RESPONDING TO OIL SPILLS IN COASTAL MARSHES: THE FINE LINE BETWEEN HELP AND HINDRANCE

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Introduction

Marsh environments are highly sensitive to oiling and thus receive high priority for protection during oil spills. When protection fails, and marshes are oiled, questions arise about the advantages and disadvantages of cleanup in these sensitive habitats. Follow-up studies from past spills have documented that inappropriate response activities can cause additional harm to oil-impacted marshes. Less clearly delineated are the conditions when cleanup is desirable in a marsh; which methods should be employed and at what point intervention is no longer useful.

The basic lessons about impacts of oil and subsequent response activities in marshes have been known for years (Mattson et al. 1977, Westree 1977, McCauley and Harrel 1981). The *Amoco Cadiz* spill in France illustrated the complications from sediment removal at the Ile Grande marsh, when such activities greatly increased erosion of the marsh and substantially delayed vegetative recovery (Baca et al. 1987, Vandermeulen et al. 1981). However, in cold temperate environments, it has also been clearly documented that heavily oiled marshes where oil is *not* removed may be impacted for decades (Table 1). The *Metula* spill in Chile is an extreme example of slow recovery; after 20 years, little change has occurred (Vandermeulen and Jotcham 1986, Teal et al. 1992, Baker et al. 1993). At some spills occurring in warmer regions that are less severely impacted by crude oils, very limited cleanup has constituted a successful "response" and recovery has been relatively rapid (e.g., Neches River UNOCAL spill; NOAA 1994, Table 2).

Monitoring studies conducted in oil-impacted marshes and experimental research during the past two decades have documented the complexity of marsh ecology and the parameters that affect the severity of impacts to these systems (De la Cruz et al. 1981, DeLaune et al. 1984, Alexander and Webb 1985). This knowledge complicates decisions regarding cleanup in marshes, because parameters such as substrate type, plant species, season of impact, oil type, and climate may all affect the eventual recovery of an oil-impacted marsh (Table 3).

Table 1. Examples of oil-impacted marshes with recovery times of five years or more, documented by follow-up studies.

Location	Vegetation	Oil type	Date of oiling	Cleanup	'Recovery time'
Chile *Metula* [1]	*Salicornia ambigua* *Suaeda argentinensis*	Arabian crude Bunker C	Aug. 1974	none	>20 years
Quebec *Miguasha* [2]	*Spartina alterniflora,* *Spartina patens*	Bunker C	Sept. 1974	sediment removal manual burning digging	> 11 years <11 years
Brittany, France *Amoco Cadiz* [3]	*Salicornia* *Suaeda* *Halimione*	Arabian light, Iranian light crude Bunker C	Mar. 1978	sediment removal	5 to >8 years
West Falmouth, MA , *Florida* [4]	*Spartina alterniflora,* *Salicornia europaea,* *Spartina patens*	No. 2 fuel	Sept. 1969	N/A	> 8 years
Buzzard's Bay, MA, *Bouchard 65* [5]	*Spartina alterniflora,* *Salicornia virginica*	No. 2 fuel	Oct. 1974	N/A	> 3 years

1) Baker et al. 1993
2) Vandermeulen and Jotcham 1986
3) Baca et al. 1987
4) Burns and Teal 1979; Teal et al. 1992
5) Hampson and Moul 1978
N/A: Information not available

Table 2. Examples of oil-impacted marshes with recovery times of five years or less, documented by follow-up studies.

