Marine Pollution Bulletin 82 (2014) 19–25

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Impacts, recovery rates, and treatment options for spilled oil in marshes

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ARTICLE INFO

Keywords:
Marshes
Oil spills
Recovery
Treatment

ABSTRACT

In a review of the literature on impacts of spilled oil on marshes, 32 oil spills and field experiments were identified with sufficient data to generate recovery curves and identify influencing factors controlling the rate of recovery. For many spills, recovery occurred within 1–2 growing seasons, even in the absence of any treatment. Recovery was longest for spills with the following conditions: Cold climate; sheltered settings; thick oil on the marsh surface; light refined products with heavy loading; oils that formed persistent thick residues; and intensive treatment. Recovery was shortest for spills with the following conditions: Warm climate; light to heavy oiling of the vegetation only; medium crude oils; and less-intensive treatment. Recommendations are made for treatment based on the following oiling conditions: Free-floating oil on the water in the marsh; thicker oil (>0.5 cm) on marsh surface; thinner oil (<0.5 cm) on marsh surface; heavy oil loading on vegetation; and light to moderate oil loading on vegetation.

1. Introduction

Marshes provide many important ecological services and functions and are habitat to many highly valued species. When an oil spill affects these habitats, impacts can be severe; however, impacts from inappropriate response methods can increase these impacts and slow overall recovery of the habitat and those resources that rely on them. Every spill is a unique combination of conditions–oil type, amount of oil, location of oiling, extent of oiling on the soils and vegetation, vegetation types and sensitivities to oil, time of year, presence of wildlife of concern, degree of exposure to natural removal processes, etc. Responders have to evaluate all of these factors and make a decision on the best course of action, quickly. By understanding the basics of marsh ecology and learning from past oil spills in marshes, we can better plan for, protect, and make appropriate decisions for how to respond to future oil spills. In this paper, the body of literature on oil toxicity and spill impacts to marshes and the likely recovery rates for a range of oil types and spill conditions is summarized. Based on this knowledge, appropriate cleanup endpoints and response options for different oiling conditions are recommended.

2. Factors affecting the impacts of oil on marsh vegetation

The following factors affecting the impacts of oil on marsh vegetation are discussed:

- Oil type
- Extent of contamination of the vegetation
- Extent of contamination of the marsh soils
- Exposure to waves and currents
- Time of year of the spill
- Species sensitivity to oiling

2.1. Oil type

The type of oil spilled influences the potential type and degree of impacts to marshes because of differences in behavior, persistence, and toxicity. In this section, the likely impacts from spills based on case histories and experiments are summarized for: (1) light refined products; (2) light to medium crude oils; and (3) heavy crude oil and refined products.

2.1.1. Light refined oils

Light refined products, such as jet fuel, kerosene, No. 2 fuel oil, home heating oil, and diesel, have been shown to have the highest acute toxic effects on marsh vegetation. These types of oil have low viscosity and high rates of loss by evaporation and dispersion into the water column under even low-to-moderate wave energy.

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http://dx.doi.org/10.1016/j.marpolbul.2014.03.030
0025-326X/

When spilled on open water, they usually spread into thin slicks and sheens and often do not persist long enough to cause significant shoreline oiling. Those spills that did result in extensive plant mortality and long-term impacts involved large volumes released to sheltered waterbodies, resulting in heavy oiling of marsh habitats.

Based on ten spills and field or greenhouse experiments where marsh plants were exposed to No. 2 fuel oil, impacts can be summarized as follows:

- No. 2 fuel oil can be highly toxic to salt marsh vegetation and more toxic than other types of oil under similar exposure conditions.
- The severity of impacts was directly related to the amount of plant covered by the oil. Studies by Booker (1987) supported the hypothesis that oil exposure affected cell membrane permeability, which would reduce tissue viability through an impaired ability to maintain chemical balances and metabolism in the cells.
- There was a dose-response relationship between the degree of oil in the marsh soils and impacts to plants.
- Both direct physical damage (e.g., smothering) to contacted tissues plus translocation of toxic components of the oil from stems to the root system caused death or a reduction in the ability of the root system to regenerate shoots.
- Where the rhizomes die (rather than just the vegetation dying back), recovery depends on regrowth from plants outside the oiled area; thus spills affecting large areas may not recover quickly.
- Spills in confined waterways, where the oil is not able to spread out and strands on the shoreline quickly, have the highest risk of causing long-term damages.
- Offshore spills, small spills, and those where the oil is dispersed by wave action before stranding onshore have a lower risk of impacting sensitive marsh habitats and associated communities.

