Oiling
Cleanup
Issues
Wetlands,
M/T *Julie N* Spill,

PORTLAND, MAINE

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NOAA Technical Memorandum NOS ORCA 132

Seattle, Washington
August 1998

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Please cite this report as:

NOAA. 1998. Oiling and Cleanup Issues in Wetlands, M/T Julie N Spill, Portland, Maine. NOAA Technical Memorandum NOS ORCA 132. Seattle: Hazardous Materials Response and Assessment Division, National Oceanic and Atmospheric Administration. 28 p.

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INTRODUCTION

This report discusses the cleanup issues associated with the September 1996 allision (the collision of a moving object with a stationary one) and subsequent oil spill from the *M/T Julie N* in Portland Harbor, Maine. The focus is primarily on the assessment and cleanup options for the oiled marshes of the upper Fore River. Extensive areas of marsh vegetation, both *Spartina alterniflora* and *S. patens,* were heavily oiled, raising many questions about how best to minimize impacts to the marsh habitat and its wildlife. Four cleanup methods were used, including low-pressure flushing, shoreline cleaning agents, cutting, and natural removal. Also, various techniques were used to assess impacts to wetlands, including aerial photography, ground-truth surveys, transects, and chemical sampling. Chemical analyses of oiled vegetation were used to quantify changes in oil concentrations and document fate and transport processes and enhanced oil biodegradation trends. Our objective is to describe the use and effectiveness of these cleanup and assessment techniques and the natural removal process in the oiled marshes of the Fore River.

SPILL BACKGROUND

On the afternoon of September 27, 1996, the *Julie N,* owned and operated by Maritime Overseas Corporation, entered Portland Harbor under pilotage carrying a cargo of No. 2 home heating fuel. The pilot prepared for passage through the "Million Dollar Bridge," an extremely narrow drawbridge **(Figure 1)**, affording less than 1.5 meters (m) of clearance on either side of the vessel's midsection.

The *Julie N* struck the southern side of the bridge. Over the course of the next 12 hours, while under transit to and tied up at the terminal **(Figure 2)**, the *Julie N* lost a total of 179,634 gallons of oil: 86,436 gallons of No. 2 home heating oil, and 93,198 gallons of IFO 380. At times during the night, oil was estimated to be up to 20 centimeters (cm) deep inside the boom surrounding the vessel. Overall, the greatest success with respect to oil removal was achieved in the first night and following day by skimming from inside the boom around the vessel. Vacuum-trucks, small floating skimmers, and the Marine Spill Response Corporation's vessel *Maine Responder* were used to recover as much as half the total amount spilled.

Impacts to the shoreline from the *Julie N* were primarily in the upper Fore River area, upstream of the "Million Dollar Bridge" (Figure 2). Shoreline types included salt marsh (*Spartina alterniflora* and *S. patens*), sheltered and exposed tidal flats, pebble/cobble beaches, medium-grained sand beaches, and man-made structures (including rubble riprap, granite block riprap, piers, pilings, and construction-debris materials). Man-made structures represented the bulk of the shoreline seaward of the Interstate 95 bridge and Sprague Terminal, varying from turn-of-the-century granite block seawalls to newly placed steel sheet-piling. In several areas, the shoreline consists of very poorly sorted rubble riprap.

North of the active harbor, the upper Fore River is dominated by tidal flats and marshes. Both sides of the river consist of several large fringing marshes with mud or sand flats in the lower intertidal, of which the so-called "Thompson Point" marsh was one of the most heavily oiled. Much of the shoreline along the upper Fore River has a narrow fringe of marsh with a steep scarp in the peaty marsh substrate, fronted by a wide tidal flat. The marsh vegetation is dominated by *S. alterniflora* along the outer fringe, and a highly variable band of *S. patens*. The *S. alterniflora* includes a short (<1 m along the outer fringe) and a tall (>1 m along the inner fringe) assemblage.

