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Long-term Impact of Five Major Oil Spills in US Waters on Ocean and River Ecosystems and Phytoplankton Communities

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ABSTRACT

The article delves into the overlooked long-term repercussions of oil spills on water ecosystems, particularly focusing on microbial communities and environmental recovery post-disasters. Highlighting five major US oil spills, it unveils how crude oil's enduring effects persist well beyond initial cleanup, impacting microbial foundations crucial for ecosystem health. As global energy demands surge, petroleum remains a primary source, emphasizing the dire environmental consequences of spills during transportation. While immediate impacts on species are extensively studied, the report probes into the extended aftermath, spotlighting the harm to marine phytoplankton—essential for Earth's carbon cycle. Revelations from disasters like the Exxon Valdez and Deepwater Horizon unveil remnants of crude oil that endure for decades, undermining microbial communities and hindering ecosystem revival. Such residues, trapped in sediments, disrupt oxygen and nutrient levels, impeding microbial degradation and slowing removal rates. Harmful algae blooms proliferate, disrupting ecosystems and posing risks to marine life and human health. The article emphasizes the cyclical harm: oil's persistence weakens beneficial microbes, exacerbating future damage from subsequent stressors. Examining compounded environmental disasters showcases the lasting impact on coastlines, with shoreline retreat and marsh ecosystem losses doubling post-spill. Such crises, examined through the lens of Hurricane Katrina's legacy, amplify erosion rates, permanently altering recovery baselines. The article underscores the need for intervention strategies, emphasizing the importance of replenishing microbial communities and reevaluating recovery tactics post-spills. It advocates for a shift towards cleaner energy sources to mitigate further harm to water ecosystems.

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Introduction

The increasing global energy demand, predominantly met by fossil fuels like petroleum hydrocarbons, raises concerns about their environmental impact, especially during transportation. While immediate effects of oil spills on aquatic ecosystems have been extensively studied, the paper focuses on the less understood long-term repercussions on foundational microbial communities. The significance of marine ecosystems, particularly the role of photosynthetic microorganisms like phytoplankton, in maintaining ecological balance underscores the importance of studying oil spill impacts comprehensively.

Analysis

The immediate impacts of oil spills on native species and ecosystem health have been extensively studied, but the long-term effects crude oil can have on foundational microbial communities and environmental recovery from future disasters are not as well understood. This paper will examine five major oil spills on US waters to shed light on the long-lasting impact oil can have on water ecosystems. These disasters will help us understand the mechanisms that allow oil to persistent long after cleaning efforts have been ceased, how crude oil's impact on microbial communities can trickle down to harm the greater environment, and how these spills cause permanent damage to an environment's ability to recover from future stressors. It is important to examine how spilled oil continues to impact an environment and recognize that ecological damage and recovery don't happen in isolation. This will help better inform future clean-up and prevention efforts.

With the growing populations and industrialization worldwide, global energy demand is increasing. The U.S. Energy Information Administration projects a 28% increase in world energy use by 2040 (Doman et al., 2017). Fossil fuels, such as petroleum hydrocarbons, are primary energy sources relied on to support daily life and industrial operations (Vandana et al., 2022). Petroleum hydrocarbons not only play a big role in the human carbon footprint, but also can cause immense environmental disasters when crude oils are spilled during transport. Crude oils and refined petroleum are imported to the US by sea from Canada and Mexico (Allison et al., 2018). Although transportation is largely safe, the quantities of oil being moved is immense, causing even the smallest spill to have significant environmental implications for water ecosystems.

