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Assessing the Impact of Oil Spills on Marine Organisms

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Abstract

In a world with increasing crude oil production, oil spill accidents cannot be neglected when addressing pollution issues. The availability of crude oil constituents in the environment has posed serious threats to the marine community. Even biodegraded byproducts have also been discovered to be toxic to animals hence the need to know the impacts and future remediation methods. Marine organisms such as vertebrates and invertebrates are known to be affected by PAHs from the free floating embryo and larvae to their sexually matured adults. Impacts from lethal to sub-lethal dose of PAHs include habitat destruction and loss, mass mortality, impaired physiological functions such as reduced feeding, growth and development, respiration problems, loss of locomotion, balance and swimming. Most of these marine organisms take very long periods to recover and some never recover from these impacts which in tend affect the overall health and serenity of the marine environment. This paper seeks to review the lasting impacts of these spills on marine life and possible remediation methods.

Keywords: Oil spills; Polycyclic aromatic hydrocarbons (PAH); Marine vertebrates; Marine invertebrates; Physiological functions

Introduction

The marine environment has been continuously threatened by oil spills in spite of the essential technical developments in the safety of extraction and transport of crude oil and gas. These spills pose and cause severe and decade long havoc on marine and coastal ecosystems and the organisms that sustain them [1]. Within the period of 2010-2014, 5,000 tons of the average 10,000 billion tons of crude oil transported by sea yearly was spilled due to accidents, cleaning operations or other causes [2]. For example, washing ballast tanks account for 36,000 metric tons (11.2 million gallons) of oil entering the oceans globally every year; human induced activities and non-tank vessels [3]. Although natural seeps releases oil into the marine environment, the oil is mostly released at low rates to which deep sea organisms are adapted to unlike the unexpected swift discharge of large quantities that occur during an oil spill or extraction accident [4]. The enhanced technical standards for oil production has reduced large spills (which ranges from 7-700 tons and above 700 tons of oil) drastically during the past decades to an average of 5.2% for the 7-700 tons and 1.8% for those above 700 tons per year, whiles smaller spills (less than 7 tons of oil) representing an estimated 80% of all recorded spill has been going unnoticed and unreported [3]. The concentration of dissolved and dispersed hydrocarbons that marine organisms are exposed to is highest during initial stages of the spill [5,6]. Hence the major toxicity mechanisms for smaller spills are from immediate exposure which disappears from sight during the first few days without the oil been necessarily degraded from the sea surface [7]. According to Brussaard et al. measurements on the ES-2009 spill specified that slick concentration and dissolved oil compounds were high and spread from the water body and travelled directly underneath the slick to distances of at least 500 m from the spill even though slick was not visible after ~20 h. They also discovered that the dissolved oil components were available immediately to the biota in the earliest spill samples (2 h and 6 h after the spill). These data helps conclude that accidental oil availability even in smaller quantities in the marine ecosystem is of much concern and hence studies on the impact of oil spills on marine organism needs to be assessed (Figure 1). Also rising demands for marine oil exploration is likely to increase rather than decrease hence an increased frequency of small spills. Various researches has documented oil toxicity at its highest during the initial stages of a spill [5,6] hence even smaller spills can possibly cause prolonged impacts and pose a serious risk to marine ecosystem health and biota. For instance, major shipping routes on the North Sea is recurrently contaminated with oil, either from unintentional spills or maybe from natural oil and gas seeps [5,8] discovered a lot of unsupervised and undocumented spills within the major shipping routes on the North Sea. Even though some of these spills were small and not visible on the surface water, they release very high C30-C38 concentrations (above 80 µg/l), significant alkane and PAH levels (20-60 µg/l) and showed high toxicity values. The marine ecosystem comprises of various animals from microorganism, vertebrates (fish, birds, mammals, and turtles), and invertebrates (copepods, mollusks, crustaceans, and echinoderm). These organisms are exposed to various degree of impact during an oil spill accident. Various research have detailed the toxicological effects of oil (such as increased mortality or as sub-lethal injury, impaired feeding and reproduction and avoiding predators) on fish communities [9,10], estuarine communities, mammals, birds and turtles [11,12], deep-water corals [13], plankton [14], foraminifera [15], and microbial communities [16]. This paper seeks to review the various toxicological effects of oil spills on the marine vertebrates and invertebrates.

