SPILL RESPONSE THAT BENEFITS THE LONG-TERM RECOVERY OF OILED MANGROVES

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SUMMARY: *We revisited three sites in Florida and Puerto Rico that were oiled 23 to 29 years ago, analyzing them and the published literature to determine that mangroves follow a 6 to 25 year recovery cycle. We reviewed response methods and determined that the use of offshore dispersants, the booming of tidal creeks and inlets, the use of onshore sorbents, low-pressure flushing and the manual collection of oily debris provide benefits for recovery at least in the short term. Non-beneficial response efforts that have degraded mangroves include forest cutting, heavy equipment and personnel traffic, tree burning, onshore use of chemicals, and plantings in toxic soil. Perhaps the most detrimental response effort studied was the impoundment of basin forests that has resulted in long-term losses and slow recovery rates. The intertidal use of dispersants has been shown to be beneficial to mangroves, however their use has also caused damages to nearshore environments such as coral reefs. In summary, once the oil has reached sheltered mangrove forests there exist only short-term benefits from traditional response efforts. More likely there are only non-beneficial results compared to natural attenuation. We conclude that the only long-term beneficial response method appears to be a combination of non-intrusive oil collection and booming techniques in heavily oiled, sheltered areas with closely monitored natural recovery in forests more lighly oiled. This should be paired with mitigation programs involving habitat creation either in unoiled areas or in the impact zone following the attenuation of oil and removal of debris from the deteriorating forests.*

Approach

Baker (1995) proposed the Net Environmental Benefit Analysis (NEBA) approach as a means of examining the advantages and disadvantages of various response strategies. According to Lindstedt-Siva (1999) one of the key steps in the NEBA process is to review previous spill case histories and experimental results that are relevant to an area and response method being assessed. On the basis of previous experience a likely prediction of environmental outcomes using a proposed response method can be made and compared with natural recovery (or attenuation). Our focus was to first examine the nature of long-term recovery in oiled mangroves and then to characterize response strategies, judging them in terms of their net environmental benefit. We began by cataloging and reviewing our own raw data and photographs from 1973-1999. During that time we worked as advisors and contractors on 8 major oil spills and 2 field experiments involving mangroves in Florida, Puerto Rico and Panama. In addition, the Smithsonian Tropical Research Institute had published dozens of papers on the effects and recovery from the 1986 Refineria Panama spill including the initial effects summarized by Jackson et al. (1989) and the 5-year follow-up studies summarized by Duke & Burns (1999). We also reviewed a recent, exhaustive summary of the published literature on the subject of quantifying natural resource damages to oiled mangroves (Michel, 2001). Our next step was to revisit three of the historical spill sites for which we had original data and to re-occupy field transects established by us 23 to 29 years ago. In July 2002 we reoccupied our former transects and plots at the spill sites of the Zoe Colocotronis, Peck Slip and Howard Star in Puerto Rico and Florida. The findings from these field observations and the combined literature were used to assemble a chronological summary of the mangrove forest recovery from oil spills. We then summarized oil spill response approaches (including mitigation) that have been carried out in oiled mangrove forests and attempted to evaluate the benefits of each method in terms of the long-term recovery of oiled mangroves. From these findings we then were able to suggest an approach to spill response provides the greatest benefit for long-term recovery of oiled mangroves.

Results

Michel (2001) concluded that recovery occurs from as short as less than one year to greater than 23 years in all cases reviewed of oiled mangroves. Our observations agree, but our examination was of larger spills and revealed a narrower time frame, in the range of 6 to 25 years, longer where there were multiple (or chronic) spills. To further examine this, all significant observations on recovery from the field and literature were listed and displayed chronologically (Table 1; Figure 1). This revealed a trend of continuous colonization (and re-colonization) of plants and animals even during the acute or initial stages of the spill that continued throughout a period of destruction and decay of the forest structure. Throughout this period the re-oiling during the initial phase and the presence of mobile and destructive debris often caused setbacks to recovery through toxic and physical damages of structural degradation. Then after 5-7 years the forest appeared to reach a point in most cases where its structure was stable and the extent of substrate oiling was greatly reduced. After that successful invasion by propagules, development of a seedling understory and the eventual formation of mature forests proceeded in substrates that were free of toxic elements of oil and the destructive forces generated by loose and floating debris from decomposing forests.