At the most inland end of the spill zone, the river narrows to only a few meters and is navigable only by canoe. At this point, upriver of the Congress Street Bridge, extensive *Spartina* marshes border both sides of the river with *S. patens* dominating behind a narrow fringe of *S. alterniflora*. *S. patens* extends from about near high water to the edge of terrestrial vegetation. This area, managed by the local Audubon Society as a bird sanctuary, received very little oiling.

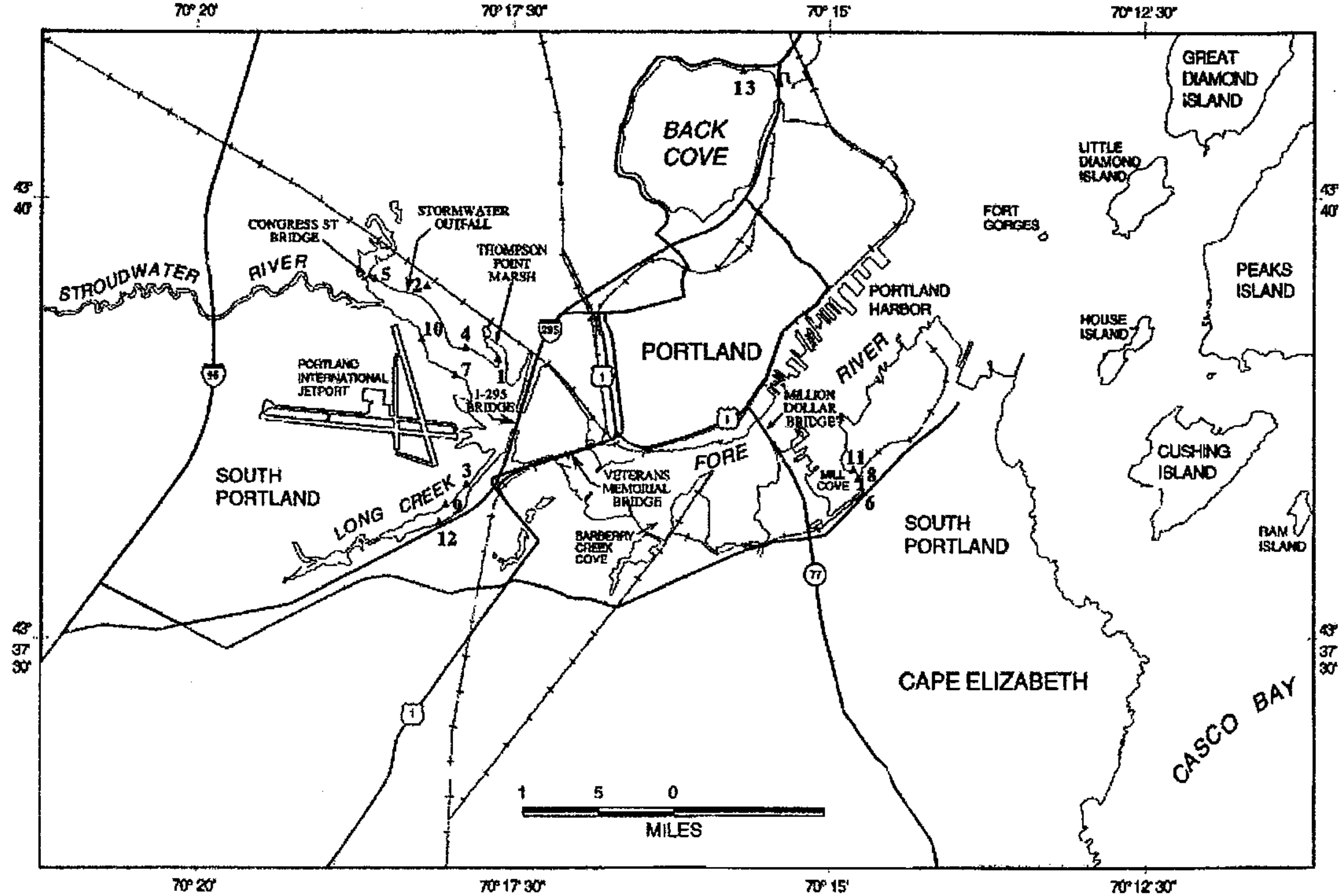

Figure 1. *General location map of the Fore River, Maine. The triangles indicate the transect stations and sites where vegetation was sampled for monitoring of oil content and weathering stage.*

