IPIECA REPORT SERIES

VOLUME SIX

BIOLOGICAL IMPACTS OF OIL POLLUTION: SALTMARSHES

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CONTENTS

PREFACE

This report is one of a new series commissioned by the International Petroleum Industry Environmental Conservation Association (IPIECA). The full series of reports will represent the IPIECA members' collective contribution to the global discussion on oil spill preparedness and response, initiated by major oil spill incidents during 1989/90.

In preparing these reports—which will represent a consensus of membership views—IPIECA has been guided by a set of principles which it would encourage every organization associated with the transportation of oil products at sea to consider when managing any operations related to the transportation, handling and storage of petroleum and petroleum products:

- It is of paramount importance to concentrate on preventing spills.
- Despite the best efforts of individual organizations, spills will continue to occur and will affect the local environment.
- Response to spills should seek to minimize the severity of the environmental damage and to hasten the recovery of any damaged ecosystem.
- The response should always seek to complement and make use of natural forces to the fullest extent practicable.

In practical terms, this requires that operating procedures for transportation, storage and handling of petroleum and petroleum products should stress the high priority managements give to preventative controls to avoid spillages. Recognizing the inevitability of future spills, management responsibilities should also give high priority to developing contingency plans that will ensure prompt response to mitigate the adverse effect of any spills. These plans should be sufficiently flexible to provide a response appropriate to the nature of the operation, the size of the spill, local geography and climate. The plans should be supported by established human resources, maintained to a high degree of readiness in terms of personnel and supporting equipment. Drills and exercises are required to train personnel in all spill management and mitigation techniques, and to provide the means of testing contingency plans which, for greatest effect, are carried out in conjunction with representatives from the public and private sectors.

The potential efficiencies of cooperative and joint venture arrangements between companies and contracted third parties for oil spill response should be recognized. Periodic reviews and assessments of such facilities are encouraged to ensure maintenance of capability and efficiency standards.

Close cooperation between industry and national administrations in contingency planning will ensure the maximum degree of coordination and understanding between industry and government plans. This cooperative effort should include endeavours to support administrations' environmental conservation measures in the areas of industry operations.

Accepting that the media and the public at large have a direct interest in the conduct of oil industry operations, particularly in relation to oil spills, it is important to work constructively with the media and directly with the public to allay their fears. Reassurance that response to incidents will be swift and thorough—within the anticipated limitations of any defined response capability—is also desirable.

It is important that clean-up measures are conducted using techniques, including those for waste disposal, which minimize ecological and public amenity damage. Expanded research is accepted as an important component of managements' contribution to oil spill response, especially in relation to prevention, containment and mitigation methods, including mechanical and chemical means.

INTRODUCTION

Saltmarshes are priority areas for protection following oil spills, because they can trap and retain large quantities of oil and are difficult to clean. They are included in the ‘most vulnerable’ category of habitats, as defined by international shoreline vulnerability indices. However, whilst some oiled marshes may take decades to recover, others have shown excellent recovery within one to two years. This report considers factors affecting the fate and effects of oil on saltmarshes, and provides guidelines on clean-up options. The report includes information on the ecology and uses of saltmarshes.

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SALTMARSH ECOLOGY AND DYNAMICS

Saltmarsh vegetation develops on sheltered shores between approximately mean high water level of neap tides (MHWN) and the highest high waters of spring tides.

Saltmarshes may be found all over the world from subpolar regions to the tropics, and depending on latitude, the vegetation may be dormant for varying periods of time in the winter, or may continue growing all year. This has a bearing on predicting what may happen to the vegetation if it becomes oiled—temperate or cold region marshes which are oiled in the autumn or winter may show little sign of recovery for months, simply because it is not the growing season. In Mediterranean systems growth may be slow for much of the hot summer period.

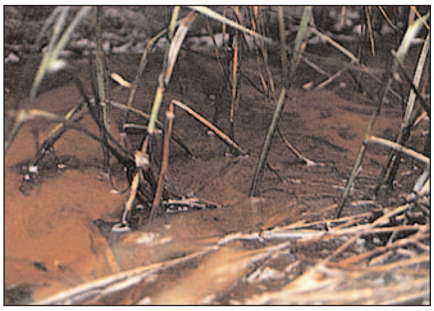
There are extensive tropical saltmarshes, for example Australia has more than one million hectares of saltmarsh and sparsely vegetated high level tidal flat with the greater proportion of this being tropical. Tropical saltmarshes are species poor and species richness increases with more temperate conditions, for example in Australia the richest saltmarsh floras are found in Tasmania and Victoria. Saltmarshes often occur in conjunction with mangroves, the mangroves occupying the lower, regularly tidally inundated part of the intertidal zone and saltmarsh the upper zone above the mangroves.

