*Shipwreck of the F/V Swordsman 1 aground on a coral reef at Pearl and Hermes Atoll, in the Western Hawaiian archipelago, June 2000. (USFWS)*

# CHAPTER 4. RESPONSE METHODS FOR CORAL REEF AREAS

## Key points

- Remote locations, lack of response equipment, and waste disposal issues limit options for spill response in some coral regions.
- Mechanical cleanup and salvage efforts should avoid additional impacts to coral by using floating lines and minimizing coral damage from boats and anchors.
- In-situ burning can remove large amounts of oil rapidly, containing up to 90% or more of the oil.
- Smoke plumes from burning oil present a health hazard from fine particulates; monitoring protocols (SMART) can aid in setting safe boundaries around smoke plumes.
- Natural containment areas or special fire-resistant boom can collect oil for burning.
- In-situ burning needs fewer personnel and less equipment than mechanical cleanup methods, and creates little waste material.
- Heat from in-situ burning penetrates only a few cm below the water surface.
- Dispersants are chemicals that break up oil slicks, allowing oil particles to disperse into the water column.
- Chemically dispersed oil biodegrades at a faster rate than non-dispersed oil.
- Dispersing oil at sea can help reduce shoreline impacts and mortality of birds and other wildlife.
- Dispersants are most effective on light to medium oils, and are less effective on more viscous oils.
- The window of opportunity for effective use of dispersants is short.

The goal of spill response in coral areas is the same as in any other habitat—to minimize damages caused by the accident and any associated spillage. All potential response options need to be evaluated to determine whether the ultimate benefits from the response action outweigh the costs (or impacts) of the action. Choosing response methods carefully, with an understanding of the sensitivities of the reef environment, will minimize any additional impacts incurred from the cleanup.

Variables such as location, weather, and availability of equipment for salvage, lightering, or cleanup will determine which options can be considered during a response in coral reefs. In the best-case scenario, modern response equipment will be available and salvage or lightering may be able to prevent any oil from spilling. Contingency plans may already be in place and specific response techniques can be evaluated and prepared, even if they turn out to be unnecessary. At the other end of the spectrum, response may be constrained by a remote site where equipment such as booms, skimmers, and sorbents may not be readily available. It may take long periods of time for salvage vessels to reach the scene and attempt to pull a damaged vessel off a reef (see Rose Atoll case study). Even when containment and collection of spilled oil is feasible, storage and disposal of collected waste products may limit cleanup operations.

## General response considerations

In addition to toxic impacts from spilled oil, vessel accidents can hurt coral reefs in other ways, including groundings and other physical impacts, anchor damage, and release of ballast water or hazardous materials (Figure 4.1).

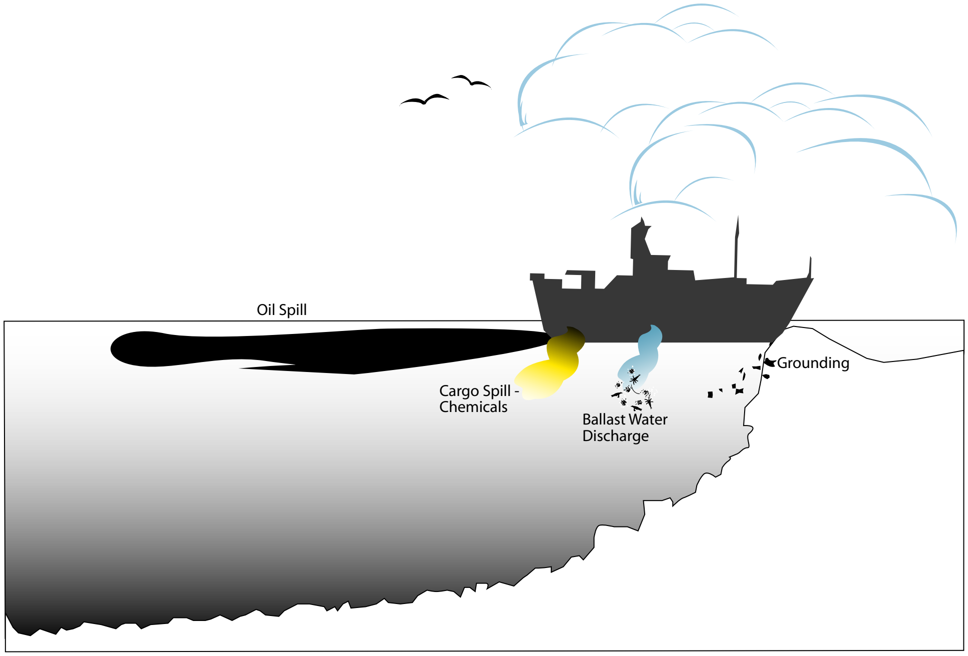


*Figure 4.1. Overview of possible impacts at a vessel accident, including ballast water discharge, potential oil or chemical spillage, and physical impacts to reef structures from grounding.*

