Biogenic - **In mangroves, the trees themselves create the habitat. Biogenic also means "resulting from the actions of living organisms."**

CHAPTER 3. Response

Key Points

- Mangroves are highly sensitive to oil and often are priority areas for protection.
- Winds and tides carry spilled oil into mangrove forests, where oil coats the soil surface, aerial roots, and propagules.
- Dispersing or burning oil offshore can prevent or lessen impacts to mangroves.
- Spill containment and cleanup techniques should minimize any additional impacts to mangroves and other natural resources at risk.

As detailed in the previous chapter, mangroves are particularly sensitive to oil and, where they are native, often are priority areas for protection. The objective of spill response in mangroves, as in any habitat, is to minimize the damage caused by the accident and released oil. Spill containment and cleanup techniques should minimize any additional impacts to mangroves. Mangrove forests are a biogenically structured habitat—the trees themselves create the habitat. Death of the trees, the structuring organism, causes loss of habitat, with corresponding impact on the suite of associated species dependent upon them, including offshore resources such as coral reefs. Potential response strategies should be evaluated to determine whether the ultimate benefits from the response action outweigh any environmental costs to the mangrove forests and associated sensitive habitats at risk.

Variables such as oil type, weather, location, and availability of response equipment will determine initial spill response options. In the best-case scenario, oil is prevented from moving into and contaminating mangrove areas. Promising, on-water response techniques that can help prevent oil from reaching mangrove forests include chemical dispersion and in-situ burning.

On-Water Response Options to Prevent Mangrove Oiling

Mechanical Recovery Offshore

Mechanical containment and collection of spilled oil on water using equipment such as booms and skimmers are primary initial cleanup methods used at many spills. Experience has shown, though, that mechanical recovery alone usually cannot adequately deal with very large spills offshore. Weather and sea conditions, the nature of the oil, and other factors may limit the effectiveness of mechanical recovery. In such cases, alternative open-water response techniques, such as dispersant application or in-situ burning of oil on water, may significantly reduce the risk that oil will reach shore and impact mangroves and other sensitive intertidal and shoreline habitats.

