Introduction

Mangroves around the world have been exposed to oil both from individual spills and from chronic pollution from refinery and storage tank discharges. Well-documented oil spills in mangrove areas provide us with a good idea of some of the complexities and variability of the impacts and response options. We have highlighted techniques (learned from field trials, toxicology, and laboratory studies) to measure the health of mangroves. With help from NOAA's IncidentNews.gov database and from colleagues around the world we searched for case studies of oil spills impacting—or potentially impacting—mangroves. We kept our focus on individual incidents and did not include cases involving long-term pollution. However, we know that some spills occurred at sites that had been impacted by spills in the past (Bahía las Minas, Panama and Roosevelt Roads, Puerto Rico). We also focused more on the direct and indirect effects of oiling and cleanup on the mangroves themselves, less on associated fauna and flora. The incidents include a wide range of documentation and a wide range of oil types. From these we identified several case histories that provided information about the incident, response methods, and long-term impacts and recovery. These are briefly reviewed below in chronological order.

One lesson that is quite clear from even a few of the cases is that the full extent of damage to mangroves is not apparent for many months or years after an incident, regardless of the fuel type and extent of response (other than full protection). Many questions remain about most studies. The most important is, How long does recovery actually take? Although a number of post-spill studies were conducted for as long as 10 to 20 years, we were able to find only a few reports where monitoring continued long enough to confirm full recovery.

Zoe Colocotronis, *La Parguera, Puerto Rico, 1973*

On March 18, 1973, the *Zoe Colocotronis* ran aground on a reef 3.5 miles off the La Parguera tourist area on the southwest coast of Puerto Rico. The master intentionally released 37,579 barrels (1.58 million gallons) of Venezuelan (Tijuana) crude oil. An estimated 24,000 barrels (1.01 million gallons) stranded on the beaches of Cabo Rojo. Three separate pools of black oil 6-8 inches thick oiled the shore of Cabo Rojo on the Bahía Sucia side. On March 21, a large number of sea cucumbers, conchs, prawns, sea urchins, and polychaete annelids washed ashore. Organisms died in the *Thalassia* seagrass beds and oil moved into mangrove forests composed of white, red, and black mangrove trees (Nadeau and Berquist 1977).

Response

Cleanup efforts were conducted outside the mangrove areas and involved booming, digging sumps, and pumping the collected oil into tank trucks. On March 23, before the oil in the mangroves could be recovered, an unexpected wind shift drove patches of oil out of the mangroves and into other areas and beaches. By March 24, 604,000 gallons of nearly pure oil had been removed from other areas using sumps, skimmers, and vacuum trucks. Steam cleaning was not used because there was no accessible source of fresh water. No cleanup was conducted in the mangroves.

Impacts

EPA scientists surveyed the mangrove areas for a week beginning 24 hours after the spill. Detailed surveys were conducted of all oiled areas during the second week after the spill and again during the thirteenth week. Additional EPA site visits were made in January 1974 (10 months later) and January 1976 (34 months later) providing some idea of long-term effects. In one well-studied area, one hectare of red and black mangrove trees was defoliated and died during the three years following the spill. However, the EPA scientists also noted that much of the associated invertebrate life had recovered (Nadeau and Bergquist 1977).

In November 1973, eight months following the spill, oil chemists from Bowdoin College in Maine visited several oiled sites and noted a re-emergence of young trees. Although sediment oil concentrations remained high, the oil was heavily weathered and degraded. These observations suggested that the toxic components were gone in about half a year. This team had also visited oiled black mangrove sites four times between April 1979 and April 1981, 6 to 8 years after the spill. The scientists measured ratios of sodium and potassium in some plants, supporting the idea that oil injured the trees by disrupting salt and water balance and that such disruption might have been alleviated by directed cleanup. However, they made no comment on the visible health of the mangroves at that time (Page et al. 1979; Gilfillan et al. 1981).

Eleven years after the spill other chemists took sediment cores from several previously oiled mangrove sites and found concentrations ranging from 10,000 to 100,000 ppm (dry weight, total unresolved hydrocarbons) in a layer 6 cm below the relatively clean surface sediments. In addition, they found oil, possibly from the 1962 *Argea Prima* spill, 14-16 cm below the surface. These last researchers did not report the status of the mangrove trees themselves (Corredor et al. 1990).