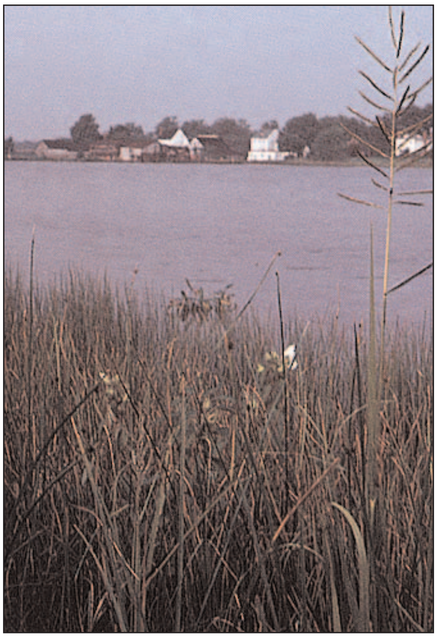
Saltmarshes in temperate or cold climates, such as these in Iceland (top left) and New Brunswick, Canada (top right) have a dormant season in winter, unlike tropical marshes such as these in Gabon (bottom left) and north-east Sumatra, Indonesia (bottom right).

*Saltmarsh (*Sarcocornia*) and mangrove (*Avicennia*) at Towra Point, NSW, Australia. Towra Point is a wetland of international significance listed under the Ramsar Convention; it has been affected by a number of oil spills.*

Within saltmarshes, species are commonly zoned according to tidal height. The zonation is sometimes dynamic, reflecting a successional process whereby the marsh surface with its vegetation accretes sediments thus increasing height relative to tidal datum. This eventually leads to a change in environmental conditions, favouring other species. Sometimes the grass *Spartina*, by enhancing accretion of fine mud, tends to bring about the waterlogged reducing conditions which cause natural dieback. This phenomenon was first reported from the Southampton Water-Lymington area in southern England and, as it sometimes occurs in areas liable to oil spills, needs to be distinguished from oil pollution effects (e.g. by carrying out sediment analyses).

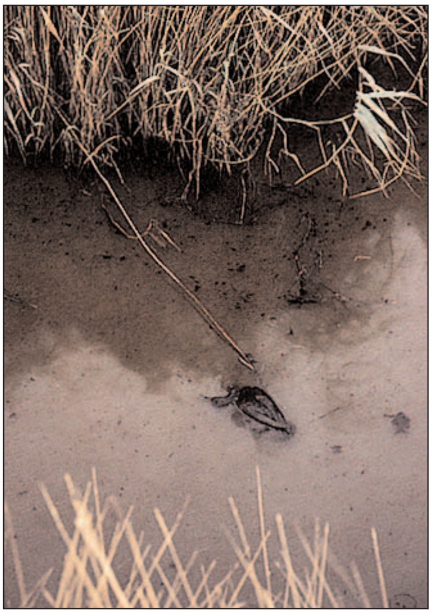
Another factor influencing species composition is salinity, with some species being characteristic of low salinity waters. The extreme cases are virtually fresh water marshes or reedbeds which occur in the uppermost reaches of some estuaries. They are under tidal influence with respect to changes in water level, and oil may be carried into them at high tide. Low salinities may also be caused by freshwater seepage from the hinterland. This affects, for example, many Arctic marshes.





*Low salinity marshes on the Moruya River, NSW, Australia (top left), on the Nanticoke River, Maryland, U.S.A. (right), and reeds (*Phragmites*) on the River Humber, England (bottom left). These reeds were oiled following the *Sivand* spill in 1983.*

Saltmarsh fauna includes crabs, molluscs and worms, with some of the species burrowing into the sediments and thus providing biological pathways for oil penetration in the event of a spill. Insects feed on the vegetation, and are often preyed upon by spiders. A food web applicable to saltmarshes is given in the IPIECA Report: *Guidelines on Biological Impacts of Oil Pollution*. At the top of the food web are birds and fishes, feeding upon a variety of invertebrates. Saltmarshes are recognized as an important habitat for birds (including many migratory species), whilst fishes may come into the marsh at high tide and feed there. There is also the export of plant detritus from marshes—this contributes to food webs in estuaries and other nearshore areas.



Saltmarshes are home for many invertebrates, such as these winkles climbing on the vegetation in a Virginia marsh, U.S.A. (above). They are also important for birds, which are particularly vulnerable to oil. This mallard duck floating in a tidal reedbed channel (left), died as a result of oiling.