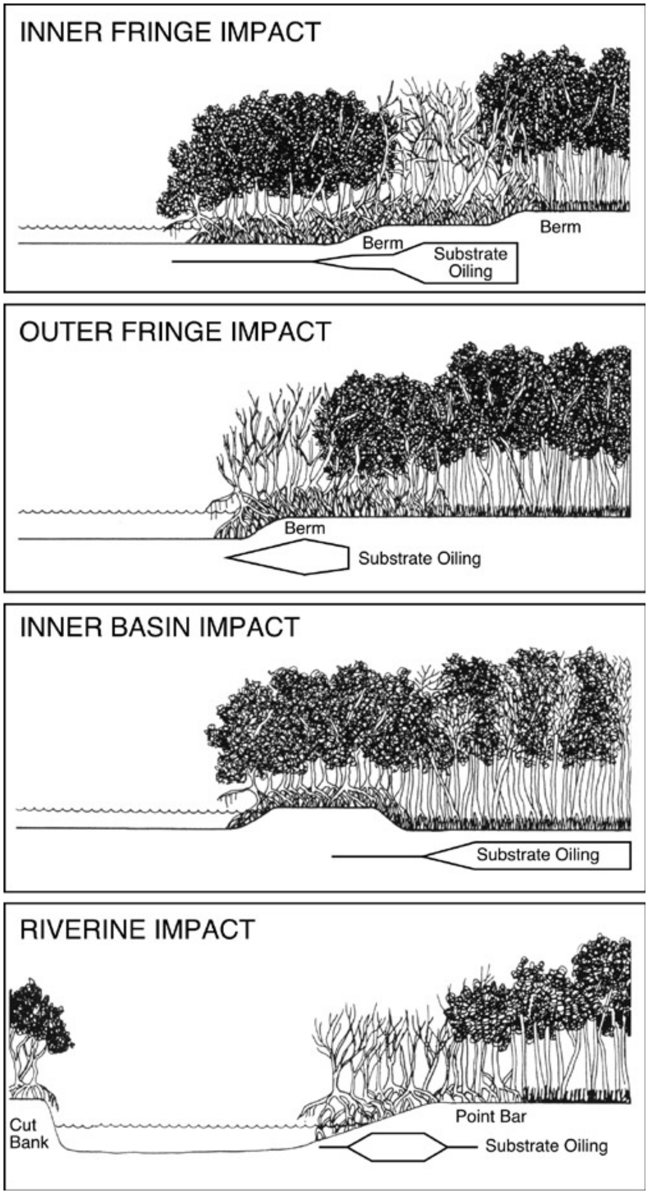

Figure 3.1 Schematic showing possible impacts to different types of mangrove forests from oiling (Research Planning Inc.).

Offshore Dispersant Application

Chemical dispersants are products applied to oil on the water surface to enhance formation of fine oil droplets, which mix into the water column and are dispersed by currents. Most oils physically disperse naturally to some degree due to agitation created by wave action and ocean turbulence. Chemical dispersants enhance and speed up this natural dispersion process. Dispersing oil soon after release minimizes impacts to wildlife at the water surface (e.g., birds and marine mammals) and reduces the amount of floating oil that reaches sensitive nearshore and shoreline habitats. If applied appropriately offshore, chemical dispersants can be an effective tool for protecting mangrove forests and the habitat they provide. Tradeoffs among other resources at risk, such as potential effects of temporarily higher concentrations of oil in the water column on pelagic organisms and coral reefs, should be considered before dispersant use. When applied appropriately in sufficiently deep water, impacts to corals are expected to be minimal.

Offshore In-situ Burning

In-situ burning is a response technique in which spilled oil is burned in-place. When used appropriately, in-situ burning can remove large quantities of oil quickly and efficiently with minimal logistical support. Like dispersants, in-situ burning can help minimize impacts to wildlife at the water surface and reduce the amount of oil that reaches sensitive nearshore and shoreline habitats, including mangroves. A potential disadvantage of open-water in-situ burning is that a small percentage of the original oil volume may remain as a taffy-like residue after the burn. Floating residue can be collected but residues that sink or escape collection and move inshore could potentially contaminate mangroves.

Wrack – Organic material, usually from dead seagrass or algae that wash up on shorelines.

It is important to note that, in contrast to open-water burning, in-situ burning should **not** be conducted within mangrove forests, as explained below under "Response Techniques Inappropriate for Mangroves."

Oil Behavior in Mangroves

Mangroves grow in low-energy depositional areas, which also tend to be the sites where oil accumulates (Figure 3.1). Spilled oil is carried into mangrove forests by winds and tidal currents. Oil slicks generally move into mangrove forests when the tide is high, depositing on the soil surface and on aerial roots and propagules when the tide recedes. The resulting distribution of deposited oil is typically patchy due to the variability in tidal heights within the forest. If there is a berm or shoreline, oil tends to concentrate and penetrate into the berm or accumulated detrital wrack. The oil can penetrate into the soil, particularly through crustacean burrows and other voids like those formed by dead mangrove roots. Lighter oils tend to penetrate more deeply into mangrove forests than heavier and more weathered oils, but will not persist unless they mix into the soil. However, crude oils and heavier refined products can pool onto sediment surfaces and are highly persistent. These heavy oils and emulsified oil can be trapped in thickets of red mangrove prop roots and black mangrove pneumatophores and are likely to adhere to and coat these surfaces, as well as other organic materials, such as seagrass wrack. Re-oiling from resuspended oil, particularly as tides rise and fall, may further injure plants over time. Where oil persists, sheens may be generated for months or years (Figure 3.2).