Crude Oil Toxicity

Crude oil is primarily made of a combination of hydrocarbons and 10% of molecules with heteroatoms such as Sulphur, Oxygen and Nitrogen [17]. The combination of hydrocarbon varies from small unstable and explosive monocyclic aromatic hydrocarbons to large non-volatile polycyclic aromatic hydrocarbon [3]. These hydrocarbons are categorized principally by their chemical structure. However, in the marine environment; their solubility, molecular weight and availability

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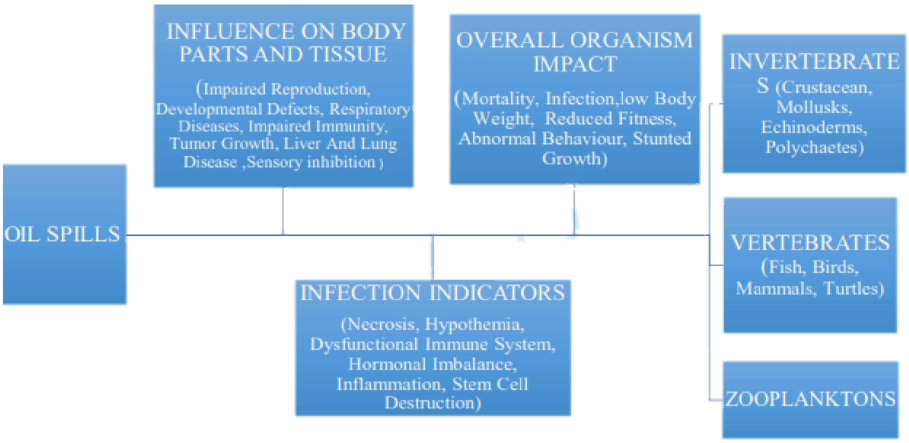

Figure 1: Summary of the impacts of oil spills on marine organisms.

determine their final impact and state [18]. The toxicity in oil is mainly from aromatic hydrocarbons, particularly polycyclic aromatic hydrocarbons [19]. Monocyclic aromatic despite their explosive nature are less persistent hence are not accumulated in water, sediments and tissues of marine organism [19,20]. PAHs exhibit this toxicity due to their binding ability to DNA and protein [21] less solubility and high persistence hence carcinogenic and causing long term chronic impact even when available at small levels to marine organisms. PAHs are mostly prevailing in fresh oils or weathered oils depending on the number of rings. Current observations have suggested that not only PAHs are responsible for the toxicity but the presence of oil droplets causes harsh impacts [22]. This suggestion was established when Atlantic haddock (*Melanogrammus aeglefinus*) showed extreme sensitivity to dispersed oil which was assumed and related to direct interaction with oil droplets [23-25].

Currently, photo oxidation and microbial biodegradation are important processes used to breakdown or eliminate oil from the marine environment [26]. However, research over time has proven the risk posed to aquatic organisms by the by- products from these biodegradation processes [27,28] discovered toxicity of microbial degradation to the early life stages of crabs, sea urchin and marine worms. For photo oxidation by-products; early life stages of mussels and oysters had enhanced oil toxicity [27] and copepods, oligochaete worms died when exposed to it [29].