Location	Vegetation	Oil type	Date of oiling	Cleanup/ Impacts	'Recovery time'
Harbor Is., TX *Am Petrofina pipeline* [1]	*Spartina alterniflora* *Avicennia germinans*	crude oil	Oct. 1976	none sorbents burning clipping	6 months to > 6 months
Houston Ship Channel/ Galveston Bay, TX[2]	*Spartina alterniflora*	No. 6 fuel	Oct. 1977	sorbents raking	1 year to 19 months
Neches River, TX *Esso Bayway* [3]	*Spartina patens*	Arabian crude	Jan. 1979	none sorbents flushing burning cutting	7 months . to > 7 months
Galveston Bay, TX, Dickinson Bayou pipeline [4]	*Spartina alterniflora* *Juncus roemerianus*	light crude	Jan 1984	none sorbents flushing	8 months . to > 2 .5 years
Nairn, LA *Shell pipeline* [5]	*Spartina patens* *Spartina alterniflora* *Distichlis spicata*	Louisiana crude	Apr. 1985	flushing trampling	4-5 years.
Fidalgo Bay, WA Texaco pipeline[6]	*Salicornia virginica* *Distichlis spicata*	Prudhoe Bay crude	Feb. 1991	flushing vacuuming trampling	3-4 years.
Aransas River Chilitpin Creek. TX [7]	*Spartina alterniflora*	S. Texas light crude	Jan. 1992	burning	>2 years.
Neches River, TX *UNOCAL* [8]	*Spartina alterniflora*	light crude	April 1993	none sorbents flushing	1 year *

1) Alexander and Webb 1987
2) Webb et. al 1981
3) McCauley and Harrel 1981, Meyers 1981, Neff et al. 1981
4) Holt et al. 1978
5) Fischel et al. 1989; Mendelssohn et al. 1990; Mendelssohn et al. 1993
6) Hoff 1995
7) Tunnell et al. 1995, Gonzalez and Lugo 1994
8) NOAA 1994
* no follow up study had been conducted as of summer 1994, but local observers reported little difference between the oil impacted marsh and adjacent marshes.

Table 3. Data from field studies on impacts to marsh vegetation from experimental, single-dose oiling.

Location	Vegetation	Oil type	Time of oiling	Cleanup	'Recovery time'
Galveston Bay, TX [1]	*Spartina alterniflora*	Arabian crude Libyan crude No. 6 fuel No. 2 fuel	Nov. 1981	none	1 year 1 year 1 year 2 years
Louisiana [2]	*Spartina alterniflora*	S. La. crude	June 1981	none flushing cutting	3 months 3 months 2.5 years
York River, VA [3]	*Spartina alterniflora*	S. La. crude: fresh /weathered	Sept. 1975	none	>1 year
St. Louis Bay, MS [4]	*Juncus roemerianus*	Empire Mix crude Saudi crude	Mar. 1974	none	1-3 years

1) Webb et al. 1985
2) DeLaune et al. 1984
3) Bender et al. 1977
4) De la Cruz et al. 1981

A myriad of questions awaits responders faced with an oiled marsh. Under what circumstances is cleanup appropriate not only in removing oil, but in speeding recovery of the marsh? If the decision is made to respond in a marsh, what methods should be employed and how should these be chosen? Where is the line where cleanup should cease lest it cause more harm than good? How can seemingly conflicting resource needs be balanced in cleanup decision-making? Marsh cleanup is often suggested as a way to prevent oiling of birds or other animals and to prevent oil from moving to nearby environments. To develop some general guidelines for answering these questions, I have reviewed the scientific literature on this subject, and evaluated numerous follow-up studies conducted after oil spills. Primarily these involve spills in marine or estuarine marshes, though limited freshwater examples are also included.

Cleanup Decision-Making

A starting point for determining whether cleanup is appropriate for an oiled marsh is assessing the severity of the impact, and attempting to estimate the timeframe for recovery. Predictions of future recovery times can only be approximated, but it is usually possible to estimate whether impacts are likely to be of short duration (one to three years), medium duration (three to five years), or long-term (more than five years). Having an idea of the likely timeframe for recovery without cleanup makes it possible to assess whether cleanup is likely to speed the natural recovery process or to impede it.

Defining recovery

Recovery is an easily misunderstood and difficult term to define, but the concept is a necessary endpoint for environmental monitoring studies. Generally, "recovery" is used to denote a return to some unimpacted state of the environment in question. Given that ecological communities are not static and undergo changes based on environmental perturbations both naturally occurring and human-caused, a common technique measures recovery by comparing oil-impacted sites with nearby "control" (unimpacted) sites. When these sites resemble each other in important ecological parameters (such as percent cover of vegetation for marshes) they are considered to be recovered.