Assessing the extent and distribution of stranded oil can be difficult, particularly in dense forests, because the forest interior sometimes can be oiled even if the mangrove fringe is not, due to its lower tidal height. Access to interior areas of forests usually must be limited in order to minimize damage. Also, the tree canopy may hide oil on the ground during oil-observation overflights. Affected areas may become more apparent from the air as trees die or defoliate. Oiled trees may start to show evidence of effects, such as leaf-yellowing, within weeks after oiling. Trees may take months to die, especially with heavy oils.

Figure 3.2 Oil stranded in and around mangrove islets in Tampa Bay (Bouchard Barge B-155 *spill, 1993; NOAA OR&R).*

Cleanup of oiled interior mangroves can be particularly difficult because some mangrove forests are nearly impenetrable. Intrusive cleanup operations may significantly damage roots and seedlings, and also trample oil deeper into sediments, where it is slower to break down. Consequently, access to interior areas of mangrove forests should be limited and highly supervised. During later, less-supervised stages of mangrove cleanup on Eleanor Island at the 1993 Bouchard *B-155*

Bunker oil spill in Tampa, Florida, cleanup workers reportedly spread oil from the mangrove fringe to the roots of previously unoiled mangrove plants in the mangrove interior as they moved back and forth removing surface sediment contamination. In spills of relatively fresh, lighter oil, such as diesel or crude, sediment penetration and toxic damage can occur very rapidly and the oil can break down relatively quickly. In such cases, cleanup operations are not expected to save many mangrove trees or effectively remove much oil, and any benefits are probably outweighed by the potential additional damage from access for cleanup.

Anaerobic – **Occurring with little or no oxygen.**

Natural processes will eventually remove remaining oil. Tidal action and precipitation can help physically flush stranded oil out of contaminated mangrove areas. Weathering processes degrade the oil, gradually reducing quantity and toxicity. Oiled substrate may not be able to support mangrove growth while toxicity levels remain high. Oil can degrade quickly in warm tropical environments, but more slowly if degradation is inhibited by anaerobic soil conditions. Oil may persist for very long periods in the peaty or muddy sediment where mangroves are most often found. Heavier oils can persist in mangrove sediment for decades after a spill.

Cleanup Options for Oiled Mangroves

If mangrove forest shorelines are oiled, extreme caution must be exercised in selecting cleanup activities. Potential benefits of oil removal must be weighed against the risks of potential additional harmful impacts from the cleanup technique.

No Action/Natural Recovery

There are several circumstances under which it is appropriate to do nothing. The foremost of these situations is when cleanup would cause more harm than benefit to mangroves or other associated habitats, or when shorelines are inaccessible. When no cleanup is conducted, oil will slowly degrade and be removed naturally, assisted by natural and storm-generated flushing. (See *Era* spill case study, Chapter 5.)

Spills of light oils, which will naturally evaporate and break down very rapidly, do not require cleanup. Such light oils are usually gone within days. Furthermore, light fuel oils such as gasoline and jet fuels typically impart their toxic impacts immediately, and cleanup can do little to reduce the damage. The only light refined product that might warrant some cleanup is diesel (No. 2 fuel oil) if sediment could be contaminated. It is important to recognize, though, that even where no cleanup is advisable, light oils can cause significant injury and contaminated mangrove habitats may require many years to recover.

Cleanup also is not recommended for small accumulations of oil, regardless of product type. Impacts caused by light accumulations generally do not warrant the tradeoffs associated with cleanup activity. Even for major spills, there may be cases for which it is best to take no action, depending on the nature of the oiling and the characteristics of the mangrove forest affected. Generally, cleanup should not be conducted in interior areas of mangrove forests because of the risk of damaging mangrove roots and seedlings, trampling oil into the sediment where it will degrade much more slowly, and spreading oil into previously unoiled areas. Exceptions may be made if access is possible from upland areas or if vegetation is sparse enough to permit access without injury to pneumatophores and prop roots. If cleanup is attempted in interior mangroves, experienced personnel must constantly oversee cleanup crews to prevent further injury.