Salt and freshwater ecosystems are delicate environments home to diverse communities of aquatic animals, plants, and microorganisms. Many studies have examined the immediate detrimental effects oil spills have on the ocean ecosystem, from fish larvae and cetacean kills to immense loss of infauna diversity (Fisher et al., 2016). This report will focus on long term effects and indirect impacts major oil spills on US waters have on the environment, with an emphasis on ocean microbes and phytoplankton. Photosynthetic microorganisms like phytoplankton form the base of the food chain and their carbon-fixation is key to Earth's carbon cycle, removing 50% of the atmosphere's CO_2 and providing 70-80% of the atmosphere's O_2 (Falkowski et al., 2012). As carbon emissions continue to exponentially increase worldwide, photosynthetic microorganisms that can sequester CO_2 are more important than ever (US EPA 2016).

Current research has shown that chemicals from oil spills can persist decades later, despite rigorous cleanup efforts, and continue to damage shorelines and beaches (Lindeberg et al., 2018). It is important to examine how these lingering chemicals affect the microbial communities that form the foundations of ocean ecosystems and are deeply involved in maintaining the Carbon cycle. This report will examine 5 major oil spills in US waters to explore the long-term impacts oil spills can have on marine phytoplankton and how they indirectly harm the rest of the ecosystem. This will help put into perspective the true damage lingering undegraded crude oil can continue to cause to marine ecosystems and the atmosphere.

Due to the nature of rapid water currents and winds, oils and toxins released after a spill are seldom confined to the initial location of the spill. The 2010 Enbridge oil spill in the Michigan Kalamazoo river was the biggest inland oil spill in U.S. history. Over 3.2 million gallons of crude oil were spilled in 56 km of river habitat (Otten et al., 2022). Cleaning efforts were long and expensive as submerged oil remained hidden at the river bottom and poisonous hydrocarbons were released into the air, forcing many homes and businesses to evacuate (Otten et al., 2022). Seven years later, the cleanup was still ongoing and it is uncertain if the oil will ever be completely cleared up (YoungDyke, 2017). The Argo Merchant ship was grounded and split open off the Massachusetts coast in 1976. Oil was spilled into the Atlantic ocean and carried by the current away from the shorelines and beaches, making early confinement and cleanup of the spill difficult (Ailin, 2011). The opposite problem, the sequestration of oil, can also be a big problem as exemplified by the Exxon Valdez tanker spill. The 1989 Exxon Valdez oil spill was one of the worst oil spills in the US, spilling 10.8 million gallons of crude oil into Alaska's Prince William Sound (Lindeberg et al., 2018). The immediate damage of oil spills to native species has been extensively studied. While over 35,000 dead birds were retrieved, models suggested that total seabird deaths were in the hundreds of thousands (Wiens 2018). Equally alarming is the persistence of toxic oils in oceans and shorelines and the continued harm they can do to the environment. Cleanup efforts were terminated after Shoreline Cleanup Assessment Teams assumed that oil spilled from the tanker had been completely removed or naturally degraded, but research decades later showed that remnants of the spill still lingered (Lindeberg et al., 2018). The spill occurred over 30 years ago, but recent research indicates that 0.6%, more than 64 thousand gallons, of the oil spilled remains sequestered in shorelines in Prince William Sound (Lindeberg et al., 2018). This means that the oil remnants are trapped in the sediment layers of gravel beaches and protected from hydrological washing that would release the oil and allow it to be cleaned. The toxicity of the remaining oil also causes lower levels of oxygen and nutrients which are necessary for microbial survival and growth. The lack of microbial degradation means that removal rates for remaining oil residues have slowed to nearly zero and projections suggest that complete removal will take decades (Lindeberg et al., 2018). Similarly, after the 2010 Deepwater Horizon spill, it was also assumed that the coast had a plethora of highly efficient soil-degrading microorganisms that would eventually break down the oil. However, field studies have shown that the oil persisted for several decades and formed toxic tarmacs under the beach (Clements et al., 2022). Although pre and post-spill microbial levels were not compared, the ultimate absence of these oil-busting microbes is indicative of a larger problem in ocean ecosystems. Further research will be needed to identify the exact causes behind microbial disappearances at different sites.