HUMAN USE OF SALTMARSHES

Many of the values of saltmarshes have not been recognized in the past, and marshes have often been degraded or destroyed, e.g. by rubbish tipping or land reclamation. From the economic point of view the importance of marshes as nursery grounds for fish (including many of commercial importance) is now well documented. Moreover plant material from marshes contributes to the food webs which sustain nearshore fisheries. In some parts of the world marshes provide valuable grazing areas for sheep, cattle or horses.

Boundary fence between sheep-grazed marsh (left) and ungrazed marsh (right), Bridgwater Bay, southwest England.

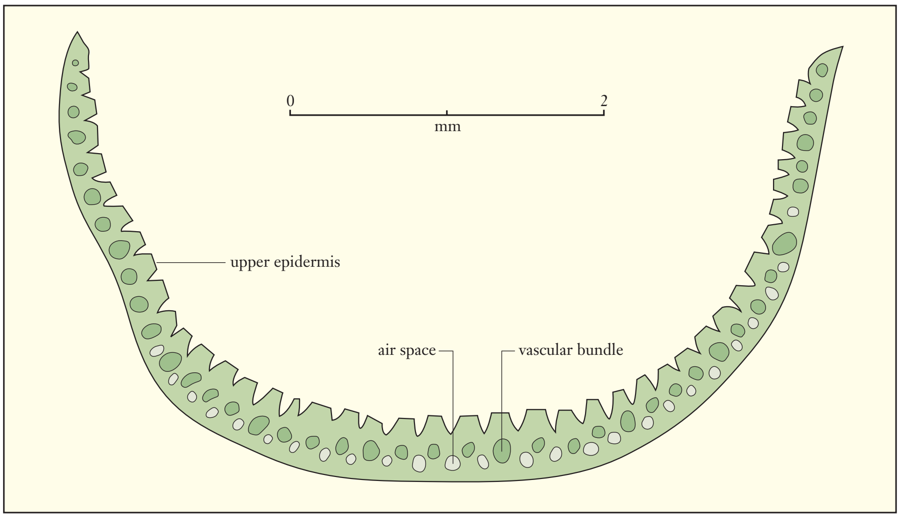
In recent years the significance of saltmarshes in dissipating wave energy has come to be realized (Allen and Pye 1992). Experimental work has shown the effectiveness of marshes acting as natural berms in front of sea walls. Reductions in marsh width cause an increase in the volume of water coming over the defences, or require an increase in the height of the sea wall to provide the same degree of protection. Conservation of saltmarshes thus becomes a strategy for cost-effective coastal protection, especially now that there are concerns about rising sea levels and increased coastal erosion.

Marshes are also, in an unplanned way, used as treatment systems for wastes discharged into estuaries and nearshore waters. In particular they remove and assimilate sewage nutrients such as phosphorus, which can cause problems if the estuaries become overloaded. Gosselink *et al* attempted costings for the various functions of tidal marshes, and concluded that the value of marshes for waste assimilation was particularly high—bearing in mind the high cost of artificial treatment.

Marshes may be valued for conservation reasons, for example because they provide feeding grounds for birds, and also high tide roosting areas. This sometimes has an economic aspect in the form of ‘ecotourism’.

FATE AND EFFECTS OF OIL

Cross section of Spartina *leaf, showing high surface area of upper epidermis, and air spaces. The air spaces are part of an oxygen diffusion pathway which leads from the leaves (where oxygen enters through small pores on the leaf surface) to the root tips. There is experimental evidence that oil on the leaves can reduce the oxygen diffusion to the roots; thus oiling of the aerial parts of the plant may indirectly affect the health of the underground system.*



Experiment on saltmarsh grass turves, showing the influence of weathering on the toxicity of oil. Fresh Kuwait crude (left) killed many of the grass shoots, but recovery was starting after three months. Application of Kuwait residue (centre), simulating a well-weathered oil, resulted in growth stimulation compared with the untreated control turf (right). Turves are 30 x 40 cm, oil treatments were 600 ml per turf, and the photographs were taken three months after oil application. The effect of growth stimulation has also been observed after some spills. One of the reasons seems to be an increase in nitrogen supply to the plants resulting from the activity of nitrogen-fixing bacteria—stimulated by the additional carbon source provided by the oil.