In any case, attempts should be made to control the movement and spread of any mobile oil within the mangroves to prevent contamination of adjacent areas. Several response techniques described below, including barriers, passive collection, and flushing can be used to help control and contain mobile oil.

Barrier Methods

Several forms of barriers can deflect or contain oil, including booms, sediment berms, dams, and filter fences. Barriers can be used along mangrove shorelines and inlets to prevent oil entry. Proper strategic boom deployment in sheltered lagoon areas may be highly effective in trapping large quantities of mobile oil and reducing oil impact to interior mangroves. To be effective, barriers must be deployed immediately after a spill before oil moves into mangrove areas. This means that appropriate types and sufficient amounts of barrier materials must be stockpiled and available at the time of the spill, and that strategies for boom placement and deployment have already been established and tested.

Because of the soft substrate and sensitivity of prop roots and pneumatophores, barrier methods should be deployed carefully and maintained vigilantly to prevent physical damage during installation and removal. Untended boom that breaks loose can become entangled in the mangrove fringe, breaking off pneumatophores, prop roots, and juvenile plants. Boom deployed under inappropriate conditions or improperly deployed can cause additional harm, so caution must be exercised in planning where, when, and how boom will be used.

There are some shorelines where barriers will be ineffective due to physical characteristics, such as current strength and water depth. Where barrier methods are not an option, mangrove forests will remain vulnerable to contamination. For example, booms generally cannot be deployed successfully along mangrove shorelines with strong currents or along sections of mangrove shorelines behind shallow flats. Also, boom usually is not effective with light oils because they can readily mix into the water column and pass under floating boom. Heavier oils are more likely to remain at the water surface and so are more easily controlled with booms, although very heavy oils can sometimes become negatively buoyant and pass under boom.

Manual Oil Removal

Manual removal, using hand tools and manual labor, is often conducted to remove bulk oiling by heavier oils, such as crude oil or Bunker C oil, stranded in mangroves. Manual removal can help prevent other areas from becoming contaminated as the oil moves around, and helps limit long-term sediment contamination. Consideration should be given, however, to the trade-off between these benefits of manual removal and the mechanical damage to the mangroves that often accompanies manual cleanup. It is nearly impossible to reach the tangle of prop roots and pneumatophores of most mangroves without causing physical damage. Trampling of oil deeper into the sediment from foot traffic can be another harmful consequence of manual cleanup. Garrity and Levings (1996) observed that black mangrove pneumatophores along paths used by cleanup workers were significantly more likely to be killed than those in areas accessed by one or a few workers. Where pneumatophores had been dense at the time of the spill, paths often were bare substrate by 15 months post-spill as broken pneumatophores died and rotted away. (See Bahía las Minas case study.)

If manual removal is conducted in mangroves, and particularly in interior areas, consideration should be given to ways to minimize foot traffic and other impacts. Conducting activities from boats, when possible, is advisable. Close supervision of cleanup crews is essential.

Passive Collection with Sorbents

Sorbent boom or other sorbent materials can be placed at the fringe of oiled mangrove forests to passively recover any mobile oil, including sheens. Sorbents are oleophilic and either absorb or adsorb oil. They can be composed of either synthetic or natural materials, and they come in a variety of forms, including sausage boom, "pom-pom" or snare boom, sheets, rolls, pellets, and loose particulates. Sorbents vary in their effectiveness depending upon oil type, degree of oil weathering, and sorbent absorption or adsorption capacity. Sorbent materials must be placed and removed carefully to minimize disturbance of sediments and injury to mangrove roots. Sorbent materials must be closely monitored to ensure they do not move and damage mangrove roots, and must be removed when they become saturated or are no longer needed.

Sorbents have been used to wipe heavy oil coating from mangrove surfaces. Before using sorbents in this way, consideration should be given to associated physical damage. This activity is best conducted under close supervision and only in areas where substrate is firm enough to prevent oil mixing into it.