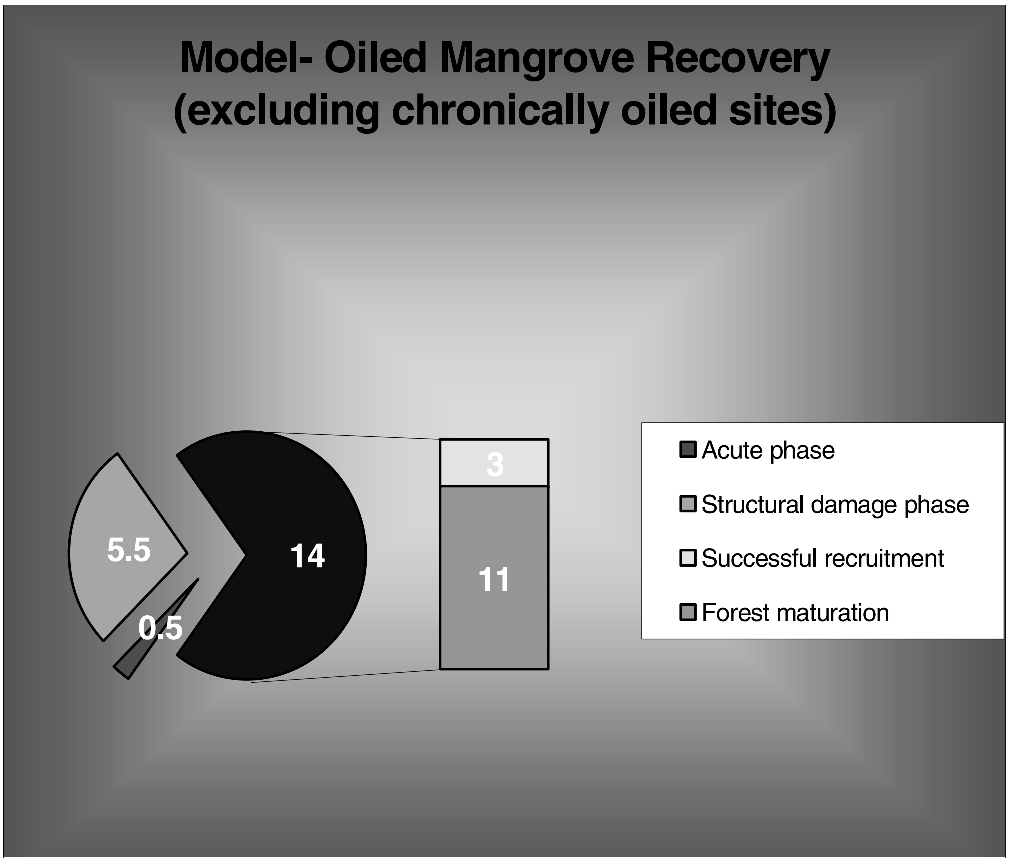


Figure 1. Chronology of oiled mangrove recovery.

In July 2002 we reoccupied the 12 original transects at the 29-year old spill site of the Zoe Colocotronis in southwestern Puerto Rico and compared them to data from 1973, 1974, 1979, and 1982. Tree measurements and photographic comparisons were made (Figure 2). The outer fringe forests have fully recovered with mature 10-15 cm diameter at breast height (DBH)) red mangroves (Rhizophora), 5-7 meters in height with a closed canopy. A tidal basin forest was observed with mature (5-8 cm DBH) red and black (Avicennia) mangrove understory 3-4 meters in height beneath an older but recently killed, chronically oiled mature forest. In July 2002 we reoccupied established 2 of the original transects at the 23-year old spill site of the Peck Slip in eastern Puerto Rico and compared them to data from 1979, 1982 and 1994. Tree measurements and photographic comparisons were made (Figure 3). The entire mature forest of 9-meter trees oiled in 1978 had been destroyed. A new forest of mature (4-8 cm DBH) red mangroves 3-4 meters in height has been reestablished. Aerial photographs from 1993 indicate that the spill site was heavily damaged and destroyed by Hurricane Hugo in 1989. In July 2002 we reoccupied established 5 of our original transects at the 23-year old spill site of the Howard Star in Tampa Bay and compared them to data from 1978, 1979 and 1980. Tree measurements and photographic comparisons were made (Figure 4). The outer and inner fringe forests have fully recovered with mature (2-14 cm DBH) red mangroves 4-8 meters in height and a closed canopy.

