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CHAPTER 19

Impact of oil spills on mangrove forests

ROY R. LEWIS, III

Mangrove Systems, Inc., Post Office Box 24748, Tampa, Florida 33623, U.S.A.

Introduction

Mangrove forests are the dominant intertidal plant community along most low wave energy shorelines in the tropics (Macnae 1968; Lugo and Snedaker 1974). Their value as habitat and detrital food sources for marine organisms as well as their direct commercial value as lumber, firewood and tanning agents are well documented (Odum and Heald 1972; Chapman 1976).

Increasingly large amounts of petroleum are entering the marine environment, primarily from three routes: natural seeps, 0.6 million metric tons per annum (mta); offshore drilling and production, 0.08 mta; and transportation losses, 0.77 mta (National Academy of Sciences 1975). These figures are presently being updated by the National Academy of Sciences and certain figures may increase substantially due to such events as the IXTOC I oil well blowout of 1979–80.

Due to the fact that floating oil is transported by waves and currents and strands on shorelines, low wave energy ecosystems such as mangrove forests are routinely sites where oil accumulates after a spill. In addition, the inaccessibility of most mangrove forests makes oil removal very difficult, if not impossible, and the fine grained anaerobic sediments characteristic of mangrove forests severely reduce the rate of microbial breakdown of oil (Lee 1980).

These factors plus the burrowing activities of crustaceans characteristic of mangrove forests can lead to persistent, high levels of oil contamination, not only on the soil's surface but also deep in the sediments in the mangrove root zone.

Table 1 lists thirteen oil spills, worldwide, where some documentation of impact to mangroves has been observed and reported. Most of the earlier reports are anecdotal with little or no quantification as to the levels of oil contamination, the actual type of oil stranded in the forest, the areal extent of mangroves oiled, or the actual numbers, sizes, or areal coverage of mangroves killed or stressed by the oil spill. Often, the species of mangroves involved was not mentioned. In addition to impacts to the trees themselves, the faunal component of the ecosystem is usually treated by noting dead or stressed animals at the time of the spill, or attempting to quantify losses or changes by one-shot, non-seasonal sampling. In particular, the sampling of infauna, in many of these cases, has not taken into account the normal seasonal variations in infaunal species and numbers. All these problems may lead to widely different observations of the 'impact' of a spill by different investigators, as will be discussed.

Materials and methods

Within 24 hours of the *Howard Star* (5 Oct 1978) spill, personnel were on site documenting the extent of the spill and any immediate mortalities of invertebrates, fish, or birds. Samples of dead inverte-

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Table 1. Comparison of oil spills impacting mangroves.(modified from Baker *et al.*, 1981).

Source of spill and date	Type of oil	Amt. of oil	Mangrove species affected	Location	Impact on mangroves	Authors
Argea Prima, vessel, 7/16/62	Crude	10,000 tons	Unidentified	Guanica, Puerto Rico	'... this habitat was virtually destroyed'	Diaz-Piferrer, 1962
Whitewater, vessel, 12/13/68	Diesel oil and bunker C	20,000 barrels	*Rhizophora mangle* *Avicennia* sp.	Galeta I., Panama	Death of young mangroves, loss of sessile animals and algae on prop roots (loss still visible 66 months after spill)	Rutzler and Sterrer, 1970; Birkeland *et al.*, 1976
Pipeline break, 1970	Light crude	100,000 barrels	Unidentified	Tarut Bay, Saudi Arabia	Defoliation, but many survived	Spooner, 1970
St. Peter, vessel, 2/76	*Crude*	*243,442 barrels* carried; quantity spilled unknown	*Rhizophora* sp. *Avicennia* sp.	Colombia, Ecuador	No 'noticeable long-term biological effects ...'; temporary decline in fishery harvests and clam harvesting	Jernelöv and Linden, 1980; Hayes, 1977
Garbis, vessel 7/18/75	Crude oil and water emulsion	1500–3000 barrels	*Rhizophora mangle* *Avicennia germinans* (referred to as *A. nitida*)	Florida Keys, U.S.A.	Death of young red mangrove seedlings and some dwarf black mangroves	Chan, 1977
Zoe Colocotroni, vessel, 3/18/73	Venezuelan crude	37,000 barrels	*Rhizophora mangle* *Avicennia germinans* (referred to as *A nititda*)	Cabo Rojo, Puerto Rico	Death of adult trees (red and black) over an area of 1.0–2.7 ha within 3 years	VAST/TRC 1975; Nadeau and Berquist, 1977; Page *et al.*, 1979; Lewis, 1979a; Martinez *et al.*, 1979; Gilfillan *et al.*, 1981
Showa Maru, vessel, 1/6/75	Arabian light Berri and Murban crude	54,000 barrels	*Sonneratia* sp. *Rhizophora* sp.	Indonesia	Some dead trees (both species) unquantified; areas of greatest impact in sheltered bays; low numbers of crabs and snails associated with oil in sediments	Baker, 1981; Baker *et al.*, 1981
Pipeline rupture 10/13/76	Crude	377 barrels	*Avicennia germinans*	Corpus Christi, Texas	Mangroves burned to remove oil died; uncleaned mangroves recovered after minor defoliation	Holt *et al.*, 1978
Unidentified vessel, 3/77	Venezuelan Crude	1000 barrels	*Rhizophora mangle*	Guayanilla Bay, Puerto Rico	Damage to mangrove root community, trees survived	Lopez, 1978

