related to one another and closely related to the type strain of the genus *Cycloclasticus, C. pugetii* PS-1."[12] Other studies found that other types of bacteria in the genera "*Pseudomonas, Flavobacterium, Moraxella, Marinobacter, Vibrio, and Sphingomonas*"[12] were also PAH-degrading strains. The phylogeny showed that through natural selection and evolution, strains of bacteria had evolved to utilize hydrocarbons as a source of food. Most likely, the microbes adapted to this environment through the natural presence of oil in the seeps of the ocean. One thing to note between these different strains was that not all were able to degrade every type of aromatic compound.

Another question scientists inquired about was whether microbial degradation of crude oil was mostly done under aerobic or anaerobic respiration. Polluted areas from crude oil may have different qualities, and one is whether the oil is surrounded by muddy areas in the deep ocean where the area may lack oxygen, or if the oil is spread out onto the surface of the ocean where the microbes could participate in aerobic respiration.

As referred to earlier, each strain of bacteria is unable to metabolize all of the hydrocarbons, but each can degrade specific saturated, aromatic and polar hydrocarbons. A study from the Amoco Cadiz oil spill studying methods of degradation found that in aerobic biodegradation “the bacteria responded differently to the various hydrocarbons tested. The most complete degradation was noted for the normal alkane hexadecane. Metabolism of the branched alkane pristine was less complete and presumably slower. The biodegradation potentials for aromatic compounds were also slow relative to biodegradation of normal alkanes.”[13] The study highlighted that the difference in the rates of biodegradation for the different hydrocarbons was a function of environmental conditions. Aerobic microbes have a tendency to utilize more normal or unbranched alkanes rather than branched or aromatic compounds. Gradually, the concentration of the normal alkanes decreases as the concentration of the branched and aromatic alkanes increases. These studies indicate the importance of tracking changes in hydrocarbon composition both temporally and spatially.

To study the difference in anaerobic degradation, a salt marsh can be used as a model. A salt marsh is an area near the upper coastal intertidal zone that exists between the land and the salty (brackish) water. The salt marsh typically has low oxygen levels due to the decomposing plant matter (peat) clogged with low-oxygen content water, creating a rotten egg smell on the marsh and mud flats. The salt marsh might be a good example of an environment in which anaerobic respiration of crude oil occurs because it is a natural environment that could represent the anaerobic parts of the deep ocean. A study led by Ward found that anaerobic degradation of oil does not occur, or very little oil is oxidized with the rate: “at best several orders of magnitude slower than aerobic biodegradation."[13] From this data, it is possible to infer that anaerobic degradation of crude oil in the deep ocean, even if it occurs, would be minimal. If oxygen is present, however, the degradation rates would be faster.

If anaerobic respiration does not occur in the salt marshes, aerobic respiration must be operative for oil degradation. This leads to a significant concern among scientists about the potential for the development of hypoxia after an oil spill. Hypoxia occurs when the dissolved oxygen concentration is below the level necessary to sustain most animal life. Hypoxia is a condition of low oxygen levels "where the concentration of dissolved oxygen in the water column decreases to a level that can no longer support living aquatic organisms. The largest hypoxic zone currently affecting the United States, and the second largest hypoxic zone worldwide, is the northern Gulf of Mexico adjacent to the Mississippi River."[14] This phenomenon is a short term impact because the water, nutrients and oxygen in the Gulf are replaced annually by the flow of water from the Mississippi delta. In the Gulf of Mexico, concentrations of nutrients such as carbon and oxygen are regulated through a chain of events. The figure below shows the process in the ecosystem when there is an imbalance or excess of nutrients that enter the Gulf.

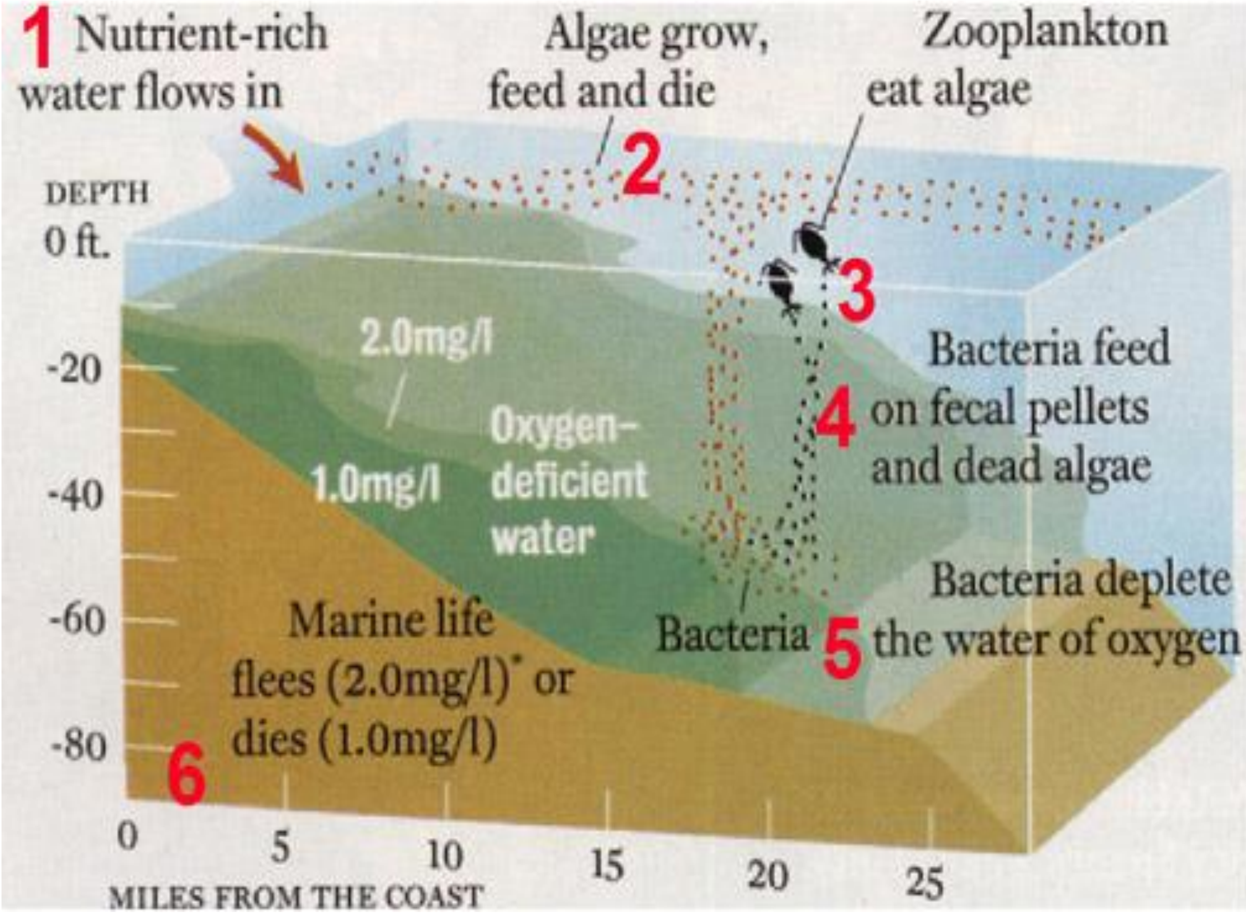

Figure 2-2: Process of nutrient incorporation into the ecosystem and the consequences of hypoxia in situations of excess nutrients.[14]

Initially, the nutrient-rich water flows in from the Delta, or when an oil spill like the Deepwater Horizon oil spill occurs, the excess hydrocarbons of the oil accumulate in the water. Gradually, the primary producers, such as algae, that participate in photosynthesis increase in number. The zooplankton that depend on the algae grow. However, as fecal pellets from the zooplankton and the algae die, these organic compounds accumulate at the bottom of the ocean, which is normally between 60-80 feet below the surface. The bacteria at that level, utilize aerobic respiration, which depletes the oxygen in the area. This creates hypoxia in an area home to a majority of marine life, resulting in a depletion of both oxygen and marine life.[14] This is a significant short term concern for the ecology of the region and possibly a concern for the long term impacts on the marine life.

As shown from this model, many times when an oil spill occurs, hypoxia occurs in many areas near the surface of the ocean, but scientists were unsure of the consequences after the Deepwater Horizon oil spill regarding deeper parts of the ocean. Due to the natural circulation of water, the ocean typically has a high dissolved oxygen concentration close to the surface that gradually decreases, then increases to substantial levels at deeper sections of the ocean. Scientists have studied oxygen levels at different depths of the ocean. In a study following the Deepwater Horizon oil spill, a group of researchers examined oil degradation by bacteria in the Gulf of Mexico. The different graphs in the figure (Figure 2-3) show the different cell densities and dissolved oxygen concentrations with respect to depth at different distances away from the wellhead. As seen in the figure, the oxygen levels remain relatively constant while the microbial concentration tends to increase at certain depths. However, since the oxygen curve remains the same, the study concluded that long term hypoxia concerns in the deep parts of the ocean may not be as significant as scientists had initially thought.[15]