Importance of Marine Organisms

The marine ecosystem is a home of many life forms from microorganisms, plants and algae, invertebrates to vertebrates. Plants, algae and some plankton serve as the primary producers for major food webs and also serve as food to other higher trophic level organisms. They contribute to major commercial fisheries and are important part of human diet providing essential nourishment for the body. They also serve ecotourism purposes. Marine tetrapod such as mammals, birds, and turtles are mostly displayed in aquariums for tourist viewing among other beautiful marine organisms. Most marine species provide ecological and ecosystem functions. Zooplanktons help in biogeochemical cycling and the changing aspects of marine food web among other functions. Marine invertebrates offer a lot of functions. For example, Crustaceans such as krill and copepods play an important role in pelagic food web, provide food and sustenance to large vertebrate and invertebrate predators, large foraging fish and support commercial fishery e.g. shrimp, lobsters, and crabs [30]. Crabs help in sediment turnover and escalate the available oxygen and nutrients in sediments [4]. They also act as an ecological link between marine, marsh and terrestrial ecosystems. Some amphipods also play significant role in the food webs as herbivores and prey to higher vertebrates and invertebrates and also help in the degradation of plant and animal matter to make nutrient accessible to other members of the marine ecosystem. Some mollusks also play vital environmental functions such as enhancing clearness and quality of the water system provide home and hunting places for fish and other a major commercial fishery source.

Impacts of Oil Spills on Vertebrates

Fish

Oil spills affect fishes in various ways; including increased mortality [31], kill or cause sub-lethal damage to fish eggs and larvae e.g., morphological deformities, reduced feeding and growth rates, increase vulnerability to predators and starvation [23,32], habitat degradation, loss of hatching ability of eggs, fouling of gill structures, impaired reproduction, growth, development, feeding, respiration [4]. Fish stock has been revealed to be at risk and susceptible to large oil spills [31]. However, this susceptibility is mostly experienced at the early stages i.e. egg and larvae [27] due to their under developed membrane and body structure, and detoxification structure [33]. The early life stages of fish are susceptible to polycyclic aromatic hydrocarbons even when available in little concentration and can cause death, malformed morphological structures, circulatory failure, stunted development and low appetite [23]. These effects according to Sorhus et al. were due to the impact crude oil had on the genes (change in expression) that control the ion, amount of water and purpose or morphogenesis of specific tissues and organs. The impacts are also related to the alterations in composition, structure and life history of marine fish eggs and larvae. The polycyclic aromatic hydrocarbon also interrupts the normal development and role of the heart which can further cause pace and contractility flaws at the scale of the emerging heart and failure of circulation [24,31]. Barron MG et al. discovered that when juvenile pink salmon (*Oncorhynchus gorbuscha*) were exposed to crude oil, they exhibited stunned reaction, slow and low movement, loss of stability and balance, melanosis and inconsistent swimming. However, these responses were not heightened by phototoxicity due to its high skin pigmentation [34,35].

The haddock, cod and zebrafish are fish species mostly used in crude oil toxicity experiment [23-25]. According to Sorhus et al. oil stains were found on the chorions of haddock upon the introduction of crude oil droplets documented that the sticky nature of the surface of the chorion that enhance the binding of oil stains is known to decline through the early development stages to hatching when the embryos are exposed at late stage of embryo growth, the oil droplets attach to distinct parts of the chorion. Both haddock and cod are sensitive to very low concentrations (<10 μg/L tPAH)) of oil causing toxicity; however, haddock is more affected by oil droplets than cod. This is because of the added membrane of adhesive material covering the primary egg envelop of haddock eggs and also the distinct structure of the haddock chorion hence allowing oil droplets to interact and adhere to it however Cods are more sensitive water-soluble fraction of PAHs [36]. PAHs in haddock and cod samples measured were found in their internal embryo. For haddock this was related to the binding of oil to the chorion exposing and increasing PAHs uptake by the embryo leading to extreme and heightened toxicological responses such as deformation and cardio-toxicity [25].

Tetrapod vertebrates (birds, mammals, turtles)

Exposure to oil can have detrimental effects on bird health and behavior, and when consumed can cause harm to the lungs, liver and kidney. One of the common impacts of oil on birds is the ensnaring of their feathers which alters the feather microstructure [37].