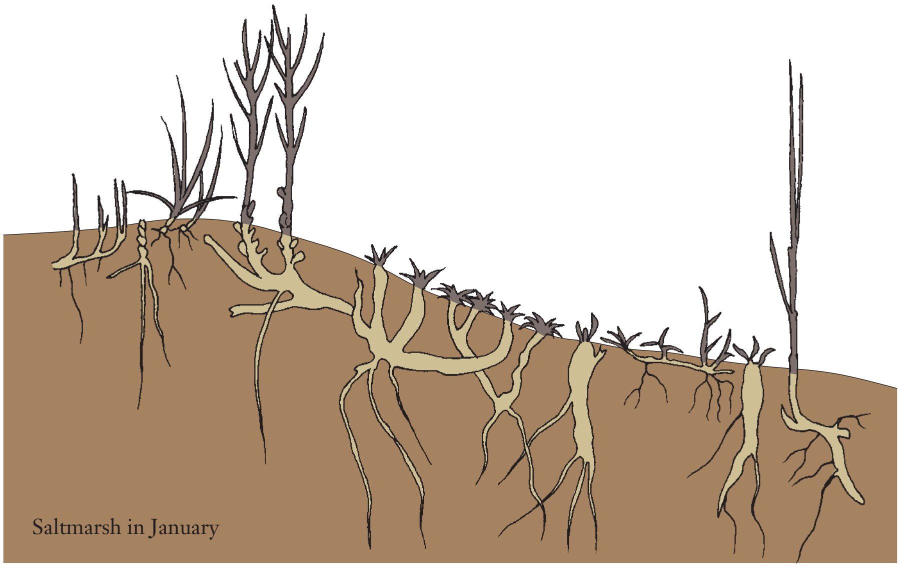
Saltmarshes tend to trap oil for a number of reasons: they occur in sheltered conditions, much marsh vegetation is in the strandline zone, and the vegetation offers a large surface area for oil absorption. Furthermore, many saltmarsh grasses, for example species of *Spartina* which can be dominant over large areas, have corrugated leaf surfaces which increase the holding capacity.

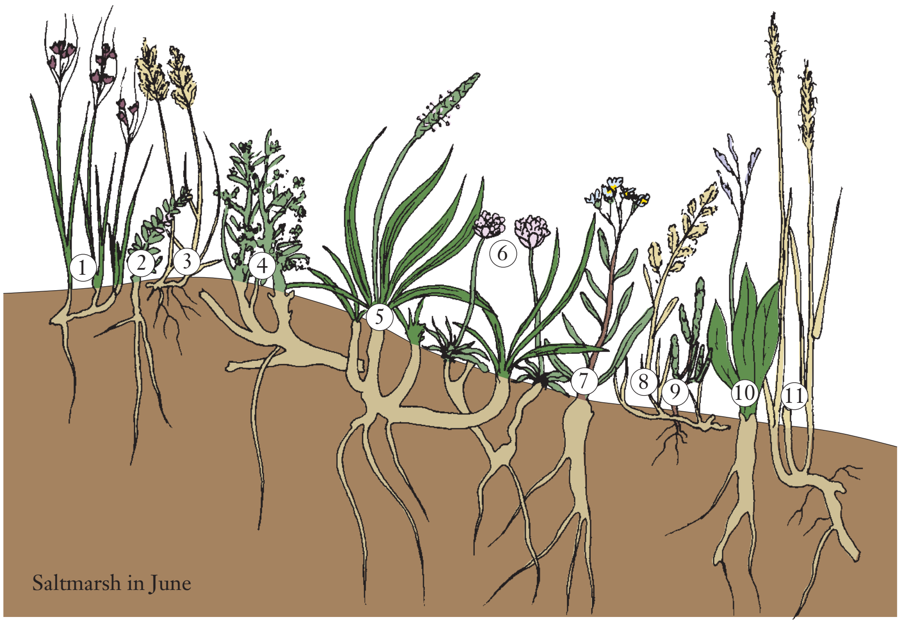
Evidence from case histories and experiments shows that the damage resulting from oiling, and recovery times of oiled marsh vegetation, are very variable. Factors which are important in influencing degree of damage and recovery times are discussed in the IPIECA Report: *Guidelines on Biological Impacts of Oil Pollution*. Of importance on saltmarshes are oil type and degree of weathering, with the lighter more penetrating oils more likely to cause acute toxic damage than heavy or weathered oils.



Two further factors are season of the year and species present. On temperate and cold region marshes where there is natural seasonal die-back of vegetation, perennials are relatively well protected during the winter. Spring is a vulnerable time for seedlings of any species, and during summer the annual species are susceptible because their underground systems are less well developed than those of some of the perennials.

On this northern saltmarsh (Cook Inlet, Alaska), there is a long dormant season (left, January) and rapid growth in the summer (right, June).





