An introduction to Marine oil spills

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Summary.
This essay provides information on the components of an oil spill in the sea, the effects of different parts of the spill on marine organisms and ecosystems and the potential for long term recovery of ecosystems. Oil spilled at sea breaks into many different chemical and physical components that spread throughout the system- floating, suspended in the water, sunk to the bottom, buried in sediments and coating organisms and coastal habitats. Marine organisms-plants and animals – from smallest plankton to largest whales, can be affected by both the physical and chemical impacts of oil, tar and toxic oil compounds. While the immediate effects can be catastrophic, and medium and long term effects last for years or decades and affect all parts of the system, marine ecosystems are resilient and eventually recover.

Introduction.

The current Deepwater Horizon Oil spill in the Gulf of Mexico has raised serious concerns about the likely environmental impact on the inshore waters and shores of all the Gulf States (Florida, Alabama, Mississippii, Louisiana and Texas) a multi-agency task force and oil company teams are working to contain the spill and minimize its spread and damage, but some impact along these coast seems unavoidable. Catastrophic oil spills in other places, from both tankers and oil wells (notably the Torrey Canyon in the English Channel, Exxon Valdez in Alaska and the extensive oil well destruction during the Iran-Iraq war in the Arabian Gulf) provide some background and information on what we can expect in the Gulf of Mexico. Each of these oil spills involved attempts to contain the oil spread, use of dispersants and other means to reduce its impact and extensive scientific study and monitoring of the effects. The following provides summarized and simplified information on oil spill impacts.

Anatomy of an oil spill.

Crude oil is a complex mixture of hydrocarbons with the initial appearance and consistency of thick dirty used oil. When crude oil is released into the sea a number of physical and chemical changes occur:

The oil initially floats in a layer up to several inches thick at the water surface which is spread and moved by wind and water currents. Immediately, more volatile components begin to separate and disperse into the atmosphere and water soluble components (called polycyclic aromatic hydrocarbons, PAHs) leach into the surrounding water. Lighter insoluble components form thin films that spread and move more extensively than the thicker oil. The warmer the sea and air temperature, the more rapidly these components separate. Wave action separates the mass into smaller areas and patches, and eventually into smaller globules, some of which emulsify ('mix') with seawater. Oil-water emulsion has the characteristic tan- yellow color often seen in floating oil slicks. Dispersants (detergent like substances) distributed to break up the oil slick facilitate the formation of emulsions, distributing the oil as droplets of oil and emulsion throughout the water column.

As the lighter components dissolve, the remaining oil develops a thick gooey consistency, and breaks into pieces anywhere from mm to several cm diameter. Depending on the temperature, water content and the surface to volume ratio of these globules, they may remain buoyant, become suspended in the water column, or sink to the bottom. The 'oil slick' therefore contains a number of components, thick mats of oil, oily films, oil/water emulsions, particles and lumps (tar balls) that may float or sink and material dissolved in the water below and dispersed into the air above. This mixture of components becomes progressively more dispersed and difficult to contain as time goes by, and as wave action and temperature have their effect.

As the slick approaches the shore, some of the denser oily components ('tar') become mixed with sand, mud and floating debris forming 'tar balls' with variable buoyancy and mobility. These particles may be mixed into the bottom sediments, roll around on the bottom, or wash up on the beach or marsh. In warm climates, tar balls may melt on hot days, break up, remix and harden again, continually breaking up and releasing additional soluble and volatile components.

Although the majority of spilled oil remains floating at or near the sea surface, components may be spread throughout the marine environment, water column, bottom and bottom sediments, and shoreline habitats.

Box 1. Components of an oil spill

- Floating crude oil
- Lighter insoluble components in water films
- Soluble toxic components dissolved in seawater
- Volatile components in atmosphere
- Floating emulsions of oil and seawater
- Particles and globules of oil and emulsion floating, suspended and sunk
- Oil, films, emulsion and tar coating marine substrates and organisms
- Oil, emulsion, and tar buried in marine and coastal sediments
- Tar balls, floating and buried in underwater and coastal sediments

Effects on marine ecosystems

These components affect living organisms in many ways. Some of the soluble components and emulsions are poisonous, particularly to small organisms that do not have protective coverings or shells- Fish larvae, single celled algae and many kinds of plankton are vulnerable and these are the basic foundation of the marine food chain. In shallow water these toxic substances may directly kill algae, coral and sea grasses. These components may also be passed in the food chain or directly ingested or absorbed through the gills of fish and other larger marine organisms. The effect may be to kill the animal or contaminate its tissues.

A thick film of oil on the sea surface may reduce sunlight penetration and reduce photosynthesis.

Small particles and emulsions may be ingested or block the feeding mechanisms of invertebrates such as oysters, starfish, sponges and corals. These particles also may have toxic components, so the effects can be physical, chemical or both.