In summary, different forest types within each of the 23 to 29 year postspill sites showed different rates of recovery. Exposed forests showed full recovery within 6-25 years. Sheltered forests (basins, inner fringe and riverine) showed slower recovery, especially in chronically oiled areas such as Zoe Colocotronis. We suggest a recovery sequence in the absence of hurricanes and chronic oiling (Figure 1) updated for long-term recovery observations from those published by Lewis (1983) and Lamparelli, et al. (1997).

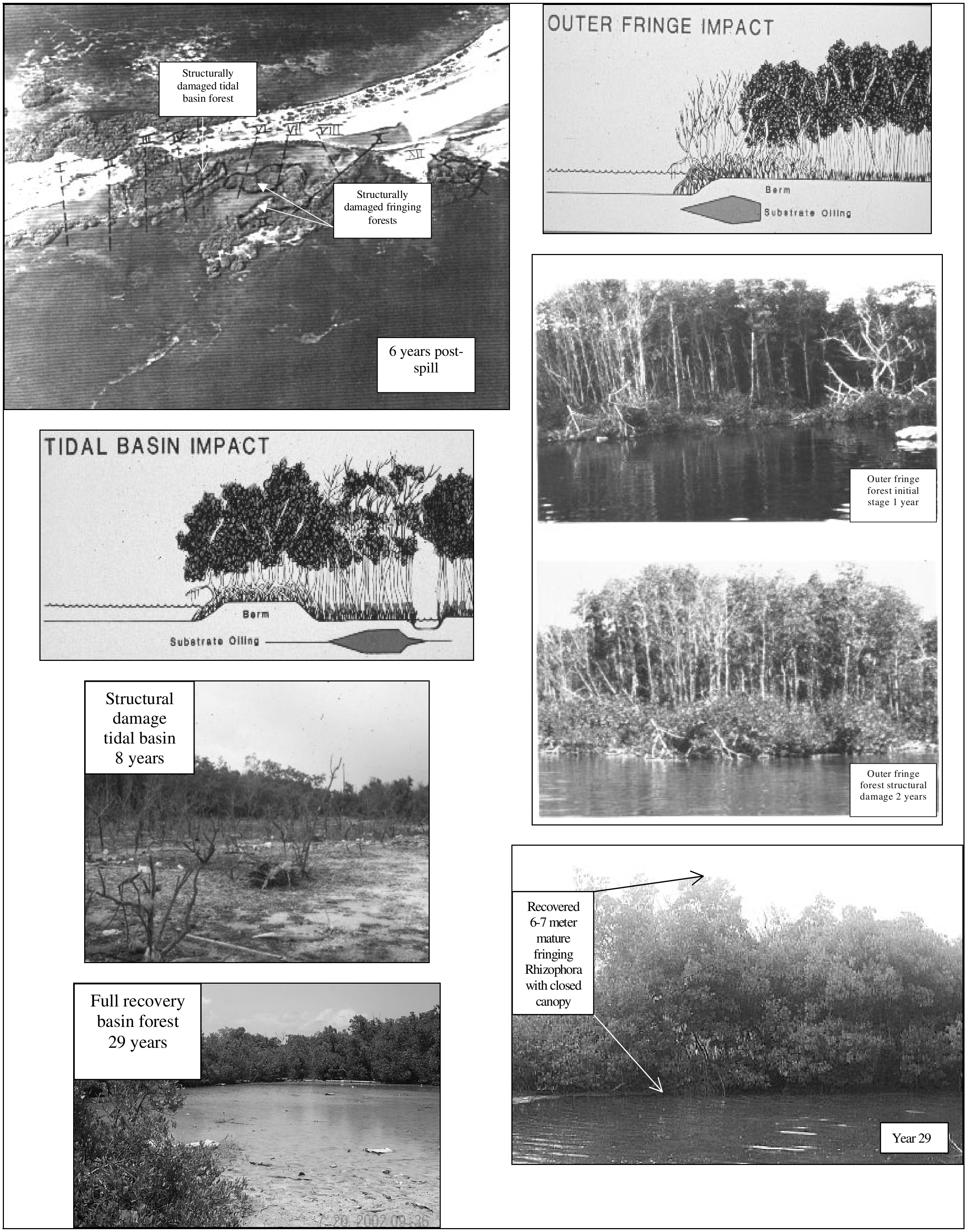
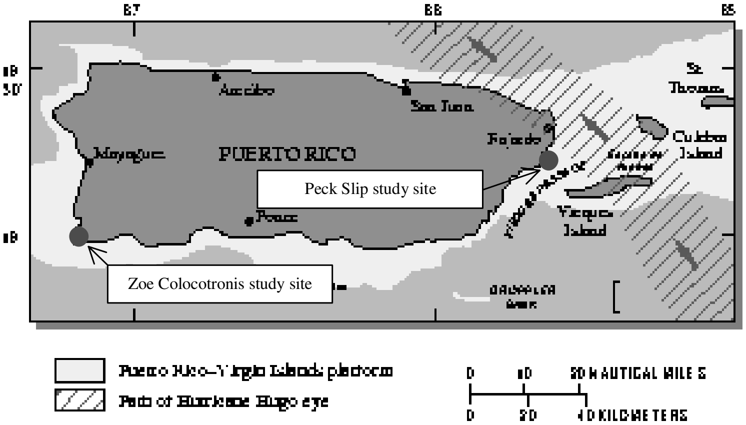
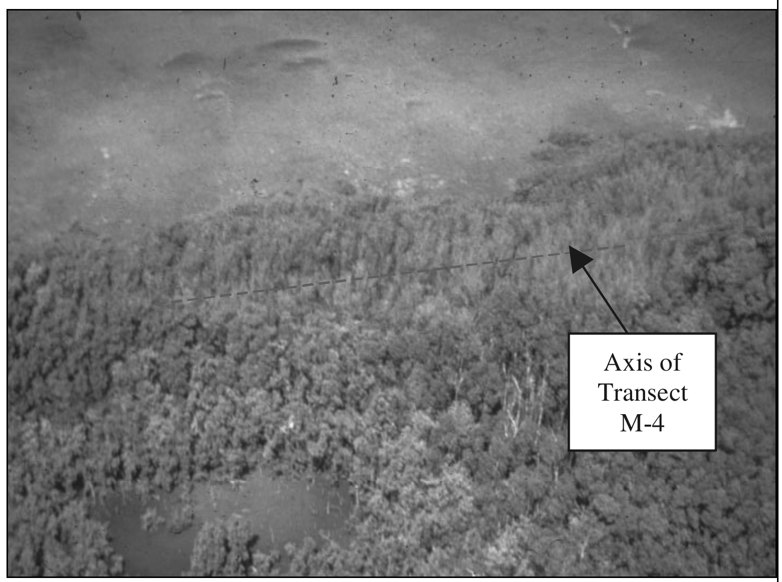