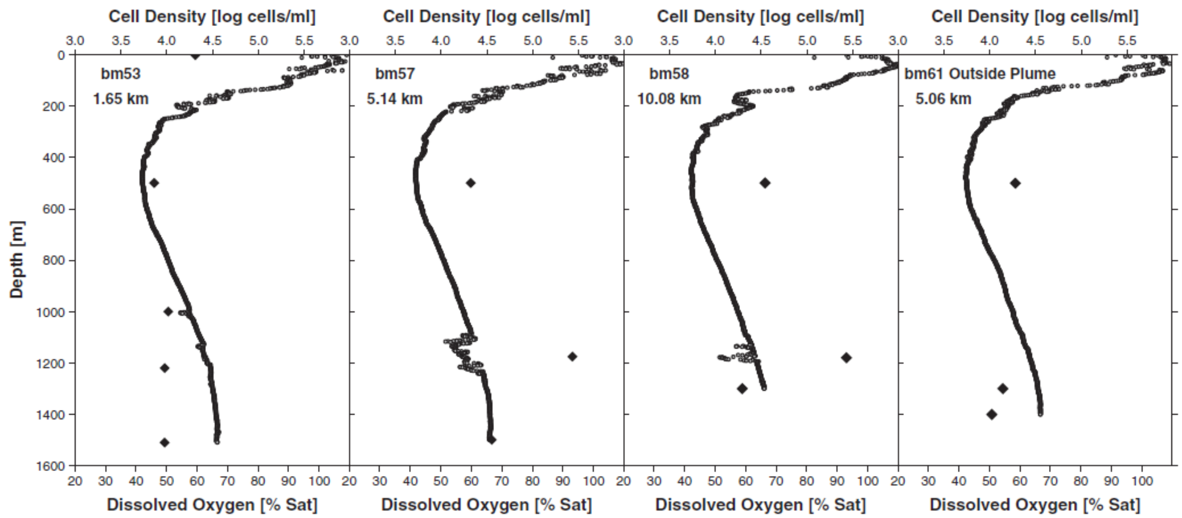

Fig. 1. Characteristic depth profiles of cell density, fluorescence, and dissolved oxygen for distances from the source (BM53, BM57, and BM58) and one nonplume site (BM61). Diamonds indicate cell density.

Figure 2-3: A comparison of cell density and dissolved oxygen with respect to depth. Oxygen levels seem to not change at deep parts of the ocean, even when cell density changes.[15]

While oil composition may change in response to the differential microbial degradation, bacterial populations also change in size in response to a spill. In a study led by Ward, an un-oiled salt marsh and beach had a hydrocarbon utilizing population of 520 and 380 bacteria/gram, respectively.[15] However, in oiled sites, the study observed 14,000,000, 350,000, 18,000, and, 390,000 hydrocarbon-utilizing bacteria/gram in the salt marsh, oiled beaches, high intertidal estuary, and low intertidal mud flat estuary, respectively.[15] The increase in cell density in oiled sites showed that the microbial populations evolved as a chemical spill occurred. The microbes capable of utilizing the crude oil survived and multiplied extensively in areas where the oil spill had occurred, in contrast to control-sites that did not contain oil.

Even in the deep sea, it was found after the Deepwater Horizon oil spill that, deep-sea oil plumes may have supplemented the indigenous oil-degrading bacteria. The oil spilled at the surface or shore can be cleaned by human efforts or by evaporation due to the volatility of many of the components of the oil and warm temperatures provided by the sun's radiation. However, oil trapped in the bottom of the ocean is difficult to clean up by human hands because of the limited access. Nevertheless, the oil must be cleaned up and considered in calculations since benthos or other organisms may be affected by oil trapped at the bottom of the ocean.

In a study that examined which genes were being utilized by the bacteria in degrading petroleum (e.g. γ-Proteobacteria), scientists found that a diverse range of microbial populations were capable of digesting petroleum living in the deep sea. The diversity in the microbial species implied that a "potential for intrinsic bioremediation of oil contaminants in the deep sea exists and that oil-degrading communities could play an important role in controlling the ultimate fates of hydrocarbons in the Gulf."[15] Even if bioremediation is an effective method to clean up oil, it is important to understand it's efficacy.

The previous results suggest that microbes are an important factor when cleaning up an oil spill. While there are many ways that an oil spill can be cleaned up, bioremediation is a more natural method that results in minimal ecological effects because it uses natural processes and can lead to complete conversion of the oil components to innocuous products such as carbon dioxide and water. There are two ways to clean up an oil spill using the bioremediation process: 1. Usage of the indigenous microbial populations that are already living at the oil spill site (seeding), and 2. Add non-indigenous microbial populations to the oil spill site so that these microbes could digest the oil and remove the petroleum pollutants (nutrient enrichment). In the latter method, the microbes used, are select types of non-indigenous microbes with hydrocarbon-degradation capabilities of the specific aromatic compounds found in the spill. An oil spill that widely used bioremediation as a natural solution to the problem of oil pollutants was the 1989 Exxon Valdez oil spill.

The studies on bioremediation after the Exxon-Valdez oil spill focused on determining the effectiveness of treatment. The scientists sought to determine whether “indigenous microbial populations were capable of degrading the wide range of potential substrates present in such complex mixtures as petroleum.”[16] The study found that after a 3-5 day lag period, the effectiveness of the treatment showed significant progress in the clean-up of oil. The study noticed that the “the field trials of adding non-indigenous populations to the Exxon Valdez spill failed to demonstrate enhanced oil biodegradation by these products.”[16] Most studies found seeding to be ineffective, except in the Mega Borg spill trial off of the Texas coast. However, the result of the Mega Borg trial remained inconclusive because it lacked scientifically sound evidence to show that seeding did enhance the rates of petroleum biodegradation.[16] Both the seeding trials of the Exxon Valdez and Mega Borg cases indicate the lack of effectiveness of seeding to remedy the pollution.

The other method of bioremediation involves nutrient enrichment. When polluted areas were treated by supplementing the microbes with nutrients, noticeably different results were observed compared to the results found from seeding. Three types of nutrient supplements can be used to treat oil spills: water-soluble, slow-release, and oleophilic compounds. The study concluded that the oleophilic (compound that is soluble in oil instead of water) fertilizer produced the most successful results. The oleophilic fertilizer used in Exxon Valdez was a compound called Inipol EAP 22. This compound was able to stimulate “biodegradation so that the surfaces of the oil-blackened rocks on the shoreline turned white and were essentially oil-free within 10 days after treatment. The striking results strongly supported the idea that microbial oil degradation in Prince William Sound was nutrient limited, and that fertilizer application was a useful bioremediation strategy.”[16] The fact that oil was so effectively cleaned up after treatment proved it's efficacy. In the Exxon Valdez case, the oleophilic nutrient supplementation bioremediation technique seemed to be very effective in increasing the rate of oil biodegradation. Actually, it was found to be more effective than the seeding technique.

On the contrary, another study found similar results for the effectiveness of seeding, but with a slightly different conclusion. This study was based on a more recent and better controlled experiment. In this study, scientists created a limited and experimental oil spill on the shoreline of the Delaware Bay, and treated three different areas with a "no-nutrient addition control, addition of water-soluble nutrients, and addition of water-soluble nutrients supplements with a natural microbial inoculum from the site."[17] In their results, they found that biodegradation occurred to a certain degree in all three areas. Although there was a difference in the initial rate of biodegradation that occurred between the treated and untreated plots, they did not find a significant discrepancy in the amount of biodegradation between plots treated only with nutrients and the plots treated with nutrients and bacteria. They concluded that the "rapid intrinsic rates of biodegradation without human intervention was ascribed to high level of natural nitrogen concentrations along the coast of Delaware Bay."[17] In other words, the natural environment of the Delaware Bay and the warm temperatures permitted the microbes to have favorable conditions for biodegradation to occur without the addition of extra nutrients. When attempting to gauge how much biodegradation of crude oil would occur for an expansive oil spill, the study suggested that the natural nutrient concentrations should be measured in the spill area. This is because like in the Delaware Bay, nutrient supplementation would not be necessary for the bioremediation oil clean up if natural nutrient concentrations were high enough to sustain the microbial populations to degrade the oil. An ample source of nutrients may be present due to nearby agricultural practices or industrial discharges to easily support near optimum hydrocarbon biodegradation activity that would have “continuously renewable concentrations of 1-2mg of nitrogen/L of interstitial pore water.”[17]

Venosa’s results from the study could be further explained using Darwin’s theory of evolution and natural selection. Darwin’s theory of evolution argues that “environmental pressures on organisms, such as climate and availability of natural resources such as food, act to select, by natural processes, those individuals better adapted to survive and who thus will pass viable traits related to survival to subsequent generations… Selected individuals of a species are better adapted to their environmental conditions than others and thus survive (‘survival of the fittest’). Therefore, those individuals with the most favorable genes for survival will be the most ‘fit’ for reproduction and pass these ‘survival’ genes to offspring.”[18] Essentially, when Darwin’s theory is applied to this situation, the microbes most fit will survive and pass on their traits so the next generation will evolve to be more like the species that were the most fit. Venosa’s study concludes something similar regarding the survival of the fittest between naturally living bacterial populations and those grown in the laboratory. He concludes that “If indigenous microbial cultures that are adapted to the environmental conditions of the oil spill site do not accelerate the degradation rates, organisms enriched from different environments, grown in the laboratory, and not acclimated to a particular climatic or geographical location should be even less able to compete with the natural populations.”[17] Again, individuals, or individual population types of bacteria better adapted to survive will pass on their genes to the next generation and only the most fit will pass their genes to offspring. Essentially, microbial seeding of the spill area will not be as effective as nutrient enrichment because the bacteria will be from laboratory conditions - different from the environment’s conditions, regarding the cleanup of an oil spill using bioremediation. Instead, the microbes that have been living, growing and adjusting to the local environment will more effectively adapt, survive, and reproduce. Therefore, the indigenous bacteria are more fit. Bioremediation should attempt to utilize these bacteria to degrade oil, instead of introducing different populations of bacteria that were effective in laboratories, because “hydrocarbon degraders are ubiquitous in nature, and when an oil spill occurs at a given site, the large influx of biodegradable carbon will cause an immediate response in the abundance of hydrocarbon-degrading populations. If nutrients are limiting, however, the rate of oil biodegradation will be less than optimal.”[17] Supplying the necessary nitrogen and phosphorus nutrients will enhance the degradation of crude oil by the indigenous microorganisms, but adding more bacteria to degrade oil would be unproductive because they will still lack the necessary nutrients that allow growth on oil.