Santa Augusta, vessel, 1971	Crude	12.5 million liters	*Rhizophora mangle*	St. Croix, U.S. Virgin Islands	5 ha completely destroyed, little or no recolonization after 7 years	Lewis, 1979b; Lewis and Haines, 1980
Funiwa 5, offshore oil well, 1/17/80 to 2/1/80	Crude	8.4 million gallons	Unidentified	Nigeria	Under study	Baker, 1981; OSIR 1980a; OSIR, 1980b
Peck Slip, barge, 12/19/78	Bunker C	440–460,000 gallons	*Rhizophora mangle*	Between Punta San Agustin and Yabucoa, Puerto Rico	Significantly affected mangrove, crab, snail, and epiphyte populations	Gundlach *et al.*, 1979; Getter *et al.*, 1981
Howard Star, vessel, 10/5/78	20% diesel 80% Bunker C	40,000 gallons	*Rhizophora mangle* *Avicennia germinans* *Laguncularia racemosa*	Tampa, Florida	Death of all three species of mangroves, death of molluscs and polychaetes, root abnormalities	Lewis, 1979b; Grundlach *et al*, 1979; Lewis, 1980a; Getter *et al.*, 1981; Snedaker *et al.*, 1981

brates were either identified to species on site or collected and preserved for later identification. Estimates of the number of dead invertebrates were made from random surface counts of dead animals in m^2 quadrats. Dead animals were particularly evident near the origin of the spill.

Twenty-five mangroves of all three species (black, *Avicennia germinans;* white, *Laguncularia racemosa;* and red, *Rhizophora mangle*) that had been oiled were tagged, and DBH (Diameter Breast High), height, and amount of oiling recorded (e.g. height and relative oiling on pneumatophores, prop roots, and stems). A group of twenty-five control trees (not oiled) were also tagged and measured.

All of the stations were visited at approximately monthly intervals between October 1978 and August 1980. Individual areas were regularly photographed and the health of individual experimental and control trees noted. Vertical, false-color, infrared aerial photographs of the stations were taken in November 1978, April 1979, and November 1979.

On 21 March 1980 ten three-inch PVC cores eight inches long were taken at each of the eight stations. These were sieved in the field through a 0.5 mm mesh and the residue and organisms retained on the sieve were relaxed in a propylene phenoxytol/sea-water mixture, preserved with 10% formalin, and stained with rose bengal.

These cores were transported to the Mote Marine Laboratory in Sarasota, Florida. Due to the very high cost of sorting organisms from the plant material retained on the sieve, only five of the cores were analyzed from each station. All organisms were removed from the samples, identified to the lowest practical taxonomic level and enumerated.

On 2 April 1980 four two-inch sediment cores were taken at each of the eight stations by the Bowdoin College Hydrocarbon Research Center. The cores were taken to a depth of approximately 20 cm. Each core was taken with a stainless steel coring device that was rinsed with solvent between each station. After the core was taken, it was cut longitudinally into four quarters. Three of these were discarded and the last used as a subsample. Four subsamples from a given station were combined as the final sample for analysis of hydrocarbons. Samples were transported on ice from

Tampa to Bowdoin College, Brunswick, Maine for analysis.

In addition to the sediment samples taken in April 1980, samples of oil collected by the Coast Guard during the oil spill in October 1978 were transferred from the Coast Guard Central Oil Intelligence Lab (COIL) to the Bowdoin College Hydrocarbon Research Center for analysis and comparison with the sediment samples. These included samples of oil taken from fuel tanks on board the *Howard Star* as well as freshly spilled oil. Oil analysis was performed using the same techniques as described in Gilfillan *et al.* (1981).

The Bahia Sucia site was visited on 17–18 March 1979, six years to the day after the *Zoe Colocotroni* oil spill.

Previously established transects (Page 1979) were walked and standard measurements (DBH, height, surface salinity and interstitial salinity) taken at locations along the transects. These are the same transects that had been established previously for chemical analysis of the sediments for oil (Page 1979). Surface and interstitial salinities were taken with an A.O. temperature-corrected refractometer.

The intent of the survey was to examine the mangrove community for any evidence of (1) oil damage to mature trees; (2) stress or death in young mangroves, and (3) salinity stress indicated by high salinities in unoiled areas. Heights of 1–2 m indicate young trees if the diameter (DBH) of the stem is small (1–2 cm) and the canopy (leaf cover of stems) is also small. Scrubby mangroves also are 1–2 m tall, but the diameters are larger (greater than 2 cm) and the canopy more extensive. Due to recent rains, the soil was extremely soggy in some areas and could not be reached on foot.

In addition to oblique color aerial photographs of the site taken by Dr. David Page in November, 1978, five other vertical aerial photographs (1966–1977) of the area were photointerpreted.

The site is dominated by red mangroves (*R. mangle*), with fewer black mangroves (*A. germinans*) found either mixed with the red mangroves or as uniform stands in the more saline areas behind the red mangrove fringe. White mangroves (*L. racemosa*) were very uncommon.

Case histories

Three oil spills in particular will be discussed in order to amplify the problems of describing oil spill impacts to mangrove forests and the attendant legal and scientific arguments that result.