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Peck Slip, *Eastern Puerto Rico, 1978*

On December 19, 1978 the *Peck Slip* released between 440,000 and 450,000 gallons of Bunker C oil into open waters offshore of eastern Puerto Rico. Within two days oil had stranded in segments along 26 km of eastern Puerto Rico shorelines, mostly sand beach. However, some oil entered outer and inner fringing mangroves in three areas, and inner basin mangroves in one of these areas.

Response

No cleanup actions were undertaken although observers noted floating absorbent pads at one site. Surveys of mangroves were conducted shortly after the spill (December-early January 1979; Robinson 1979), about three months later (Gundlach et al. 1979), 10 months later, and 18 months later (Getter et al. 1981).

Impacts

Mangroves on a small island (Isla de Ramos) were lightly impacted (prop roots had a 15-cm band of oil 50 to 60 cm above the substrate) and apparently did not suffer long-term injury. Near Punta Medio Mundo, about 2.6 acres of inner fringe and inner basin mangrove roots were heavily oiled (prop roots with up to a one-meter band of oil) and two acres moderately oiled (0.3 to 0.45-m band of oil; Robinson, 1979). An estimated 3.5 tons of oil coated the mangrove roots. Algae growing on the prop roots absorbed the oil. Another two acres of mangroves at Pasaje Medio Mundo were moderately oiled with an estimated 1.3 tons of oil (prop roots oiled by a 0.2-meter band on oil).

Within two to three months the heavily oiled inner fringing and basin mangroves at the Punta Medio Mundo forest were defoliated. Prop-root oiling had widened to a band of over two vertical meters, possibly from oiled climbing crabs. Later site visits confirmed that mangroves with the most heavily oiled prop roots remained defoliated 10 and 18 months later (Getter et al. 1981).

This was one of five sites studied by Getter et al. (1981). From these studies the authors urged that inner fringing and inner basin mangroves receive highest priority for protection from oil spills.

Restoration

No restoration activities were undertaken at this spill.

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Figure 5.1 Oiled crab and snail on red mangrove trunk at the Peck Slip spill in 1979. (OR&R)

JP-5 Jet Fuel Spills, Roosevelt Roads, Puerto Rico (1968 and 1999)

In 1986 and again in 1999, Roosevelt Roads Naval Air Station storage tanks released JP5 jet fuel into a cove in eastern Puerto Rico. Before the 1986 and 1999 JP-5 spills, the area had been contaminated by oils from several past spills: a Bunker C spill in 1958 and a diesel spill in 1978, both from onshore storage tanks, and a 210,000-gallon diesel spill in 1981 from a tanker. All of these spills contaminated mangrove areas but effects of the earlier spills are unknown. In both recent cases, mangrove forests were contaminated, though response strategies differed markedly. Effects on mangroves were monitored at both spills.

On November 27, 1986, 59,000 gallons of JP-5 fuel washed down a catchment stream (tidal creek) and into Ensenada Honda. Two mangrove forest areas were contaminated, one in the tidal creek and the other at the head of the saltwater bay.

On October 20, 1999, 112,000 gallons of JP-5 fuel spilled from a day-tank at the U.S. Navy Base. The oil flowed into an underground drainage pipe, which runs under a runway and several roads for several hundred yards. The pipe empties into an open drainage ditch, which drains to a 12-hectare mangrove forest. This forest drains through a culvert into Ensenada Honda Bay.

Response

No cleanup actions were mentioned in reports dealing with the 1986 incident, presumably because of the high evaporation rate of JP-5 jet fuel in open conditions.

In the 1999 incident the Navy's primary environmental concern was the bay. In the face of an approaching hurricane, USN Construction Battalion (Sea Bees) personnel constructed a dam to plug the culvert between the first impacted mangrove (later named "mangrove A") and the mangrove adjacent to the bay (later named "mangrove C"). This dam trapped the water in mangrove area A. The final reports should be consulted for specifics as there were many details to the flow diversion response. Fuel was recovered, where practical, using under flow dams, skimmers, vacuum trucks, and sorbent materials. Attempts to manually remove oil with sorbents proved both ineffective and a human health risk for responders from inhalation of jet fuel fumes. It was estimated that 15 to 20% of the product was recovered, over 70 percent evaporated, and some 10 to 15% (approximately 11,200 - 16,800 gallons) remains unaccounted for; presumably stranded in the mangroves or in the sediments near the spill site.