At a different spill site, the Amoco Cadiz spill, researchers observed that naturally developed bacteria removed the more easily degradable nonvolatile components of the oil, such as normal alkanes. When microbial populations were continuously exposed to oil in aerobic environments, the microbes biodegraded the branched and cyclic aliphatic and aromatic components, while in anaerobic environments, barely any biodegradation occurred. Thus oil spilled in deep parts of the ocean that lack oxygen remains confined to the deep water column because the oil will not be biodegradable by the microbes, or the rate of the biodegradation may be very slow. Indeed, aerobic respiration is more effective than anaerobic respiration in the degradation process of oil.

In summary, to clean up an oil spill using bioremediation, two methods are feasible-enriching the indigenous bacteria with nutrients or seeding the area with bacteria. When using nutrients, many studies found that oleophilic nutrients like Inipol EAP 22 were most effective. Studies indicated that a bioremediation technique that provides the native populations of bacteria with nutrients created a better response in degrading the crude oil, hence in cleaning up the oil at the spill site. In conclusion, whether bacteria may be indigenous or exogenous, both types of microorganisms would require nutrients to grow. Since bacteria were found to only participate in aerobic respiration to degrade oil, hypoxia in shallow areas of the Gulf is a significant concern.

III. Animals

Although microbes may play a large role in cleaning up oil, understanding the food web, and the amount of damage incurred on animals may be useful in understanding the oil spills' impacts on diversity. Animal fatalities are often highlighted by the media after an oil spill because they generate an emotional response as humans are extremely sensitive to seeing a marine organism or bird covered in oil. Endangered animals often attract even greater media attention and highlight the potential for oil spills to impact ecological diversity and the food web.

The food web in the Gulf of Mexico begins with an energy conversion process of photosynthesis which uses the sun's radiation to provide the energy for growth. Producers participate in this process, such as seagrass, phytoplankton, algae and terrestrial plants. Then, these producers are consumed by the primary consumers in the food web, such as the annelids, oysters, crustaceans and zooplankton. If petroleum covers the producers and primary consumers, they will then have hydrocarbons in their systems. Minnows, mollusks, small fishes, mullets, sandpipers, crabs, shrimp and herons are the secondary consumers in the next level of the food web in coastal environments. At the top of the food chain are the tertiary consumers like the whooping crane, red snapper, sea trout, tarpon, pelicans, dolphins and even humans, that consume the secondary and primary consumers. In regards to the food web, man is the least vulnerable of all the organisms because man can choose whether or not he will eat contaminated food and can remove the contaminated food from his diet. In nature, since the food web is interconnected through many different organisms, when one animal is damaged, the rest of the chain of animals may be affected.[19]

When a spill occurs, there are three different factors affecting the toxicity of oil that scientists must be concerned about: chemical, physical and biological. Initially, chemical factors affect the toxicity of oil as more soluble species will dissolve in water (shorter chains, aromatics, low boiling point). These soluble components can be consumed and assimilated into the environment.[19] Physical factors include weathering, burning and adsorption. Weathering occurs as soon as oil comes into contact with the water and smaller and more volatile molecules evaporate. This process removes many of the more chemically toxic molecules from the environment since many of these molecules are volatile. Additionally, in weathering "other hydrocarbons undergo photo oxidation, a process in which they are broken down into smaller molecules by solar radiation in the presence of oxygen. Although this process is not as fast as evaporation, it continues to break down the large molecules after the smaller ones have been lost through evaporation."[19] Over time, weathering helps to decrease the amount of toxic molecules, implying that the oil becomes less toxic over time by oxidation or evaporation. Next, burning is a form of weathering which often occurs after an oil spill. This process removes the oil, but the flames, smoke and pollution can potentially affect more marine and terrestrial life.

Finally, biological factors can also detoxify oil through the process of biodegradation. Biodegradation is extensively discussed in the previous section to understand how effective and the extent to which microbes utilize biodegradation when an oil spill occurs. However, in biodegradation, the crude oil can be incorporated into the food web. As discussed earlier, the animals lower in the food chain may consume oil thereby eliminating it from the environment, but because these organisms will be consumed by higher level organisms, the hydrocarbons could be spread throughout the entire ecosystem. In the body, the hydrocarbons undergo three fates: “1) the molecule is stored in tissue and accumulates; the animal has no enzyme or transport system to get rid of it, 2) the molecule is metabolized; the animal possesses the enzymes necessary to break it down, or 3) the molecule is transported out of the body; the animal gets rid of the molecule with the waste products of cellular respiration or cellular breakdown.”[19] The ideal situation to get rid of oil would be excretion or metabolism. If neither of these mechanisms are operative, it may cause the animals to experience symptoms associated with oil exposure.

i. Sea Turtles

Slow animals like sea turtles can especially be vulnerable to oil. Sea turtles can suffer internal and external damage from oil, and are vulnerable to it in all of their life stages. They are especially vulnerable because they do not avoid oiled waters. When a sea turtle is exposed to oil, “the sea turtle’s skin and body can cause skin irritation, chemical burns and infections. Oil exposure for just 4 days can cause sea turtles’ skin to continually fall off in sheets…even after they are … treated. Inhalation …can damage the respiratory tract…[and] ingesting oil or dispersants may cause injury to the gastrointestinal tract, which may affect the animals’ ability to absorb or digest foods. Turtles of all life stages exposed to tar balls have been found with tar blocking their digestive systems leading to toxic exposure and ‘floating syndrome’ where gas prevents the turtle from diving and therefore feeding. This can lead to starvation.”[20] This study shows that of all the symptoms, skin and digestive symptoms are the most prevalent in oiled sea turtles. Furthermore, just as oil can affect human organ function, the same symptoms were shown in turtles, including damage to the liver, kidney, brain and reproductive organs. Regarding reproduction, the oil also had a tendency to “increase egg mortality and lead to potential deformities in the hatchlings that do survive.”[20] Especially since many of these turtles were already on the endangered species list; if developing sea turtle eggs are killed by oil, sea turtle populations may not be able to recover out of their endangered species status.

The species most affected by the Deepwater Horizon spill and the Ixtoc I spill in the Gulf of Mexico were the Kemp's Ridleys, the smallest sea turtles in the world. These turtles nest near the Texas, Alabama, Florida and Mexican border and oftentimes migrate to Louisiana to feed on the abundance of food. In 1979, when Ixtoc I occurred, these sea turtles were in grave danger because their nests and eggs were severely impacted by the spill; and the same impact was expected for the Deepwater Horizon spill. The Kemp's Ridley sea turtles are a group on the endangered species list, making them more vulnerable to the spill. Another species of sea turtles, the loggerheads, are also on the endangered species list and were exposed to a similar threat as the Kemp's Ridleys because their feeding grounds and nesting areas were impacted by the oil spill. Other sea turtles such as the leatherbacks, hawksbills and greens were similarly impacted from these oil spills. One of the issues that exasperated the impacts on the sea turtles was that they are "slow to reach sexual maturity, which makes it difficult for them to build their population sizes, especially when their numbers [were] already severely compromised."[20] Due to their slow reproductive rates, sea turtle populations are severely impacted from oil spills, and these can be long term impacts for the endangered populations.

Sea turtles are important in the marine ecosystem because they help maintain seagrass beds and coral reefs-habitats that other animals depend on. Although animals can be on the endangered species list, animals can also be classified as ecologically extinct-a situation when "the number of individuals in a species becomes so small that it is unable to perform its ecological role."[21] This is a situation that is occurring for many sea turtles but has already occurred with the Caribbean green sea turtles. Green sea turtles are herbivores that forage on seagrass so that the grass does not accumulate. It is important to maintain the grass because the "leaves in the plots grow faster initially and have more nitrogen than leaves in ungrazed areas…[since] nitrogen generally is considered to limit seagrass production"[22] By clipping off the leaves, the sea turtles decrease the amount of nitrogen, allowing the grass to grow more readily. If the seagrass is not maintained, this in turn affects plant species, nutrient recycling and predator-prey relationships, making the food web less productive, which in turn could affect the commercial fish population and decrease the amount of fish available to humans. Furthermore, hawksbill sea turtles affect coral reefs by removing sponges that competitively grow with the coral. If the sponges are not removed by the hawksbill sea turtles, coral reefs are unable to grow, changing the structure and dynamic of the coral, which in turn affects the marine population dependent on the area.[21] Finally, another lasting impact that could be seen is from the jellyfish and fish population if the sea turtles become ecologically extinct. Loggerhead, green and leatherback sea turtles all consume jellyfish. In the marine ecosystem, the jellyfish population competes with the fish population for food. When the sea turtles become ecologically extinct, the jellyfish population increases and feeds on the same foods as the fish, and the fish eggs and larvae. In this situation, the fish population tends to grow smaller which again affects human consumption of fish.

As a middle ground species able to live on land and the ocean, sea turtles maintain the balance of many aspects of the ecosystem. When oil spills diminish the number of sea turtles, habitats and fish populations can be severely affected. It is difficult to accurately assess the number of sea turtles lost due to an oil spill because sea turtles spend a majority of their lives in the ocean. NOAA estimated that 212 hatchlings were killed from the 1993 Barge *Bouchard* spill near Florida, and between 56 and 180 in the 1983 Nowruz oil spill.[23] As of November 2010, 456 visibly oiled live sea turtles, 18 visibly oiled dead sea turtles and 272 dead sea turtles with an unknown cause of death were collected in the Gulf of Mexico due to the Deepwater Horizon oil spill.[24]

The extent of damage from the Deepwater Horizon oil spill can be seen by the number of actual and potential deaths of sea turtles. Unlike other species, once sea turtle populations vanish, sea turtles have difficulty recovering in population size. This is especially due to the fact that many sea turtles live up to 20-30 years, and do not reproduce as often as fish might-which lay thousands of eggs in one year. Over the long term, it is difficult for turtle populations to recover. One lasting impact would be the ecological impacts due to the lack of sea turtles in the ecosystem.