For marsh studies, the most commonly measured parameter is the percent cover of vegetation, sometimes accompanied by indices of species diversity, biomass, and height and density of individual plants. However, each follow-up study is different and may measure other parameters. For the purposes of this paper, recovery will refer to vegetative cover, largely because this is the measurement common to most studies. Some measurable concentration of petroleum hydrocarbons often remains in sediments of marshes that appear to be "recovered" from looking only at the vegetation. It is important to remember that vegetative recovery may not include more complex ecological measurements such as differences in species diversity or use of the habitat by other organisms.

Timelines for "recovery"

Documented recovery times for oiled marshes range from a few weeks to decades (Tables 1 through 3). As might be expected, the cases on the extreme ends of this spectrum are the easiest to delineate. On the worst-case side are several well-studied marsh sites where recovery times ranged from five years to more than 20 years. These include two sites in Buzzards Bay, Massachusetts; the *Miguasha* spill in Quebec; the *Metula* in Chile; and the *Amoco Cadiz* in France (Table 1). These examples share the following characteristics:

- ❐ north or south temperate (cold) environments
- ❐ sheltered location
- ❐ heavy oiling
- ❐ spills of fuel oils (bunker C or no. 2 fuel)

- ❐ in some cases intensive cleanup methods delayed recovery

In contrast, recovery times of three years or less have been documented for sites at the following spills (examples are taken from the Gulf of Mexico): Neches River, Texas (*Esso Bayway*); Harbor Island, Texas pipeline; and the Houston ship channel (Table 2). Experimental spills (Table 3) also document some quick recovery times from oiling, though many of these were conducted in relatively small plots and may not be representative of conditions in a larger area. These marshes showing quicker recovery share the following characteristics:

- ❐ warm climate
- ❐ light to moderate oiling
- ❐ usually spills of light-to medium crude oil
- ❐ variety of cleanup methods used
- ❐ often no cleanup resulted in fastest recovery time

Based on these examples, it is easy to conclude that marshes lightly oiled in warm climates have a good potential to recover on their own relatively quickly and that cleanup may hinder more than it helps. However, decisions to implement a "no response" option may be complicated by other concerns, such as potential oiling of birds or other animals or concerns about re-mobilization of oil that might impact nearby environments.

In contrast, heavily oiled marshes in colder climates can be impacted for many years, depending on the type of oil spilled and the degree of penetration of the oil into the marsh substrate, among other parameters (Vandermeulen and Singh 1994). Cleanup in these situations may accelerate recovery of the marsh, if only because oil left to weather naturally may remain for many years.

Between these two extremes, however, lies the vast middle ground of spills with less clear-cut solutions to the cleanup question. Examples of spills showing recovery times of three to five years include the Shell pipeline spill in Louisiana and the Fidalgo Bay spill in Washington (Table 2). These examples include moderate to heavy impacts in marshes in warm or temperate climates, spills of medium crude oils or refined oils, and issues involving conflicting resource uses. Deciding when cleanup activities are appropriate and which cleanup methods to use are challenging issues that usually must be made on a site-specific basis. Since all cleanup techniques have some detrimental impact associated with them, choosing any particular technique requires that the expected gains be balanced against the costs. Many techniques can be applied judiciously, to minimize their detrimental impacts.

Marsh Cleanup Techniques

Most techniques available for oil spill cleanup in marshes have been tried at one time or another. Table 4 summarizes the advantages and disadvantages of several techniques that are either commonly used or are of strong research interest.

Table 4. Cleanup techniques used in marshes and their advantages and disadvantages.