The fuel flowed through the mangroves and some portion of the oil changed color from almost clear with a slight yellow tint to brown/black, similar to a light crude oil. It is unknown as to whether this was as a result of tannins from the mangroves dissolving into the oil or the JP-5, liberating heavier product remaining from previous spills.

Impacts

1986 Spill.

In the 1986 incident two mangrove areas were contaminated by JP-5 fuel: (1) the northernmost red mangroves drained by the tidal creek, and (2) the mixed species mangroves adjacent to the Coast Guard pier in Ensenada Honda. Local responders noted visible effects on adult trees within 10 days of oiling. Follow-on surveys were conducted in the second area 17 months later and again 23 months later. During these surveys 10 x 10-meter grids along transects documented tree height, canopy, tree death, percent open canopy, seedling counts, and invertebrate biota. There were three transects in oiled areas plus two in unoiled areas. In June 1987 false-color aerial photos were taken of the impacted forest.

Detailed surveys five months later found most adult trees in the oiled areas dead and/or defoliated. However, there were live seedlings with highest densities along the forest front. Furthermore, sediment oil concentrations were extremely low (less than 1 ppm) and similar to concentrations in unoiled areas. Because of the low impact on seedlings and the near-absence of fuel oil six months later, researchers concluded that there was no smothering effect from the jet fuel. Adult tree defoliation and mortality was likely caused by initial direct toxicity of the fuel to root structures.

Apparently these mangroves recovered sufficiently from the 1986 JP-5 spill to merit no comment from personnel responding to the 1999 spill, other than that they were protected by the response itself. Given the location of the 1999 contamination (tidal creek mangroves), very little cleanup was possible. However, the series of water diversion activities resulted in preventing oiling of the mangrove (C) in Ensenada Honda.

1999 Spill.

Tidal creek mangroves (areas A and B) were clearly damaged from the 1999 incident, due either to fuel toxicity or extended flooding, or both. Follow-up studies through October 2001 indicated that there was some recovery in the flooded area A two years after the incident, with new propagules and new shoots on injured trees. However, there were no signs of recovery in area B. Of a total of 50 acres of injured mangrove forest, about 30 acres showed no signs of recovery two years later (Csulak 2001).

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Vesta Bella *Oiling and Cleanup of U.S. Virgin Islands Mangroves, 1991*

On March 6, 1991, the barge *Vesta Bella* sank southeast of Trinidad, releasing an unknown amount of high aromatic No. 6 fuel oil. The barge continued to leak for more than 20 days. Some oil moved north, eventually stranding on several beaches on the north side of St. John, in the U.S. Virgin Islands. Beach surveys began there on March 23. Red mangrove oiling was not extensive: one-meter prop roots of individual or small groups of mangrove trees were oiled 30 to 35 cm above the substrate. However, the short (15 cm) prop roots of supratidal white mangroves were heavily coated. These trees were also stressed before the spill due to beach erosion.

Response

A modest level of cleaning was attempted with a planned revisit to the site a year later. Roots were carefully wiped by a select group of workers, and then snare boom was strung and allowed to scrub roots with the rise and fall of the tide. Snare boom was removed after 24 hours. One year after the spill the mangroves were revisited and measured for a variety of plant health indicators.

Impacts

The white mangroves at one site were heavily defoliated but also showed extensive new growth on both oiled and unoiled trees, growth that apparently began six to twelve months post spill. There was some sign of chlorosis and no signs of oil on roots. Close inspection of formerly oiled fringing red mangroves indicated these trees were healthy—fully foliated, with no signs of chlorosis. Only one tree was severely oiled and cleaned at the time of the spill: measurements indicated this tree was in good health.

Unfortunately, no oiled mangroves were left uncleaned, to serve as a reference, so it is difficult to ascribe the good condition of the trees one year later, to the cleaning. However, it is clear that this level of cleaning did not cause any mortality to the trees. The authors caution that this cleanup method was done in areas with a firm substrate. Finally, they confirmed that there was very little contamination of the substrate.

Restoration

No restoration activities were undertaken at this spill.

