OILING OF MANGROVE KEYS IN THE 1993 TAMPA BAY OIL SPILL[1]

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On August 10, 1993, three vessels collided in the channel leading from the Gulf of Mexico into Tampa Bay, Florida. More than 300,000 gallons of No. 6 fuel oil and 30,000 gallons of gasoline, Jet-A fuel, and No. 2 fuel oil were discharged into Tampa Bay. Most oil moved out to sea and weathered until August 14. Onshore winds then moved the slick onto beaches and into Boca Ciega Bay. Four mangrove keys inside Johns Pass were oiled with No. 6 fuel oil. Floating oil washed through two keys, but slicks and oil patty stranded against berms or elevated sections of two others. Oil contacted three species of mangroves: black (Avicennia germinans), red (Rhizophora mangle), and white (Laguncularia racemosa). Nine months after oiling, significantly more juvenile red and black mangroves were dead at three oiled keys than at unoiled sites or a fourth oiled key. Juvenile plants died if leaf shoots were oiled. Where the oil patty was stranded in greatest amounts, adult red mangroves defoliated and died, and surviving red and black mangroves showed significant deterioration of fringing prop roots and pneumatophores.

On August 10, 1993, three vessels collided in the channel leading from the Gulf of Mexico into Tampa Bay (Figure 1). More than 300,000 gallons of No. 6 fuel oil from Bouchard Barge *B-155* and more than 30,000 gallons of gasoline, Jet-A, and diesel from Maritrans *Ocean 255* barge were discharged into Tampa Bay.[8] Oil moved seaward on a falling tide and formed a slick approximately 17 miles long by 2.5 miles wide. Winds held oil offshore until August 14, then shifted and blew the slick ashore, primarily onto barrier beaches in Pinellas County. Oil entered Boca Ciega Bay through Blind Pass, Pass-a-Grille, and Johns Pass. Oil (No. 6 fuel oil from the Bouchard Barge *B-155*) entered Johns Pass as slicks, tar balls, and oil patty.[9] The movement of slicks and tarballs within the bay was controlled by wind and tidal currents; negatively buoyant oil patty was carried along the bottom by tidal currents.

Oil contacted four mangrove keys inside Johns Pass probably between August 14 and 20, 1993. Based on the height of oil bands on fringing mangrove roots, much floating oil stranded or washed through mangroves around high tide on August 15, 1993, a spring tide of +2.6 ft.[4] Oil patty stranded in intertidal areas at least through September 1993. Differences in the amount of oiling of mangroves among and within keys were observed. Some oil was removed manually from mangrove sediments on

Eleanor Front Key. Workers entered the outer fringe and scooped oil patty into 5 gal buckets for removal by boat.

The goal of this study was to assess the amount of natural resource injury to the mangroves on the four oiled keys inside Johns Pass caused directly or indirectly by the oil spill. We recorded the amount and persistence of visible oiling of sediments and plants, estimated lethal and sublethal injury to adult trees and juvenile plants, and measured sublethal injury to the prop roots of red mangroves and the pneumatophores of black mangroves. We present preliminary results through June 1994.

Study sites

Mangroves in Tampa Bay are close to the northern end of their range and suffer periodic damage from freezes. The four mangrove islands (keys) inside Johns Pass, oiled after the spill, are shown in Figure 2. Little Bird Key and Rookery Key are bird rookeries. All are at least partially overwash islands covered with well-developed, mixed stands of black (*Avicennia germinans*) and red (*Rhizophora mangle*) mangroves. White mangroves (*Laguncularia racemosa*) are present on all but Rookery Key. The keys are within 1 km of each other. Eleanor Front is closest to Johns Pass and is separated from Eleanor Back Key by a channel 3 to 30 m wide.