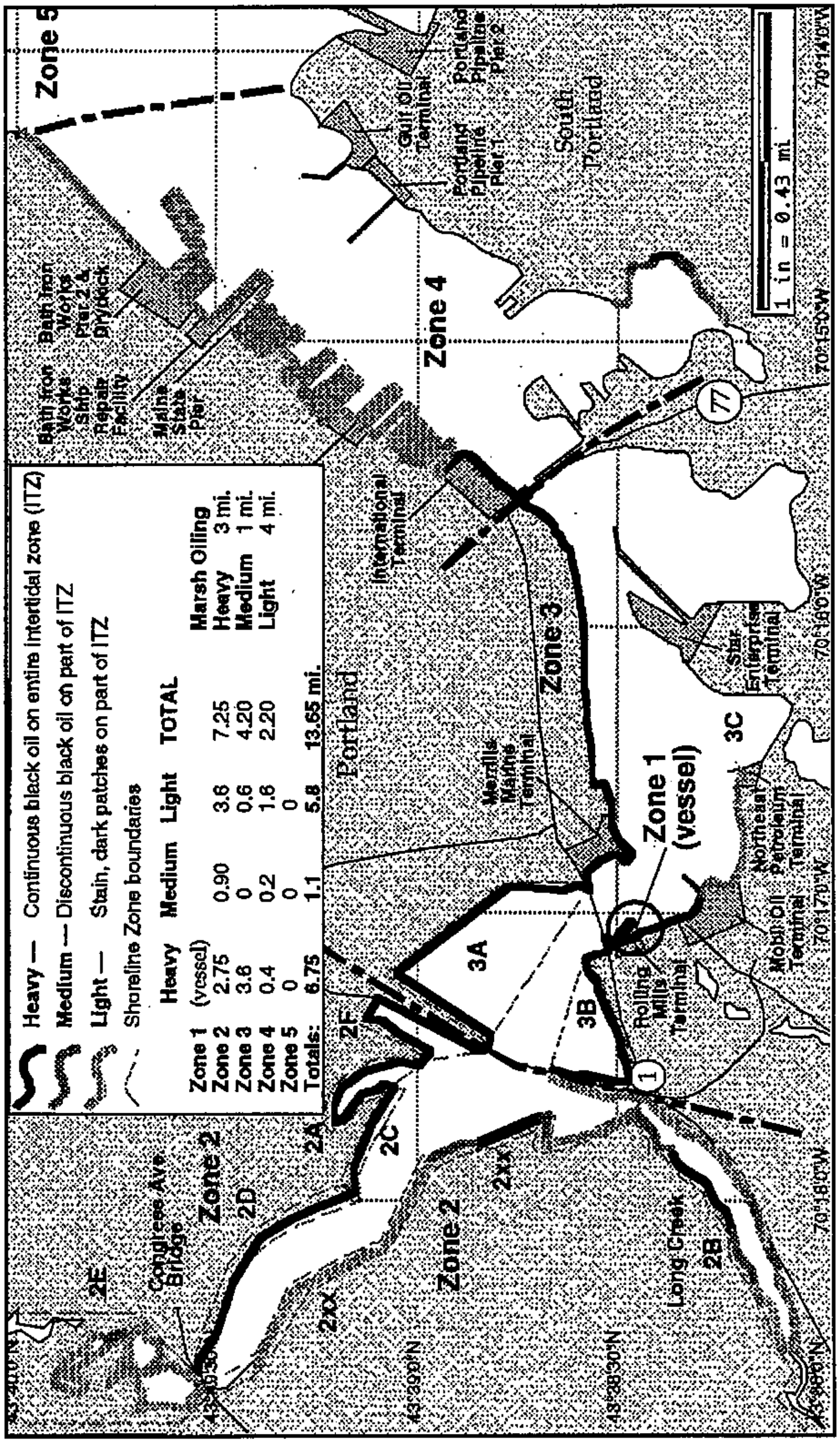

Figure 2. Shoreline oiling map of the Fore River, showing the extent and degree of oil contamination, based on observations during overflights and ground surveys.