### Physical impacts

Vessel traffic, anchor deployment, dragging lines, and physical contact by response workers can detrimentally impact coral reefs and associated habitats. Responders working near coral reefs must take care to avoid physical damage to coral, especially in shallow waters. Using floating lines, especially for salvage, but also for boom deployment and other operations prevents damage to coral structures from dragging heavy lines over the reef itself. Response methods such as skimming and placement of certain types of booms will need to be limited to deeper waters (greater than 3 m) to avoid direct physical impacts to coral. In areas where coral is exposed at low tides, workers should avoid walking on reefs.

Ship groundings frequently damage reefs, and are discussed in more detail in Chapter 5. Physical damage from a ship grounding may be the main impact to coral, especially when the ship is successfully refloated or lightered without spillage. Removal of a grounded vessel can add to the detrimental impact on the reef, especially if new channels have to be opened or constructed to remove the vessel (see the Rose Atoll case study).

### Ballast water

To lighten and remove a grounded vessel from a coral reef, ballast water may be discharged. Ballast water may contain spores, eggs, larvae, or other life stages of marine life not indigenous to the reef ecosystem at the wreck site and thus may introduce these non-native organisms into areas where they can significantly alter the existing community structure. Response options can include treatment of ballast water before discharge with ozone, chlorine, or heat.

### Hazardous cargo

Stricken or stranded vessels may release hazardous cargoes into a coral reef area. These can include many substances that are bulk-transported aboard ships: bulk organic (petro) chemicals, pesticides or herbicides, ores (such as copper), bulk acids and bases (such as caustic soda or ammonia), and cement (as at the *M/V. S. Zakariadze* in Puerto Rico). Other items that have spilled include shipping containers, fishing gear (longlines, traps, or set nets), and decomposing animal matter such as bait or fish. Response options for these situations need to be developed on a case-by-case basis.

Multiple aspects of an incident can require simultaneous attention. For example, the bulk carrier *Igloo Moon* stranded on a coral reef near Miami, damaging the coral reef. It was also at risk of spilling its cargo (butadiene), oil (bunker and diesel fuel), and potentially contaminated ballast water. The response sequence resembled a medical triage, in which activities were organized to maximize risk reduction. The coral reef was injured by the initial impact and subsequent vessel extraction, but presumably a much larger and longer-lasting disaster was prevented by careful treatment and discharge of the carrier's ballast water and cargo, and fuel lightering.

## Booming and skimming

### Advantages/disadvantages

Physical containment and collection of spilled oil on water using booms and skimmers is the primary cleanup method used at many spills. High current speeds, heavy wave action, or shallow water may limit the effectiveness of either booms or skimmers and necessitate consideration of alternative cleanup strategies. Skimming operations will most likely be conducted outside the reef in deeper waters, to prevent oil from coming over the reef crest. It may be difficult to anchor collection booms on the reef slope, because of great depth.

Booms must be anchored so they do not damage coral, and tended regularly to maintain effective positioning and avoid damaging shallow coral. Sorbent booms can be deployed to catch oil leaching from shorelines, but must be tended and changed frequently so they do not become a source of oiling themselves. In some circumstances, oil can be collected via vacuum pumps, if it is concentrated nearshore on water, provided there is appropriate access for the mechanical equipment.

Once the oil is collected, adequate short-term storage is necessary, as well as a disposal plan for the waste oil and other waste products. Disposal issues can be significant, especially in remote areas, and lack of available collection facilities can limit skimming operations. At the *Morris J. Berman* barge oil spill in Puerto Rico, the pools of a large swim stadium were put into service for temporary waste oil collection.

### Using skimmers and booms

- Limit collection and skimming operations to water deeper than 3m
- Tend booms regularly so they do not harm shallow reefs
- Do not damage coral when anchoring booms
- Route boat traffic away from shallow reefs and seagrass beds to avoid propeller damage and increased sedimentation

## In-situ burning

In-situ burning is a response technique in which spilled oil is burned in place. It has been adapted and used in settings as varied as the open ocean and in marsh areas.