Advantages	Disadvantages
No response	
minimal impact (if oil degrades quickly) no physical impact	potential oiling of birds or wildlife oil may impact adjacent areas heavy oils may degrade slowly or form asphalt
Vacuum/pumping	
can remove large quantities of oil	access /deployment of equipment physical impacts
Low pressure flushing	
assists in removal by herding oil lifts oil off sediment surface	requires careful monitoring pressure must be controlled physical impacts
Burning	
potential to remove oil quickly can minimize impacts from trampling	potential damage to plant roots and rhizomes little known about impacts due to season, inundation of marsh, species composition, air pollution, regulatory concerns
Sediment removal	
may be only remediation possible for heavily oiled sediments	"destroy marsh to save it" increased erosion potential elevation changes may impede regrowth of plants replanting necessary
Vegetation cutting	
leaves most of plant intact prevents oiling of birds	may kill plant potential for increased erosion must be carefully monitored
Bioremediation	
great theoretical potential low impact	few case studies available potential for nutrient enrichment oxygen may be limiting

Natural degradation/no response

No response at all is an ideal approach when natural weathering and biodegradation are expected to occur quickly (see Table 4 for more details). Choosing natural degradation/no response is the only way to eliminate physical impacts resulting from workers or mobilization of equipment, providing care is taken to keep response activities away from the marsh. Natural degradation is often used as the last stage of a response where some oil has already been physically removed, since most physical removal methods reach a point where oil can no longer be effectively removed, leaving some level of residual oiling.

The no-response option has a cost when oiling is heavy and/or degradation is expected to be very slow (greater than one to two years). Asphalt pavements may form from heavy layers of oil left undisturbed, especially in very sheltered areas or when oil strands in the upper or supratidal zone. Such pavements were found at the *Metula* spill, in experimental "set-aside" plots at the *Exxon Valdez*, and were observed from historic spills in the Persian Gulf. In these cases, initial efforts to remove thick layers of oil (or manually remove asphalt after hardening) are warranted.

To ensure that areas left to degrade naturally do not contaminate adjacent sites sorbents may be used to collect sheen or other mobile oil.

Vacuum/pumping

Physical removal of pooled oil on marsh sediment or water surfaces using vacuum or pumping apparatus has been quite successful at a number of marsh spills (e.g., Nairn pipeline, Louisiana and Fidalgo Bay, Washington). Large quantities of oil can be removed, though at some point residual oiling will remain after most of the heavy oil is collected. Vacuum removal in conjunction with low-pressure flushing can also be successful.

There are two main environmental impacts from using this technique:

- ❒ The physical impact of deploying the equipment and the workers to operate it.
- ❒ The potential to inadvertently remove plants or sediment along with oil.

Careful monitoring of this technique in the field is important to minimize impacts. Access to remote sites may also be difficult, although vacuums can be deployed from barges as was done at the Tampa Bay spill in 1993 to clean an area of oiled mangroves.

Low-pressure flush

Low-pressure flushing is usually used to help move oil towards collection points where other removal equipment is operating, such as vacuums or boom/skimmer collectors. Flushing can also help lift oil off the sediment surface when the marsh is not flooded.

Flushing may be difficult to apply correctly, since slight changes in water pressure can turn a low-impact technique into a high-impact one (i.e., causing erosion of sediment as opposed to simply lifting oil off the sediment surface). Thus, workers must be carefully supervised, and it is a good idea to undertake flushing trials to work out the details of application. Foot traffic will also physically impact the marsh, and this should be minimized, either by working from boats during high tide or by using board walkways.

Vegetation cutting

Cutting of oiled vegetation has been tried in numerous spills, many times with quite drastic consequences: death of plants, increased erosion, and permanent loss of marsh (Zengel and Michel 1995). When oil covers sediment surfaces, cutting near the base of the plant can permit oil penetration into the sediment, damaging plant roots. Studies that have monitored oiled and cut marshes show that uncut areas may recover as fast or faster (e.g., *Esso Bayway* spill and the American Petrofina pipeline spill). However, cutting impacts in many of these studies were confounded with impacts from physical trampling by workers (Hershner and Moore 1977, Mattson et al. 1977, Holt et al. 1978, McCauley and Harrel 1981).