GENERAL CLEANUP ISSUES

Although two oils were spilled (No. 2 home heating fuel and IFO 380) in almost equal amounts, most of the shoreline impacts and, consequently the focus of the cleanup efforts, can be attributed to the IFO 380, a black oil similar in composition and behavior after evaporative weathering to a No. 6 fuel oil. Presumably, much of the No. 2 home heating fuel was contained in the boom deployed around the vessel within moments of its arrival at the Sprague Terminal. Much of the oil that was not contained evaporated within a day or two of the spill. The heavier oil remaining in the river impacted high into the marshes due, in no small measure, to the highest tides of the month [+3.2 m (+11.2 feet) at high tide] and strong southeasterly winds. Although the oil did not adhere to the substrate in any significant way, it stuck to the vegetation, often covering the entire plant stem.

Along the man-made shorelines, particularly the rubble riprap, the oil penetrated the porous substrate. Because of the porosity of the riprap, cleanup efforts were never completely effective in removing the oil, despite the use of high-pressure, heated water. In one such area, the riprap was ultimately removed and replaced with clean material to control the continued leaching. Despite repeated raking and flushing of the mixed sand and gravel sediments, high levels of oil beneath the surface were found in some sheltered areas during surveys more than one year post-spill. Additional cleanup was conducted in June 1997 to remove a small amount of tarmat from one such area.

ASSESSING IMPACTS TO WETLANDS

Aerial Photography

Deciding on appropriate cleanup options in the wetlands required documentation of the extent and degree of oiled wetlands throughout the impact area. Also, trustee agencies wanted clear documentation of the extent of wetland vegetation as well as oiling conditions as part of the natural resource damage assessment. Although shoreline survey teams had conducted preliminary assessments along readily accessible routes, it was obvious that access was difficult in many areas and foot traffic would disrupt the vegetation and substrate. As a result, high-resolution vertical aerial photography was deemed necessary to fully document the extent of oil in the marshes for both response and damage assessment activities. On the morning of September 30, vertical aerial true color photography at a scale of 1:2,400 with a 40% overlap was obtained for most of the oil-contaminated shoreline. The photographs were also scanned, and a photomosaic was generated. This photomosaic was registered using ground control points, resulting in an accuracy of ±5 m on the ground across approximately 75% of the image. The photomosaic plots were easier to work with, compared with groups of individual aerial photographs with a high degree of overlap.

Ground-truth surveys were conducted to document the wetland species affected, substrate type, degree of oiling on the vegetation and substrate, width of oiling, and general observations on effects. Two types of ground-truth data were collected: 1) detailed observations along permanent transects; and 2) general observations along the shore noted directly onto the aerial photographs. Each approach is described below.

Permanent Transects

Thirteen permanent intertidal transects perpendicular to the shoreline were established October 4-8, 1996 in areas representative of the various types of vegetation, degree of oiling categories, and relative exposure to wave action in the Fore River (Figure 1). Transects 1 to 3 were located in heavily oiled areas that were relatively sheltered from direct wave attack. Transects 4 to 6 were located in more exposed, heavily oiled areas. Transects 7 to 9 were located in areas of moderate oiling, and transects 10 to 12 were located in lightly oiled areas. Transect 13 was a reference site located in Back Cove. The transects were surveyed during two hours around low tide and usually terminated at the seaward extent of intertidal vegetation.