### Advantages/disadvantages

In-situ burning can remove large amounts of oil relatively rapidly. Estimated removal efficiencies of 90 percent and above (of contained oil) far exceed those for mechanical or chemical response methods. Burning requires less equipment, logistical support, fewer personnel, and produces less waste material than other cleanup techniques. In remote locations where many coral reef spills occur, these offer significant advantages logistically and environmentally. As long as oil has not emulsified (if the water content is greater than 25 percent, it will not burn) the response window for burning can last several days.

In-situ burning produces large amounts of highly visible smoke and other combustion by-products, which can be a significant deterrent to its use, especially in regions with larger human populations. The smoke plume presents both a human and animal (e.g., marine mammals) health risk, primarily from fine particulate material that may aggravate respiratory conditions. The smoke is also a problem of perception: a massive black plume appears formidable and menacing. However, the remoteness of many potentially affected coral reef areas may minimize this concern. SMART monitoring protocols, developed by the U.S. Environmental Protection Agency, the U.S. Coast Guard, NOAA, and the Agency for Toxic Substances and Disease Registry, can be deployed when burning is conducted near population centers to monitor particulate levels and provide real-time feedback to the responders. This feedback helps responders determine safe boundaries where smoke levels do not pose health risks to people.

In order to sustain burning oil, the slick must be approximately 2-3 mm thick. Either the spilled oil must be present in that thickness in the slick or natural collection area, or specialized (and expensive) burn boom can be deployed to collect and retain the oil for burning. In-situ burning is less effective if winds are greater than 20 knots and seas are greater than 2-3 feet.

### Burning in coral reef areas

To our knowledge, there have been no intentional large-scale in-situ burns in coral reef habitats. During World War II, many ships and aircraft that were attacked near corals released oil and were set ablaze, particularly in the Indo-Pacific region. For understandable reasons, the environmental impacts of these events were not documented. During the 1968 *Witwater* spill in Panama, small patches of heavy oil apparently were burned as a shoreline oil removal technique, but this was a limited and small-scale application.

### Environmental impacts

There are no studies of in-situ burning in coral regions. Burning is a relatively new spill response method, and studies on its environmental effects and toxicology are limited. The Newfoundland Offshore Burn Experiment (NOBE) provides much of our current information on burning oil at sea. Crude oil was intentionally released, ignited, allowed to burn, and extensively studied, including water-column toxicity to marine organisms, and associated physical effects from the burn.

The results from NOBE experiments and other studies indicate that crude oil burn residue has a low inherent toxicity to test organisms, and incurred no additional toxicity over unburned oil. Extrapolation of these results to tropical areas and coral reefs should be done cautiously, however.

In some instances the physical characteristics of burned oil residue could be a concern, especially if the density is increased from that of the source oil. Burned oil usually floats on the water's surface. There have been some observations from both controlled burn experiments and from actual ship fires, however, that burn residue can sink under specific circumstances. Specifically, residue may float when warm, then sink as it cools off, allowing potential subsurface exposure to residues. Based on the previously mentioned studies, the inherent toxicity of the material is believed to be low; but the physical impacts of contact (such as fouling or smothering) may be a concern. Given the alternative of much greater volumes of unburned oil impacting nearby resources, the tradeoff offered by burning seems reasonable; as always, however, the assessment of net environmental benefit must take place on a case-by-case basis.

Water temperatures under a burning slick can reach near boiling in the top few millimeters in a static situation. However, water only a few centimeters below the slick remains unaffected. If a fire boom containing a burning oil slick is being towed or if underlying water is moving, then there is no appreciable rise in water temperature.

### Using in-situ burning

- Burning may be effective on many oil types, except emulsified oil (water content of greater than 25%). Burning heavy oils may produce residue that sinks.
- Oil must be 2-3 mm thick to sustain a burn—it can be collected in natural containment areas, or in special fire boom that can be towed on water.
- Weather conditions are conducive for burning when winds are less than 20 knots and seas are less than 2-3 feet
- SMART monitoring protocols can help delimit areas where smoke plumes do not present a health risk for people.