Additionally, adult and embryonic sea turtles are affected by the harmful fumes and chemical nature of oil and tar balls; the oil can lead to starvation of adult sea turtles and embryonic mortality. Especially since turtle embryos are hard to recover once lost, it is imperative to try to maintain and save the turtles before they become extinct.

ii. Birds

It seems that birds would not be as severely affected by an oil spill because they could fly, but "birds can be killed or brought to the brink of death by exposure to spilled oil, mostly from the effects of oiling of feathers."[25] But this may not be the only problem when birds are covered in oil since oil can be "acutely toxic when applied to eggs and that ingested oil produces a variety of nonspecific, debilitating conditions in adult birds."[25]

Oftentimes, birds are exposed to oil because as they fly, they may land in oil to rest or catch prey. Birds are also exposed to oil when the oil has washed ashore, causing the birds to walk around a beach that is covered in oil. Furthermore, it is difficult to clean oiled birds especially if their nesting and feeding areas are contaminated because they could transfer the oil from their feathers and beaks to their eggs. According to a NOAA fact sheet, when a bird is exposed to oil, "the oil sticks to its feathers, causing them to mat and separate. This affects the bird's waterproofing capabilities, and the bird cannot stay afloat or regulate its temperature. Instinctively, the bird tries to get the oil off its feathers by cleaning itself (preening) and may ingest oil when doing so. This can cause severe damage to the bird's internal organs. While trying to preen, this causes the bird to be vulnerable to such things as severe weight loss, anemia, and dehydration. Many oil-soaked birds lose their buoyancy and cannot swim, so they beach themselves in their attempts to escape the cold water."[26] Although oil itself could harm a bird's health, oil can also affect the bird's vulnerability to natural harm.

Due to the extensive impacts of oil, one study researched impacts of oil on birds. This study tried to determine the amount of oil in wildlife tissue and found, "only small amounts of aromatic compounds less than 0.7 ppm [were] found in birds of all analyzed hydrocarbons…in the control tissues, whereas nearly 6 ppm of hydrocarbons were present in the exposed eggs."[25] The 10-fold difference in the amount of hydrocarbons in the birds versus the eggs revealed how sensitive the eggs were compared to the adult birds. A feeding experiment in the same larger study showed that although the adult birds were able to survive even after being exposed to oil, they still experienced different physiological changes such as "depression of growth, impaired avoidance behavior, liver hypertrophy, spleenic atrophy, kidney degeneration, hyperphagia, biochemical lesions, hemolytic anemia, and depressed egg production."[25]

After the *Exxon Valdez* oil spill occurred, thousands of birds were affected by the spill, and a study attempted to determine how the abundance and distribution of 12 taxa changed following the spill. Starting with the year of 1984/1985, 3,788[27] individuals in the 12 taxa were recorded. After the oil spill, “6 (50%) of the 12 taxa examined showed no significant changes in abundance during any of the 3 post-spill years. During all 3 post-spill years, Red-necked Grebes, Pelagic Cormorants, and Pigeon Guillemots decreased significantly, whereas Glaucous-winged Gulls increased significantly…Bald Eagles were classified as exhibiting an overall increase because they were significantly more abundant in both 1990 and 1991.”[27] Oddly, the survey found a disparate abundance of birds with certain species to increase in population while others to decrease in population. The same type of disparity was shown with the amount of oiling effects in different species of birds. Some of the birds responded negatively to the oiling effects while some responded positively. Specifically, the Pigeon Guillemots were negatively affected by the spill, but had a very fast recovery. These species began to increase in abundance 1-2 years after the oil spill had occurred. But the Red-necked Grebes did not have either a positive or negative response to the oil. The study explained that this incongruent data could be explained possibly by the fact that the recordings were done in different seasons instead of at the same time.

This study showed that the impacts of the oil spill in Prince William Sound, Alaska were only significant during the year the oil spill actually occurred; and in two years after the spill, the abundance and distribution of the birds were the same as before. They concluded that the birds found the habitats suitable enough to live in. However, due to the fact that the surveys were done at different seasons, this study did not seem to show definite proof of habitats returning back to pre-spill conditions.

In another study determining the exact number of seabirds killed after *Exxon Valdez,* they found “36,115 dead seabirds were recovered from beaches and processed at morgue. In addition, most or all of 1,888 live oiled seabirds brought to rehabilitation centers also died.”[28] To estimate the amount of carcass (remains of the dead animal), approximately “30,000 of the total 41,263 carcasses accounted for died from oil pollution. In five months after the oil spill, most (72%) carcasses recovered were shearwaters and gulls that apparently died from natural causes (starvation)."[28] Although these deaths cannot be directly associated with the oil spill, these numbers do portray the extent of the possible damage that an oil spill can do to the avian population. As a result, the numbers of the birds may recover after a period of few years, but the extent of the damage right after the oil spill is expansive, especially if the oil spill occurs during migration season.

Over the long term, the oiling effects on the large populations of birds may not be very severe due to the recovery of the birds once the habitats are cleaned up. However, observing the short term impact of the oil spill, many birds are killed due to oil sticking to the bird's feathers. By December 14, 2010, following the Deepwater Horizon oil spill, 2067 visibly oiled birds were found dead, 1058 visibly oiled birds were found alive and 865 oiled birds from unknown sources were found.[28] These data were not definitive because the oil had not been cleaned up by the time of the report, and the live oiled birds that were being treated may have potentially died. The fact that 2000 birds had already died was a significant number, as well as a major short term loss even if these birds did recover in population size.

Anthony F. Amos, a researcher at the University of Texas Marine Science Institute has been documenting and following birds, tar balls, beach debris, and any other environmental issue that could be affected at Port Aransas, TX during the last several decades. His data collected since 1979 the year Ixtoc I spilled, showed 3,013 oiled birds-many of them caked with oil.[29] Thousands of birds were observed to be impacted by the oil spill from Ixtoc I, but the populations were able to eventually recover within a few years. Unlike the sea turtle population that was in immediate danger of becoming extinct due to their near extinction status and slow reproductive rate, birds were able to recover at a faster rate.

Birds have major severe and short term impacts from oil spills. When oil coats the birds' feathers, they lose their abilities to regulate their internal temperatures, causing them to catch hypothermia, lose their ability to fly and swim due to the changes in buoyancy. Birds also get distracted when coated with oil as they preen and oftentimes drown. However, many oil spill studies have shown that many bird populations do recover after an oil spill. Even though the initial impact on the population may be severe, studies seem to state that bird population sizes eventually recover. One thing to note is that there seems to be a lack of studies on the impact of diversity by oil spills. Unless scientists can definitely find that diversity in species return to pre-spill conditions-it is premature to assume that there are no long term repercussions from oil spills on bird populations.

iii. Marine Mammals: sea otters

Sea otters spend a majority of their lives in the ocean floating on their backs while attached to and feeding on kelp. While they float on their backs, they are one of the few animals to utilize tools to consume their food. Sea otters smash open mollusks, sea urchins or crabs using rocks to open their delicious meals. They mostly live floating on kelp forests and help maintain them along the coastal waters near the Pacific Ocean, near California, Canada, Alaska and Japan.

Sea otters are thought to be an important factor in determining the littoral community structures by controlling the herbivore invertebrate populations in the ecosystem. By predating on the benthic invertebrates, they reduce the competition for food and space for these organisms.[30] Sea otters have been on the Endangered Species list since 1911 when they were almost at the brink of extinction. Since then, they have been recovering. Like sea turtles, sea otters take a longer time to recover from massive devastations because they are long-lived organisms with a relatively low annual reproduction rate. The females produce single offspring each year.[31]

Unlike other marine mammals, sea otters lack blubber to maintain a warm internal temperature. Instead they are equipped with two layers of thick water-resistant fur and an elevated metabolic rate, enabling them to survive in the cold aquatic waters of the Pacific Ocean. Their fur is known to trap air to help them stay buoyant on top of the water. To maintain their fur, they must groom themselves with their mouth and forepaws for several hours each day to maintain the insulating quality. Therefore, sea otter fur is highly sensitive to contamination, especially from oil spills. Just like how birds are severely injured when their feathers are exposed to oil, when oil contaminates a sea otter's fur, it ruins the insulating property of the fur making it especially vulnerable to the cold and frigid waters along the coast. As a result, these oiled otters die from hypothermia or from ingesting the toxic oil.

After the *Exxon Valdez* oil spill, approximately 361 otters were brought to rescue centers. Of this number, 197 survived to be released back into the wild, and over 1,000 sea otter carcasses were collected.[32] Many of the sea otters brought to rescue centers from the *Exxon Valdez* oil spill were unable to survive because of oil contamination and stress from cleaning the oil off of their fur. After the Exxon Valdez oil spill, researchers estimated the overall annual growth rate of otters at 0.04, and 0.05 in 1995-2000, concluding that sea otter recovery was indeed occurring in Prince William Sound eight years after the spill. But the rate was less than the predicted values used in other recovery models.[31] A possible explanation to this was because the, "nearshore invertebrates that sea otters prey on (e.g. clams and mussels) occur in habitats that serve as repositories for residual oil, and they accumulate[d] hydrocarbons in their tissues. Because sea otters consume invertebrates that sequester hydrocarbons and they excavate large volumes of sediments to recover prey, they [were] potentially exposed to residual oil through 2 pathways (i.e. in sediments and in prey)."[31] Researchers found that while sea otter populations were recovering, their prey was also recovering from the oil spill, explaining why the sea otter recovery rate was not as fast as predicted. In addition to the lack of prey, the lack of population growth seemed to be caused also by emigration from the oiled sites and elevated mortality due to the spill.