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T/V Era, *Spencer Gulf, South Australia, 1992*

On August 30, 1992, the tanker *Era* released an estimated 296 tonnes (974,000 gallons) of heavy Bunker oil (a blend of diesel and heavy residual) at a jetty near the head of Spencer Gulf, South Australia. On the night of September 1-2, an estimated 20 tonnes (5,500 gallons) stranded along 10-15 km of mangrove (*Avicennia*) forest south of Port Pirie, S.A. However, subsequent surveys estimated that the actual quantity stranded in the mangroves was 57 tonnes (15,600 gallons).

Response

Within two to three hours of the release, the oil slick was treated from vessels spraying dispersants Corexit 9527 and 7667; the following day, aircraft also sprayed slicks with Ardrox dispersant. Responders were advised that cleanup within the mangrove forest was not feasible and would likely increase damage to adjacent, unimpacted areas. Thus, all subsequent activity in the mangrove forest was restricted to detailed and long-term monitoring.

Impacts

Oiled mangroves were monitored for four years after the spill. This is perhaps one of the most well documented accounts available of the fate and effects of oil in a mangrove forest. Only a brief, highly simplified account can be given here and the reader is advised to consult the report for important details and qualifications (Wardrop et al. 1997).

Due to an extremely high tide, oil penetrated far into the mangrove forest (50 m) coating leaves as well as stems, trunks, and sediment. Oil concentrations and visible damage to mangrove trees were recorded over four years. About 75-100 hectares were oiled: 4.2 heavily, 7.3 moderately, and 38.0 lightly. In 1992 heavy oiling of canopy and extensive mats of oiled sea-grass debris characterized heavily oiled areas. By November 1992 mangroves over a total area of 2.3 hectares suffered extensive defoliation; the area expanded slightly to 3.2 hectares by 1995 and then stopped increasing. Trees that were totally defoliated did not recover during the four-year period. Defoliation and degree of sediment oiling were correlated: heavily oiled areas were completely defoliated and moderately oiled areas were "severely" defoliated. In lightly oiled areas trees had less leaf damage and recovered rapidly. "Overall the extent of damage in each of the studied locations, and the speed with which it occurred, has correlated to the oiling classification assigned in the first survey" (Wardrop et al. 1997). Finally, the veracity of the original recommendation of "no cleanup" was supported: injury to mangrove trees was restricted to those initially impacted by moderate to heavy oiling.

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Witwater *and Texaco Storage Tank Spills, Bahía Las Minas, Panama, 1968 and 1986*

Two large oil spills, 18 years apart, resulted in long-term injury and recovery to a portion of the 1,200 ha of mangroves of the Bahía Las Minas area of Panama.

***Witwater*.** On December 13, 1968, the oil tanker *Witwater* broke up in heavy seas off the Atlantic coast of Panama, spilling 14,000 barrels (588,000 gallons) of Bunker C and diesel oil into the water 5 miles from Galeta Island. Strong seasonal winds pushed the slick towards the island, oiling sand beaches, rocky coasts, and mangroves.

Texaco Storage Tank. On April 27, 1986, a Texaco storage tank at a refinery on Isla Payardi, Panama, ruptured, releasing approximately 240,000 barrels (10.1 million gallons) of medium-weight crude oil. Approximately 140,000 barrels (5.9 million gallons) of oil flooded through a dike and overflowed separators and a retaining lagoon and flowed into Bahía Cativá, an arm of Bahía las Minas.

Responses

***Witwater*.** Several thousand barrels were pumped from the waters surrounding Galeta Island, and approximately 5,000 barrels (210,000 gallons) were ignited and burned along shorelines in the bay. By December 17, pumping and shoreline burning cleaned up approximately half of the spilled oil.

Texaco Storage Tank. Refinery personnel reported that 60,000 barrels (2.52 million gallons) of oil were recovered. It is not known how much of this recovered oil was from the sea. Dispersants were applied in Bahía Cativá, Islas Naranjos, offshore of Bahía Las Minas, near Portobelo, and along the northern breakwater at the mouth of the Panama Canal. Although dispersants appeared to be ineffective due to the weathered state of the oil and the calm seas, skimmers recovered some floating oil. Vacuum trucks were used as part of the shore-based cleanup effort. Several channels were dug through the mangroves to drain the oil. These channels appeared, instead, to have helped move the oil inshore. Increased disturbance due to the construction of the channels may have also contributed to subsequent erosion. Oiled rocks and debris were manually removed along the more accessible shorelines. Seawater was sprayed on some sandy areas to aid oil removal. Pumping to recover floating oil appeared to be the most effective oil recovery method. The shallow waters and mangroves rendered many oil spill cleanup techniques impractical.