## Dispersants

Dispersants are chemicals containing surfactants, like those in soaps and detergents, which have both a water-soluble and an oil-soluble component. When applied to oil slicks, they reduce the surface tension of the oil and promote the formation of small oil droplets that "disperse" throughout the water column. Dispersants are sprayed directly on floating oil as a fine mist, either from aircraft or boats. Oil also disperses naturally, especially lighter fuels and oils spilled in areas with heavy wave action.

Dispersants have been used on a number of tropical oil spills, but the follow-up data are scarce, especially on potential impacts to coral reefs. Regional contingency plans that pre-approve the use of dispersants generally place greater restrictions on their use in nearshore waters. Currently, some regions are rethinking conditions under which dispersants may be safely and effectively used close to shore. This involves understanding the toxicity and fate of dispersed oil, and balancing possible tradeoffs when oil may impact sensitive shorelines such as mangrove forests.

### Advantages/disadvantages

Dispersing oil may reduce the damaging effects of surface slicks on birds, sea turtles, and mammals and helps prevent oil from stranding on tourist beaches, or from impacting sensitive shoreline habitats such as mangroves, marshes, or enclosed lagoons. Dispersants treat large slicks quickly, deterring the formation of emulsions, and accelerate the biodegradation of oil in the water column. Dispersants are an important cleanup tool, and offer a response method that can be deployed during weather conditions that preclude mechanical recovery methods. Dispersion is the primary response option in 36 of 149 nations and the secondary option in another 62. Many tropical islands, atolls, and reefs are too remote to deploy mechanical protection and cleanup methods, but dispersant use may still be an option if pre-planning efforts have stockpiled dispersants in readily available locations.

Under the proper conditions, lighter fuel oils to medium crude oil can be easily dispersed, but heavier bunker oils are much more difficult to disperse. Weathering increases oil viscosity, and may cause formation of water-in-oil emulsions, which are less amenable to dispersion. A moderate amount of turbulence is needed to mix dispersed oil into the surface waters. Vertical mixing and diffusion then dilute and disperse the oil further into the water column. Test applications of dispersants can be used to determine the viability of response-scale applications at a given spill.

### Dispersant use in coral reef areas

During the past three decades, dispersants were among the countermeasures used to combat several spills impacting tropical coasts. However, we have little documentation of these events, especially the benefits or impacts to coral reefs and adjacent habitats (see case studies for *Ocean Eagle*, Bahía las Minas, and field studies). The fate of dispersed oil has been studied in several Northern Hemisphere offshore and nearshore locations, but there have been very few studies in tropical areas near coral reefs. Field and laboratory research studies provide the following picture.

A common misconception is that dispersed oil sinks to the bottom. In fact, wave action and currents rapidly dilute and disperse the plume of dispersed oil and transport it away from the treated site. The subsurface plume may move in a different direction and at a slower rate than the untreated surface slick. Within several hours the plume grows and oil concentrations greatly decrease. Within a day or two, dilution, spreading, and transport reduce the concentration of dispersed oil by a factor of 100, 1,000, or even 10,000.

Dispersed oil degrades via natural processes, including biodegradation. Laboratory studies indicate that, in cooler water systems, dispersed oil biodegrades much more quickly than undispersed oil (on time frames of a few days to several weeks). Although no comparable work has been done in tropical settings, it is likely that dispersed oil degrades much faster than in temperate areas because of warmer temperatures.

Given the right oceanographic conditions, dispersant use may be appropriate near submerged coral reefs (i.e., where water depth increases quickly, and subsurface currents are likely to carry dispersed oil away from the reef). NOAA has modeled such situations for potential spills, when dispersants were considered as a response tool near a coral reef. Usually, these determinations are made after considering the potential shoreline impacts and evaluating local weather and oceanographic conditions at the time of the spill.

In the Caribbean and some parts of the Pacific, shorelines adjacent to coral reefs contain mangrove forests, which are highly sensitive to oil. At many tropical oil spills, the most severe impact is to mangroves, sea turtle nesting areas, or other sensitive shoreline habitats. Recovery of severely impacted mangrove forests takes decades, and often has associated impacts, including shoreline erosion, decimated nursery areas, or chronic leaching of oil from contaminated sediments (see Bahía las Minas case study). When conditions are appropriate to minimize impacts to coral, using dispersants or in-situ burning on floating oil can be an effective and environmentally advantageous cleanup strategy that reduces long-term impacts.