Custom field forms (shown in **Figure 3**) were developed to assure consistent recording of all information from transect surveys. Observations were made along the transect, using the following descriptors:

- **Vegetation type** estimates of percent abundance of major species present. The following species were noted: *Spartina alterniflora* and *S. patens*, and a high marsh community consisting primarily of sea lavender, sea plantain, and seaside goldenrod;
- **Substrate type** estimates of grain size (gravel, sand, and mud) and relative amount of organic peat in the top 15 cm of the substrate;
- **Interval of oiling** measured in centimeters above the substrate, averaged for the vegetation in the interval;
- **Height of vegetation** measured in centimeters above the substrate, averaged for the vegetation in the interval;
- **Oil thickness on vegetation** as either stain (translucent) or coat (opaque);
- **Percent oil cover on vegetation** using coverage ranges as follows: Trace <1%, Sporadic 1-10%, Patchy 11-50%, Broken 51-90%, and Continuous >90%;
- **Oil type on the substrate** using standard descriptors, such as sheen, coat;
- **Percent oil cover on substrate** using coverage ranges (as above); and
- **Thickness of oiled substrate** measured in centimeters, determined by digging trenches.

Stem density was measured in 1/16-m^2 quadrats for selected vegetation zones along the 12 oiled and 1 reference transects. The quadrats were located within the selected interval by randomly throwing the quadrat down. Stem height was measured for the five tallest plants in representative intervals and in all intervals where stem density measurements were made. These transect surveys were jointly supported by response and damage assessment interests. For response, these surveys would provide more quantitative documentation of the wetland impacts under the natural recovery option than is usually available.

Shoreline Surveys

In addition to the transect data, much of the marsh edge was walked to annotate vegetation types and degree of oiling categories directly on the aerial photographs. Some areas on the aerial photographs were obscured by shadows, requiring field measurements of the width and degree of oiling and vegetation types.

Chemical Sampling and Analyses

During the response, the question of how much oil was adhered to the vegetation was raised in two contexts: 1) as part of the mass balance for the spilled oil when evaluating the effectiveness of oil recovery efforts and 2) during the evaluation of the effectiveness of shoreline cleaning agents, for comparison with the amount of oil that was released during flushing.

On October 5, two composite samples of heavily oiled *S. alterniflora* were collected from the marshes at Thompson Point and Long Creek. These samples were sent to Arthur D. Little, Inc. (ADL) in Cambridge, Massachusetts for analysis of the total extractable hydrocarbons on the vegetation, using a gravimetric method.

A separate set of oiled vegetation samples was collected before and after the test of a shoreline cleaning agent at the Thompson Point marsh, on October 5. A third set of oiled vegetation was collected from three sites on November 8, after the major storm event (see discussion below): 1) Thompson Point marsh, which showed the most evidence of sedimentation and oil loss; 2) near Transect 5 just northeast of the Congress Street bridge, which showed moderate effects of sedimentation; and 3) east of the stormwater outfall on the north side of the

Station No. ______________ Date ______________ Observers ______________

						Transect Angle				Photos
										Page of
				Oil Characteristics						Back Stake cm Front Stake cm
Distance (cm)	Elev. (cm)	Dominant Vegetation Types	Sediment Type/ Samples	Interval on Veg (cm)	Height of Veg (cm)	Oil Thick-ness on Veg	% oil cover on Veg	% oil cover on substrate	Depth oiled sed (cm)	Other observations/photos/ sediment samples Stem density (# 1/16 m2)

Figure 3. Example field form used to record field observations along the permanent transects

upper Fore River, which showed the least effects of sedimentation (see Figure 1 for locations). These October 5 and November 8 samples were sent to the Institute for Environmental Studies at Louisiana State University (LSU) for detailed chemical characterization using gas chromatography/mass spectrometry techniques. Splits of the vegetation samples collected on November 8 were also sent to ADL for total extractable hydrocarbons. The objective of the ADL analyses was to quantify the amount of oil physically removed from the vegetation between the two sampling periods. The LSU analyses were designed to quantify the changes in oil composition due to weathering.

EXTENT OF OILED MARSHES

In a separate study, Research Planning Incorporated (NOAA 1997a) measured the areal extent of oiling of above-ground vegetation in the Fore River marshes delineating four wetland species or assemblages (*S. alterniflora, S. patens*, *Phragmites*, and mixed high intertidal community), and four oil coverage categories as follows: Heavy >67%, Moderate 33-67%, Light 1-33%, and Trace <1%.