Vegetation cutting is often considered when oil is trapped in dense vegetation, making flushing and removal ineffective. In these cases, cutting means clearing entire areas of vegetation (plants are cut near the base of the stem above the sediment). Since impacts to vegetation may be severe, this technique is reserved for situations where erosion is not a risk, with plant species that are either very hardy, or with undesirable invasive species. However, such intrusive use of cutting should not be considered in the majority of marsh environments.

A more moderate use of cutting can be considered when only upper parts of the plants are oiled—either from high-tide or aerial exposure such as from a pipeline blowout. In these cases, especially when other concerns are present, such as possible oiling of birds or other animals from contact with oiled plant fronds or aesthetic issues in areas of high public use, judicious use of cutting that will minimize detrimental impacts is possible.

At the *Canadian Liberty* spill on the Delaware River, (an estuarine environment) careful cutting of *Phragmites* and *Scirpus* minimized risk of oiling to birds using the marsh. Cutting was conducted by boat or with a small crew on land to minimize physical impact, and most plants were cut individually. Only oiled portions of plants were cut, leaving roots and large portions of the stem intact. Follow-up monitoring indicated short-term impacts to vegetation three months after cutting, but apparent full vegetative recovery one year after the spill. No obvious adverse impacts were observed such as increased erosion or loss of sections of marsh (Levine et al. 1995).

In general, vegetation cutting in marshes, especially wholesale clearing, should be avoided except in the special circumstances outlined above, since there is a high probability that plants may be killed and permanent damage inflicted on the marsh through increased erosion and loss of habitat.

Burning

Burning of marsh grasses has been practiced as a vegetation management technique for many years, but burning of oiled marshes is relatively new. Two recent incidents where burning was used to remove oil in a freshwater marsh in Maine and a brackish marsh in Texas, have sparked increased interest in this technique. Burning of oil in marshes can remove large quantities of oil quickly while potentially minimizing physical impacts.

However, the technique has not yet been well documented and many questions remain about the specific conditions under which burning can be successfully used in marshes. The recent burns in Texas and Maine were conducted while the marshes were inundated; the Maine burn was conducted under ice and snow conditions. Both burns were successful in removing large amounts of oil from the marsh, but studies of long-term impacts show mixed results. At the Maine marsh, monitoring conducted four months after the burn showed good re-growth of all vegetation types in the marsh, dominated by cattails (U.S. Navy 1994). In contrast, monitoring from the Texas burn (at upper Copano Bay) indicates more detrimental, long-term impacts. Sampling conducted more than two years after the spill documented that the oiled and burned marsh had significantly more bare patches and less species diversity than the control unoiled marsh (Tunnell et al. 1995). Some of the impacts at the Texas site may be because repeated burns were conducted and large amounts of burn residue remained, resulting in residual-oil contamination of the burned area.

Remaining questions about this technique include the conditions necessary to minimize burn impacts, such as inundation of the marsh at the time of burning, how to deal with residues that may remain after the burn, and how to minimize impacts to plant roots and rhizomes that may result in slow recovery of vegetation. These issues, as well as information on the effects of burns on a variety of plant species as well as particulars about recovery of marshes after burning, are topics for further research. For a recent review of burning in wetlands, see Mendelssohn et al. 1995.

Bioremediation

Bioremediation is similar to burning with respect to what is known about its effectiveness in oiled marshes. There is great interest in using the technique, and positive data from laboratory studies, but little information on its successful use in oiled marshes. From experimental data we can infer that bioremediation would be a potential low-impact cleanup technique for residual oiling of marsh sediments. Questions remain about the possibility of creating conditions of eutrophication in marsh environments from the addition of fertilizers and about low-oxygen conditions in marsh sediments that may limit biodegradation.