The most dramatic impact of oil spills is the coating of larger animals with oil. Animals that breathe at the surface like dolphins, sea turtles and manatees may inhale oil and toxic vapors. Sticky oil may also coat their bodies. Coating with oil is particularly devastating to birds. Even a thin coat of oil compromises the waterproof quality of feathers, causing the bird to become water logged and loose heat. Animals, like some sea turtles, that feed at or near the surface may ingest tar balls and particles that then physically blocks their intestines and may be toxic as well.

At the shoreline, shallow waters and coastal estuaries and marshes, the impact of the layer of oil, floating and suspended emulsion and particles can be devastating, coating plants and benthic animals like corals, crabs and shell fish, preventing photosynthesis and breathing and blocking filter feeding mechanisms. These materials become mixed into shoreline sediments and remain in the system for years.

'Dispersants' are detergent like substances that can be applied to an oil slick and accelerate the emulsification, break-up into particles and dispersion of the thick oil. This limits the spread and the distance that a slick moves. However it is important to recognize that the oil does not go away- its all still there, just in the form of smaller particles and emulsion that is less mobile. In addition, dispersants may also be toxic or have deleterious effects on the natural environment, particularly on small single celled organisms.

Box 2. Summary of oil spill effects

- Crude oil separates into a variety of forms that distribute throughout the marine environment.
- The longer the time, warmer the temperature and stronger the wave and wind, the more dispersed into different components the oil becomes.
- These may have direct toxic effects.
- Toxic effects my directly kill an organism or may contaminate its tissue and pass through the food chain to other organisms.
- Many components of a spill (liquid oil, emulsions, particles, tar balls) have physical effects, blocking feeding, photosynthesis or respiration, or compromising feathers and fur
- Dispersants may break up and prevent further spread of liquid oil, but do not remove the oil from the system, which remains in solution, particles, emulsions. Dispersants may have their own toxic and physical effects.

So, while the most spectacular and disturbing effects of an oil spill are liquid oil caking beaches and animals, in fact the most serious effects may from other parts of the spill, on numerous parts of the ecosystem that affect its basic integrity and productivity.

Vulnerability of the Gulf of Mexico.

The Gulf of Mexico and its coastal shoreline has some special features that will affect the outcome of a major oil spill.

- Warm Temperature
- Vigorous Wave action
- Ocean currents
- Low Shoreline profile
- Vulnerable coastal fisheries

As we approach summer, air and water temperatures in the Gulf will be warm 65-75^{o} F water temperature and 80-95^{o} F air. These warm temperatures will keep crude oil and tar liquid and mobile and speed the dispersion processes. In the longer term(years), warmer temperatures will probably accelerate the rate of decay of oil and the eventual recovery of the system, but this will not be evident for several years.

The Gulf of Mexico is infamous for generating short steep waves with relatively little wind. These waves tend to break and foam easily. This will speed up mixing and emulsification of oil and water in the spill.

The Gulf is dominated by the 'Loop current' a precursor to the Gulf Stream which flows counter clockwise from Texas, parallel with the shore, down to the Florida keys where it flows through the Florida Straits and becomes part of the Gulf Stream. The loop current flows well offshore, approximately along the edge of the continental shelf, which lies 200-300 miles west of the Florida peninsula. Like other major ocean currents, the Loop current throws off eddies- circular swirls of current -that can spin east and northeast across the Florida shelf and close to shore. The Loop current and its eddies will likely transport oil from the spill along Florida's coast.

Most of the Gulf shoreline is characterized by low flat shorelines. Extensive shallow offshore sea grass beds give way to shallow coastal marsh along much of the coast, and extend for miles inland. Parts of the coast have raised sandy beaches and dunes. The generally flat profile of much of the Gulf shoreline will result in penetration of oil across a very large area of shallow water and coastal marsh. In contrast to steeper rocky shores In Alaska (Exxon Valdez) and English Channel(Torrey canyon) where oil impacted a narrow strip of shoreline, in much of the Gulf coast, the penetration of oil will cover hundreds of square miles of shallow coastal habitat.

The productive waters of the Gulf coast support several significant commercial and recreational fisheries that will likely be impacted by the physical and chemical effects of oil. These fisheries are strongly dependent on shallow coastal waters, and periodic tidal ebb and flow. Among these are oysters, scallops, shrimp, crabs, redfish and spotted sea trout all of which depend on seagrass and shallow marsh and tidal creeks.

Consequences of marine oil spills.