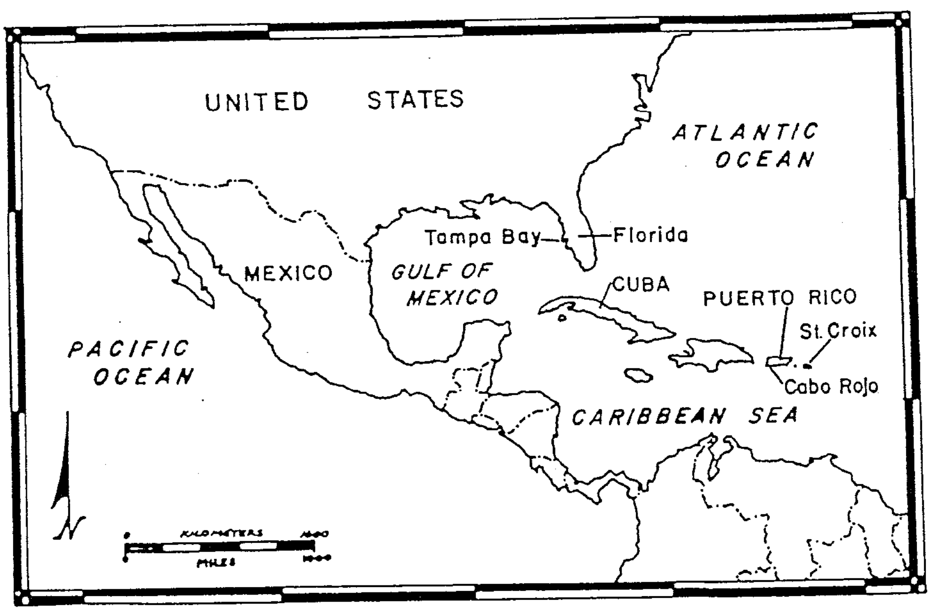

Fig. 1. Location map for oil spill sites at St. Croix (*Santa Augusta*), Cabo Rojo (*Zoe Colocotroni*) and Tampa Bay (*Howard Star*).

The first spill to be discussed is the *Santa Augusta* spill of 12 June 1971. This spill occurred when a tanker ruptured several of its tanks after striking an unidentified submerged object at the Hess Oil Refinery on the island of St. Croix, United States Virgin Islands (Fig. 1). An estimated 12.5 million liters (3.3 million gallons) of crude oil was spilled and much of it stranded on the south shore of the island. No reports of biological damage were made at the time of the spill. Lewis (1979b) and Lewis and Haines (1980) concluded after examination of historical aerial photography and recovery of weathered oil in concentrations of 50,000 ppm that an area of approximately 5 ha of mostly red mangroves, *Rhizophora mangle*, had been killed by the spill (Fig. 2). Natural regeneration seven years after the spill had been minimal and successful restoration efforts were conducted during 1978–1979 (Lewis and Haines 1980).

The second spill is that of the vessel *Zoe Colocotroni* on 18 March 1973 offshore of Cabo Rojo, Puerto Rico (Fig. 1). This spill was caused when the ship grounded on a reef and the captain decided to lighten the vessel by pumping 5.7 million liters (1.5 million gallons) of crude oil overboard. The oil was carried by currents and winds into Bahia Sucia, a semi-enclosed bay where much of it stranded along sandy shorelines and mangrove forests. The primary area of concern was located on the western side of the bay where a 4.9 ha mangrove forest was heavily oiled (Fig. 3), although oil also stranded in mangroves just south of this site and on the eastern sided of Bahia Sucia (Nadeau and Berquist 1977; Page *et al.* 1979; Gilfillan *et al.* 1981), most of the

Fig. 2. Mangrove forest dominated by red mangroves, *Rhizophora mangle*, seven years after being impacted by spilled oil from the vessel *Santa Augusta*, St. Croix, U.S. Virgin Islands.

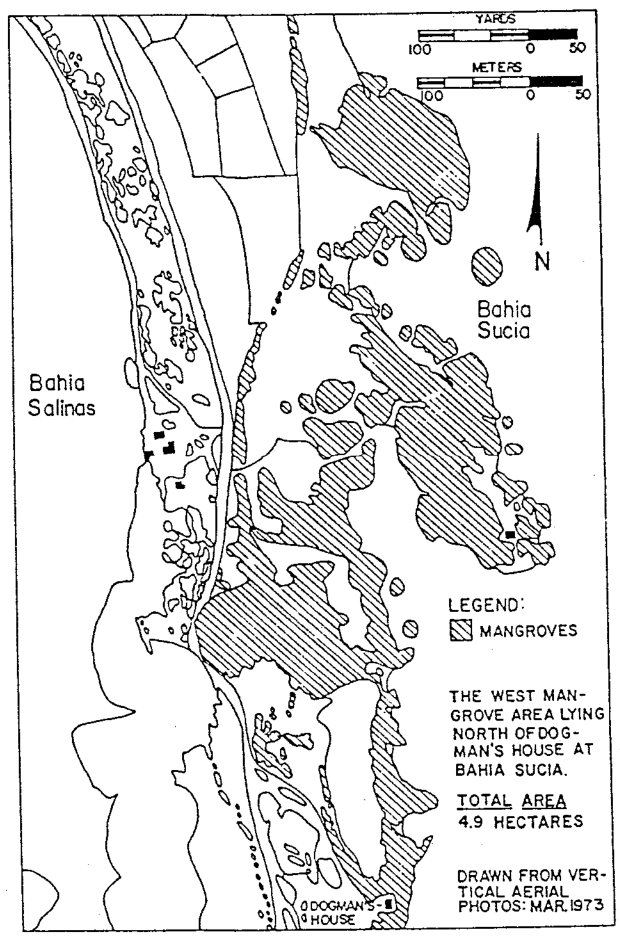

Fig. 3.

observed damage was in this area.

The effects of the spill have been the subject of litigation since the time of the spill, and which is still ongoing (1982). A number of precedent-setting legal decisions have been rendered and numerous conflicting reports have been prepared (VAST/TRC 1975; Nadeau and Berquist 1977; Page *et al.* 1979) and many volumes of legal testimony generated.