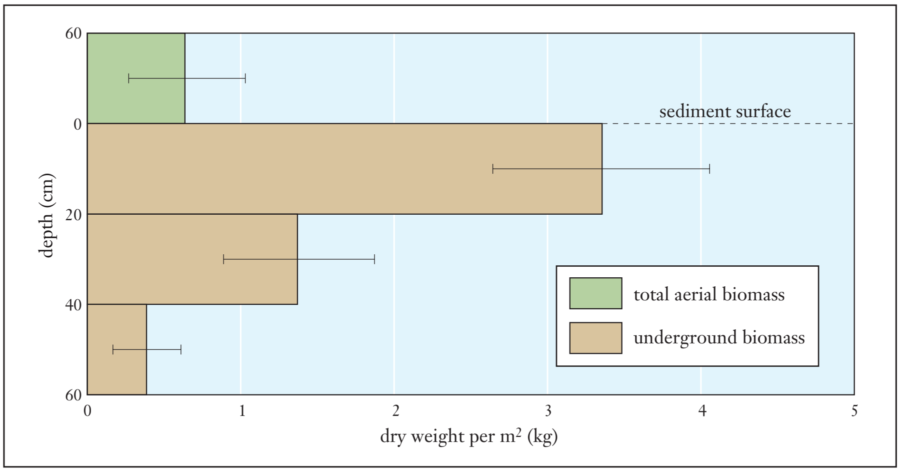
Left: Plants on a British saltmarsh in January (above), showing parts protected by soil and naturally dead vegetation (dead vegetation is shown in grey). Below are the plants in June, showing parts susceptible to oil—leaves, stems and flowers. Annual plants such as Salicornia *are particularly susceptible because unlike most of the perennials they do not have substantial underground systems with protected buds and food reserves. Moreover* Salicornia *does not have a persistent seed bank in the soil, so if killed before seed is set, recolonization will depend upon dispersal of seeds from elsewhere.*

Key. 1: Juncus, *2:* Glaux, *3:* Festuca, *4:* Artemisia, *5:* Plantago, *6:* Armeria, *7:* Aster, *8:* Puccinellia, *9:* Salicornia, *10:* Limonium, *11:* Spartina.

In addition to the above factors, recovery times are influenced by oil loading (thickness of deposit) and degree of penetration of oil into the sediments. Bearing all these factors in mind, three different scenarios with respect to recovery are given below.

- Light to moderate oiling, oil mainly on perennial vegetation with little penetration of sediment. The shoots of the plants may be killed at least in part, but recovery can take place from the underground systems. Good recovery commonly occurs within one to two years.

Oiled Spartina *marsh. Crude oil is trapped on the shoots (top) but there is little penetration into the sediments (bottom left) where most of the plants' biomass is to be found. Good recovery took place within one year, with new shoots growing up through the oiled ones (bottom right).*



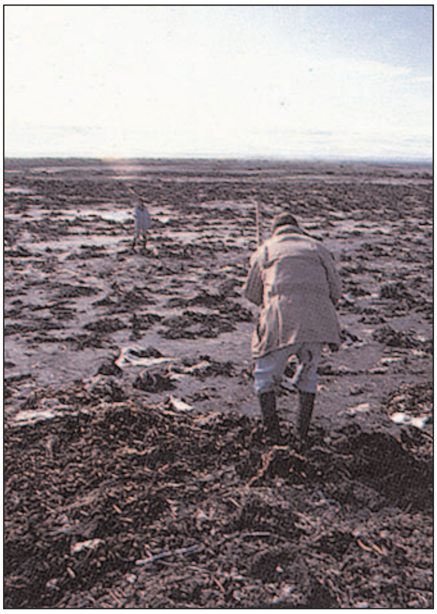
Left: The distribution of Spartina *biomass on a Welsh marsh in summer. The underground system of roots and rhizomes (underground stems) far exceeds the aerial shoots in biomass, with the greatest concentration being in the top 20 cm of sediment. The plant parts in this top 20 cm are particularly vulnerable if there is subsurface penetration by light toxic oils. Horizontal bars on the figure are the statistical 95% confidence limits.*

- Oiling of shoots combined with substantial penetration of oil into sediments. This is more likely to happen with relatively fresh light crude oils or light products such as No. 2 fuel oil, because these are less viscous. Damage to the underground systems results from the sub-surface oil, and recovery is delayed. An example is provided by the *Florida* spill of No. 2 fuel oil in Buzzards Bay, Massachusetts, 1969. Apart from damage to the underground systems of plants, oil in the sediments affected the marsh invertebrates such as fiddler crabs. Recovery of fiddler crab populations was correlated with the gradual disappearance of toxic aromatic hydrocarbons from the sediments, which was not complete after 7 years (Krebs and Burns 1978). After 20 years the marsh surface was visually normal, but detectable traces of oil remained in some of the sediments on a small part of the marsh (Teal *et al* 1992).