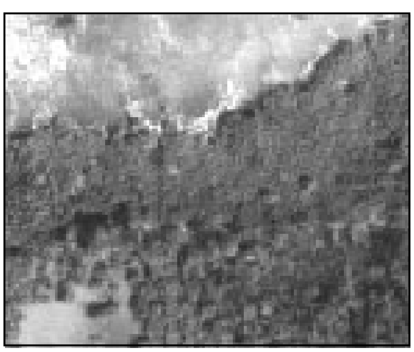
Figure 2. Zoe Colocotronis observations.



Structural damage at transect M-4 4 years postspill.



Structural damage 4 years postspill.



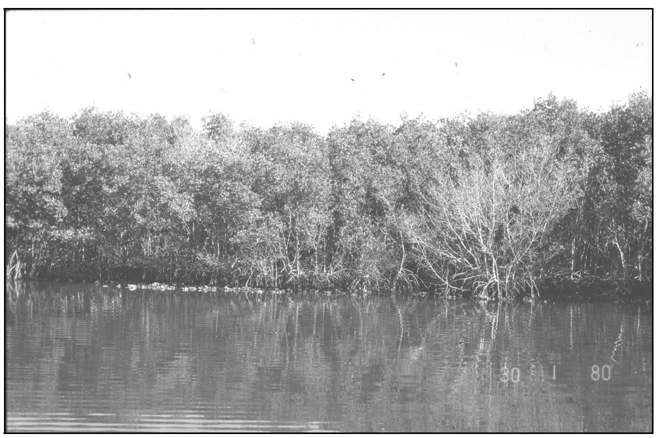
Recovering forest 4 years post hurricane,
23 years post-spill.

Recovering forest 4 years post hurricane, 23 years post-spill.

Figure 3. Peck Slip observations.

Site 3 in 1978.

Site 3 in 2002.



Site 5 in 1978.

Site 5 in 2002.

Figure 4. Howard Star observations.

Discussion

Methods that prevent oil from entering sheltered mangroves are documented as successful at preventing short-term damages. These include the offshore use of dispersants and collection of oil before it can impact forests. The booming of tidal creeks and inlets was observed by us during the Peck Slip, Howard Star, and Refineria Panama spills preventing additional, significant amounts of oil from entering sheltered forests. These critical boom locations are shown on NOAA's spill response (Environmental Sensitivity Index) maps, as are sheltered mangrove forests (ESI=10b) that have the highest priority for protection. Once inlets are boomed, cleanup crews in these spills focused upon collection of oily debris and sorbents that effectively prevented re-oiling. Low pressure flushing using seawater was effectively used, even on prop roots, with recovered oil collected in sorbents and removed. In the Garbis spill workers used rakes to pick up oiled sorbents with foot traffic burying oil in deep sediments. In the Peck Slip spill, abandoned oiled sorbents became sources of future oiling.

Teas et al. (1993) conducted laboratory tests to determine if Corexit 9580 (a shoreline cleaning agent) would increase the survival rate of oiled red mangroves. They concluded that there was a higher survival rate after oiling with Bunker C if the agent was applied within seven days. Bioremediation has been demonstrated experimentally (Teas et al. 1991; Duke et al. 1999). A field experiment at the Refineria Panama spill site showed the survival and growth of seedlings planted in oiled mangrove soils was much less than those planted in holes backfilled with upland soils. (Fertilizer addition only slightly enhanced propagule growth and was not recommended since propagules have reserves and the fertilizer washed away with the tides. Low pressure flushing may work on smaller spills. Ibanez (1995) used low-pressure flushing, removal of oiled sediments, addition of organic fertilizers, and planting of seeds. The treated area showed good regrowth within three years.

Chan (1976, 1977) described significant alterations to supralittoral and intertidal wetlands during the Garbis spill. This occurred when 1000 feet of fiberglass road material was installed to facilitate access of heavy equipment being moved to an oiled shoreline. The surface of the substrate was flattened and furrowed by tires with the weight of heavy equipment. This resulted in deeper burial of oil, the removal of marsh and mangrove plants, and the alteration of surface water drainage patterns. In addition, ditching through mangroves impedes recovery, especially when excavated soils are deposited into nearby mangroves. Duke (1999) observed large access tracks cut through damaged mangrove forests a year after the Refineria Panama spill. Quilici et al. (1995) showed that a shoreline cleaner (without subsequent water washing) reduced photosynthetic capacity of leaves and reduced soil respiration. Dodge et al. (1995) documented reduced impacts to mangrove forests when dispersants are used, although cautions that inshore use of dispersants may lead to decade-long impacts to near-shore corals. Oiled sites planted in heavily oiled substrate have been attempted without success (Teas et al 1989). Propagules planted in oiled sediments died while seedlings survived. Plantings need to be delayed until the sediments lose their toxicity. Plantings conducted prior to forest degradation resulted in the loss of plantings due to debris from degrading forests moving as swash with tides over areas of plantings even 4-5 years after the spill (Duke 1999). Impounding and flooding oiled forests (Lehmann et al. 1999; Wilkenson et al. 2001) led to slowed recovery and destroyed mangrove forests (Figure 5). The mechanism involved appears to be flooding and the significant lengthening of exposure times to spilled oil.

Tampa Bay 1993 oil spill mitigation at planting.