From the preceding information it is obvious that the oil spill can cause extensive mortality throughout the marine ecosystem from the basic foundations of phytoplankton , algae, coral and seagrass to the largest and most mobile organisms. Additionally, the spill contaminates the tissues of organisms and plants which then pass into the food chain. These effects result from numerous different parts of the spill and different mechanisms and affect the marine environment from the open ocean to the shore and coastal estuaries and marshes.

Surprisingly, many studies suggest that while there is evidence of high mortality of fish, birds, sea turtles etc. that the majority of these larger organisms, and many smaller creatures, actually survive the early phases of the spill. Large mobile organisms like birds, fish and dolphins avoid the spill and take advantage of gaps in the spill coverage. Many animals survive partial exposure to oil, emulsion and tar. While the effects are unsightly, they may not be immediately lethal.

Box 3. Vulnerable marine organisms

- Phytoplankton (single celled marine algae) -soluble toxins, entanglement in emulsions, shading
- Zooplankton -soluble toxins, emulsions
- Sea grass and algae- shading, coating, toxins
- Eggs and larvae of fish, crustaceans, molluscs-soluble toxins
- Pelagic invertebrates (e.g. squid, jellyfish, salps)- toxins, reduction and contamination of prey
- Pelagic and coastal small fish- ingested particles, absorbed toxins
- Pelagic and coastal large fish- ecosystem effects, reduced productivity and prey, tissue contamination
- Mobile benthic and coastal invertebrates (e.g. crabs, shrimp, octopus, conch, scallops)-toxicity, food contamination, coating, tissue contamination.
- Fixed benthic and coastal invertebrates (e.g. mussels, oysters, corals)- toxicity, coating, impaired feeding, ingestion, tissue contamination.
- Sea turtles- breathing, coating and ingestion of particles, food (contamination of benthic invertebrates, algae and sea grass).
- Cetaceans(dolphins and whales)- breathing, coating and ingestion of particles, reduction and contamination of prey
- Manatees -breathing, coating and ingestion of particles, system effects- sea grass mortality
- Birds-coating, ingestion, system effects food contamination

More subtle medium term effects are the result of the disruption and contamination of marine food chains. The failure of plankton, small prey fish and invertebrates causes later problems of starvation, low birth weight, reduced egg clutch size and reduced survival for predators in the upper levels of the food web such as seals and seabirds. These effects may not appear for months or until subsequent breeding seasons. Poisoning and shading of seagrass beds results in reduced photosynthetic productivity on which a host of creatures depend, and is followed by erosion in coastal waters when sediments are no longer secured by seagrass roots. Similar effects can occur in coastal marshes when emergent marsh grasses are covered and killed. These effects likely affect fish and other commercially fished species but are more difficult to demonstrate or prove.

Longer term effects are poorly understood, but the removal of particular vulnerable species from marine ecosystems may change the way the system works- affecting 'the balance of nature'. Persistent non-lethal effects of contamination on reproduction are suspected to persist for years. These can be exacerbated as storms and wave action uncover oil and tar buried in coastal sediments and beaches- re-exposing organisms to their effects.

<u>System recovery</u>.

Despite these gloomy predictions, the effects of oil spills are not permanent and complete. Marine systems show remarkable resiliency and as the oil becomes sequestered in less active forms (tarballs, buried oil etc.) and is broken down by sunlight and bacterial action, the systems recover. Survivors reproduce and recolonize habitats. Some creatures adapt to tar and oil covered substrates and some crabs and mollusks actually eat the tar and the bacteria and fungi growing upon it, and aid its degredation. The oil in its several forms is dispersed, diluted and broken down until only small pockets and particles remain. Marine systems are by their very nature open- that is connected by the sea, wind and currents to distant uncontaminated regions. Many marine organisms have mobile life phases(floating eggs, larvae) that recolonize and re-establish populations. Some of the creatures affected by a spill also routinely suffer catastrophic mortality from other causes (e.g. some colonial nesting seabirds) and are well adapted to recover. Large mobile animals like sharks, sea turtles, large fish and whales that moved away from the spill move back. Although there may be significant mortality of some of these animals, overall the impact on their populations is usually not permanent.

In the well studied cases in the Arabian gulf, Alaska (Exxon Valdez) and English Channel (Torrey Canyon), the appearance of the system returned close to normal within a few years. Although there was still oil and tar present in the sediments, and continuing effects among the organisms there was visible recovery of major parts of the system (seagrass beds, rocky intertidal habitats, coral reefs). With the passage of time, approximately a decade or so, and rebalancing of ecosystem and the creatures living in it, the system continues to function and returns to productivity, fisheries recover and many of the organisms are restored to their previous abundance. While such widespread intense disruption may causes changes in the balance of nature- which species are present and how numerous they are- nature itself survives. Although such catastrophic events are very damaging and economically expensive at a human scale, on an ecological time scale they are passing disruptions and on an evolutionary timescale, barely perceptible.