Left: Two years after a light fuel oil spill. There is a belt of marsh where Spartina *was killed by the oil, which penetrated into the sediments.*

- Thick deposits of viscous oil or mousse on the marsh surface. Vegetation is likely to be killed by smothering, and recovery delayed because persistent deposits inhibit recolonization. An example is provided by the *Metula* spill of Light Arabian crude oil in the Strait of Magellan, Chile, in 1974. One very sheltered marsh received thick deposits of mousse, and in 1993 these were still visible on the marsh surface (Baker *et al* 1993). A survey in 1991 showed that there was very little plant recolonization in the areas with the thicker deposits (mean oil depth 4.1 cm), but some recolonization was recorded in deposits with a mean depth of 2.4 cm. Individual plants of various sizes were rooted below the oil with aerial parts spreading out over the oil surface. Plant establishment appears to have resulted from seeds falling through cracks in the weathering oil layer.

Nineteen years after the Metula *spill, thick mousse deposits are inhibiting recolonization (below). This site is being used experimentally to test new approaches for treatment. Where thinner deposits are weathering and cracking some plants have become established (right). This is a result of seeds lodging in cracks and germinating (bottom right).*



Another type of delayed recovery can occur if the species composition is altered because some species are sensitive to oil and some tolerant. Tolerant species can gain a competitive advantage which may last for some time. For example, on an upper saltmarsh in Wales experimental oiling eliminated the sea rush *Juncus*, but the tolerant fast-growing creeping grass *Agrostis* rapidly came to dominate the oiled area. 14 years later there were still signs of *Agrostis* dominance—not because any residual oil was still inhibiting the *Juncus* but because it was naturally slow to recolonize an area which had come to be dominated by another species.


This upper saltmarsh vegetation in Wales is naturally dominated by the sea rush Juncus *(top left), but after experimental oiling with Kuwait crude (top right), the recovering vegetation was dominated by the grass* Agrostis *(bottom left, the year following oiling). Eight years after, the oiled area was still grass-dominated (bottom centre) and the rush had still not finished recolonizing after 14 years (bottom right). In this experiment, subsurface penetration and retention of oil was minimal.*



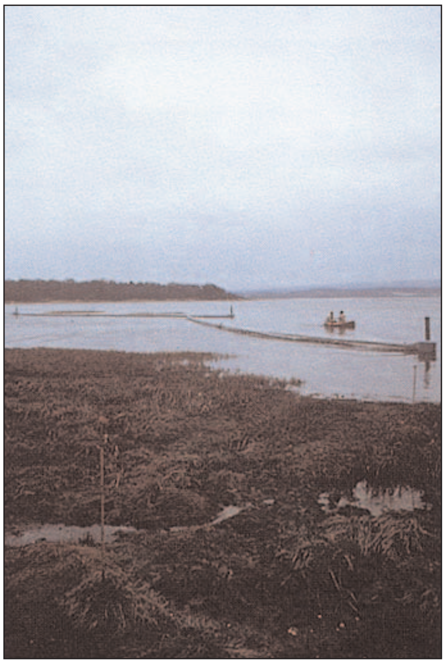
OIL SPILL RESPONSE

The protection of saltmarshes should be afforded a high priority at an early stage in oil spill response since cleaning of oiled vegetation and sediments is very difficult and may cause more damage than the oil itself. The main protection options are:

- mechanical recovery offshore from the marsh;
- dispersal (using oil spill dispersants) offshore; and
- booming of saltmarsh shorelines and inlets.

Mechanical recovery offshore has the advantage of removing oil from the water surface, but in many situations it will not be possible to collect oil quickly enough to prevent some of it from entering marsh systems. Chemical dispersal offshore can be effective if the type of oil is dispersible, although again it may not be possible to deal with all the oil in time, and the possible effects of dispersed oil on organisms in the water column need to be considered (see the IPIECA Report: *Dispersants and their Role in Oil Spill Response*). Long lengths of boom may be needed to protect marshes and this can present anchoring and other deployment problems. As booms are likely to strand at low-tide, special shoreline barriers may be needed that remain upright and effect a good seal between the boom, sediment surface and any water channels. It is essential to remove any oil which accumulates in the boom to prevent it migrating elsewhere, but this may be difficult because of limitations on access, both from the land and sea.

Deployment of a shoreline barrier at Furzey Island in the south of England, with fixed anchor points which allow the boom to respond to tidal changes.



If saltmarshes become oiled, there are a number of options. The first to consider should be 'natural cleanup', i.e. leaving the oil to degrade and the marsh to recover naturally. Case history evidence shows that many oiled marshes recover well naturally, and as cleanup operations are difficult and may be damaging, this is often the best option. Intervention may be considered necessary in the following cases:

- free oil is present in saltmarsh creeks and pools, or on sediment surfaces, such that it may spread with tidal action and contaminate a wider area;
- oil on the marsh surface is a threat to birds or other wildlife;
- recovery time of vegetation in the absence of any intervention is predicted to be unacceptably long (e.g. several years). This may be because of sub-surface penetration of oil, or thick deposits of oil on the marsh surface, as described previously.