Impacts

Archived aerial photographs (1966, 1973, 1979, and 1990) and ground surveys were keys to understanding the effects of these two spills on mangrove forests.

***Witwater*.** Despite the cleanup, both red and black mangrove trees were severely oiled, and the majority of the red mangrove seedlings were killed. Oil also damaged many of the mangrove forest inhabitants. Initial reports did not indicate that adult trees had suffered. Aerial survey photos from 1966 and 1973 were used to assess deforestation, oil gaps, and open canopy. About 49 hectares of mangrove forest (representing 4 percent of the total mangrove forest) had been completely deforested in 1973 (five years after the spill). Most deforested areas had new recruits by 1979 (eleven years after the spill) but 3 ha were lost to sea-margin encroachment. Observable differences (oil gaps, and canopy height and structure) and oiled sediment persisted into 1992, 23 years after the *Witwater* spill.

Texaco Storage Tank Spill. The distribution of oil was surveyed from aircraft for two months following the release. A total of 51 miles of shoreline was heavily oiled, including some mangroves recovering from the *Witwater* spill. In a central embayment (Bahía Cativá), approximately half the surrounding forested area (and halfway up the intertidal zone) was killed. Oiled habitats within this distance included extensive mangroves, intertidal reef flats, seagrass beds, and subtidal coral reefs. Re-oiling of the shoreline and mangroves was a continuing problem. Oil slicks were regularly observed within Bahía las Minas for at least four years following the spill with oil coming predominantly from areas of fringing mangroves. As the oiled red mangrove trees decayed, it was believed that eroding, underlying sediments released trapped oil.

An affected reef flat habitat was the site of an ongoing study at the Smithsonian Tropical Research Institute's field station at Punta Galeta. A detailed study of mangrove trees revealed that one- to two-year-old seedlings appeared to survive whereas the surrounding adults died. It was believed that, somehow, young seedling structure (perhaps lack of prop roots) enabled the young trees to tolerate periods of oil immersion. It was suggested that the disruption of the substrate before replanting may remove such survivors, hampering forest recovery. Oil persisted in the mangroves through May 1989. Initial oiling of the trees produced measurable amounts of oil on 100% of all the roots that were sampled. Through May 1989, the mangrove roots in the open coast and channel areas showed 70% oiling, while the oiled proportion in the stream mangroves remained 100% oiled. The decrease in oil coverage resulted from weathering, microbial degradation, and loss of oiled bark or encrusting organisms. Root mortality was greater in oiled areas.

Subsequent aerial and ground surveys indicated "recovery of the 1986 spill was well-advanced by 1992" (Duke et al. 1997) due, in part, to extensive restoration. However, about 5 hectares of fringing forest were lost to sea-margin encroachment and there remained important differences between sheltered and exposed areas.

Although ten times more oil was spilled in 1986 than in 1968, this did not result in ten times more damage to mangroves. Calm winds, lower tides, different oil type, and longer weathering time before impact may have resulted in less toxicity.

Restoration

Because of extensive mangrove mortality, several replanting projects were conducted at Bahía las Minas, in hopes of speeding mangrove forest recovery, which was at the time estimated to take 20 years or longer (Teas et al. 1989).

Experiments to determine whether propagules could survive if planted directly in oiled sediment found 100% mortality up until six months post spill. By nine months post-spill, propagules survived at rates similar to those at unoiled sites. Beginning 12 months after oiling, red mangrove seedlings that had been raised in a separate nursery area were planted (with added fertilizer) in areas of the damaged mangrove forest. A total of 42,000 nursery plants and 44,000 propagules were planted.

Studies conducted in 1989 (33 months post-spill) looked at the effectiveness of the plantings conducted in 1987, by comparing mangrove densities in areas that had recruited naturally with those that were replanted. Though planted seedlings had survived in all areas studied, naturally recruited plants were most dense. Thus, natural recruitment was more effective at recolonizing oil-damaged areas and, over time, natural recruits out-competed planted seedlings. Researchers also noted detrimental collateral impacts from planting, including cutting and removing dead timber for boat access (which removed shelter for seedlings), trampling sediments, digging holes (which accelerated erosion), and damaging existing seedlings (Duke 1996). Overall, planting did not result in a net benefit to the mangrove forest. However, since recolonization of mangroves was lowest in exposed areas, Duke suggests that an effective restoration activity could be to protect very exposed areas until mangrove trees are well established.