2.1.2. Light to medium crude oils

Light to medium crude oils can range widely in terms of their fate and effects on marshes, depending on their chemical composition and the degree of weathering prior to stranding on the marsh. There have been several summaries of the literature on the impacts of crude oil on the marshes of the U.S. Gulf Coast (Pezeshki et al., 2000; DeLaune et al., 2003; DeLaune and Wright, 2011). Based on the eighteen studies reviewed and extensive experience at other spills, crude oils can have acute, short-term toxicity if relatively fresh oil comes in contact with the plants and if most of the plant surface is covered by the oil, but recovery often occurs quickly. Crude oils can also cause physical smothering, as discussed in the next section on heavy oils. It is difficult to summarize the impacts of light to medium crude oil spills on marshes because of the range of spill conditions and the importance of other factors. Most of the other factors controlling the initial impacts and recovery rates from exposure to crude oils are discussed later in this paper.

2.1.3. Heavy crude oils and refined oil products

Heavy crude oils (including crude oils derived from tar sands) and heavy refined oil products, such as heavy fuel oil, No. 6 fuel oil, and intermediate fuel oils (IFO) 180 and 380, are thought to affect marsh vegetation primarily via physical effects from coating and smothering of the vegetation and/or soil surface because they generally have low amounts of acutely toxic compounds. Based on published studies and personal observations at many spills of heavy refined products in marshes, long-term impacts (>2 years) are likely to occur for the following:

- There is chronic re-oiling. Baker (1973) performed pioneering experiments on repeat oiling that showed good recovery from up to four oiling events, but large-scale changes from eight and twelve oiling events;
- The marsh soils are heavily oiled, either by thick layers on the surface or penetration into the soil;
- The entire plant surface is covered with oil during the growing season; or
- There has been aggressive treatment that causes damage to roots and mixes oil into the soils.

Relatively short recovery periods (1–2 growing seasons) are likely to occur when:

- Oiling degree is light;
- Oiling occurs in the fall or winter when the plants are in senescence;
- There is little to no contamination of the marsh soils; or
- The oiled areas are exposed to waves or currents that speed natural removal rates.

2.2. Extent of contamination of the vegetation

The extent of oil on the vegetation is an important factor in determining the initial impact on vegetation. Although there are important differences between field spills and greenhouse experiments, the greenhouse experiments provide good control to demonstrate this effect. Review of past spills and experiments show that:

- When the entire plant and the soil surface is covered with 1.5–2 liters per square meter (L/m^2) of light refined oil, there is usually 100% mortality of the aboveground vegetation and sometime high mortality of the entire plant;
- Similar exposures by heavy refined oils and crude oils in greenhouse experiments result only in a slight decrease in aboveground biomass for a few months; and
- At spills where at least the upper one-third of the vegetation remains unoiled, the plants tend to have high survival rates.

There is a general dose-response relationship in terms of the degree of oiling of the vegetation, with emphasis on the leaves versus the stems. The leaves are responsible for respiration, transfer of oxygen to the roots, photosynthesis, and, in some cases, salt extrusion. Light oils exert a chemical toxicity, damaging the plant cells and their functions. Heavy oils are thought to exert a physical toxic effect through coating and smothering. Both mechanisms of toxicity are a function of the amount of oil coverage of the leaves.

2.3. Extent of contamination of the marsh soils

Marsh plants have variable degrees of tolerance to oil contamination of their soils. Greenhouse experiments allow for the careful comparison of plant responses to various degrees of oil (Lin and Mendelssohn, 2008, 2009; Lin et al., 2002), and again there is a dose-response relationship, particularly for light refined products. However, thresholds of oil contamination from greenhouse experiments are higher than what is normally found in field studies, so they must be used with caution. The water table level in the marsh sediment is a factor, being lower near the creek banks during low tide, allowing penetration into crab and root macropores.

There is another subfactor in this category – the persistence of a thick layer of oil on the marsh surface–that can lead to very long-term impacts. There are four spills that demonstrate the importance of this factor: a small spill in 1969 in Wales where a 5 centimeter (cm) thick oil layer on the marsh surface was not