The main subject of these disagreements revolves around two points. The first is how many benthic invertebrate organisms were killed by the oil and the second is how many hectares of mangroves died as a result of the oiling they received. In the first legal decision on the case (Commonwealth of Puerto Rico *vs.* the SS Zoe Colocotroni, 456 F. Supp. 1327, 1978), it was determined by the judge that 92,109,720 marine organisms (11,371,570 per hectare over an area of 8.10 ha) had been killed and that they were worth U.S. $ 5,526,583.20 in damages. In addition, the judge determined that 8.10 ha of mangroves existing in oil-contaminated sediments would need to be removed and replanted and that 1.21 ha of healthy mangroves would be disturbed in the process. At U.S. $ 40,762 per hectare, the total replanting would cost U.S. $ 379,500 (9.31 × 40,762) plus U.S. $ 180,000 for monitoring and fertilization for five years. The total damage award totaled U.S. $ 6,086,083.20, or U.S. $ 751,368.30 per hectare of damaged mangrove forest. Considerable controversy as to the actual number of organisms killed followed the decision and its appeal to the United States Court of Appeals in Boston, Massachusetts, U.S.A.

Dr. G.L. Voss of the University of Miami took 254 41.85 cm^2 cores during March 1979, and found 0–3107 organisms per m^2 depending on the sampling point (pers. comm.). A total of 18 species were recorded. He concluded that the patchiness of the density of benthic invertebrates precluded any conclusions as to the actual loss of invertebrates due to the oil spill. Gilfillan *et al.* (1981) reported that in their sampling in 1978 in the same area that nine 78.5 cm^2 cores taken in mangroves that still had significant quantities of oil contained an average of 113.1 organisms per m^2 of four species. Cores taken in previously oiled areas now containing very low oil residues ranged from 0–20,001 organisms per m^2, again depending on the station. Gilfillan *et al.* (1981) concluded that only 0.81 ha of previously oiled red mangroves still showed a reduced number of infaunal organisms due to remaining oil residues.

The original decision that 92,109,720 organisms were killed was based upon sampling at just four stations at Bahia Sucia where six 41.85 cm^2 cores were taken at each station and compared with four control (unoiled) stations. One of the pair of stations was not used in the final calculations for questionable reasons. In the three remaining paired stations, the results were: first station, 0 organisms/m^2 oiled site versus 955/m^2 at the control; second station, 0/m^2 at the oiled site versus 1846/m^2 at the control; third station, 21/m^2 at the oiled site versus 637/m^2 at the control site. This is an average difference of 1138 organisms/m^2 which was the basis for the 92,109,720 number. A number of questions have been raised (Gilfillan *et al.* 1981) about the biasing of these sample locations since they were chosen in areas where '...there was a large quantity of hydrocarbons present...' (testimony of Dr. David Ballantine) and may not have been representative of the entire 8.1 hectare under question.

The second point of disagreement involved the actual area of mangroves damaged by the oil spill. All parties seem to agree that approximately 8.1 ha of mangroves on both the *east* and *west* sides of Bahia Sucia were oiled, but no claim was made by the Commonwealth of Puerto Rico for damages to mangroves on the *east* side of the bay. Within the mangroves on the *west* side of the bay where oil residues remain (Fig. 3) a total of 1.0 ha of mixed red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangroves were reported to have died by 1976 (Nadeau and Berquist 1977), three years after the spill. After examining both pre-spill and post-spill aerial photography and inspecting the site, it was determined that 1.4 ha of dead mangroves attributable to oil contamination were present in March of 1979, six years after the spill (Fig. 4). Martinez *et al.* (1979) reported that 2.7 ha of mangroves were killed by the oil. Support for the figure of 8.1 ha of damaged mangroves used in litigation is lacking.

The major problem with determining the area of

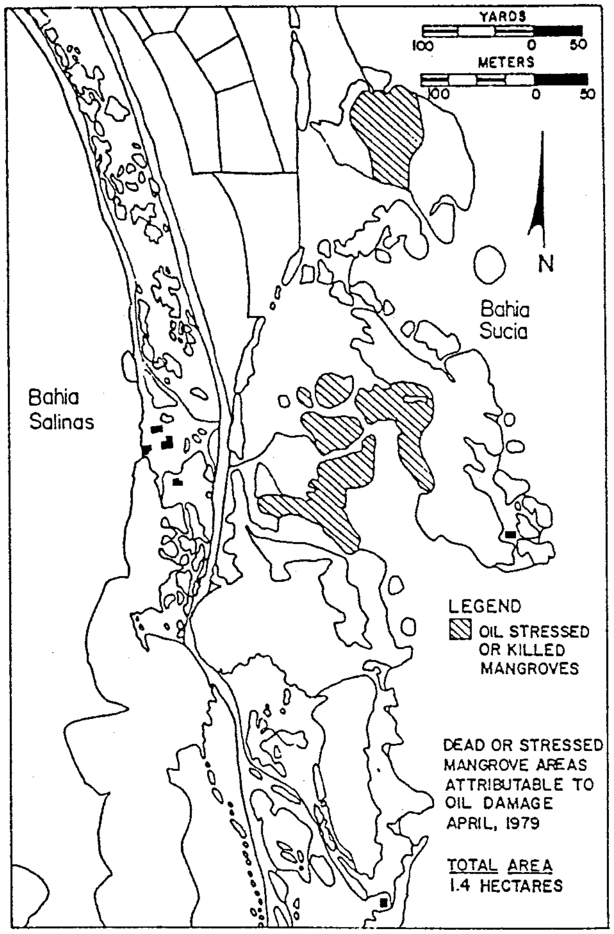

Fig. 4.