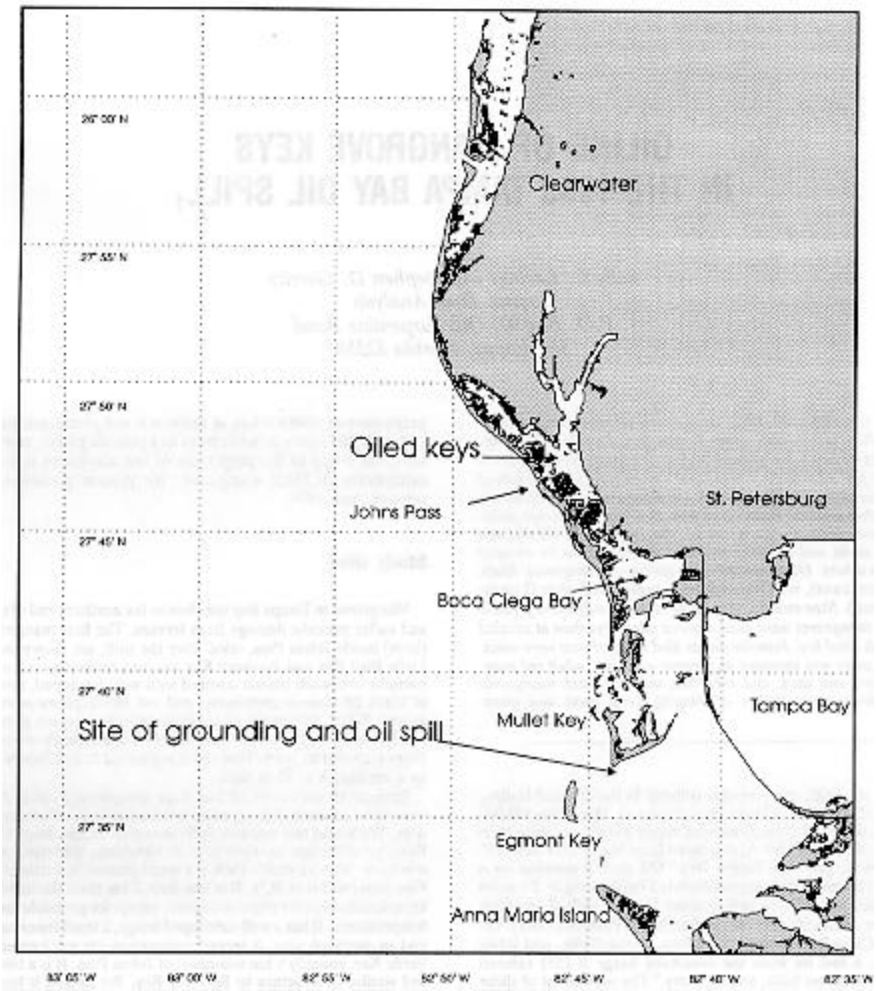
Because shorelines of all four keys immediately inside Johns Pass were oiled to some degree, none were suitable as reference (unoiled) sites. We found two unoiled, reference sites within Boca Ciega Bay. Both were similar to oiled keys in elevation, exposure, and forest structure. War Veteran's Park is a small peninsula northeast of Johns Pass (see Proffitt et al.[6]). It is less than 2 km from the oiled keys and experiences a similar physical regime, except for probable lower winter temperatures. It has a well-developed fringe, a small inner basin forest, and an overwash area. A second comparison site was located at Tierra Verde Key, roughly 9 km southeast of Johns Pass. It is a bird rookery and similar in structure to Rookery Key. We judged it less likely to freeze than the other sites because of its more southerly location.

Methods

The extent of penetration of stranded oil from the outer mangrove fringe inward was estimated by running transect lines perpendicular to the shore of each site along a compass course from the outer fringe through the interior mangrove forest (Figure 2A). Two or more transects along each site's shores were examined. At each meter along the transect a 1 m^2 quadrat on the substratum ahead and to the right was scanned for visible oil. Categories of visible oil on sediments included: heavy patty (>80% cover of oil patty), moderate patty (cover >20% but <80%), light patty (cover >1% but <20%), and trace patty (cover <1%), black or brown oil present, iridescence present, silvery sheen present, and no visible oil (based on NOAA-DAC categories,[5] also see Descleves and Pellen[1]).

We ran transects through to the fringe on the opposite shore of a site or to ±6 m past the point where oil stopped. We noted the presence and amount of oil on mangrove surfaces (pneumatophores,

prop roots, seedlings, and tree trunks) when they occurred within quadrats, and recorded habitat changes (e.g., fringe, overwash, berm) likely to affect oil penetration. The amount of visible oil on mangrove surfaces was recorded using standard categories: none, trace (<1% of surface), light (1 - 20% of surface), moderate (20 - 80% cover), and heavy (80 - 100% cover).[5] Since Eleanor Front was a major area of stranded oil patty and of manual cleanup efforts, 11 additional transects were marked there in October 1993. Each began at a randomly chosen point along approximately 150 m of the northwest fringe and ended at the berm. We recorded sediment and mangrove oiling at each meter of each short transect.



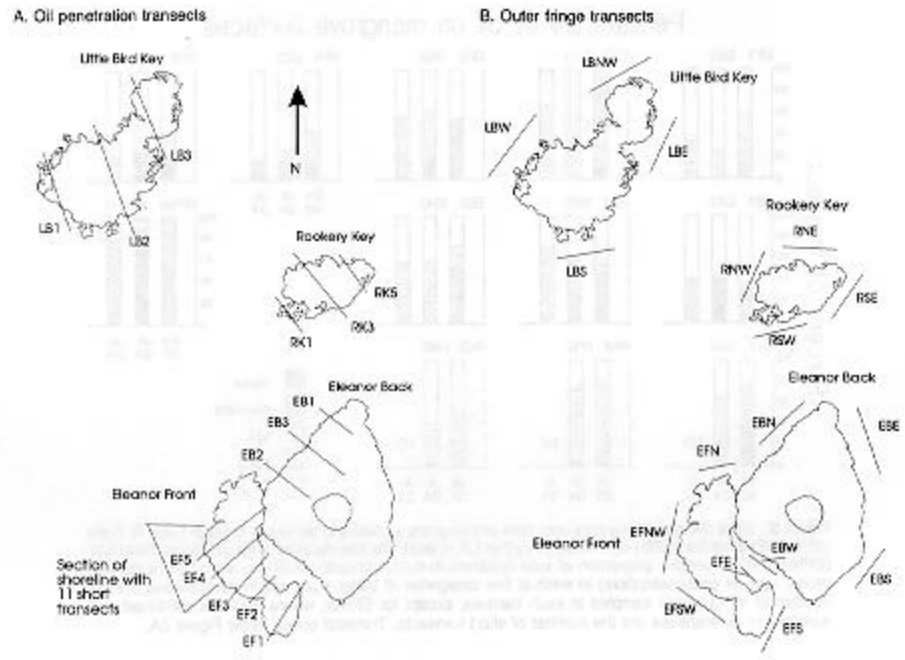
1.