## Toxicity of dispersed oil

Toxicity studies screen dispersant products and provide data for planning dispersant use during spills. In tropical areas, there is continued reluctance towards using dispersants nearshore (closer than 3 miles) because of concerns about possible detrimental impacts to coral and associated reef inhabitants. In Chapter 3, we discuss methods used for laboratory studies of oil toxicity and how these impact the resulting data. As with coral toxicity studies on oil alone, laboratory protocols should be carefully evaluated before applying toxicity lab results to real-life dispersed oil scenarios. Table 4.1 summarizes relatively recent studies on toxicity of chemically dispersed oil.

*Table 4.1. Laboratory studies of toxicity of chemically dispersed oil to coral.*

| Response | Exposure | References |
|---|---|---|
| **Varied with exposure: stress responses to tissue death** | **2 and 4 ppm, dispersed fuel oil WAF<br>6 - 48 hrs, semi-static system** | **Harrison et al. 1990** |
| **Varied with exposure: Unsuccessful larval settlement to death** | **5 – 5000 ppm (nominal conc.), dispersed crude oil WAF,<br>2-96 hrs, static system** | **Epstein et al. 2000** |
| **Reduced photosynthesis in zooxanthellae (reversible)** | **20 ppm, dispersed crude oil,<br>8 hr, flow-through system** | **Cook and Knap 1983** |

Field studies provide more realistic guidance about dispersed oil toxicity in larger systems. Table 4.2 summarizes field studies from Bermuda, the Arabian Gulf, and Panama on impacts to coral from chemically dispersed oil. Coral follows the pattern of most other organisms: its sensitivity to dispersed oil depends on the dose (the concentration and the length of exposure). Very high dispersed oil concentrations and long exposures can kill coral, whereas lower doses show few, if any, impacts, many of which are reversible. Thus, dispersants and dispersed oil may be less damaging in real field conditions than had been suggested by older laboratory toxicity tests. These results highlight the importance of evaluating toxicity in the context of realistic exposures, which can be estimated from oceanographic models.

*Table 4.2. Field and mesocosm studies examining impacts of chemically dispersed oil to corals.*

| Response | Exposure | References |
|---|---|---|
| **Delayed sublethal impacts** | **5 days, 1-2 ppm, crude oil** | **Legore et al. 1989** |
| **Coral stress symptoms (reversible)** | **24 hrs, 20 ppm, crude oil** | **Knap et al. 1983** |
| **Coral death, invertebrate death** | **24 hrs, 12-20 ppm, Prudhoe Bay crude** | **Ballou et al. 1989** |
| **No effects on growth parameters** | **6 hrs, 6- 50 ppm, Arabian light crude** | **Dodge et al. 1984** |

## Using dispersants

- Dispersants are applied using spraying systems, mostly aerial or from vessels, at a specific treatment rate, (e.g., 5 gallons per acre of oil, or dispersant:oil ratio of 1:20). Multiple applications may be needed over several days.
- The window of opportunity for effective use of dispersants is small: it depends on the oil type, and narrows with oil weathering and increases in viscosity and emulsification.

- Dispersant use is not likely to be 100% effective, and thus will not eliminate the need for other response methods
- Available dispersants are much less toxic than older versions; most toxic impacts are from the oil itself
- Dispersant trade-offs center on potential impacts to water-column organisms versus impacts to birds, mammals, turtles, and shoreline resources (such as mangroves)
- Recommendations from the National Research Council (ASTM 1987) on dispersant use around coral reefs:
  - *Whenever an oil spill occurs in the general vicinity of a coral reef, dispersant use should be considered to prevent floating oil from reaching the reef.*
  - *Dispersant-use decisions to treat oil already over a reef should take into account the type of oil and location of the reef.*
  - *Coral reefs with emergent portions are high-priority habitats for protection during oil spills.*
  - *The use of dispersants over shallow submergent reefs is generally not recommended, but the potential impacts to the reef should be weighed against impacts that might occur from allowing the oil to come ashore.*
  - *Dispersant use should be considered to treat oil over reefs in water depths greater than 10 m if the alternative is to allow the oil to impact other sensitive habitats on shore.*
  - *Dispersal is not recommended to treat oil already in reef habitats having low-water exchange rates (e.g., lagoons and atolls) if mechanical cleanup methods are possible.*

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*A helicopter brings response personnel to the grounded barge Morris J. Berman off San Juan, Puerto Rico, 1994 (NOAA OR&R)*