Tampa Bay 1993 oil spill mitigation at 1 year.

Figure 5a. Beneficial response methodologies.

Ensenada Honda impoundment point.

Ensenada Honda loss of mangroves to freshwater marsh.

Figure 5b. Destructive response methodologies.

The site of the Zoe Colocotronis is along a near-shore shipping lane. It, has received oil from at least two major oil spills, and may have chronically high levels of substrate oiling (Corredor et al. 1990), possibly slowing recovery in basin mangrove forests there. Duke (1999) discussed multiple spills in the Whitwater/Refineria Panama impact sites, both of which impacted some of the same inner fringe and sheltered mangrove forests. In both cases it appears that total recovery will exceed the 6 to 20 year recovery cycle seen in other oiled forests. At the site of the Peck Slip spill in southeast Puerto Rico extensive hurricane damage was observed. The entire 9-meter mangrove forest that was oiled in 1978 and monitored thereafter was removed. Aerial photographs from 1993 showed extensive areas of dead mangroves in the area. The eye of Hurricane Hugo struck the site on September 17, 1989, as a category-four hurricane with sustained winds of 140 miles per hour. It caused significant wind related damage to mangrove forests at Naval Station Roosevelt Roads and on the nearby island of Culebra where over 20 acres of mangroves had to be replanted. In Culebra, most of the dead trees were cleared, while some were left to serve as breakwaters for the new trees. Germinated seeds (propagules) were then collected from the unaffected red mangrove forest of the southwest coast of Puerto Rico to be planted at the newly cleared site (Coastal America 2000). The literature for mangrove recovery from hurricanes projects reports recovery periods of approximately 20 to 25 years, roughly the recurrence rate of major hurricanes in many parts of the Caribbean Sea (Roth 1992; Warner 1990).

Martin, et al. (1990) successfully restored a mangrove forest using the construction of a channel to increase flushing. TPH levels in soils decreased from 8000 ppm to 1000-3000 ppm after 3 months; and to below 1000 ppm at 16 months. We have assisted in the mitigative creation and enhancement of forests following two oil spills: one in the Virgin Islands (Lewis and Haines 1980), the other in Florida (Mauseth et al. 2001, Figure 5). Lewis and Streever (2000) have applied and strongly advocate for restoring natural processes to reestablish mangrove habitat. They state that mangrove habitat can self-repair in 15 to 30 years if normal tidal hydrology is not disrupted and availability of waterborne seeds/seedlings from adjacent stands is not disrupted or blocked. They conclude that the single most important factor in restoration design is the hydrology. Planting is advocated only if it is demonstrated that natural recruitment is not occurring.

Recommendations

First, if possible prevent oil from reaching sheltered mangroves through effective planning using the environmental sensitivity-mapping concept pioneered by RPI in the late 1970's. These maps have been prepared for and by NOAA and include shoreline maps for US mangroves, for example southwestern Puerto Rico (NOS/SEA 1998). Initial response efforts should consider using dispersants in deep, well-flushed waters, and effectively placing booms across tidal creeks and inlets. Avoid mechanical cleanup, chemicals and burning in forests, but consider boat-platform placement of sorbents, low-pressure flushing and manual collection of oiled debris. In addition, integrated with NRDA activities, immediately develop a mitigation plan for the region, considering an equivalent or greater area than the mangroves that will be lost. The mitigation plan should include the following:

1. Determine the cause or causes for the death or disappearance of mangroves from the area of interest. If a chronic stressor is still present (i.e. remaining oil or deteriorating mangrove debris), it may prevent successful restoration. It is generally a waste of time and money just to attempt to replant mangroves without understanding why they died or why they have not recolonized on their own.
2. Remove the chronic stressor. For example put a culvert under a road that was constructed (without regard for tidal flushing or freshwater drainage). It is very common to see such roads with dead mangroves on the isolated side, and healthy mangroves on the waterward side. Areas of mangroves that are diked also often suffer extended flooding. Reconnection to tidal waters is essential before restoration can proceed.
3. If removing or adding fill material to a restoration site is proposed, the design and careful monitoring of the final target grade (i.e. ground elevation relative to a surveyed datum or reference point) is very important. The single most common error made in mangrove restoration is the failure to reestablish the correct tidal hydrology.
4. It is essential to understand the depth and duration of flooding tolerances for the mangrove species you are dealing with. Typically, the elevation is designed too low, and thus tidal inundation is too deep and/or too frequent. Planted mangroves will fail to thrive or die, and volunteer mangroves do not establish successfully.
5. An important component in mangrove forest restoration is the design and placement of tidal creeks and channels. Tidal streams provide access for fish and other mobile mangrove fauna, and allow for drainage of floodwaters.
6. Before deciding to plant mangrove seeds or seedlings, determine if natural seed recruitment will occur. The need to actually replant mangroves varies greatly from site to site. The decision as to whether to plant, or to use nurse plant species like Batis, depends on the expertise of the design team and observations from similar areas over a period of years.