Vacuuming

Vacuuming can remove pooled oil or thick oil accumulations from the sediment surface, depressions, and channels. Vacuum equipment ranges from small units to large suction devices mounted on dredges, usually used outside vegetated areas. Generally, vacuuming should be conducted only at the outer fringe of mangrove forests; it is most feasible and least damaging where vegetation is not very dense, enabling easy access. Vacuuming can be used effectively on heavier and medium oils, providing they are still reasonably fluid. Lighter, more flammable petroleum products such as jet fuel and diesel generally should not be vacuumed.

As shown in Figure 3.3, vacuuming was used effectively to remove thick mats of Bunker C oil that stranded in mangroves during the 1993 Tampa Bay oil spill response (see Case Studies for more details). Vacuuming worked particularly well where oil stranded on sand substrate at the mangrove fringe. The technique was less effective over fine sediment and oyster beds. In order to minimize cleanup damage, care was taken to place the vacuum barge over firm sand substrate, where there were no seagrass beds.

Ambient Water Flooding (Deluge) and Low-Pressure Ambient Water Flushing

Low-pressure flushing with ambient seawater can wash fluid, loosely adhered oil from the sediment surface and mangrove vegetation into areas where it can be collected, as long as it can be done without resulting in significant physical disturbance of the sediment. Generally, flushing is most feasible at the outer fringe, but can sometimes be used to remove oil trapped within the mangrove forest. Flushing at water levels high enough to submerge sediments may help minimize impact to the substrate. If substrate mixing is likely or unavoidable, responders should allow the oil to weather naturally. Flushing is not effective with heavy oils, such as Bunker C, or highly weathered oils. Oil should be flushed only during ebbing tides to move it out where it can be collected.

Flushing can be a useful technique to help control the movement and spread of mobile oil in mangrove areas to prevent contamination of adjacent areas. When flushing free-floating oil, care should be taken to minimize emulsification.

Chemical Shoreline Cleaners

Chemical shoreline cleaners are products sprayed on oil-coated surfaces to “loosen” the oil so that it can be flushed off with ambient water. Tidal waters or water sprays alone cannot effectively wash away heavy oil. Shoreline cleaning products vary in their toxicity and recoverability of the treated, mobilized oil. Chemical shoreline cleaners loosen or dissolve heavy oil deposited over the lenticels on coated prop roots or pneumatophores so the residue can be washed away and lenticel functioning restored. Functioning of the lenticels, which enable delivery of oxygen to the subsurface roots, is critical to survival of the trees.

Some experimental studies (Teas et al. 1987, 1993) have reported promising results using chemical shoreline cleaners on mangrove trees coated with oil. A shoreline cleaner (Corexit 9580) applied to oiled red mangroves coated with Bunker C oil and then washed with seawater (within 7 days of oiling) reportedly effectively reduced oil adhesion and exposed the lenticels, restoring their air permeability. The study concluded that mangrove trees can be saved with shoreline cleaners if the interval between oiling and cleaning is no longer than about a week. Another study (Quilici et al. 1995) reported harmful effects on mangrove trees treated with shoreline cleaner without flushing. Results likely depend on the particular product used and application technique. Further testing and more experience with the effectiveness and effects of using shoreline cleaners on mangroves are needed to determine whether their use is advisable.

Figure 3.3 Cleanup worker removing heavy oil by vacuuming among mangrove prop roots in Tampa Bay during 1993 spill (NOAA OR&R).

Nutrient Addition/Bioremediation

Nutrient addition can enhance biodegradation of oil under nutrient-limited conditions. Microbes and essential nutrients for oil degradation generally are not limited in mangrove habitats, so nutrient enrichment may not offer much benefit. Studies conducted by Teas et al. (1991) and Quilici et al. (1995) concluded that adding fertilizer does not significantly enhance biodegradation of oil in mangrove sediment. Another study (Scherrer and Mille 1989) reported that oleophilic fertilizer enhanced the oil biodegradation process in peaty mangrove sediment, though the fertilizer in this experiment was added to the oil before the mangrove vegetation was contaminated. In any case, applied nutrients would be difficult to keep in place as tides flood through mangrove forests. There is also some risk that nutrient application might cause localized eutrophication and acute toxicity, particularly from ammonia, due to low mixing rates and shallow waters.