The feathers of birds help to generate warmth and prevent them from sinking to the bottom. Ensnaring causes the organisms to loss their floating and flying ability due to compressed plumage and allows water to contact the skin [38] causing hypothermia and eventually death most especially during cold weather. Birds exposed to oil experiences impaired health such as ulcerations, cachexia, hemolytic anemia, and aspergillosis [39]. According to Antonio et al. [40] coastal birds were most affected after the deep-water horizon oil spill. Bird species such as *Pelecanus occidentalis, Thalasseus maximus, Morus bassanus, North America loon Gavia immer, dunlins Calidris alpine* were affected ranging from high rate of oiling, increased PAH in plasma, to disturbance of resident communities. Finch et al. studied the impact of weathered oil on mallard duck *Anas platyrhynchos* embryo and discovered that the 7 day old bird embryo died on exposure to even small doses of weathered oil (or 0.5 mg/g egg) [11,41].

Marine Mammals are mostly exposed to oil on the sea surface and shoreline causing eyes and adenoidal tissue damage low immunity, lung and adrenal diseases [42,43]. Sea otters, dolphins, whales and sea turtles are mostly affected by oil spills. Sea otters have their fur soiled which hinders insulation and water repellence. During cleanup it consumes oil causing tissue damages [42]. Although little research is available for the impact of oil spills on mammals; following the Deep-water horizon oil spill, the US National Oceanic and Atmospheric Administration, Office of Response and Restoration (NOAA), documented the various response of marine biota to oil spills. Dolphins, sea turtles and whales are known to breathe at sea surface and ingest oil after an oil spill resulting in respiratory irritation, inflammation, Emphysema/ pneumonia, gastrointestinal inflammation, ulcers, bleeding, diarrhea, and may cause damage to organs. Furred mammals (seal, sea otters) are at risk of hypothermia whiles mammals without furs (Cetaceans and manatees) are not. Carmichael et al. assumed stress from bacterial attacks and reduced diet resources were responsible for the death of bottlenose dolphins. Analysis of live bottlenose dolphin exposed to oil had lung and adrenal ailments coupled with other poor health disorders [44,45]. Other research confirmed the vulnerability of the dolphins to bacterial infections and other health ailment that could possibly lead to death [46,47]. Sea turtles experience esophageal papillae in their throats from oil ingestion and since they can inhale for extended times, ingested oil may be highly absorbed into their bodies [48]. Oil components in female turtles are inherited by their young ones and impede growth and survival of sea turtles developing in the eggs. Oil coated sea turtles experience impaired diving, feeding, mating and also expose them to respiratory problems which eventually puts them at risk of fatigue and lack of fluids in their system [48]. Although various research [40,49-51], have not directly linked oil contamination to turtle mortality, survival of sea turtles severely smeared in oil is unlikely without medical attention [48].

Impacts of Oil Spills on Invertebrates

Biological remediation methods such as biodegradation have been given much attention to help prevent long and short term effects of oil in the marine environment [13]. It has been noted that biological entities, for example microorganisms are adapted to small and slow releases from natural seeps hence need some adaptation on the presence of large quantities of oil [51]. The degradation rate cannot prevent oil from reaching the coasts, deep seas and estuarine communities which serves as habitat for most invertebrate communities although they found throughout the oceanic ecosystem and impact negatively on them by destroying their food webs and causes acute and chronic toxicity [3]. The reaction of invertebrates to oil varies based on the way they feed, how they respond to ingested contaminants, and their living environment [1]. Although some spills don't have deadly impacts on invertebrates, they can cause long lasting effects on their physiological activities such as respiration and reproduction among others [34]. The intensity of the impact can however depend on the developmental stage of the organism, its migrating ability, the organism characteristics and the characteristics of the oil spilled [20].

Crustaceans

Marine crustaceans are divided into planktonic (open waters, free living, ability to move) and benthic (deep sea, terrestrial, estuaries, mobile, attach to substrates and rocky areas) crustaceans [30]. Crustaceans are susceptible to oil through digging into oiled sediments, food ingestion, and direct interaction [52] and are known to be very sensitive to pollutants and experience high mortality after oil spills [53,54] . Crabs are mostly exposed to oil toxicity through coating on surfaces and body suffocating, feeding on oil polluted sediments which causes ensnaring and blockage of the gills, and low feeding [55,56]. Heavy coating of oil on the crab's body has detrimental impact such as impaired physiology and behavior, interfering ecosystem roles and transferring to crab predators [57]. Various research have recorded high death of crabs exposed to oil spills whiles surviving members have impaired movement and digging ability [57,58]. Discoveries made showed that these impacts are long lasting and sometimes full recoveries are never made [55,58].