See Lewis and Streever (2000) for additional technical guidelines in mangrove restoration.

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Jacqueline Michel of Research Planning, Inc, Columbia, South Carolina shared her natural resource damage assessment library with us. Winston Martinez of US Naval Station Roosevelt Roads, Puerto Rico provided local knowledge, historical aerial photographs, field and logistical support for revisiting the Peck Slip spill site.

Table 1. Recovery observations made during months 0-6, characterized as the period of free oil attenuation or the acute phase, also called the acute phase by Lewis (1983) and the initial phase of Lamparelli et al. (1997).

Post Spill Period	Observations	Spill/Reference	
3 months	Overall reduction in soil and water oil levels; Infauna incl. polychaetes & arthropods returning to nearshore waters; return of crabs (Uca and Ocypode) to basin forest; return in diversity of lower prop root communities beginning	Zoe Colocotronis 1973	TRC 1975
3 months	Fish assemblages in outer prop roots normal	Era, S. Australia 1992	Connolly and Jones 1996
3-6 months	Several species of crabs returning to mangrove fringe	Florida Keys 1996	Chan 1977
3-6 months	Nearshore seagrass (Thalassia) recovering from fouling algae	Refineria Panama 1986	Jackson et al. 1989
6 months	Infaunal recruitment begins in nearshore waters	Refineria Panama 1986	Jackson et al. 1989

Table 2. Recovery observations made from 6 months to 6 years characterized as the sediment oil attenuation period accompanied by the onset and completion of structural forest damages. This period corresponds to the structural phase of Lamparelli et al. 1997.

Post Spill Period	Observations	Spill/Reference	
11 months	Previously heavily oiled sediments now light to moderate sheen; much less oil on prop roots and trunks; lenticels forming through weathered oil; tree crabs returning to former numbers; seedling colonization in formerly heavily oiled areas; heavy flowering of stressed trees; some refoliation of stressed trees	Peck Slip 1979	Getter et al. 1980
11 months	Heavy seedling colonization outer fringe	Ensenada Honda 1986	Ballou & Lewis 1989
12 months	Mangrove tree snail population recovery complete	Panama TROPICS experiment 1984	Ballou et al. 1989
18 months	Burrowing crabs returned	Truck spill in Queensland 1994 –vs- Refineria Panama 1986	Burns & Codi. 1998
1 year	50% reduction in sediment oil content	Era, S. Australia 1992	Wardrop et al. 1996
2 years	Seedlings established & growing successfully in many areas	World Encouragement	Allaway 1982
2 years	Patchy recovery of foliose algae and sessile invertebrates nearshore	Refineria Panama 1986	Jackson et al. 1989
2 years	Subtidal-sessile invertebrates (shallow coral reef) recovered	Panama TROPICS experiment 1984	Dodge et al. 1995
2 years	Adult trees recovering in oiled substrate	Persian Gulf Spill 1991	Boer 1993
2 ½ years	Early stage of seedling recovery & sediment oiling in exposed areas	Showa Maru 1975	Baker et al. 1980
4 years	Regeneration in areas with strong flushing; dense growth of seedlings & saplings with deformed leaves and high rates of herbivery; oil being metabolized by bacteria	Zoe Colocotronis 1973	Lugo 1974
4 years	The results showed that the oil would weather to non-toxic concentrations in 4 years	Refineria Panama 1986	Burns & Codi 1998
4 years	Some colonization of red and black mangroves observed	Zoe Colocotronis 1973	Nadaeu & Berquist 1977
4 years	Significant reduction in substrate oiling	Zoe Colocotronis 1973	Page et al. 1979
4 years	Tree canopy reduction has peaked; trees in light to moderate oiled areas now showing 6-20% refoliation; 69% reduction in oil content in soils	Era tanker spill 1992	Wardrop et al. 1996
5 years	Dead trees becoming debris scouring the surface recruited seedlings	Refineria Panama 1986	Duke & Burns 1999
5 years	Dense new recruits	Refineria Panama 1986	Duke & Pinzon 1993
5-6 years	Recruiting trees killed by dead mangrove tree debris	Refineria Panama 1986	Duke 1996
6 years	New recruits with 100% mortality; oil in sediments	Seripe Pipeline 1984	Lamparelli et al. 1997