The impact of a long history of neglecting water ecosystems can be seen in how coastlines that should have ample microorganism communities are struggling to recover from oil spills like the Exxon Valdez and Deepwater Horizon spills. Studies indicate that microbial mortality may rely more on exposure time to oil than anything else (Lee et al., 1977). The longer they are exposed, the more likely they are to die. The reduction of microbial communities in places like the Prince William Sound and Nantucket coast and the slow recovery of these environments after oil spills is a vicious cycle. The longer crude oil remnants remain, the more likely they are to wreak havoc on beneficial microorganism populations. However, since tolerance to oil varies by phytoplankton species, it can be difficult to determine how spills impact these communities. For example, diatoms and green algae are usually more resilient to crude oil while cyanobacteria are more sensitive (Sargian et al., 2007). The shift in nutrients caused by an oil spill may cause blooms of a single species, called harmful algae blooms. Studies of disaster zones like the Deepwater Horizon spill have indicated that bloom-forming microbes like Pseudo-nitzschia often become more abundant after an oil spill (Quigg et al., 2021). Analysis of phytoplankton populations before and after the Deepwater Horizon oil spill indicates that toxic bloom-forming microbes like Karenia brevis and Prorocentrum minimum even tend to increase their toxin production after exposure to crude oil (Quigg et al., 2021). This has negative implications for the rest of the ecosystem as helpful microorganisms are killed and toxic species that may cause mass fish kills, illness of marine animals, and human illness or death from ingestion or inhalation are elevated.

The ultimate long-term effects on coastlines and animals is dire, and examining the combined impacts of multiple environmental stressors illuminates the need for greater interventions. Years after the BP Deepwater Horizon spill, several studies were conducted to examine how the Louisiana coastal marshes were recovering from the spill. While the marshes were able to confine the oil to the edges of the marsh to prevent contamination of the interior, this led to accelerated shoreline retreat in the long-term (Silliman et al., 2012). This is because as the oil encroaches on marsh grasses, vegetation dies off and exposes the sediment to coastal waves. Shoreline retreat was doubled, leading to permanent marsh ecosystem loss (Silliman et al., 2012). The most affected areas were the areas already weakened by human-induced stressors. The additive effect of environmental stressors can also be seen when we examine the legacy effects of 2005's Hurricane Katrina on marsh recovery after the Deepwater Horizon spill. Erosion rates increased significantly after Hurricane Katrina, and studies comparing baseline rates before and after both the hurricane and the spill indicate that the Hurricane reset the baseline erosion rate to a higher level (Deis et al., 2019). After the Deepwater Horizon spill, the marshes could not recover to their pre-Katrina condition due to this new baseline. Although this study reviewed the impact on marsh shorelines in depth, there was inadequate analysis on how biotic factors changed before and after Katrina. Further research on how important foundational species were harmed by compound environmental disasters are needed. Environmental disasters don't happen in isolation and it is important to understand how the long-term effects of one disaster can exacerbate future incidents.

Conclusion

The long-lasting impact of oil spills on marine environments cannot be understated. Consistent environmental stressors weaken important marine microbial communities, which makes recovery after an oil spill more difficult without the help of natural hydrocarbon degraders. This creates a vicious cycle as oil remains undegraded and continues to damage any remaining beneficial microbes, compounding with other stressors to cause permanent damage. Future research should focus on replenishing microbial communities by inhibiting the growth of harmful blooms and promoting the flourishing of beneficial colonies after an oil spill. Accidents are sometimes inevitable, but improved recovery tactics can greatly reduce the long-term impact oil spills can have on water ecosystems. It is important to recognize that the persistence of oil in water can have continuous negative effects on water ecosystems if left unaddressed. This is an important and necessary step forward if we continue to rely on imported fossil fuels for energy. While pivoting to cleaner energy sources will take a great amount of time and commitment, the least we can do to protect our environment is to prevent our fossil fuel use from doing any additional harm.

Conflict of interest

The author declares that there was no conflict of interest.

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