Map of the oil spill site and location of oiled keys inside Johns Pass in northern Boca Ciega Bay, showing the collision site and entrance to Johns Pass

Along the outer mangrove fringe, the cover of oil on submerged red mangrove prop roots and black mangrove pneumatophores was estimated using percent cover methodology.[3] At each site, we marked two to five approximately 150 m stretches of outer mangrove fringe/site (Figure 2). For 20 randomly chosen roots that had entered the water but were not anchored in bottom sediments, we recorded percent cover of oil and condition, such as live, dead, broken, or with new tips. At each site

where black mangroves were present in the outer fringe, 10 randomly selected pneumatophores within 2 m of the outer fringe were cut off at ground level and percent cover of oil and condition were subsequently recorded.

Seedlings, saplings, and trees were individually marked at each study site (n = 855) in September - October 1993. Plant condition, the extent of oiling, and the amount of oil in sediments around each plant were recorded. For trees, diameter at breast height (DBH) and the amount of defoliation or other damage were recorded. Tagged plants were relocated in January, April, and June 1994. Juvenile plants were grouped subsequently into size classes for each species. Seedling density was estimated in September - October 1993 by species and size class by counting plants in 0.5m^2 quadrats placed every 5m on transect lines marked for oil penetration. These data were combined with data on percent mortality of marked plants and a survey of area oiled^2 to estimate the number of juvenile plants that died in oiled areas.



2.

Map of oiled keys: A. location and code names of oil penetration transects, B. location and code names of outer fringe transects

Oil penetration and persistence

Unoiled sites. No oil was recorded on sediments or mangrove surfaces (n = 125 m, 4 transects) at either reference site in September 1993, January 1994, or June 1994. A single, oiled oyster shell was found at War Veteran's Park in January 1994.

Little Bird Key.

Little visible oil was found on sediments or mangrove surfaces in September 1993 on Little Bird Key. In three transects (n = 262 m, Figure 2A), silver sheen or iridescence was visible on sediments in

20 m. Most was near the middle of the transects, not the outer fringe. Some oil stranded on mangrove surfaces across the width of the key (maximum amounts: trace = 122 m, light = 67 m, moderate = 6 m). Data suggest oil washed through this key. Because of potential disturbance to nesting birds, transects were not monitored in 1994. Instead, shoreline sediments were examined as we walked around the key's circumference (January 1994). No oil was observed.

In the outer fringe (see Figure 2B), oil cover was 8 - 23% on prop roots in September 1993 (range of mean percent cover, n = 4 outer fringe transects) and 3 - 11% on pneumatophores (n = 4). Oil cover dropped to <10% on prop roots and 3% on pneumatophores by February 1994 and was <5% overall in April 1994.

Rookery Key.

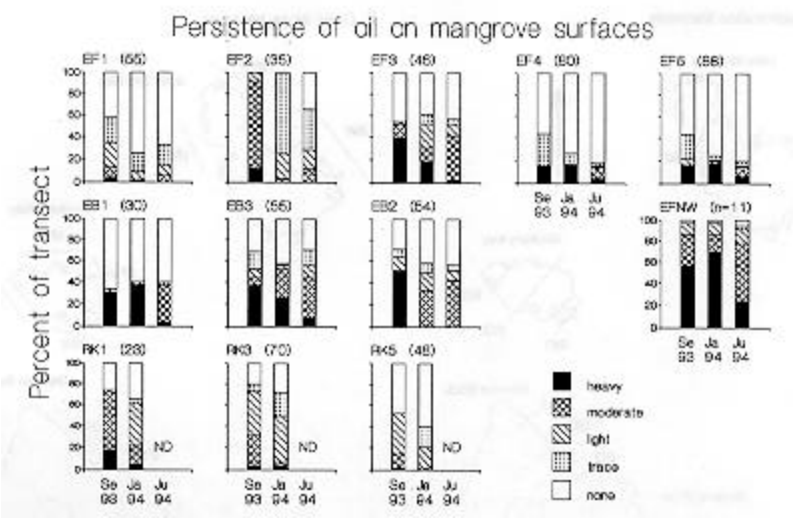
On Rookery Key, we ran three transects shore to shore through overwash mangrove forest (n = 141 m, Figure 2A). In September 1993, visible sediment oiling, mostly silver sheen or iridescence, occurred in 116 m. Only 2 m contained oil patty. Mangrove surfaces were lightly (52 m), moderately (39 m), or heavily oiled (7 m, Figure 3). In January 1994, no oil was visible on sediments and mangrove surfaces were more lightly oiled (trace or light oiling in 74 m, moderate in 8 m, heavy in 3 m). Transects through Rookery Key were not sampled in June 1994 due to the presence of nesting birds.

Along the outer fringe (Figure 2B), oil coated 37 - 60% of prop root surfaces in September 1993 (range of mean percent cover, n = 4) and 1 - 27% of pneumatophore surfaces (n = 4). Prop roots were most heavily oiled in transects along the northwest (site RNW) and southwest (RSW) shores. Pneumatophores were most heavily oiled along northwest and northeast (RNE) shores. Oil cover on prop roots dropped to 10 - 15% cover in April 1994 except on the northwest face (26% cover). Oil cover on pneumatophores dropped to <5% by February 1994.

Eleanor Back Key.