Sediment removal/replanting

Sediment removal followed by replanting falls more properly under the category of remediation than response since it is, in many ways, a technique of last resort. It may be the only option for some cases where sediments are very heavily oiled. However, this is indeed an example of destroying the marsh to save it, since existing vegetation and roots are removed along with sediment. There is great potential for increased erosion and a danger if sediments are not replaced; changes in elevation will prevent plant regrowth or cause a change in species of plants colonizing the area. Several of the long-term impact case studies (e.g., *Miguasha* and *Amoco Cadiz*) provide examples of the unsuccessful use of this technique (Vandermeulen and Jotcham 1986, Baca et al. 1987). Therefore, it should be considered a last-resort option and used with great caution.

A less intrusive, related technique is tilling contaminated sediments to try to break up heavily oiled sediments. This provides aeration and possible channels for seeds to reach cleaner soil. Tilling may also help increase rates of natural biodegradation of oiled sediments by reducing soil contamination and thus assisting the overall recovery of the marsh. Preliminary results from a study in Fidalgo Bay, Washington indicate that tilling oiled sediments may facilitate plant recolonization of heavily oiled areas that were devoid of vegetation for more than three years after initial oiling (Hoff 1995).

Conclusions

Deciding how to respond in an oiled marsh is clearly a complex issue for which there can be no single answer. Decisions need to be made on a case-by-case basis, and usually with a degree of uncertainty. However, the lessons of the past give a good deal of guidance about what techniques to avoid and where to tread cautiously. The following guidelines give a simple outline for making these decisions and are summarized in Table 5.

Begin by evaluating the impact, estimated oil residence time, and general situation:

1 Assess the impact of oil by conducting a field survey. Estimate the oiled percentage of the marsh, degree of oiling, and whether the species impacted are known to be sensitive to oil or more tolerant.

2 Estimate the likely oil residence time by considering the potential for natural weathering and biodegradation, along with the characteristics of the marsh, such as the deposition rate and the type of vegetation.

3 Identify other cleanup concerns, such as wildlife that may be at risk of being oiled, whether the area is used by the public, or has other special concerns associated with it.

Review whether cleanup is necessary or desirable. Cleanup in a marsh is justified when oil can be removed with minimal impact, when other resources are at high risk of being oiled (such as migrating birds), and when unassisted recovery is likely to be very slow (more than two to three years).

Natural (unassisted) recovery may be the best option in cases where oiling is light and natural recovery is likely to occur in a shorter timeframe (one year or less), where cleanup activities would detrimentally impact the marsh, and where wildlife is at low risk of being oiled.

Table 5. Factors to consider when evaluating whether impacts to marshes from spilled oil are likely to be short-term (one to two years) or longer.

Evaluation factors	Examples
Severity of impact	
oil persistence and toxicity	oil type surface area covered, thickness percent of plant oiled
oil penetration in sediment	substrate type, coarseness oil viscosity
type of marsh vegetation	sensitivity of plants (annuals, perennials)
season of impact	growing season vs. dormant season
Oil residence time without cleanup	
weathering	exposure, tidal flushing precipitation
biodegradation "potential"	oil type temperature/climate previous exposure to oiling
Ability of marsh to self-recover	
sedimentation over oiled layer	deposition rate
recolonization	intact adult plants nearby plants reproductive strategy
elevation	location ideal for species or marginal?
environmental stresses	abnormal weather: heavy rainfall, cold temperatures, drought
Other cleanup concerns	
use of site (over short and long term)	human users ecological users
species of special concern	migrants, endangered species
impacts to adjacent areas	mobility of remaining oil sensitivity of adjacent habitats

To proceed with cleanup options, review the site limitations and consider the options that seem appropriate, keeping in mind the need to minimize the physical impacts on the marsh. In many cases, different cleanup techniques will help determine which technique is appropriate at a given site. Trials can refine techniques such as low-pressure flushing to make sure they are having the desired effect. Most responses rely on a combination of cleanup techniques. It is most important to keep the ultimate objectives of the response in mind: to minimize adverse impacts of oil on the marsh itself, on the organisms that use it for habitat, and to speed its ecological recovery.

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