damage is that the mangroves at Bahia Sucia were not thriving *prior* to the spill and large areas of saline lagoons devoid of mangroves and stands of dead mangroves due to salinity stress were present at the time of the spill. Martinez *et al.* (1979) describe the Bahia Sucia mangroves as follows:

> In general, fringe mangroves are the dominant physiographic type . . . and basins are poorly developed. Poor development of the basins bay be due to at least two factors: (1) the lack of runoff to prevent salt accumulation; and (2) wave exposure . . . wave action in this particular coastal strip is high enough to contribute to the deposition (within the mangrove fringe) of berms of sand and *Thalassia* debris. These berms may be low, 10–15 cm, but effectively reduce the exchange of water in the inner fringe and basin. Salinity behind the berm (interstitial) is much higher and rapidly approaches more than 60‰ . . . In most sectors, salinity increases so rapidly that only a narrow fringe of red mangrove is found. Behind this fringe, the typical profile contains a *zone of dead mangroves* and a shallow hypersaline lagoon which end in a wide salitral or salt flats [emphasis added].

The arid nature of this portion of Puerto Rico creates natural stresses on the mangroves and combined with storms, is responsible for the natural cycle of death and regrowth of mangroves. As noted by Cintron *et al.* (1978) in describing mangroves of arid environments in Puerto Rico:

> The cycle mortality and expansion of mangrove forests in response to cyclic climatic events appears to be a common feature of arid coastlines. The climatic cycles may be associated with hurricanes (periods of 10–30 years) or with rainfall (periods of 5–10 years). This association has at least two implications for mangrove management. First, managers should consider open water areas and salt flats as part of the mangrove ecosystem and not as separate ecosystems. Failure to recognize this fact may result in incompatible land uses that may affect the normal expansion of the mangrove forest during periods of high rainfall and lower soil salinities. Secondly, periods of high mangrove mortality are normal occurrences in these environments, and care should be taken before attributing this mortality to other factors, including man and isopods.

Apparently, much of the confusion about the 8.1 ha of 'oil damaged' mangroves resulted from the inclusion of normal areas of mangrove mortality in the calculations.

In any case, U.S. Court of Appeals ruled on 12 August 1981 that (1) the Commonwealth of Puerto Rico could not collect damages for the loss of the 92 million organisms since there was no plan to actually purchase the organisms and use them to restore the area and (2) rejected the claim of U.S. $559,500 for replanting mangroves in the oiled areas due to previously mentioned conflicts as to exactly how large an area of mangroves was damaged and the fact that replanting mangroves in oiled sediments seemed 'pointless'.

The court remanded the case back to the District Court in Puerto Rico with the suggestion that an alternate site (unoiled) be considered for restoration. Such a suggestion had been made by Dr. Howard Teas during the court case and is presently being negotiated by the parties to the case based upon restoration of tidal flow and planting of mangroves in a large saline lagoon due south of the oil damaged site.

The final example is the *Howard Star* oil spill of October, 1978 (Fig. 1). The ship apparently accidentally pumped 151,000 liters (40,000 gallons) of a fuel oil mixture (80% Bunker C, 20% diesel) overboard in the upper harbor area of Tampa Bay. The resulting slick moved south stranding oil in at least four sites that contained mangroves (Lewis 1979a; Gundlach *et al.* 1979; Lewis 1980) (Fig. 5–7).

One of the common problem with observing the acute, short term impacts of oil in mangroves is that trained observers rarely are present due to the unplanned nature of an accidental spill. Lewis (1979a) noted that during the *Howard Star* spill, large numbers of molluscs (*Melongena corona*) and polychaetes (*Laeonereis culveri*) were killed during the first 24–48 hours of the spill, decayed rapidly due to the warm temperatures, and were not obvious as oil spill mortalities as soon as four days after the spill. Thus an observer arriving as soon as one week or even two months after a spill is handicapped by the rapid decay of soft-bodied invertebrates and general unfamiliarity with the area. Nadeau and Berquist (1977) arrived on the scene of the *Zoe Colocotroni* spill site 24 hours after the spill and reported 'large numbers of sea cucumbers, conchs, prawns, sea urchins, and polychaete annelids were being washed ashore' on the third day after the spill. Chan (1977) noted mortalities of crustaceans and molluscs soon after the *Garbis* spill.

In contrast to these, Jernelöv and Linden (Jernelöv *et al.* 1976) visited the *St. Peter* oil spill site three months after the spill, and Baker *et al.* examined the *Showa Maru* spill site two years after the spill (Baker *et al* 1981). The *Zoe Colocotroni* site was visited six years after the spill (Voss, pers. comm. 1979). These time frames limit the ability of the investigator to describe the impacts of a given oil spill.

The chronic impacts of the *Howard Star* oil spill have been reported by Getter *et al.* (1981) and Lewis (1979a; 1980). These reports document death of three species of mangroves (*R. mangle*, *A. germinans*, *L. racemosa*) due to oiling at a number of sites along the path of the oil slick. Estimates of the area of mortality are 0.5 ha with 1.0 ha of sublethal damage for a total of 1.5 ha requiring restoration.