Most oil came ashore along the northern shore. We ran three transects (n = 140 m) roughly north-south into the island (Figure 2A). An extensive mangrove fringe fronted upland mangrove forest. There was no berm, but a gradual rise in elevation shoreward. In September 1993, black oil and small amounts of oil patty occurred on sediments up to 10 m into the fringe and traces of iridescence and scattered silver sheen were found up to the edge of upland forest (up to 31 m inland). Oil patty was found in all quadrats within the fringe in one transect, but was rare or absent in the other two. Where oil patty was present (here and at the other sites), silver sheen, iridescence, or black oil was found on the remaining surface area. Mangrove surfaces were oiled up to 39 m in from the fringe, but only in trace amounts in upland forest (Figure 3). Heavy oiling of mangrove surfaces occurred up to 26 m into the fringe, with moderate and light oiling to 31 m.

Along the outer fringe (Figure 2B), oil cover on prop roots was heaviest (65%) on the north face (EBN) and ranged from 12 - 25% in the other three transects. Pneumatophores occurred in the outer fringe only on the north (EBN) and west (EBW) shores. Oil averaged 44% cover on pneumatophores at EBN, while those from EBW were clean.



3.

Initial oiling and changes over time of mangrove surfaces in transects through Eleanor Front (EF1-5), Eleanor Back (EB1-3), Rookery Key (RK1,3,5) and in the heavily oiled fringe of Eleanor Front NW (EFNW) - Data are the proportion of total quadrats in each transect containing a mangrove surface (trunk, root, or pneumatophore) in each of five categories of oiling. Numbers in parentheses are the number of m^2 quadrats sampled in each transect, except for EFNW, where data are combined and numbers in parentheses are the number of short transects. Transect codes follow Figure 2A.

In January and June 1994, visible oil on sediments decreased on the north face of Eleanor Back. Lighter categories of oil disappeared most rapidly (especially in upland mangroves), with decreases in both thickness of oil (i.e., brown oil to iridescence to silver sheen) and in amount (number of meters with visible oil). Heavier oil persisted longer. In one transect, all fringe quadrats contained some oil patty in September compared to 80% in January 1994 and approximately 50% in June. In a second transect, the occurrence of oil patty increased from zero to five quadrats between September and January, then decreased to zero in June 1994. In June, most visible oil on sediments was silver sheen or iridescence; and on mangrove surfaces, there was also a decrease in visible oiling over time, with little heavy oiling found (Figure 3).

In the outer mangrove fringe, oiling of prop roots remained moderate on the north face (EBN, 26% cover) in April 1994, but was light on the south and west faces (EBS, EBW, <4% cover) and had dropped by more than half on the east face (EBE, 11% cover). Pneumatophores on the west face remained clean through April 1994, and oil cover dropped from 44% in January to 26% in April along the north face.

Eleanor Front Key.

Eleanor Front was the most structurally complex key, with a partial berm behind the west- and north-facing outer fringe and interior overwash and basin forests. Oiling varied around the key, with heaviest oiling on the north- to west-facing fringe. We sampled five transects running roughly west-east

through the site (n = 304 m, Figure 2A). Oil stranded in front of west- and north-facing berms, but floated through an overwash section of the island. Less oil was deposited on the southeast tip (transect EF1) and overwash portion (EF2) of the island than in the three transects located on the west and northwest faces (EF3 - 5). A small amount of oil patty stranded in front of the berm at the southeast tip; and oil sheens occurred in the basin forest behind the berm. Mangrove surfaces ranged from unoiled to heavily oiled in front of the berm, with oil sheens on mangroves in the basin forest (Figure 3). Black or brown oil washed 20 m across transect EF2, with silver sheens along the remainder of the transect. Mangrove surfaces were heavily to moderately oiled, with less oiling at the east end of the transect. Oil patty was deposited in front of the berm in transects EF3 - 5 and in the 11 short transects on the northwest face (n = 218 m sampled). Oil patty on sediments was heavy in 23% of meters sampled, moderate in 33%, light in 19%, and covered trace amounts of sediments in 5% of meters sampled. Oil patty did not occur east of the berm, but silver sheen was present throughout the basin forest. Oiling of mangrove surfaces showed the same pattern, with moderate to heavy coatings in the north- and west-facing fringe in front of the berm and clean to lightly oiled surfaces in the basin forest. Oil on some mangrove roots and trunks extended >1 m above the tidal zone due to contact with oiled cleanup workers or their gear.

Along the outer fringe on Eleanor Front, oil coated 31 - 86% of prop root surfaces (n = 5, Figure 2B). More oil (55 - 86%) was deposited on the north (EFN), northwest (EFNW) and west (EFW) faces than on the south (EFS, 23%) and east (EFE, 31%) faces. Oiling of pneumatophores was almost complete (97%) on the northwest face, but was less on the north (31%) and west (15%) faces. Almost no oil was recorded on the south face (4%) and no pneumatophores were present on the east face.

Changes over time in sediment oiling on Eleanor Front were similar to those on Eleanor Back, even though the keys differed in topography. Sediment oiling decreased over time in both. Lighter categories of oil disappeared most rapidly, with virtually no oil found on inner basin sediments by January 1994 and none found on back (east-facing) fringe sediments by June. Heavier oil persisted in most outer, west-facing fringe quadrats (trace or greater amounts of patty) in transects EF3 - 5 through June 1994, but disappeared from fringe sediments in EF1 by January 1994. For the 11 short transects on the northwest face of Eleanor Front, the total number of quadrats (of 170 examined) containing oil patty increased from 124 to 137 between October 1993 and January 1994, then decreased to 113 in June. Amounts of oil patty within quadrats also decreased through June 1994. Oil patty abundance on sediments was high (>80%) in 26% of quadrats in October 1993, in 22% of quadrats in January 1994, and in 10% of quadrats in June 1994.