Amphipod are abundant throughout the marine ecosystem and act as scavengers, herbivores, nutrient transporters, predators and prey to other invertebrates, fishes and tetrapods. Amphipods mostly die off and exhibit a drastic change in population number when exposed to oil [59,60]. Oil exposure impacts negatively on reproduction where embryo produced are highly abnormal. These impacts takes longer years to recover for example after the Amoco Cadiz spill, amphipod population never reached pre spill population after 11 years [61], therefore organisms that normally feed on them will be terribly affected. Amphipod's high vulnerability to oil spill is mainly due to their inability to move and distribute in their environment and also their lack of planktonic larval stage. Laboratory studies also revealed acute impacts of the early life stages of amphipod to oil exposure (0.8 μg/l) and its long lasting effect on growth and reproduction.

Mollusks

Mollusks are made of bivalves, cephalopods and gastropods and all affected during an oil spill however most research has focused on bivalves and gastropods [36,62]. Gastropods on exposure to less toxic concentration of oil are known to experience impaired physiological function, behavior and ultimately death after long exposure [62]. Species of periwinkles, top shells and limpets were found dead after the Amaco Cadiz and laboratory research further confirmed low concentration of 11.7 ppm (which is lower than that measured on the shore and salt marshes after the Florida spill) causing mortality within a 96 hour period spill [58,60].

Mussels during filter feeding accumulate oil mainly through their gills which then exposes their tissues to very high levels of PAH compared to the surrounding environment due to their inability to break down the constituents of crude oil mainly PAH [62]. The continuous accumulation of oil renders mussel with reduced cell and overall immunity, reduced development and nutrition, reduction in inhabitant groups, interference with their tolerance of air and DNA destruction. Banni et al. discovered that the DNA of mussels were impaired within 48 hours of exposure and increased significantly by 72 hours. Their cellular immunity was also disrupted [63-65].

These impacts of oil on mussels also go a long way to affect the marine food web because the declines and loss of immunity causes them to lose their nutritive value and since they are major food source for other organisms in the marine ecosystem, there is a general impact experienced. For example, the exposure of *Mytilus trossulus* may have impacted sea otter (*Enhydra lutris*) that rely on them for food. Due to the chronic accumulation of oil, it takes years for total recovery and reestablishment of population abundance [62].

Oysters just like mussels also accumulate oil constituent for long period of time. They can be directly coated by oil and also entrapped in their gills during suspension feeding where nutrients and other substances are filtered [66]. Although oysters can break down PAHs to some extent, short and long term exposure causes prolonged impacts such as harmful effects on their physiological functions (development, nutrition and reproduction). Example is witnessed in *Crassostrea gigas* oysters; when exposed to 200 μg/l of PAHs for long had inhibited feeding ability to reduce the intake of contaminant which also caused a decreased growth rate [67]. Early life stages of the oyster were known to have damaged immune response due to the destruction of haemocytes when exposed to oil.

Echinoderms

Echinoderms are very vulnerable to marine contamination including oil spills [68]. They comprise of sea stars, urchins, cucumbers, and lilies. Sea urchin research discovered a constant reduction in population when exposed to oil. Although there is limited documentation of oil impact on the overall adult life, there is severe influence on the adult population of sea urchins. Dead urchins were seen to have high levels of hydrocarbons in their tissues and living urchins had missing spines. Other impacts include interference with their physiological functions such as impaired movement, feeding, reproduction and behavior. Pelikan established reduced fertilization and survivorship sea urchin species, coupled with obvious degradation of the egg layers. Despite the occurrence of fertilization and survivorship, low levels of petroleum pollutants had damaging effects on the morphology of the eggs. Sea urchins affected by bulk death take long recovery periods [68].