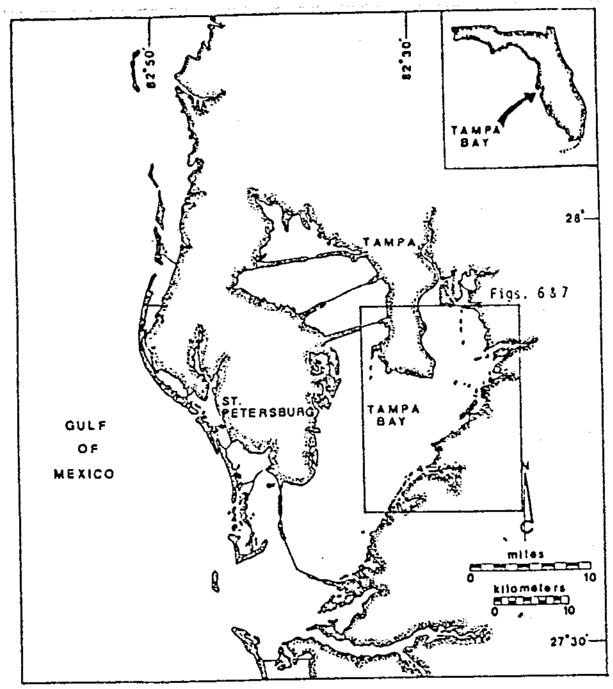

Fig. 5. Location map of Tampa Bay with inset for Figs. 6 and 7.

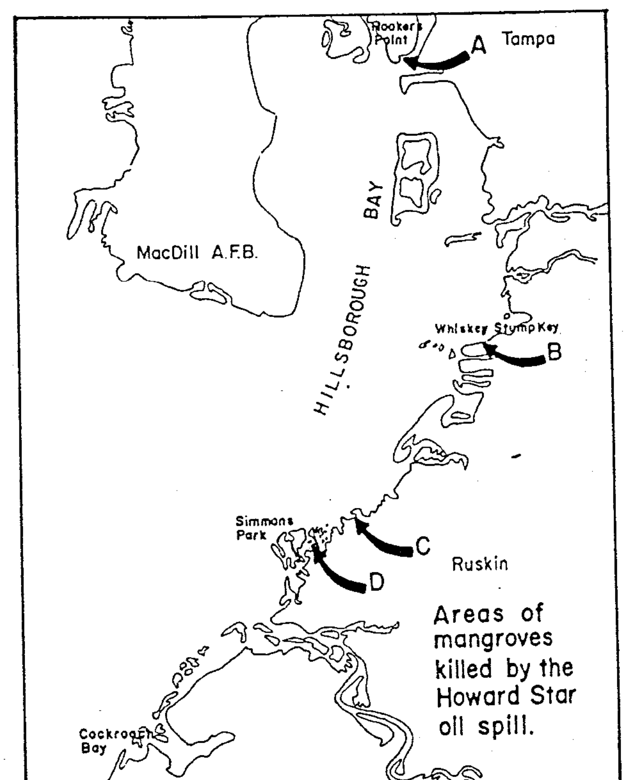

Fig. 6. Tampa Bay.

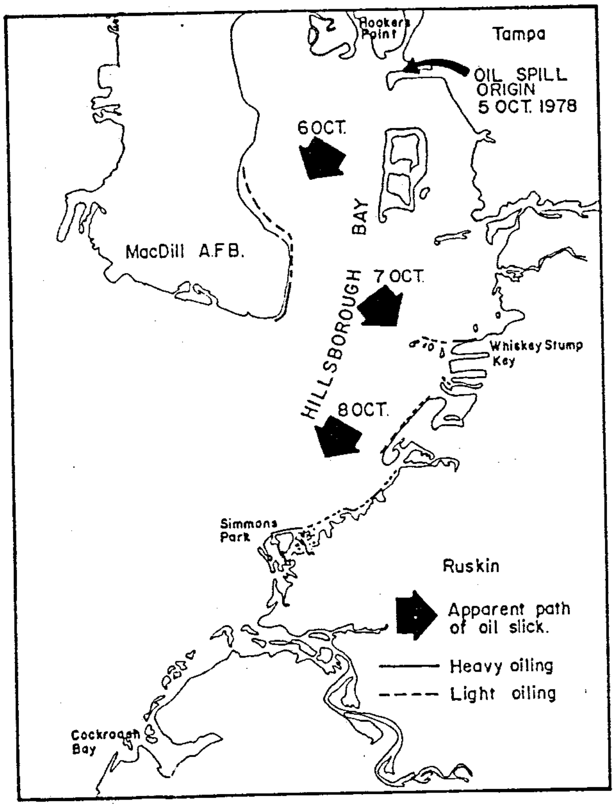

Fig. 7. Upper Tampa Bay and Hillsborough Bay showing the origin of the spill and apparent path of the slick with stranding sites.

Estimated costs for acquiring land, construction, and planting of an inland site to be converted to intertidal mangroves was U.S. $ 60,000 per hectare for a total restoration cost of U.S. $ 90,000. This damage estimate was based upon the concept of 'alternate site restoration' arising from the *Zoe Colocotroni* litigation. Any additional removal of remaining oil remaining oil residues from damaged mangrove areas was felt to be too costly and unlikely of success. A U.S. $ 750,000 clean up effort had been undertaken by the U.S. Coast Guard at the time of the spill and further expenditure of clean up money was not felt warranted.

Getter *et al.* (1981) did not estimate the areal extent of damage. Snedaker *et al.* (1981) report the death of pneumatophores of black mangroves (*A. germinans*) as a result of the *Howard Star* spill and the apparent resultant growth of anomalous aerial roots.

Getter (pers. comm. 1980) and Lewis (unpublished data) attempted a comparison of benthic infaunal density at oiled and unoiled sites. A comparison of the results of both of these analyses is presented in Table 2. It should be noted that Lewis (unpublished data) used five 7.65 cm diameter cores per station and sieved the sediments through a 0.5 mm mesh to recover infauna. Getter (pers. comm. 1980) used three 7.3 cm diameter cores per station and sieved the sediments through a 1.0 mm mesh.