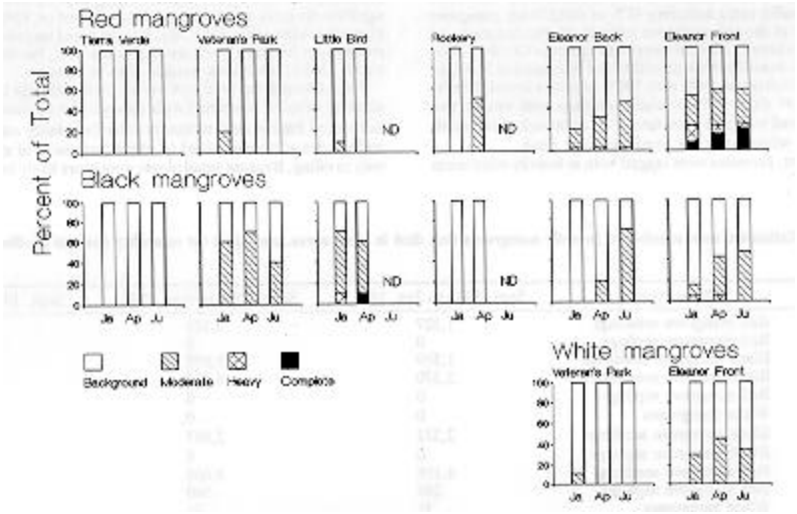
For mangrove surfaces, the total number of quadrats with heavy oiling decreased from 49 in September 1993, to 36 in January 1994, to 9 in June 1994 (Figure 3). The number of quadrats with no oil on mangrove surfaces increased over time; these were primarily located in inner basin portions of the transects. For the northwest face of Eleanor Front, oiling increased overall from October 1993 to January 1994, then decreased from January to June 1994. However, approximately 80% of all quadrats still contained mangrove surfaces that were at least moderately oiled in June 1994.

In the outer fringe, percent cover of oil on prop roots dropped rapidly on the south and east faces of Eleanor Front, dropping two thirds (to <7%) by April 1994. Oil cover also declined on the west face (13% in April 1994), mostly because thin oil sheens were gone by January 1994. On the heavily oiled north and northwest faces, approximately half the oil was gone in April, but >40% of root surfaces remained oiled. On pneumatophores, oil cover declined by approximately a third between September 1993 and April 1994 on the north and northwest faces, but oil cover was still >40% on the northwest face. Oil cover increased in January 1994 on the west face and was mixed with an ephemeral bloom of microalgae.

Mortality of adult mangroves

Black, red, and white mangrove trees with DBH ≥2.5cm were tagged at all sites in September - October 1993. Additional red mangroves were marked on Eleanor Front and Eleanor Back in January 1994. All tagged trees were found in January, April, and June 1994 except at Rookery and Little Bird Keys, which were not monitored in June because of nesting birds (Figure 4).

At unoiled Tierra Verde Key and War Veteran's Park, tree condition changed little over time. When marked, 34% of trees (n = 50) showed evidence of past natural injury (e.g., possible freeze pruning, canopy thinning) but appeared healthy. There was no oil visible on or near marked trees. All trees were in good condition 3, 6, and 8 months after tagging.



4.

Defoliation over time of marked trees at oiled and unoiled sites - Data are from individually tagged trees, relocated and scored for defoliation in January (Ja), April (Ap) and June (Ju) 1994. Each bar shows the percent of the total number of trees with different levels of defoliation: background = <20% leaf loss; moderate = >20%, but <80% leaf loss; heavy = >80%, but <100% leaf loss; complete = no leaves remaining on tree.

At Rookery and Little Bird Keys, 20% of tagged mangrove trees (n = 40) showed old injuries but were scored healthy in September - October 1993 (no to light defoliation, no mechanical damage

of red mangroves, and up to moderate defoliation of black mangroves at Little Bird). Red mangroves remained in good condition through April 1994, except for one individual with fresh mechanical injury to a major stem. On Rookery Key, half the tagged red mangroves were moderately defoliated in April 1994, because resident brown pelicans pruned branches for nesting material. All black mangroves at Rookery Key remained in good condition. Similar to unoiled Veteran's Park, black mangroves at Little Bird Key were moderately defoliated when marked and remained so over time. Some trees increased in defoliation over time and one tree that was heavily defoliated in January was dead in April. At both Rookery and Little Bird Key, marked trees were lightly to moderately oiled on intertidal sections of trunks, prop roots, and pneumatophores, but did not have soft or rotting tissue, adventitious pneumatophores, or bark fissures.

On Eleanor Back, 40% of the marked trees showed old injury but all were in good condition in October 1993. Red mangroves (n = 10) had heavily to moderately oiled prop roots, two were lightly defoliated, and oil patty coated sediments around trees. Black mangrove trunks (n = 10) were located further into the fringe, were moderately to lightly oiled and were not surrounded by oil patty. In January 1994, defoliation of red mangroves increased; and in June 1994, 46% (n = 35) were at least moderately defoliated. In January 1994, tagged black mangroves were in good condition, with trace to light defoliation. Defoliation of black mangroves at Eleanor Back increased over time, with 20% moderately defoliated in April 1994 and 70% in June.