Wetland types and oiling categories were digitized, and tabular summaries and maps were generated for each combination of oiling and vegetation category **(Table 1)**. It is important to note that not all wetlands in each area were mapped, particularly above the Congress Street bridge and in Mill Cove, where aerial photography was not available.

Table 1. *Number and percent of acres of oiled wetlands by oiling categories and species (NOAA 1997a). Note: Not all wetlands in the oiled areas were mapped.*

Species	Category	Acres	Percent of mapped wetlands that were oiled
Spartina alterniflora	Heavy	9.78	26.6
	Moderate	2.22	6.0
	Light	4.83	13.1
	Trace	5.87	16.0
	Total oiled	22.70	61.7
	Total mapped	36.79	
S. patens	Heavy	2.17	12.1
	Moderate	0.43	2.4
	Light	0.08	0.4
	Trace	0	0
	Total oiled	2.68	14.9
	Total mapped	17.96	
High Marsh Community	Heavy	0.05	2.8
	Moderate	0	0
	Light	0.18	10.6
	Trace	0	0
	Total oiled	0.22	13.4
	Total mapped	1.67	
Phragmites	Total mapped	0.31	
Wetlands, undifferentiated (above Congress St. Bridge)	Total mapped (unoiled)	45.68	
All Wetland Species	Heavy	12.0	11.7
	Moderate	2.65	2.6
	Light	5.09	5.0
	Trace	5.87	5.7
	Total oiled	25.61	25.0
	Total mapped	102.41	

WETLAND CLEANUP METHODS ATTEMPTED

Various cleanup methods were employed to remove stranded oil from intertidal wetlands and reduce risks to wildlife. As the oil weathered, preferred cleanup options such as ambient-water flushing became ineffective and alternative methods such as shoreline cleaning agents and vegetation cutting were investigated. However, most of the oiled wetlands were left for natural recovery.

Ambient-Water Flushing

During shoreline assessment surveys on the afternoon of September 28 (day 2 of the spill), it was observed that the oil on the marsh vegetation could be readily removed by gentle flushing (i.e., when stems of *S. alterniflora* were swished under water, most of the oil came off). Since the spill, the weather had been cool and overcast. The oil on the vegetation was not very sticky, probably as a result of the mixing of the IFO and the No. 2 fuel oil. A quick test to determine the effectiveness of ambient-water flushing was initiated.

Operations quickly assembled a team and equipment (trash pumps and a fire hose) to flush the heavily oiled marsh at Thompson Point where there was easy access and a good staging area. By the time of the test, the sun had come out. Very little of the oil was removed, and agency representatives agreed that the results were inadequate. The oil had weathered to the point that it was too strongly adhered to the vegetation to be removed with ambient-water flushing. The lesson learned here is that, for heavy oils, ambient-water flushing will often not be effective for removing oil from vegetation unless it is used very quickly before the oil weathers substantially.

Use of Shoreline Cleaning Agent on Oiled Marsh Vegetation

At the end of the ambient-water flushing test, it was suggested that a similar test be conducted using a shoreline cleaning agent to determine if it would increase the amount of oil removed during flushing. The only other option being discussed at this time was vegetation cutting, and we thought it was worthwhile and efficient to test a shoreline cleaning agent as an alternative. The equipment was already mobilized; all that was needed was a product and approval from the Concurrence Network (U.S. Coast Guard, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, Department of the Interior, and the State of Maine) of the Regional Response Team (RRT). Operations agreed to conduct the test if it was approved.

The shoreline cleaning agent selected for testing was Corexit 9580, a de-aromatized kerosene (to loosen the oil) with surfactants added (to increase lifting). At that time, it was only one of two products listed on the National Product Schedule "lift and float" shoreline cleaning agents (PES-51 is the other agent), in contrast with other products that disperse the oil. The key factors in selection of Corexit 9580 were:

- When used operationally at past spills, Corexit 9580 had been found to be effective on heavily weathered oil with no adverse biological impacts (Michel and Benggio 1995, Shigenaka et al. 1995); and
- Laboratory and field tests of Corexit 9580 with mangroves and salt marsh vegetation showed no increased impacts to the vegetation from the product alone (Teas et al. 1993, Pezeshki et al. 1997).