Table 2 shows a comparison of the benthic infaunal data of Getter (pers. comm. 1980) and Lewis (unpublished data). The most obvious differences are in the numbers of species and densities, regardless of whether it was an oiled or a control site. The higher figures of Lewis are no doubt due to the smaller sieve size which allows fewer of the smaller macrobenthos to pass through. There is no consistent pattern in any of the data, all of which were collected at approximately the same time after the spill (17 months post spill, Lewis; 15 months post spill, Getter *et al.*)

Dr. David S. Page of the Bowdoin College Hydrocarbon Research Center, who performed the hydrocarbon analyses on samples collected at the *Howard Star* spill site, indicates that stations 1 and 5 show high levels of relatively unweathered oil that is closely related to oil collected by the Coast Guard from the *Howard Star* for comparative analysis. A sample of the same oil was used in Dr. Page's analysis. Stations 2 and 7 have very low levels of highly weathered oil and any adverse long term effects of the spilled oil would be expected to occur only at stations 1 and 5. Station 1 was the site of the observed deaths of polychaetes and molluscs, reported in Lewis (1979a). There were also large numbers of black and white mangroves and some cordgrass, *Spartina alterniflora*, that died at station 1. Additional oil analyses at this station showed values of 3,100–56,800 ppm total oil and grease ($\bar{x}$ = 27,900) in the area where mangroves died. Station 5 was the only other area where an oil sample was taken and mangroves were observed to have died as a result of the oiling.

As mentioned before, the benthic community data (Table 2) indicates no distinct pattern. Densities range from 965 to 37,341 organisms per meter

Table 2. Comparison of benthic infaunal densities at oiled and control sites (Lewis, unpublished data; Getter *et al.*, pers. comm.)

Station	Seive size	Oil residue present[a]	Number of species	Density	Diversity index[b]
RM-1 (oiled)[c]	1.0 mm	Not reported	4	5,423/m²[d]	1.64
CP-1 (control)[c]	1.0 mm	Not reported	6	6,619/m²[d]	3.08
1A (oiled)[e]	0.5 mm	3,640 ppm	14	25,230/m²	1.70
2 (control)[e]	0.5 mm	177 ppm	9	965/m²	2.10
3 (oiled)[e]	0.5 mm	1,120 ppm	29	19,087/m²	2.28
4 (oiled)[e]	0.5 mm	3,790 ppm	15	12,681/m²	1.67
5 (oiled)[e]	0.5 mm	36,400 ppm	8	19,658/m²	0.49
6 (control)[e]	0.5 mm	3,920 ppm	17	37,341/m²	1.73
7 (oiled)[e]	0.5 mm	2,930 ppm	14	30,759/m²	0.71
8 (control)[e]	0.5 mm	686 ppm	18	24,133/m²	1.70

[a] Total oil and grease.
[b] H′.
[c] Getter *et al.*
[d] Average of three cores.
[e] Lewis (1980).

square, with the lowest value at an unoiled station (no. 2) and the highest at another unoiled station (no. 6). Numbers of organisms at the two most heavily oiled stations (nos. 1 and 5) were midway to high. This appears to be due to very high numbers of pollution tolerant polychaete worms (e.g. *Capitella capitata*). Polychaetes of the family Capitellidae were also the most abundant benthic infauna reported by Gilfillan *et al.* (1981) for oiled sites at Bahia Sucia, Puerto Rico, and are common in areas of chronic oil input (Sanders *et al.* 1972). Although large numbers of dead polychaetes of the species *Laeonereis culveri* were observed soon after the spill at station 1, samples taken at this same station 17 months after the spill yielded 10,311 individuals of this species per m^2. It thus appears that at least some of the benthic invertebrate species have returned to normal densities at some oiled sites. Station 5 is the only oiled station where both species numbers and densities are reduced, probably due to the very high level of oil (36,400 ppm). *Capitella* is again the dominant polychaete, oligochaetes are numerous, and molluscs are completely absent.

Getter *et al.* (1981) also used a semi-quantitative 'compartmental method' of describing the presence of oiling at a site and applied a Mangrove Stress Index which uses an index number of 1–5 (1 = cryptic stress, 5 = mortality) to describe the condition of individual trees exposed to oil stress. Getter *et al.* (1981) also lists a number of typical stress responses of oiled mangroves including stunting, deformities, defoliation, modifications in the number and shape of lenticles, fissuring of root epidermis, and anomalous root formation, all of which were seen in trees impacted by the *Howard Star* spill.

Discussion

As noted by Getter *et al.* (1981), although there are many differences between oil spill sites involving mangroves, generalized responses and recovery processes have been observed to be common to many areas. This pattern of damage and recovery is dependent in time upon the type of oil spilled, the amount reaching the mangroves, the amount remaining after any clean up effort, and the various physiographic types of mangroves affected.

Getter *et al.* (1981) describe an 'inner fringe impact', an 'outer fringe impact', and an 'inner basin impact' depending on what portion of the forest shows stress symptoms and defoliation. Although mangrove overwash islands are described as being 'less sensitive to oil-induced damage', if they are isolated from normal waves, as happened in

Table 3. Generalized responses of mangrove forests to oil spills.