On Eleanor Front in October 1993, 50% of tagged red mangroves in the outer fringe (n = 20) had old injuries. However, 40% also showed recent injuries, including leaf chlorosis, wilting leaves, defoliation, mechanical damage, and trunk oiling to >1 m height (the latter two injuries resulted from oil recovery activities). Prop roots and lower trunks of all trees were heavily oiled and surrounding sediments were covered with heavy oil patty (n = 10 trees) or iridescent oil (n = 10 trees). Prop roots appeared healthy. Six of 20 (30%) marked black and white mangroves showed old injury, but no evidence of recent injury in October 1993. All were heavily oiled around the lower trunks and were surrounded by iridescent, oil-saturated sediments.

In January 1994, the condition of red mangroves had deteriorated as trees defoliated. Three trees were 100% defoliated and dead. Lenticel expansion through areas of oil ≤1 mm thick on roots was observed on 10 trees; bark fissures were seen on one. Tree condition continued to decline in April; and in June 1994, 8 of 40 were 100% defoliated and dead. However, tagged trees with background levels of defoliation (none to light) remained in approximately the same condition over time, and no new trees showed moderate defoliation in June.

Defoliation ranged from zero to light for black mangroves (n = 20) and from very light to moderate for marked whites (n = 21). Intertidal sections of all trunks were moderately to heavily oiled, lenticel expansion was observed on nine white and one black mangrove, and adventitious pneumatophores were found on three black mangroves. Sediment oiling ranged from light to heavy patty around marked black and white mangrove trees. Defoliation of black mangroves increased through June, with 47% of marked trees moderately defoliated and chlorotic individuals scattered through the fringe. Defoliation of white mangroves showed no trend over time.

Mortality of juvenile mangroves

Over 99% of tagged juvenile plants (n = 685) were found in January 1994. At unoiled Tierra Verde Key, War Veteran's Park, and Eleanor Back (for plants tagged inshore of oil penetration) <2% of tagged plants died between September - October 1993 and January 1994 (approximately three to four months after tagging). Mortality and recovery rates at unoiled sites were similar for January - April and April - June (9/175 dead, September to June), indicating a baseline mortality rate of approximately 5% over eight months. Mortality was concentrated in smaller size classes (black mangroves with one or two branches and red mangroves with a single rosette of leaves).

On oiled Little Bird Key, 88 juveniles were marked and 86 were found in January 1994 (97.7% recovery). Two small plants died (mortality rate = 2.3%). Tagged plants were lightly to moderately oiled, with most oil on stems and branches but not leaves or shoots. By April 1994, two additional small plants had died. Searches were not done on one section of the island due to the presence of nesting birds (recovery rate of 80%) and we did not revisit the key in June to avoid disturbing young birds.

On oiled Rookery Key, 72 plants were tagged and 71 found (98.6% recovery) in January 1994. Of these, 15 red mangroves were dead in January 1994 (21% mortality, all size classes combined). Plants that died had been moderately to heavily oiled on leaves and shoots in October 1993. Seven additional red mangroves were dead in April (39% mortality); the search was abandoned due to the presence of nesting birds (92% found). We did not revisit the key in June because young birds were present in nests.

On Eleanor Back within the zone of oiling, 140 juveniles were tagged and 139 found (99.3%) in January 1994. Twenty-five plants were dead (18% overall mortality rate) including 48% of small black mangrove seedlings and 25% of the red mangrove rosettes. Plants that died had been moderately to heavily oiled on leaves and shoots in October 1993. In April 1994 (99% found) overall mortality had increased to 31% and in June overall mortality was 54% with 100% of plants found. Breaking down June 1994 data, 67% of black seedlings with one or two branches, 55% of red mangrove rosettes, 13% of branched red seedlings, and 13% of white mangrove seedlings were dead.

On Eleanor Front, juveniles were tagged both in heavily oiled areas where patty oil stranded (roughly the north to west faces) and in an area where oil washed through and left little or no visible oil on sediments (southwest tip). At the southwest tip, we found 98% or more of the 50 tagged plants (all lightly oiled on stems or branches in October 1993) in January, April, and June 1994. Between September 1993 and June 1994, two small black mangroves died (4% overall rate of mortality).

Where patty oil came ashore on Eleanor Front, we found 99% or more of tagged plants in January, April, and June 1994 (n = 160). Overall, 43% were dead in January 1994: red mangrove rosettes (29% dead), branched seedlings (79%), and saplings (41%). The larger size classes (branched seedlings and saplings) that died were heavily to completely covered with thick oil in October 1993 and were partly defoliated when marked. Smaller reds (rosettes) that died were heavily oiled on leaves and

shoots in October 1993. Small (branched and unbranched seedlings) black mangroves also died (35% mortality). These plants were heavily oiled on leaves and shoots. Most larger black and white mangroves (saplings) were alive when found in January 1994 (5% dead). Many of the larger tagged plants were in poor condition or had partially defoliated. Heavily oiled plants continued to die over time. In June 1994, 49% of small (branched and unbranched) black mangroves, 37% of red mangrove rosettes, 77% of branched red mangroves, and 52% of sapling red mangroves were dead.