Like sea urchins, Sea stars also experience mortality and damaging effects on physiological functions such as nutrition and development among others [69]. The type and the intensity of the impacts are mostly dependent on the sea star species and the type of oil released. These were evident in a laboratory studies when *A. forbesi* exposed to 0.1-0.5 ppm of crude oil showed impaired feeding. *Evasterias troschelii* also experienced impaired growth and feeding when exposed to 0.2 ppm of water soluble fraction (WSF) of crude oil and stopped feeding, experience loss of arm and mortality when exposed to 0.97 and 1.31 ppm of WSF [51]. Current research about the impact of oil spills on sea stars is very limiting. Most research about echinoids focuses on sea urchins.

Polychaetes

Segmented worms are profuse from the coasts, coral, deep sea to the brackish environment [70]. These worms have diverse and complicated responses to oil exposure. Oil responses vary from population increase in some groups, and others breaking down and metabolizing oil constituents with high tolerance level of hydrocarbons. Some also help in biodegradation and experience normal to increased physiological functions [71]. Despite the positive responses, succession patterns increases leading to an unsteady community. For instance, *Capitella capitate* after the 1969 Florida spill bloomed but decreased after some months when other benthic invertebrates flourished [72]. However contrary to this, *Harmothoe sarsi* decreased in population after the 1977 Tsesis oil spill which may be due to its different feeding method as compared to *Capitella capitate. H. sarsi* feeds mainly on *Pontoporeia affinis* whose biomass also decreased significantly and hence it was assumed that the reduced population of *H. sarsi* may be associated with decreased food source [73]. Current research has established that polychaetes are resistant to oil and hence can be used for purification and sanitation of contaminated water and shorelines [74].

Zooplankton

Zooplanktons are made of organisms that live partially or permanently in the water column. They are subjected to both liquefied droplets and floating oil [14], however zooplanktons at sea surface are more vulnerable to liquefied oil and photo degraded oil products owing to its closeness [27].

Due to the inability of zooplanktons to move against currents, they tend to be stranded in oil polluted waters and are prone to reduced physiological functions and mortality when exposed directly to oil and goes on to affect other organism that rely on them for food [27,75]. Planktonic larvae of invertebrate communities are more prone to oil spill impacts than their adult communities [27]. Free floating embryo and larvae that encounters oils revealed reduced physiological functions such as growth, egg production, nutrition which finally affects the health of the matured communities [27,76]. Planktonic copepods have been discovered to be highly affected by oil spills compared to other planktonic assemblages and hence can be used as an indicator to assess the effects of oil spills in marine ecosystem. For example, *Oithona* and *Paracalanus* are vulnerable than bigger copepods and crustacean larvae [77-80]. Almeda reported on the increased toxicity of oil and dispersants on zooplanktons as compared to only oil. For instance, the chemical dispersant Corexit 9500A was extremely lethal to coastal mesozooplankton populations [14].

Summary and Conclusion

Marine organisms have very important ecological and economic values and hence need to be given utmost attention. Most are very sensitive to pollution from the early life stages and affecting their health through to their adult stages and with oil production on the increase, much effort need to be placed on reducing the spills to eradicate lethal and sub-lethal impacts on these organisms. There is vast and current documentation on the impacts of oil on vertebrates however same cannot be said for invertebrates although they are very dominant (about 80% of all marine organisms) in the marine ecosystem. Although there is insufficient baseline data for the impacts, few studies have document lethal and sub lethal impacts such as physiological and behavioral changes and reduced immunity and overall health of organisms exposed to oil.

Remediation methods have involved biological methods and the application of dispersants. Although microbial degradation of hydrocarbon helps in reducing available crude oil constituents in the marine environment, the byproducts generated from this method have also been found to have impacts on organism just like dispersant where impacts may sometimes be higher than the initial impacts. Research data on focusing more on the level of impacts, where long term monitoring will be done to grasp the full knowledge behind the oil spill impacts on marine organisms, the impacts of cleanup exercise, dispersants and other response methods to oil spill need to be undertaken. Improved ways and response plan considering the overall environmental benefits and risk to the marine ecosystem have to be developed.

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