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Bouchard *Barge* B-155*, Tampa Bay, August 1993*

On August 10, 1993, the freighter *Balsa 37*, the barge *Ocean 255*, and the barge *Bouchard 155* collided in the shipping channel west of the Skyway Sunshine Bridge and south of Mullet Key in Tampa Bay, Florida. The collision caused three separate emergencies: (1) the *Balsa 37* was listing, threatening to spill phosphate rock; (2) the jet fuel, gasoline, and diesel caught fire on the *Ocean 255*; and (3) the *Bouchard 155* was holed at the port bow, spilling approximately 8,000 barrels (338,000 gallons) of No. 6 fuel oil into Tampa Bay. By August 15 most of the floating fuel oil had come ashore and heavily coated sand beaches, several mangrove islands, and seawalls within Boca Ciega Bay. By August 16 very little floating oil was seen offshore. In the shallow, low-energy areas along the mangrove islands inside Johns Pass and at a few locations in the surf zone, oil had mixed with beach sand and shallow sediments to form underwater tarmats, some of which came ashore on the mangrove keys.

Response

The No. 6 fuel from the barge is the only material known to have been released from this incident. Countermeasures used during this spill were mechanical or manual. Skimming operations were used to collect free-floating oil. Efficiency and effectiveness of skimming operations were extremely high. Oil in and around mangrove islands was removed by vacuuming. Areas were left oiled when it was felt that cleanup methods would cause greater impact than leaving the oil in place. Some of the submerged oil in very shallow areas was removed using buckets and shovels. Oiled seagrass beds were cleaned by gently lifting oil out of them by hand. "How clean is clean" inspections for mangroves, seagrass beds, and other sensitive areas were judged on a case-by-case basis by the inspection committee.

Impacts

Tarmats formed when sediment was mixed with oil along the shallow flats surrounding the islands. Large, thick mats coated mangrove roots, oyster and seagrass beds, and tidal mud flats. Much of this oil was vacuumed out using vacuum transfer units on grounded barges staged around the islands and shallow areas.

Scientists visited oiled and unoiled mangrove keys quarterly between November 1994 and April 1996. Individual trees, pneumatophores, and prop roots were tagged to enumerate trends in defoliation, leaf health, shoot number and length, and mortality of juvenile and adult plants or their structures. Visual oiling trends were documented through late 1995 and sediment samples for wet chemistry collected in 1996. Adult red mangrove trees at the most heavily oiled site (outer Eleanor Island) deteriorated over this time period, with moderate to heavy defoliation and soft, rotting prop roots. "Of marked trees, 20% were totally defoliated and appeared dead by June 1994" (Levings and Garrity 1995). Nine-month mortality of juvenile red and black mangrove plants was 5% at unoiled reference sites, 35% in heavily oiled areas on the protected side of the island and 50% in heavily oiled areas on the exposed side of Eleanor Island. It was predicted additional mortality would continue to occur.

The researchers also measured for signs of sublethal stress in adult trees: one to two years after the spill and cleanup, surviving red mangroves experienced graded negative responses in four measures of shoot growth and production, suggesting that sublethal long-term effects may be common in oiled mangroves. Sediments around trees experiencing these responses contained greater than 500 ppm total hydrocarbons (dry weight).

More follow-up observations are needed at these sites, but we are not aware of any extending beyond three years after the spill and cleanup.

Restoration

Trustees from state and Federal agencies and the responsible party developed a restoration plan for mangroves and associated habitats damaged in the spill. A compensatory plan provided mangrove and associated wetland habitat for fish, birds, and epibenthic communities at a site in the same watershed but not necessarily actually impacted by the spill.

The responsible party purchased a former dredge disposal site in Boca Ciega Bay and deeded it into public ownership. This site contained degraded mangrove forest that was restored through increased tidal exchanges and removal of exotic plants and debris. On the bayward edge of the mangrove forest, smooth cordgrass (*Spartina alterniflora*) was planted to create a fringing saltmarsh buffer that could eventually provide habitat for mangrove seedlings. A monitoring program was established with specific "success" criteria outlined, including vegetative cover and height of mangroves, absence of exotic species, and functional tidal exchanges.

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