The oil impacted the sea otters because of their inabilities to cope with oil contamination on their coats. This made them unable to regulate their normal body temperatures. Since sea otters are unlike other marine mammals that have a layer of blubber surrounding their bodies, they became extremely vulnerable to the frigid waters due to the oil spill. Even after the oil was cleaned up, they still had difficulty recovering because of their slow reproductive rates and the lack of prey. Just like sea turtles, sea otters were already on the endangered species list, and were one of the animals classified to be in immediate danger from an oil spill.

Sea otters function as an important ecological role, just like the sea turtles. Due to their endangered species rating and slow reproductive rates, sea otters are slower to recover from oil spills. The initial short term damage, as seen by the sheer loss in carcass after oil spills depict an immediate short term impact. Sea otters may slowly recover, but should still be studied closely to make sure there are no other issues preventing them to recover to pre-spill conditions in the long term.

IV. Subconclusions

The entire marine environment is connected through an elaborate food web. The ecosystem that Mother Nature created works together and depends on component to maintain a well-balanced and dynamic equilibrium. Although this study did not review every aspect of the ecosystem affected by the oil spill, certain relevant and important animals were chosen for the study.

Each animal is a component of the ecosystem whether it is to maintain the habitat that they live in, or to maintain population control of the prey that they consume. Without their presence in the ecosystem, the marine ecology is altered and the complex food web is altered. This creates problems that nature has not had a need to fight against. Each animal seems to act like an individual block on a wooden tower. Each block depends on the block above and below and each piece helps to retain the structure of the entire tower. When one block is removed, the tower may still stand, but it becomes less stable. As more and more pieces are taken out, the tower loses its stability and eventually falls apart, once past the critical threshold. In this way, each species is a member of the tower and helps to maintain stability in the entire ecosystem.

An underlying theme with respect to each of these species studied in this thesis is that an oil spill may initially seem devastating due to the immediate harmful consequences when oil is ingested, but populations of many birds and sea otters have been able to recover after several years. An exception to this trend is seen with the sea turtles. Because of their low populations, very long lifespan and vulnerability to the oil, their recovery has been limited. The intoxicating fumes and exposure to and ingestion of oil were shown to be harmful to the animals. However, animals with special and vulnerable pelage like birds and sea otters seemed to experience more severe impacts. They became unable to perform their daily routines of maintaining their feathers and coats, causing them to lose their abilities to regulate their internal body temperatures and remain buoyant while in water. If oil spills are not taken seriously, these animals may never regain their normal status in the ecosystem or grow their populations above endangered species levels. This type of disruption would lead to changes in the dynamic equilibrium associated with the ecosystem and would constitute long term impacts resulting from the oil spill.

Microbial populations and their activity to decompose organic matter also affect animal recovery. As seen earlier, the increase in aerobic respiration closer to the surface may lead to hypoxia decreasing the amount of marine life in the area. Although oxygen levels at greater depths of the ocean were an initial concern for long term impacts of oil spills, studied showed that oxygen levels were not severely affected at significant depths of the ocean. Thus, it appears that the most significant impacts of oxygen depletion are at the surface, and these levels should be monitored.

CHAPTER 3: HUMAN HEALTH

When British Petroleum's oil wellhead burst open, crude oil rushed into the Gulf of Mexico. The crude oil spread hundreds of miles from the source and severely affected the Louisiana coastline. As oil spread to these areas, scientists were concerned about the effects of oil on human health in the nearby communities. Fortunately, yet unfortunately, the Deepwater Horizon oil spill has not been the only spill in history. Multiple spills have occurred off of the United States coastline, and some scientists have investigated the impacts of oil spills on communities.

I. Populations at Risk

Different populations are exposed to different levels or concentrations of compounds associated with oil, so they are exposed to different levels of risk. It is important to determine how risk and exposure is spread from each person, and which groups would be more vulnerable to exposure. John Howard from the National Institute for Occupational Safety and Health uses a "bull's-eye" model in determining the amount of exposure and risk. According to Howard, exposure is highest to group of volunteers or workers who work near the oil. Then, this exposure level gradually decreases from the water clean-up workers, beach clean-up workers, to the community and general public. The level of exposure to the general public is dependent upon several factors, such as the amount of exposure by seafood and the distance the fumes travel.[33]

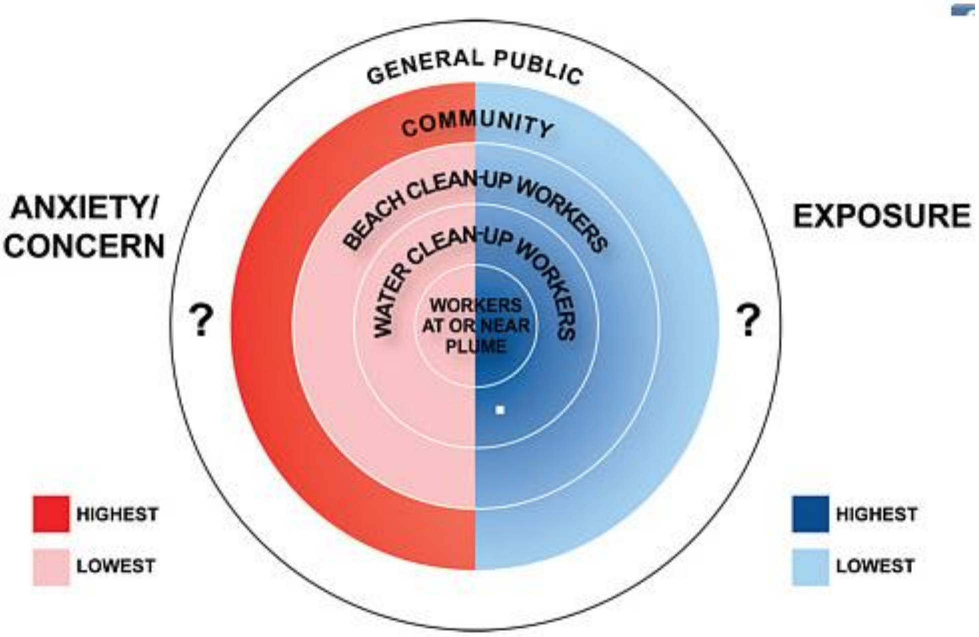

Figure 3-1: Bull's-eye model to display levels of anxiety/concern and exposure to oil spill[33]

According to the model, residents in the affected communities were at risk of being exposed to the crude oil itself, the fumes being carried by the wind or possibly even ingesting it through contaminated seafood or water.[33]

According to the study, the frequency and duration of symptoms felt would depend on the type and duration of exposure. From a national assessment for the Deepwater Horizon oil spill, the possible damages were categorized to be: "chemical (e.g., oil, dispersants, degreasers, soaps), biological (e.g., plants, animals, insects, remediation materials), biohazardous debris (e.g., syringes on shoreline), workplace injuries (e.g., slips, trips, falls, cuts), ergonomic stresses (e.g., repetitive stress, low back pain), heat stress, sunburn, and fatigue, fires (including exposure to particulate matter) and explosions, psychological stress, drowning and injuries from underwater diving, noise, [and] electricity."[33] These risks were most likely to affect the workers and inhabitants who lived near the crude oil; but without proper and adequate intervention to assess the degree of contamination, it was possible for these risks to increase. Oftentimes, it is difficult for the government to contain the contaminant to a secluded area. Since oil is a liquid and readily visible, it was easier to track its status than to track for example, nuclear fumes. It is imperative to understand the effects on these populations to prepare for the future.

II. Effects on Human Health

For workers involved in cleanup of an oil spill, a major concern deals with the level of heat stress that the body will be exposed to. Because of the long hours working under the bright and stinging sunlight, workers may experience heat stress and fatigue. However, this symptom is easily identifiable and manageable, while the effect of the oil may not be as easy to determine.

Spilled oil may consist of volatile organic compounds (VOCs), polyacyclic aromatic hydrocarbons (PAHs), heavy metals, and dispersants. Reviewing studies from past oil spills may give insights into the short term effects of exposure to these compounds on human health. A study on the MV Braer oil spill in 1993 followed community residents in the United Kingdom. Their results indicated that, "within the first 2 days of exposure following the oil spill, the researchers found evidence of neurological, ocular, and respiratory symptoms but no significant differences in lung, liver, or renal function between exposed and unexposed populations."[33] After an inconclusive result, the researchers reassessed the same population six months later and found that their general health symptom score was higher than those people who had not been in close contact to crude oil, with the only exception that there was no significant evidence on adverse effects on their organs. Other studies including those from the Sea Empress oil spill in 1996, Nakhodka oil spill in 1997, Erika oil spill in 1999, Prestige oil spill in 2002 and the Tasman Spirit oil spill in 2003 all found similar results. Most studies concluded that in the short term, groups exposed to oil were more likely to report symptoms of "acute toxicity, including neurological, ocular, and respiratory symptoms"[33] while some reporting dermal symptoms.