Table 3. Recovery observations made from 9 to 20 years postspill characterized as structural recovery characterized by a stabilized forest structure and non-toxic sediments.

Post Spill Period	Observations	Spill/Reference	
9 years	New seedlings and saplings growing and surviving; oil in sediments	Seripe Pipeline 1984	Lamparelli et al. 1997
10 years	Adult trees recovered basal area, but with fewer trees; dense seedling growth within open canopy; low levels of buried highly degraded oil	Panama TROPICS experiment 1984	Dodge et al. 1995
11 years	Canopy and forest structure recovering	Refineria Panama 1986	Duke et al. 1997
17 years	Numerous recruits but height stunted; oil in sediments of unknown origin	Botany Bay spill	Duke et al. 1999
20 years	Sediment cores collected more than 20 years after the Zoe Colocotronis spill in Puerto Rico showed a thick tar layer at 7 cm depth in several cores that was attributed to that spill. They proposed that rapid burial in reducing mangrove soils results in reduced rates of biodegradation.	Zoe Colocotronis 1973	Corredor et al. 1990

Table 4. Recovery observations made from 21 to 30 years characterized as long-term recovery characterized forests that are nearing full recovery with closing or closed canopies comprised of more numerous but smaller trees.

Post Spill Period	Observations	Spill/Reference	
23 years	Site of multiple large oil spills. Exposed fringing forests recovered with regard to forest structure in stem densities, heights, diameters and biomass; sheltered sites not fully recovered had higher densities of shorter, smaller trees with lower biomass; many of these same forests were impacted by a second large oil spill	Whitwater 1968	Duke et al. 1997; Duke & Pinzon 1993
23 years	In July 2002 we reoccupied established 2 transects at the 23-year old spill site of the Peck Slip in eastern Puerto Rico and compared them to data from 1979, 1982 and 1994. Tree measurements and photographic comparisons were made. The entire mature forest of 9-meter trees oiled in 1978 has been destroyed. A new forest of mature (4-8 cm DBH) trees 3-4 meters in height is reestablished. Aerial photographs from 1993 indicate that the spill site was heavily damaged and destroyed by Hurricane Hugo in 1989.	Peck Slip 1978	Field survey by authors in Jul y 2002
23 years	In July 2002 we reoccupied established 5 transects at the 23-year old spill site of the Howard Star in Tampa Bay and compared them to data from 1978, 1979 and 1980. Tree measurements and photographic comparisons were made. The outer and inner fringe forests have fully recovered with mature (2-14 cm DBH) red mangroves 4-8 meters in height and a closed canopy; no substrate oiling observed	Howard Star 1978	Field survey by authors in Jul y 2002
25 years	Canopy reformed with smaller trees accounting for the recovery	Ocean Grandeur 1970	Duke and Burns 1999
29 years	In July 2002 we reoccupied 12 transects at the 29-year old spill site of the Zoe Colocotronis in southwestern Puerto Rico and compared them to data from 1973, 1974, 1979, and 1982. Tree measurements and photographic comparisons were made. The outer fringe forests have fully recovered with mature (10-15 cm DBH) red mangroves 5-7 meters in height and a closed canopy. A tidal basin forest was still recovering with a mature (5-8 cm DBH) red and black mangrove understory 3-4 meters in height beneath an older but recently killed, chronically oiled mature forest.	Zoe Colocotronis 1973	Field survey by authors in July 2002

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