Stage	Observed impact	Reference
Acute		
0-15 days	Deaths of birds, turtles, fish, and invertebrates	Chan, 1977; Jernelöv *et al.*, 1976; Nadeau and Berquist, 1977; Lewis, 1979a
15-30 days	Defoliation and death of small (<1 m) mangroves - loss of aerial root community (bostrychietum)	Rutzler and Sterrer, 1970.
Chronic		
30 days - 1 year	Defoliation and death of medium (<3 m) mangroves - tissue damage to aerial roots	Chan, 1977; Lewis, 1980
1 year - 5 years	Death of larger (>3 m) mangroves, loss of oiled aerial roots and regrowth of new ones (sometimes deformed)	Lewis, 1979b; Snedaker *et al.*, 1981.
	Recolonization of oil damaged areas by new seedlings	Getter *et al.*, 1981.
1 year - 10 years?	Reduction in litter fall, reduced reproduction, and reduced survival of seedlings	Lugo, 1977.
	Death or reduced growth of young trees colonizing spill site?	
	Increased insect damage?	
10 - 50 years?	Complete recovery	

certain overwash islands at a public park in Tampa Bay, the overwash mangroves can then be more severely impacted due to oil being stranded in them. This occurred at station 5 after the *Howard Star* spill.

Tidal regime is also very critical in controlling the amount of damage to mangroves. Microtidal conditions, as seen in most of the Caribbean (tidal range less than 30 cm), would disperse the oil over a smaller lateral distance while macrotidal (3–5 m) conditions in parts of the Pacific could spread the oil farther inland.

Table 3 lists generalized responses of mangroves to oil spills in two general categories, acute and chronic exposure. Acute exposure would be short term (1–4 weeks) and may end with no further impact if the oil is removed either mechanically or by natural wave and current activity. An example of the former is the intense effort to spray seawater with portable pumps used in the *Howard Star* spill in portions of a public park accessible by road. This technique for cleaning oil from mangroves was suggested by Castle (1977). Monitoring of mangroves for two years after the *Howard Star* spill indicated no damage to the trees beyond loss of some oil soaked leaves. Uncleaned mangroves in the same park showed greater numbers of stress symptoms, and some died. Unfortunately, this technique is not applicable to most mangrove forests due to their inaccessibility.

Chronic exposure to oil and oil residues results in many of the stress symptoms previously noted. The lighter fraction of the oil, generally considered to be the most toxic, generally evaporates or degrades most rapidly (Lee 1977; Lee 1980; Page *et al.* 1979) leaving the heavier fraction as the cause of most of the chronic impacts. Exceptions to this can occur where the lighter fraction is incorporated into sediments and is thus degraded much more slowly.

Natural recovery of oil damaged mangroves can occur through recolonization of damaged areas by floating mangrove seedlings and planktonic larvae of benthic invertebrates. If the oil concentrations are still very high (30,000-80,000 ppm), however, the seeds may grow into deformed seedlings or die. Recolonization appears to be successful in many areas of Bahia Sucia after the *Zoe Colocotroni* spill, although both Gilberto Cintron (Puerto Rico Department of Natural Resources) and Ariel Lugo (Institute of Tropical Forestry, Puerto Rico) have testified that they believe these trees will either remain stunted or eventually die. Only continued monitoring will answer this question.

Active attempts to replant an oil damaged site

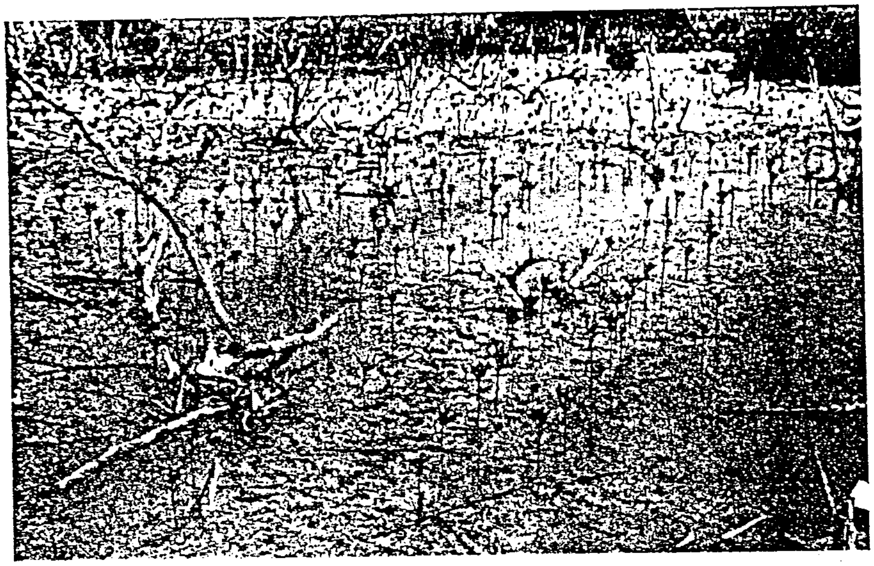

Fig. 8. A portion of the *Santa Augusta* oil spill site on St. Croix, 18 months after manual installation of 86,000 red mangrove (*Rhizophora mangle*) seedlings.

have been reported by Lewis (1979b) and Lewis and Haines (1980) for the *Santa Augusta* spill site. Natural recolonization had been prevented due to debris from the dead trees blocking movement of seeds into the damaged areas and mortality of seeds that were able to colonize more heavily contaminated areas. A total of 86,000 red mangrove seedlings were planted and 36,000 black mangrove seeds broadcast into the damaged area. Survival and growth of the planted seeds has been reported (Lewis and Haines 1980) (Fig. 8).

A key research project that would help clarify many of the questions raised here would be a controlled experimental oil spill into a mangrove forest, similar to that procedure that has been used in experimental oil spills in temperate tidal marshes (Bender *et al.* 1980; Lee *et al.* 1980). Hopefully, such an experiment will be undertaken in the near future.

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