All the symptoms that the studies reported were moderate. For example, for dermal symptoms, the residents showed erythema (redness), edema (swelling), irritation and dermatitis (rash, blisters). For ocular symptoms, they displayed signs of redness, soreness, watering and itching. For respiratory symptoms they suffered from coughs, throat irritations, shortness of breath and wheezing. For neurological symptoms they displayed signs of nausea/vomiting, headache, dizziness, irritability, confusion, and weakness of extremities. Overall, many of the residents experienced mild to moderate symptoms that would cause anyone to feel uncomfortable.[33] The important thing to note from all these spills was that even though there were a significant number of symptoms displayed by these individuals, the effects were transient and would essentially disappear after 6 months.[33]

These studies only examined respiratory, dermal, neurological and ocular related symptoms, but a different study on the Prestige oil spill studied the effects of oil from a genotoxic and endocrine perspective. The researchers initially found changes in hormone levels in individuals exposed to oil. To indicate effects, they used prolactin and cortisol, because both indicate changes in physical and psychological stress.[34] This study saw an increase in both prolactin and cortisol by the residents in the short term, but the more important discussion would be the long term effects.

It is difficult for researchers to accurately assess the long term effects of oil on human health because of the difficulty to gather a select group who fit under the criteria. Of the few studies that have tried to review the long term effects of oil on human health, one study on the Exxon Valdez oil spill saw a prevalence of social, cultural and psychological impacts. In this study, they found that "exposure was associated with increased rates of generalized anxiety disorder, post-traumatic stress disorder, and single episode depression"[35] and "younger age groups, women, and Alaskan Native residents of these communities appear[ed] to have been especially vulnerable to these negative impacts as evidenced by higher rates of psychiatric disorders."[35] Most of the psychiatric disorders were anxiety disorder or post-traumatic stress disorder. They saw a correlation that the younger the age group, and higher the level of exposure, the more likely they were going to suffer from these disorders.

The social and cultural changes seen in this group were in the traditional patterns of behavior. These were disruptions of traditional social relations and daily routine activities such as changes in social roles. The changes in social roles occurred because of the wide disparity in income from cleanup activities and the uncertainty that hazed over the community regarding how long the oil spill's consequences would last. These issues were striking to the researcher because they "reflect[ed] an overall decline in social integration and hence the social support on which individuals and families rel[ied] in times of personal and communal distress. The disruption of subsistence activities [was] particularly salient…because these activities lie at the core of Alaskan Native identity, ideology, and social organization.[35] The sociological consequences of the oil spill changed daily lives. As seen from the results of this study, altering a peoples' way of life can have a serious impact on the mental health of the community. The results showed that the Exxon Valdez oil spill seemed to propagate this issue in the Alaskan communities. This study concluded that further research would be needed to determine if these impacts were temporary or permanent, but nevertheless, this study found a change in cultural and social lives in the Alaskan communities.

Another study based on a South Korean oil spill utilized a literature review to determine the health effects of oil exposure. After reviewing 24 articles from Pub Med analyzing the effects of oil spills, a range of physical and psychological effects were seen, but none of the studies were long enough to prove that there were significant long term health effects.[36]

In summary, most studies conclude that there are definite short term effects of oil spills but due to the lack of long term studies on human health, accurate conclusions cannot be made on the potential long term effects of oil spills on human health.

CHAPTER 4: ECONOMIC IMPACT

When an oil spill occurs, scientists may be concerned with ecological issues, but government officials, corporations and entrepreneurs require information regarding the economic impacts to determine the costs of settlements associated with the spill. As stated in the introduction, economic metrics attempt to "convert nonmarket resources or effects into monetary values to allow comparison with monetary transactions or industrial accounts"[1] such as information regarding lost tourism revenues, decreased property values or opportunity costs.

In the case of Deepwater Horizon, when oil from the rupture of British Petroleum's wellhead ceased to stop flowing, more precautions had to be considered. As the damage from the broken wellhead began to worsen and thousands of barrels became into millions of barrels of crude oil, the company's representatives realized that the finance of the entire company might be at stake due to the oil spill. During the summer of 2010, British Petroleum's representatives met with various marine scientists to discuss potential contracts to investigate the effects of oil in the Gulf of Mexico. However, they were required to work under the condition that they would keep their findings confidential. One scientist, Gregory Stone stated that he was asked to keep his work confidential for three years. After asking three times if his work would be used in defense litigation, British Petroleum's responses changed from indicating that the results were not being used to maybe they would be used to, " 'It probably would.' "[37] After finding that his confidential work would most likely be used in a biased manner, Stone decided not to take the offer from British Petroleum because of the possibility of becoming involved in political partiality, rather than academic freedom and scientific integrity.[37] Other scientists however, perceived the British Petroleum contract tolerable enough to accept. On the other side of the spectrum, another marine scientist made a contract with the federal government and "received threats just for saying the Gulf environment [was] improving."[37] As seen by these responses, when an oil spill occurs, it seems highly possible for a polarizing debate to emerge among scientists contracted under secrecy by corporations, and scientists working for the federal government under full open disclosure. The main driving force for both of these decisions is based on financial issues. This controversy among these scientists depicts the importance of accurately assessing the potential for damage due to an oil spills and determining the action items required for clean up.

Not only do corporations and governments feel anxious about the economic losses from oil spills, residents and businessmen worry about the future of economies based on the ocean. After the Ixtoc I oil spill, businesses were upset that tourism declined, leaving people without jobs and marine farmers to have smaller catches. In the 2010 Deepwater Horizon oil spill, British Petroleum set up a $20 billion trust fund to pay for individual claims when they had already spent $11.2 billion in only six months.[38] Since this thesis has already examined the ecological and human health consequences that may occur from oil spills, this last section will attempt to assess the degree of the economic damage felt from residents and towns affected by massive oil spills.

I. Economy of the Gulf

The Gulf is the ninth largest body of water and is very ecologically fertile creating significant economic profit. Around the Gulf, "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."[9] A majority of these 20 million people have a job associated with and based on the Gulf of Mexico's natural resources that may include "tourism and recreation, commercial and recreational fishing and petroleum production and exploration."[9] In 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, [and] the average number of pounds of commercial fishery landings coming from the Gulf [totaled] 1.3 billion per year yielding a value of $662 million."[9] Glancing at the overall numbers of economic profits that occurred each year in the Gulf, one can easily see that the Gulf is a tremendously fertile body of water that not only provides habitats and homes for marine organisms, but also provides food, safety and economic liveliness for the United States. The Gulf of Mexico is an essential asset to the United States. Thus, the United States government has special interests in maintaining this fertile body of water.

Although knowledge of the extensive benefits provided to the United States economy by the Gulf of Mexico is important for understanding the economic impacts of the Ixtoc I oil spill and Deepwater Horizon oil spills, this may not be relevant for spills in other bodies of water. It should be noted that each body of water contains a unique set of resources that establishes its own economic community. However, the common theme that extends to all water resources is that all bodies of water will provide some source of economic activity to the active residents of the region, whether it may be fishing, tourism, exploration or petroleum. Thus, there is a clear link between the ecological consequences that result from an oil spill and the economic impacts on the community. Therefore, communities and nations have a strong interest in preserving the natural resources associated with bodies of water.

II. Impact on the Shrimp and Fish populations

When a young boy heard about the Deepwater Horizon oil spill in the summer of 2010, he felt that his lifelong dream of taking his dad's boat to catch shrimp had been all lost. Like many small businesses, many of the shrimp farmers in the Gulf are family owned and operated and passed down each generation. Recently, this trend has been changing and children have been leaving their parent's business to do other work. The few who remain, like Aaron in Delacroix Island, Louisiana, followed his father's footsteps in becoming a marine farmer. When he heard of the Deepwater Horizon oil spill, he felt that he would never be able to go out to sea and catch shrimp like he has always wanted. Aaron is one of the few thousand of the Gulf of Mexico's shrimp landings who could lose a lifelong dream job due to the oil spill.[39]

In 2008, the Gulf of Mexico produced 188 million pounds of shrimp, which represented 73% of the national total.[39] This large amount of shrimp had a total dockside value of "$367 million with Louisiana landing the largest portion 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 9.6 million pounds and $17.1 million."[40] Again, by sheer number, the shrimp industry provides an immense amount of the supply for the large seafood demand in the United States. In 2008, the commercial harvest sector, seafood processor and dealers, sea food wholesaler and distributors and seafood retailers supported approximately "1.5 million full- and part-time jobs and generated $104 billion in sales impacts and $45 billion in income impacts."[41] Solely counting the coast along the Gulf of Mexico, the seafood industry supported these jobs in the states of "Florida 108,695, Louisiana 43,711, Texas 42,541, Alabama 9,750 and Mississippi 8,575."[41] The shrimp industry is easily one of the most significant industries in the southeast United States. If oil spills cause hypoxia in the surfaces of the ocean, this may leave thousands of people unemployed.

The life cycle of the shrimp may be impacted in all stages. Initially, adult shrimp live near the bottom of the ocean as they release their eggs into the Gulf. As these new eggs grow older, they tend to migrate toward estuarine areas and return to the Gulf of Mexico when they fully develop. Different species lay a different number of eggs but on average the number can range between 250,000 to 1 million eggs. These eggs are first released at the bottom of the ocean near the location of the adult shrimp but the larvae soon hatch and rise to the surface where they will spend most of their lives. Most oil spills like the Exxon Valdez, South Korean oil spill, Torrey Canyon, Amoco Cadiz are from tanker ship accidents where tanks carry oil and release oil onto the surface of the sea. However, in the case of Deepwater Horizon and Ixtoc I, the source of release of crude oil started at the bottom of the ocean, affecting both larvae and adult shrimp populations.

After the April 20, 2010 Deepwater Horizon oil spill, NOAA released an announcement on May 2, 2010 to close fishing areas in the Gulf of Mexico while they were "taking water and seafood samples in an effort to ensure the safety of the seafood and fishing activities."[42] Especially since shrimp and seafood were vital to the economy, NOAA wanted to gather sound scientific evidence that the shrimp was safe enough to consume. The Gulf of Mexico shrimp revenue amounted to $367,029,000 in 2007 and $366,269,000 in 2008.[41] Five days later on May 7, 2010, NOAA further expanded the closures to include a larger body of the United States federal waters. These closures led to a clear short term economic impact.