Burns et al. (1999) concluded that aeration of contaminated sediments may be effective in enhancing biodegradation of oil in mangrove sediments, since mangrove sediments are usually anaerobic below surface layers. The researchers suggest a bioremediation strategy that employs selective aeration to promote the survival of the trees vital to maintaining the structural integrity of the mangrove forest. The trees also provide the habitat necessary for the return of burrowing animals to impacted sediments. Burns et al. (1999) point out that aeration is not necessarily a strategy to be used over large areas. Reports on trial experiments to test this strategy are not yet available. More testing of this potential response technique is needed.

Removal of Oiled Wrack and Debris

Heavily oiled wrack and debris should be removed if it can be done without significantly damaging prop roots, pneumatophores, and seedlings or trampling oil into the sediment. However, oiled wrack should not be removed until the threat of oiling has passed, since wrack and leaf litter can act as a sort of natural barrier sorbent and actually protect the trees from direct oil contact. Unoiled and lightly oiled wrack and leaf litter should not be removed because they provide habitat and contribute to the ecosystem.

Table 3.1 Chart summarizing recommendations for various response techniques in oiled mangrove forests. (From Characteristic Coastal Habitats: Choosing Spill Response Alternatives, *NOAA OR&R 2000.)*

	Oil Category				
Response Method	I	II	III	IV	V
Natural Recovery	A	A	A	A	A
Barriers/Berms	B	B	B	B	B
Manual Oil Removal/Cleaning	–	D	C	C	C
Mechanical Oil Removal	–	–	–	–	–
Sorbents	–	A	A	A	B
Vacuum	–	B	B	B	B
Debris Removal	–	A	A	A	A
Sediment Reworking/Tilling	–	–	–	–	–
Vegetation Cutting/Removal	–	–	–	–	–
Flooding (deluge)	–	B	B	B	B
Low-pressure, Ambient Water Flushing	–	B	C	C	C
High-pressure, Ambient Water Flushing	–	–	–	–	–
Low-pressure, Hot Water Flushing	–	–	–	–	–
High-pressure, Hot Water Flushing	–	–	–	–	–
Steam Cleaning	–	–	–	–	–
Sand Blasting	–	–	–	–	–
Solidifiers	–	C	C	–	–
Shoreline Cleaning Agents	–	–	I	I	I
Nutrient Enrichment	–	I	I	I	I
Natural Microbe Seeding	–	I	I	I	I
In-situ Burning	–	–	–	–	–

Oil Category Descriptions

I – Gasoline products
II – Diesel-like products and light crudes
III – Medium grade crudes and intermediate products
IV – Heavy crudes and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method in the specific environment and habitat for each oil type. The codes in each table mean:

A = The least adverse habitat impact.
B = Some adverse habitat impact.
C = Significant adverse habitat impact.
D = The most adverse habitat impact.
I = Insufficient information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

Response Techniques Inappropriate for Mangroves

Under no circumstances should live mangrove vegetation be cut or burned. Both techniques will destroy trees and mangrove habitat. Mangrove trees are slow-growing and take decades to be replaced by mature vegetation. The loss of a large number of trees may compromise the forest structure, making it unlikely to recover naturally. Other cleanup techniques used at some oil spills but inappropriate in mangroves include mechanical oil removal, high-pressure or hot-water flushing, steam-cleaning, slurry sand blasting, trenching, and sediment reworking, tilling, or removal. All these methods would severely damage or destroy mangrove forests and associated organisms and habitats. Techniques such as pressure washing and sand blasting risk causing severe erosion.

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