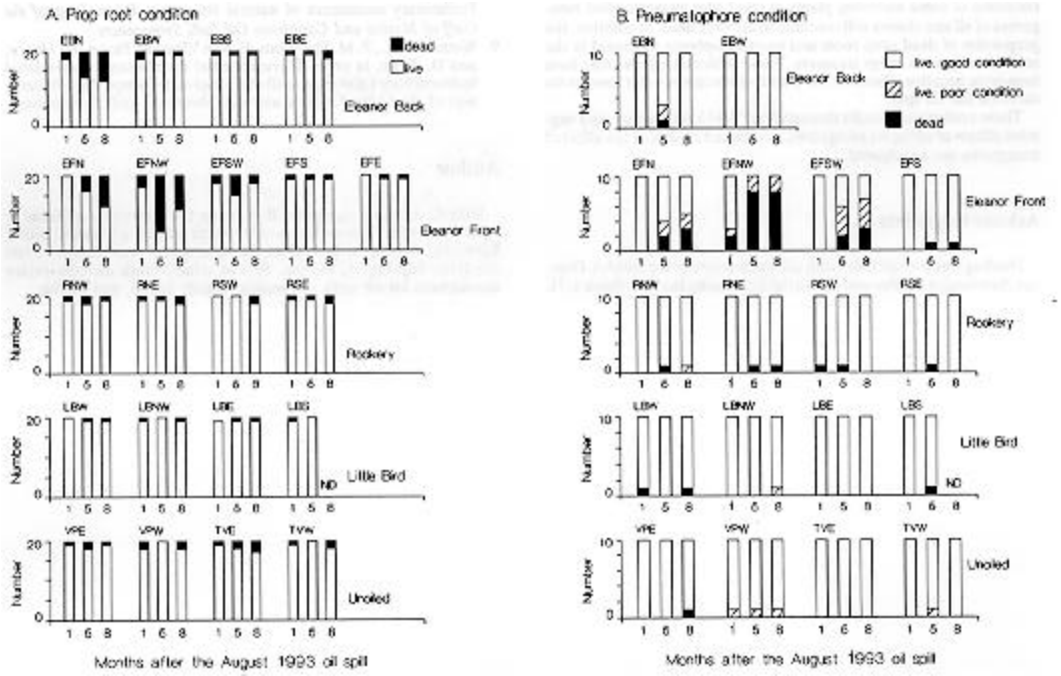
Statistical differences in mortality of juvenile mangroves between oiled and unoiled sites were tested using sequential G-tests of independence with a conservative simultaneous test procedure (STP).[7] Three groups of unoiled marked plants (from Tierra Verde, War Veteran's Park, and Eleanor Back unoiled zone) were combined and tested against oiled groups (from Little Bird Key, Rookery Key, Eleanor Back, and a lightly oiled and a heavily oiled area of Eleanor Front). Species and size classes were tested separately, as well as all groups combined. Analyses were done on data from January 1994 when all sites were visited and recapture rates were over 99%. There was significant variation in mortality among sites. For all juveniles, there were no significant differences among the three unoiled sites, Little Bird Key, and Eleanor Front-EFL ($p > 0.05$, both the latter lightly oiled). Plants at three oiled sites (Rookery Key and Eleanor Back, both moderately oiled; and Eleanor Front-EFH, heavily oiled) had significantly higher mortality ($p < 0.05$ or smaller); rates were highest on the northwest face of Eleanor Front where oil patty stranded. For the largest size class (saplings) of black mangroves, and all white mangroves, there were no differences among sites because no plants died; significantly more red mangrove saplings died on Eleanor Front-EFH than at all other sites ($p < 0.05$). The details of statistical results varied among sites for small black and red mangroves, but significantly more plants died at oiled than unoiled sites in all cases.

We estimated the total number of dead seedlings by using data on seedling density, combined with surveys of area oiled (Table 1). We subtracted background mortality rates (mortality rates by size class and species at unoiled sites) to obtain estimates of mortality related only to oiling. Because small plants were more likely to die over time at unoiled sites, the difference between rates of mortality for oiled and unoiled sites declined over time for some size classes of plants. This caused the decrease in the estimated number of dead plants seen over time for some cases in Table 1.

We estimate that approximately 13,000 juvenile plants died in oiled areas of Rookery, Eleanor Back, and Eleanor Front Keys between September 1993 and January 1994 (Table 1). Most plants that died between September 1993 and January 1994 were small (seedlings), except on Eleanor Front where red mangrove saplings also died where oil patty came ashore. Plants continued to be more likely to die at oiled than unoiled sites through June 1994. In April 1994, we estimated that approximately 2,100 juvenile plants had died on Rookery Key; and in June 1994, we estimated that approximately 16,500 juvenile plants had died on heavily oiled sections of Eleanor Front and Eleanor Back Keys

Condition of red mangrove prop roots and black mangrove pneumatophores in the outer mangrove fringe

Of the 20 roots sampled along each fringing transect (Figure 2B) in September - October 1993, 10% or fewer were dead, except along some transects at Eleanor Front and Eleanor Back (Figure 5A). There were no significant differences in the number of dead prop roots between September - October 1993 and January 1994 for 18 of 21 transects (G tests, $p > 0.05$, 1 d. f.). In most cases, dead roots were so rare that G tests may not have been reliable (cell frequencies were <5 in 20% or more cells). There were significant increases in the frequency of dead roots in outer fringe transects at EFNW (G-test, $p < 0.001$, 1 d. f.), at EFN ($p = 0.01$) and at EBN ($p = 0.05$). The frequency of dead prop roots doubled at EFSW, but changes were not significant between the two monitoring periods. These sites were all heavily oiled. Results were similar in April 1994. However, since roots that died soon after oiling (especially at EFNW) had begun to break off, fewer of total roots were dead at EFNW and EFSW, while more dead roots were recorded at EFN and EBN.