There are also studies documenting the longer term effects of oil on shrimp. One Mexican study found that two years since the Ixtoc I oil spill, the Campeche shrimp population numbers returned to pre-spill numbers. The Texas Commercial Harvest Statistics also stated that there were no significant changes in the amount of the shrimp catches after the Ixtoc I oil spill.[9]

The largest oil spill before Deepwater Horizon, was a purposeful spill during the Gulf War. In this case, a tanker spilled oil onto the surface of the ocean. In a study from this oil spill, scientists found that the shrimp populations “were damaged, but also benefited from the reduced fishing pressure during the occupation, the war, and the time directly afterwards. A few years later, it was ‘better than anyone could remember that it had ever been’, as a local fisherman put it.”[42] Oddly, fishermen found the area to be more productive after the oil spill. Perhaps, the shrimp, which 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 perturbation.”[9] Due to the shrimp’s short life cycle, less oil and ability to reproduce their offspring in large numbers, the shrimp were able to recover in a reasonable and relatively short amount of time.

Interestingly, three months after the Deepwater Horizon oil spill, NOAA released another announcement to reopen areas of the Gulf to fishing since “No oil has been observed for 30 days in 26,388 square miles [that were] to be re-opened for fishing.”[43] Then in February, NOAA reopened more than 4,000 square miles of Gulf Waters for farmers to fish for royal red shrimp.[44] This was because the shrimp population had started to recover or did not experience a significant enough effect to be closed off permanently for longer than a year. The fishermen observed a larger shrimp population because the shrimp had a chance to recover from the continuous harvest oil spill and closures. NOAA claimed that the loss to fisherman was a temporary setback and the 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.”[9] The temporary short term habitat losses could decrease the population, but the shrimp were fully capable of recovering. Observing the shrimp populations, it seems that this sector suffered a short term loss. For Deepwater Horizon, the time period lasted for three months, during which time fishermen were unable to harvest shrimp.

III. Commercial Finfish Populations

Apparently, there are over 1500 species of finfish (true fish excluding fish such as shellfish, jellyfish, starfish…) in the Gulf of Mexico but only a few are caught commercially. The finfish brought in national revenue of $2,067,302,000 in the year 2007 and $2,254,564,000 in 2008, and $145,282,000 in 2007 and $145,639,000 in 2008 solely in the Gulf of Mexico.[41] The large revenue of finfish in the Gulf of Mexico makes it especially vulnerable to an oil spill.

Like the shrimp populations near Deepwater Horizon, the closures that pertained to the shrimp populations were also applied to the fish that could have been contaminated by the oil. When the Exxon Valdez oil spill occurred, fisheries were closed especially since local consumers were very reluctant to believe that the fish were clean. In one study of the Exxon-Valdez oil spill, approximately 1,535,626 fewer chum, 29,087,523 fewer pink, 199,293 fewer coho, 1,270,714 fewer sockeye and 9,900 fewer chinook salmon were caught in harvests the year after the spill.[40] These numbers provide a means to quantify the economic impact of the oil spill. The numbers differ for each species because there were different closures for different habitats. In another study after the Exxon Valdez spill, scientists found that "in 1989 PAH concentrations were significantly greater in pink salmon tissues from oiled areas than from nonoiled areas, although by only a factor of three. In 1990, there was no difference in tissue PAH concentrations between oiled and nonoiled areas."[45] Since adult fish were capable of avoiding or leaving contaminated waters, this may have been a reason why the impact was not as severe in the Exxon Valdez oil spill. The fish initially caught in the spill may have had higher PAH concentrations, but the study concluded that this was due to the fish being able to swim and avoid the oil. This was despite the fact that there were lower oil concentrations in the water due to a lack of new sources of oil.

Estimates of the amount of fish lost during the year 1989 and 1990 reached up to $108.1 million in 1989 and $47 million in 1990.[46] These estimates were based on finfish and the shellfish caught in the area, but the amount based only on finfish was near $106.7 million.[46] The shellfish did not contribute significantly to the social costs of the area but the finfish did. In the year 1990, the area experienced a loss of $46 million.[46] These were only numbers and estimates from one oil spill, but it did reveal that the finfish populations may have had an economic impact on the local communities. Similar to the shrimp populations, the finfish industry did show signs of economic recovery.

Analyzing the finfish population changes and economic revenue seem to show that oil spills initially have dramatic impacts on the economy, but these are not the only issues that should be considered when examining oil spills. These numbers may help to determine the extent of the possible amount of impact, but they cannot determine the actual concrete loss incurred upon any society or economy. These values did not consider other economic sectors. Oftentimes, oil spills take place in areas heavily dependent on the sea, but this does not always mean that the region is entirely dependent on these resources. Furthermore, many of these numbers do not reflect the compensation that the corporations offered to those who have suffered a loss. Even if the oil spill may have caused fishermen to lose their jobs of harvesting fish, they may have been able to work and gather an income through other means. Oftentimes, residents who live near an oil spill will help with the cleanup efforts. These fishermen or those who lost a job due to the spill could have been employed by the government or a corporation to join the cleanup effort.

In summary, it seems that finfish exposed to oil may die, but after a few years the population will be able to reproduce at alarming rates. However, a study evaluating the population impacts from Exxon Valdez noticed an interesting finding. They found that chronic exposure of oil in fish was still evident years after the oil spill, which increased the amount of mortality in these populations. Soon after Exxon Valdez occurred, scientists predicted that fish would be able to survive and the populations would not be severely affected. However, these studies were based on short term laboratory tests testing for acute toxicity in the fish. In reality, these fish, especially embryos and larvae were chronically exposed to the oil that was dispersed through a large region of Alaska while these "laboratory experiments showed that these multiringed polycyclic aromatic hydrocarbons (PAHs) from partially weathered oil at concentrations as low as 1ppb are toxic to pink salmon eggs exposed for months of development and to herring eggs exposed for 16 days."[47] This explained the elevated mortality of pink salmon eggs for four years after the oil spill.

Due to the ability of finfish to swim long distances compared to shellfish and other commercial species, scientists believed and found that many of the fish avoided oiled waters. Nevertheless, scientists observed higher levels of PAH concentrations in many species of finfish, compared to finfish living in clean waters- years after the incident. Those who assume that finfish populations will remain safe for consumption and increase in population should reconsider their perspectives, since these studies have shown that finfish have elevated levels of PAH years after an oil spill.

IV. Oyster Reefs

For many women, oysters signify shiny pearls, but for fishermen, oysters are a lucrative business for both the pearls and commercial oysters. Oysters live in groups often referred to as oyster beds and oyster reefs. Certain species such as the *Crassostrea* and *Saccostrea* live in the intertidal zone and the hard shell of the oyster provides a habitat for small animals such as sea anemones, barnacles and hooked mussels. Oysters mostly live in estuaries, sounds, bays and tidal creeks in water that can range from brackish water (5 parts per thousand salinity) to seawater (35 ppt salinity).[48] In approximately two weeks, free floating oyster eggs may get fertilized, develop into larvae and form a foot (pediveliger). After settling on a suitable home, they can metamorphose into an adult in one to three years.[48] The oysters are limited in their habitat because they can only settle on a hard plate. However, females produce 15-115 million eggs in a single spawn, where growth depends on the availability of space, so most deserted oyster reefs can easily be recolonized.

These shellfish grow in abundance along the Gulf of Mexico leading the United States in the production of oysters. In 2008, the United States produced 20.6 million pounds resulting in $60.1 million, with Louisiana producing 12.8 million pounds and #38.8 million, Texas at 2.7 million pounds and $8.83 million, Mississippi at 2.6 million pounds and $6.87 million with West Florida and Alabama following these states.[40] One interesting finding in a study by Beck found that approximately 85% of the oyster habitats[49] were being lost over the entire globe. This is probably due to the fact that they are already under ever increasing stresses from warmer weather, higher salinity and dermo diseases. This means that the major source of oysters lies in the Gulf of Mexico. Any catastrophe that may endanger the oyster population will likely have major economic implications on the shellfish industry in the United States.

V. A Response to the Economic Loss

Oftentimes, oil spills utilize tort law (not criminal, but may be intentional) to determine the extent of financial repercussions the oil company should remain liable for. Government officials and citizens all discuss the importance of reimbursing and helping those affected by the oil spill. However, if this were the only opinion, large corporations who have caused the oil spill would be liable for all the damages. In reality, this is not always the case; and I want to point out and give the corporations a voice in my thesis as to reasons why some people do not receive benefits for the oil spill through the ideas of reliance, offsetting benefits and repair and replacement. In reality, when accidents cause direct damage to physical assets, the owner generally suffers from the financial repercussions depending on the situation.