If it is decided to intervene, it is usually preferable to use small crews and to avoid the use of heavy machinery, in order to minimize damage to the marsh surface and mixing of oil into the sediments. Roosting birds should be disturbed as little as possible. The main cleanup options are given below, together with comments derived from field experimental and case history evidence (e.g. that reviewed by Baker, Little and Owens 1993). For some other options not mentioned below we do not at present have sufficient information about possible benefits. For example, bioremediation (fertilizer addition to stimulate oil-degrading bacteria), tilling (to increase oxygen supply to oily sediments) and combined bioremediation and tilling are research areas of interest, as possible techniques for heavily oiled marshes.

Physical containment and recovery

Within the marsh system this could entail booming and skimming of oil on the water in creeks, and pumping of bulk oil from the marsh surface, depressions and channels. If logistically possible this is valuable because it can remove relatively large amounts of oil. Problems including damage to the marsh surface may arise when moving heavy equipment, and ways of reducing such damage include the use of road mats and low pressure tyres.

Low pressure water flushing

Results from field experiments are variable. There is minimal additional plant damage, and the method is effective if oil has remained on the sediment surface. It may be justified when large quantities of oil enter marshes subject to reduced tidal washing. The method should be initiated prior to oil penetration into the sediment as it is not effective for sub-surface oil. A watch should be kept for signs of unacceptable erosion.

Sorbents

The use of sorbents appears to have some applications in marshes. The rapid deployment of sorbents (including before the oil actually reaches the marsh) could reduce penetration of oil into sediments. Consideration has to be given to subsequent collection of oiled sorbent material, and its disposal.

In situ burning of oiled vegetation

Results are variable, with burning increasing damage in some cases. Other cases show that burning may be a valid option for treating oiled vegetation at certain times of year. Burning in the winter has the advantage that much of the standing vegetation is dead, and the ground is likely to be relatively waterlogged which will help protect underground systems from heat damage. Because there is evidence that burning can increase sediment oil content, the method is likely to be more suitable for cases where the oil is firmly absorbed on dead marsh vegetation (i.e. cases where there is little or no oil on the sediments).

Vegetation cutting

The cutting of oily large dominant marsh plants such as *Spartina* grass or the reed *Phragmites* may be justified in some cases if there is a threat to birds or other wildlife. These plants have large amounts of biomass underground, and have a good capacity for regrowth provided that the sediments are not seriously oiled, or severely compressed during the cleanup operation. The effects of cutting vary seasonally, with least effect on subsequent yield if the cutting is done in autumn or winter.

Combined vegetation/sediment removal

This is an extreme method which has on occasions been used for serious cases of either thick smothering deposits on the surface of the marsh, or substantial sub-surface penetration of oil. It is usually considered to be important to follow the stripping by rehabilitation (seeding and/or transplanting) in order to minimize erosion and habitat loss. The technique has been successfully used experimentally on a relatively small scale (Krebs and Tanner 1981), but caused severe problems as described below following the *Amoco Cadiz* spill.

Case study: The *Amoco Cadiz* marsh cleanup

Following the *Amoco Cadiz* spill in 1978, a group of marshes in Brittany were particularly heavily oiled. At one time as much as 9000 tonnes of oil were contained within the marshes and oil depths of 5–50 cm were reported. It was considered that recovery would take many years, and the decision was taken to clean the Ile Grande marshes using heavy equipment. As much as 50 cm of sediment was removed during cleanup; at the same time marsh channels were widened and straightened.

Subsequently it was realized that the very invasive cleanup operations were harmful to the marsh and it was clear that some marsh surface had been lost. Nevertheless by 1986 most of the marsh surface lying at an appropriate intertidal height for

Table 1 shows the total vegetated area of marshes in the Ile Grande area in 1971 and 1990. These marshes were extensively cleaned in 1978. Area is given in m^2.

Marsh	1971 area	1990 area	Change in area	Percent change
Small boat harbour	44,107	27,063	−17,043	−38.6
North marsh	35,020	22,746	−12,274	−35.1
Notenno	62,108	45,751	−16,357	−26.3

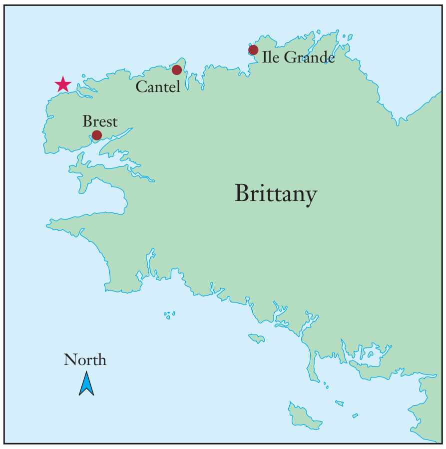
Table 2 shows the vegetated area of the Cantel marsh in 1971 and 1987. This marsh was heavily oiled in 1978 but was not subjected to mechanical cleanup. Area is given in m^2.