5.

Sublethal injury to prop roots and pneumatophores in the outer mangrove fringe following oiling - Site codes follow Figure 2B. A. Prop root condition: number of live and dead prop roots for 20 randomly chosen prop roots. Open portion of bars = live roots; filled portion of bars = dead roots. B. Pneumatophore condition: number of live and dead pneumatophores for 10 randomly chosen pneumatophores. Open portion of bars = live pneumatophores; striped portion = live pneumatophores, poor condition; filled portion of bars = dead pneumatophores.

In collections of ten pneumatophores from each of 18 sites (Figure 4B), one or fewer pneumatophores was dead at all sites in September-October 1993, except for the northwest face of Eleanor Front (EFNW) where three of ten pneumatophores were dead or in poor condition. In February 1994, zero of ten pneumatophores collected at EFNW were healthy and several pneumatophores were dead at EBN, EFN and EFSW (the sites most heavily oiled by the August spill).

Four of 40 pneumatophores were dead on Rookery Key in February 1994 while only one of 40 had been dead in September. In April 1994, results were similar, except that all pneumatophores were in good condition at EBN.

Discussion

Oil penetration inward was greatest in overwash mangroves; however, oil amounts on sediments and mangrove surfaces were highest where oil, particularly oil patty, stranded in front of berms and in the outer mangrove fringe. Visible oil persisted through June 1994 especially where oil patty stranded. Oil disappeared from sediments and mangrove surfaces where small amounts of oil washed through mangroves. On the northwest face of Eleanor Front, oil patty still coated >80% of sediments in some locations. Our estimates of sediment oiling and persistence are minimum measures of gross oil contamination, because they do not take into account any oil buried by sediments, covered by algae, or adsorbed onto fine sediments. More information on the amount of oil remaining could be obtained with trenching, sediment coring, and/or hydrocarbon content determinations.

We found almost 100% of tagged trees, saplings, and seedlings through June 1994, except for sites where nesting birds prevented searches. Baseline rates of mortality at unoiled sites were 0% for trees (diameter at breast height (DBH) ≥ 2.5 cm.) over eight months. Red mangrove trees on the most heavily oiled section of Eleanor Island deteriorated over time, with moderate to heavy defoliation and soft or rotting prop roots. Of the marked trees 20% were totally defoliated and appeared dead by June 1994. We predict additional mortality, based on the condition of surviving trees. No mortality of black mangrove trees occurred through the period September 1993 - June 1994, but defoliation increased, reaching moderate levels for 65% or more marked trees on Eleanor Front and the northern shore of Eleanor Back by June. In contrast, white mangroves varied little in condition among sites and over time.

Baseline rates of mortality at unoiled sites for juvenile plants over the nine-month period were approximately 5%, compared to approximately 35% mortality in heavily oiled areas of Eleanor Back, approximately 50% mortality in heavily oiled areas of Eleanor Front, and 39% mortality (through April 1994) on oiled Rookery Key. Significantly more juvenile red and black (but not white) mangroves died at oiled than at unoiled sites. Overall, we estimate that approximately 16,500 juvenile plants died on Eleanor Front and Eleanor Back Keys between September 1993 and June 1994 and approximately 2,100 juvenile plants died on Rookery Key through April 1994. The poor condition of some surviving plants at oiled sites suggests oiled mangroves of all size classes will continue to die over time. In addition, the proportion of dead prop roots and pneumatophores increased in the most heavily oiled fringe transects. These sublethal injuries may have long-term negative effects on the health of mangroves that have so far survived the oil spill.

These preliminary results through June 1994 have documented negative effects of oiling on mangroves. Continued studies of the affected mangroves are anticipated.

Acknowledgments

Funding was provided through contracts between the NOAA Damage Assessment Center and Industrial Economics Inc. We thank J. H. Jeansonne, J. D. Cubit, G. Henderson, R. Dawes, and J. Urquhart-Donnelly for help and information. We also thank R. Hanson of Genwest Systems, Inc., who provided computer files used to generate Figure 1.

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1. Opinions or assertions expressed in this paper are solely those of the authors and do not necessarily represent the views of the U.S. government.

Table 1. Estimated total number of juvenile mangroves that died in oiled areas, corrected for mortality rates at unoiled sites[1]

Site	Plant type	Sept. 1993 to Jan. 1994	Sept. 1993 to Apr. 1994	Sept. 1993 to
Rookery Key	Red mangrove seedlings	1,527	2,120	N.D
	Red mangrove saplings	0	0	N.D
Eleanor Back	Black mangrove seedlings	1,539	1,978	1,9
	Red mangrove seedlings	3,370	6,789	7,3
	Red mangrove saplings	0	0	0
	White mangroves	0	0[2]	0[2]
Eleanor Front	Black mangrove seedlings	2,332	2,887	2,7
	Black mangrove saplings	0	0	0
	Red mangrove seedlings	4,108	4,065	4,0
	Red mangrove saplings	299	360	360
	White mangroves	21	21	41
Total		13,196	18,220	16,4

1. Mortality calculated by multiplying the observed mortality rate by species and size class by mean seedling density (Garrity and Levings, unpublished) and the area oiled.2 For Rookery Key, the area of the key was used. Results rounded to the nearest plant. Mortality rate was corrected by subtracting the mortality rate for unoiled sites from that of each oiled site.

2. Juvenile white mangroves died at this site, but were not present in density quadrats. No estimate of number killed.