In the case of reliance, owners rely on the "continued availability of the physical asset … if that asset were damaged."[50] In a legal study by Goldberg, he depicted this situation with an analysis of a scenario comparing the market price and cost of fish that could have been affected by an oil spill. If the fish sells for $1 per pound at retail, with a wholesale price of 50 cents per pound and the market value of the destroyed fish is 5 cents a pound, society would lose the difference between the value of the destroyed fish and the fish sold at retail. From one perspective, if the materials and tools used to capture this fish were transferred to a different area, society would still have $1 worth of fish to sell retail and the net loss would be at 5 cents per pound. However, if the resources were so unique that the fishermen could only harvest the fish where the oil spill occurred, these resources would not be used so society would lose $1 per pound. In this first scenario, the fishermen relied on the fish being in the ocean while in the second scenario, the fishermen mitigated their damages by utilizing their assets in a way to still catch fish. From this perspective, it seems that the fishermen could be at fault for depending on the fact that the population of fish would remain constant. Therefore, the fishermen's "financial harm…does not, therefore, depend entirely on the behavior of the oil company. It also depends on their own efforts to mitigate their damages."[50] This may be a reason why some companies deny recovery for indirect losses. The amount of loss can be seen dependent on one's own efforts to mitigate the losses. However, in a different article, the lawyer argued that the oil company would be liable for the oil spill because they were the ones who had power whether the accident occurred or not.[50] It may seem reasonable that corporations may feel attacked and responsible for things that the fishermen should have been prepared for. However, this takes out an element of compassion. Also, the ocean is not the fishermen's properties but properties of the entire nation as a whole. As these fishermen are citizens of the country owning the Gulf, the corporations, when inflicting damage onto public should be expected to pay for their damages.

Nevertheless, the oil company remains liable to a certain extent regarding the oil spill, and oftentimes tries to make mitigation more efficient after the spill (ex post) or before the spill (ex ante). In the case of ex post, the solution is to "make the victim's compensation independent of her efforts"[50] where the victim works hard to adapt to a new response to recover what he has lost instead of remaining idle and waiting for compensation without any effort. In the ex ante scenario, the company could award those who have back-ups in case a situation occurs where the investment or asset were no longer usable.[50]

Overall, when one part of society feels a loss, generally, another group of people or community tends to experience a gain either through increased tourism in that area or through a shift in jobs and resource utilization. This situation is most clearly understood like a blockaded artery also depicted by Goldberg. When an artery is clogged, the blood moves through a different artery. Since there is no blood passing through artery A, arteries B and C receive a greater flow of blood, which is the theory behind this economic theory. In the end, society as a whole still remains equal. However, the problem is that sometimes these accidents may not be preventable or the victim may be unable to respond to the damages to mitigate the injuries.[50]

In the case of tort law, the government plays the role of surrogate plaintiff allowing individual victims to petition for government assistance. The government decides the method of compensation. Since the government decides, they are able to determine the loss to the actual whole. If individuals clean up parts of the oil spill, the oil company may not provide financial support to regions that have been cleaned up, but if the government acts as the surrogate plaintiff, anything that has been done and will be needed to clean up the oil spill will be included in the financial package. Although some oil companies may refer to the fact that the fishermen were placing too much reliance and not acting enough to mitigate the damages, since oil spills oftentimes occur only within the power of the oil company, the company remains liable for the damages that they incur onto the peoples. When the government acts on behalf of the people, like in the Exxon Valdez oil spill, the loss is addressed as a whole instead of as individual claims.

The Gulf of Mexico and the residents who lived near the Gulf heavily depended on the region's natural resources. They relied on the productivity of the ocean to sell their goods, make a profit and enjoy the delicious seafood of the oceans. These residents and entrepreneurs may have relied on the ocean, but they were powerless in determining how and when an oil spill occurred. When it did, they attempted to recover by working together to mitigate the damages through various resources and should not be held responsible to deal with the situation without compensation from the injurer.

For Exxon Valdez, NOAA mobilized scientific and support staff while state and federal agencies attempted to determine the situation, clean up the affected areas and assess the impacts from the oil spill. These assessments caused Exxon to be liable for a $900 million financial settlement, the largest at that time to compensate for any hazardous situation.[51] Furthermore, the government responded with an additional package with the passage of the Oil Pollution Act in 1990, enabling NOAA to conduct natural resource damage assessments on oil spills. This Act improved and expanded the ability of the federal government to respond and prevent oil spills.[52] Unlike Ixtoc I, following the Exxon Valdez incident, the federal government learned that they needed to develop and implement legislative policy in hopes to prevent another catastrophe.

Observing the 2010 Deepwater Horizon oil spill, one can see that the federal government and agencies realized the importance of making legislative action to prevent oil spills. In May 2010, a Congressional legislative package ensured that there was a rapid response to the Deepwater Horizon oil spill to assist those affected by the spill and update the current liability system to prevent catastrophic events. This piece of legislation created a source of immediate funding, funding to test for food safety, money to monitor and improve offshore oil exploration and provide funding to the Environmental Protection Agency and NOAA to study the impacts and improve federal response to the oil spill. For individuals and businesses, the bill assisted those unemployed due to the oil spill with nutrition assistance and employment assistance while also creating a one-stop assistance program to process claims and obtain benefits quickly. For the communities, the bill provided an economic recovery fund granted to different entities. For example a fisheries disaster fund provides funds for unemployed fishermen, and Small Business Administration low interest loans are available for suffering small businesses. Finally, the bill ensured that oil companies would be responsible by ensuring British Petroleum to compensate people affected by the spill, raising the liability caps, increasing the excise tax that funds the oil spill liability trust fund and promoting program integrity and ensuring aid dollars were spent in an appropriate manner. Compared to the earlier responses that occurred when a massive oil spill struck, Deepwater Horizon has caused a large uprising in Congress so that citizens of the United States will be taken care of and compensated for their losses. A bill for Deepwater Horizon was created in attempts by the federal government to help various people who may suffer from the oil spill.[53]

Over the years, it seems that the government had decided that the residents and entrepreneurs were powerless against the corporations and needed protection. They have progressed in making these steps to ensure that the entrepreneurs' businesses and the natural resources of the Gulf of Mexico would be restored.

CHAPTER 5: CONCLUSIONS

This thesis employed a literature review to assess the potential impacts of oil spills. While economic, thermodynamic, environmental, ecological, human health, and sociopolitical impacts of oil spills have been identified in the literature, the focus of this thesis was on three of the most important of these factors; namely, ecology, human health and economy. Literature was reviewed for each of these factors to identify the short term and long term impacts of oil spills. The reviewed primarily focused on the Ixtoc I, Deepwater Horizon, and Exxon Valdez spills; although data from other oil spills were used to support the findings.

I. Ecological Impacts

Two major conclusions were reached with respect to ecological impacts:

- Short term ecological impacts of hypoxia in the upper levels of the ocean were a significant concern, but hypoxia in lower levels of the ocean was not as significant.
- Decreases in population levels of most animal species were generally limited to the short term; however, potential long term impacts for endangered species were identified.

The presence of hypoxia following a surface oil spill is not surprising. Microorganisms predominantly perform aerobic respiration to degrade oil causing the upper levels of the ocean to become hypoxic which in turn causes marine life to flee or die. This is only a short term impact because the water is re-circulated annually. At greater depths of the ocean, it was hypothesized that longer term nutrient issues would be apparent; however, studies of the Deepwater Horizon Oil Spill showed that even in the event of an oil spill, aerobic respiration was insufficient to cause the area to become hypoxic.

It was found that animals that were already at risk on the endangered species list typically had more difficulty recovering to their pre-spill population levels. Especially impacted in population levels were sea turtles and sea otters because their pre-spill population levels were already low and they produced fewer offspring. In contrast, many species of birds showed signs of recovery to their pre-spill population densities and were clearly recovering at a faster rate than the sea turtles and sea otters because they produced more offspring, were not endangered before the spill and their offspring have shorter periods of development. These populations are expected to return to pre-spill population levels within 3-5 years of a major oil spill.

II. Human Health Impacts

In regards to human health, most acute neurological, respiratory, dermal and ocular symptoms receded quickly, but many of the residents did experience long term psychological symptoms such as depression and post-traumatic stress disorder due to the changes in their lifestyles. Quantifiable metrics for other long-term health effects were not available due to the difficulty in conducting epidemiological studies for these infrequent short term events.

III. Economic Impacts

Economic impacts were primarily associated with the commercial fishing industry and tourism. Impacts on tourism are predominantly short term. Oil spills have the potential for having both short and long term impacts on the fishing industry. Several of the impacts identified in the literature were:

- Closure of fishing areas for significant amounts of time due to oil spills can have a significant economic impact on areas where fishing represents a significant portion of the economy.

- While the long term impacts on species with short life cycles is minimal, slow growing species such as finfish may still be contaminated with oil years after a spill.

Oils spills definitely impacted the economy of the region associated with the spill because of fishing closures that resulted from potential elevated levels of oil in shrimp and finfish and because of the reduction in tourism associated with contaminated beaches. However, these closures did not last very long, and due to the lack of harvesting, farmers often found larger populations of shrimp. Finfish took a longer time to recover which impacted the fishing community in the region. Oysters can reproduce and develop very quickly but because of changes from normal conditions, many oyster resources have been lost worldwide. Their impact from oil spills is more short term with respect to their abilities to reproduce to pre-spill levels in the Gulf of Mexico.

IV. Recommendations

Certain aspects of oil spills have the potential for altering the ecosystem of the Gulf of Mexico and the economy of the region. Endangered sea turtles and sea otters, that were almost wiped out before the Endangered Species Act was placed into effect, can never be recovered once lost. These species are sensitive to the size and cleanup rate from an oil spill and should be observed carefully when an oil spill occurs. Government officials, scientists and corporations should investigate these situations when analyzing the effects of the oil spill and in trying to determine what regulations should be placed to prevent further spills.

Oil spills produce short term impacts on the ecology, human health and economy, as well as a few long term impacts. Many laws protect the Gulf of Mexico from potentially more catastrophic disasters. However, these laws must be enforced and new regulations should be considered. While it is clear that ecosystems have some resiliency and economies do recover from a single event, if frequent spills occur in the same region the ability to recover may diminish and lead to loss of a species or death of marine organisms due to hypoxia. Regulations should be created to reduce the potential for perturbations of the world's natural resources in order to prevent potential irrevocable impacts.

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