Marsh	1971 area	1987 area	Change in area	Percent change
Cantel	50,056	60,341	+10,284	+21.0

plant growth was vegetated. Changes on the Ile Grande marsh have now been studied and compared with the Cantel marsh, which was heavily oiled but not cleaned, using digital image analysis of historical aerial photographs. Results are shown in the tables on page 16 and show that:

- There were dramatic reductions in total vegetated area in the Ile Grande marshes following the spill.
- In contrast, the uncleaned Cantel marsh increased in vegetated area from 1971 to 1987 in spite of being heavily oiled in 1978.

It was concluded that the formerly vegetated areas at Ile Grande that are now bare represent those areas where the intertidal height has been reduced below MHWN and which are therefore unsuitable for plant growth. New sediment accretion to the appropriate height will be necessary before revegetation can occur.



Location of oiled marshes in Brittany following the Amoco Cadiz *spill. The star marks the site of the* Amoco Cadiz *wreck.*

Ile Grande marsh in June 1986, showing lack of vegetation on cleaned area (top), and edge of cleaned area with normal marsh vegetation in background (bottom).

RESTORATION

Restoration schemes can draw upon experience from around the world which shows that successful marsh establishment is possible in appropriate environments. For example, *Spartina* has been planted in China to create marsh pasture, and there have been plantings on dredge spoil (particularly in the US) to stabilize the spoil and provide new habitat. However, there is an inevitable focus on *Spartina* or a few other key species for such schemes—with reliance on longer-term natural processes for the establishment of greater diversity of flora and fauna.

With respect to spill sites, a restoration scheme will need to be considered if it is predicted that natural recovery will take an unacceptably long time, or if cleanup has included stripping of vegetation and sediments. It is of crucial importance that the sediments to be planted are at an appropriate height relative to tidal datum, and in some cases backfilling with suitable sediment is an option for achieving this. Aggressive cleaning can lower the marsh surface to the extent that plant growth is not possible, as has been shown by the *Amoco Cadiz* case history. In contrast, Krebs and Tanner (1981) successfully planted *Spartina* on marsh from which oily sediments had been stripped to a depth of not more than 10 cm. This removed most of the oil (which in high concentrations killed plants) and the residues remaining did not preclude good plant growth. In cases of doubt, initial small-scale experimental transplants help indicate if the sediments are suitable for full-scale planting.

Re-vegetation may be accomplished using seeds, young 'bare-root' nursery seedlings, or older potted nursery seedlings which are planted into the sediments in their biodegradable pots thus avoiding root damage. Use of nursery stocks avoids the damage which would be caused by digging plants directly from existing local healthy marsh. However, the original propagation material used by the nursery should be local as far as possible, because there is considerable geographical variability in most saltmarsh plant species. Depending on local nutrient conditions, it may be advantageous to apply slow-release fertilizer to the planting site.

Older potted seedlings are comparatively costly but are more resistant to erosion than seeds and young seedlings, are more vigorous and have a higher survival rate. Costs will also be influenced by density of planting, for example a one metre planting grid may be suitable for a sheltered marsh, and a denser pattern preferable in cases where the marsh is more exposed to wave action or tidal currents. Monitoring of transplant performance should be included in the programme.

CONCLUSIONS

Saltmarshes occur globally and fulfil many functions which are not always recognized, including coastal protection and the provision of nursery areas and food web support for fish. In some parts of the world they are used by grazing livestock, and they are an important habitat for wildlife species such as wading birds.

Saltmarshes are oil traps, but recovery times from oiling vary widely, from one or two years to decades. This depends on a number of factors, with the longest recovery times being associated with thick smothering deposits on the marsh surface, substantial sub-surface penetration of oils into the sediments, or inappropriate cleanup.

Because of the difficulties of cleanup, saltmarshes should be priority areas for protection following a spill. If oil does in fact become stranded on a marsh, there are a number of possible cleanup techniques which may in some cases be followed by a restoration programme. Heavy machinery and the aggressive technique of vegetation and sediment stripping can cause severe problems. All cleanup options should be judged against 'natural cleanup', which is often the best course of action.

ACKNOWLEDGEMENTS AND FURTHER READING

Acknowledgements

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Further reading

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