At the time of the *Julie N* spill, no other products had been tested on vegetation. Furthermore, Corexit 9580 has relatively low toxicity.

The request to the Concurrence Network of the RRT was for an effectiveness test only. There were many concerns about the feasibility of using a shoreline cleaning agent, given the difficulties of access, product application, and oil recovery within a very narrow time window around high tide. Therefore, the approach was to 1) determine if the method could be properly and effectively implemented, and, if so, 2) develop a biological-effects monitoring program. Observations during the effectiveness test would be used to optimize the biological effects monitoring, if further application was deemed appropriate.

The Concurrence Network of the RRT approved the request from the Federal On-Scene Coordinator (FOSC) to test Corexit 9580 on marsh vegetation at Thompson Point on October 2. The actual test was conducted on October 5 (day 9 of the spill) because of delays in obtaining the chemical product and the timing of the tide. The test protocol specified that the application be restricted to two hours on either side of high tide, so that the released oil would accumulate on the water surface and be recovered by skimming and/or sorbents. We wanted to "wash to water" to minimize the potential for increased sediment disturbance by the water spray and contamination by oil penetrating the substrate. High tides were during early morning and late evening, further complicating logistics for the test. Saturday, October 5, was the first opportunity to conduct the test with both high tide and daylight. The operational parameters were:

- The test site (an isolated section of *S. alterniflora*, 2.5x12.5 m) was boomed-off in a configuration of containment boom, backed by viscous sweep (snare) boom, reinforced by containment boom, and backed by sorbent (sausage) boom. Boom placement was secured by small mushroom anchors.
- A collection point was established (via containment boom configuration) on the land side of the test plot, where a vacuum truck with an attached skimmer head was set up to recover free-floating oil.
- Jon boats were used to apply the Corexit 9580 and the low-pressure, ambient-water flushing.
- Three hand sprayers (garden-type) containing 7.6 liters each were used to apply an evenly distributed application onto all surfaces of the exposed vegetation; no product was sprayed onto mud or substrate surfaces.
- When the entire test plot had been sprayed, the chemical was allowed to soak for 5-15 minutes, depending on visual observations of effectiveness.
- The next step was low-pressure, ambient water, high-volume flushing of the application area using wash pumps from the same Jon boats. The re-floated oil was herded toward the collection point with wash pumps.

The test was conducted at first light on October 5, on a falling tide. It was very cold (air temperature about -1°C) but sunny. **Figure 4** is a series of photographs of the application and site immediately after application. Because of delays, the tide went out before flushing was completed. With a spring tidal range of nearly 3.75 m, maintaining minimum water levels in the marsh was a critical, limiting factor.

Agency representatives inspected the treated area immediately and 24 hours after the test. Their observations, as reported to the FOSC, were:

- Application was mostly confined to exposed surfaces of the vegetation, particularly where the vegetation was lying down. Although the top sides of the vegetation showed evidence of removal, the undersides remained heavily oiled.
- Cold-water flush was applied using hoses with a wide, gentle spray from both the land and water sides.The vegetation appeared knocked-down right after the flushing was terminated, but regained a more erect posture within a few tidal cycles.
- Tide had dropped to the lower section of the marsh by the time of the test and flush, thus the flush area included exposed sediment rather than having a water bottom. The workers sprayed directly onto the substrate during the flushing operations to mobilize any oil left stranded by the falling water.
- Treated vegetation surfaces looked much cleaner, although there was still a heavy stain on the cleaner sections and significant amounts of oil coat as splotches, drops, and bands. The undersides were unchanged.
- Amount of black oil released from the marsh (visually estimated to be 40-50%) was less than expected by most observers. Though the black oil did remain on the surface as a slick as the tide receded, the treated

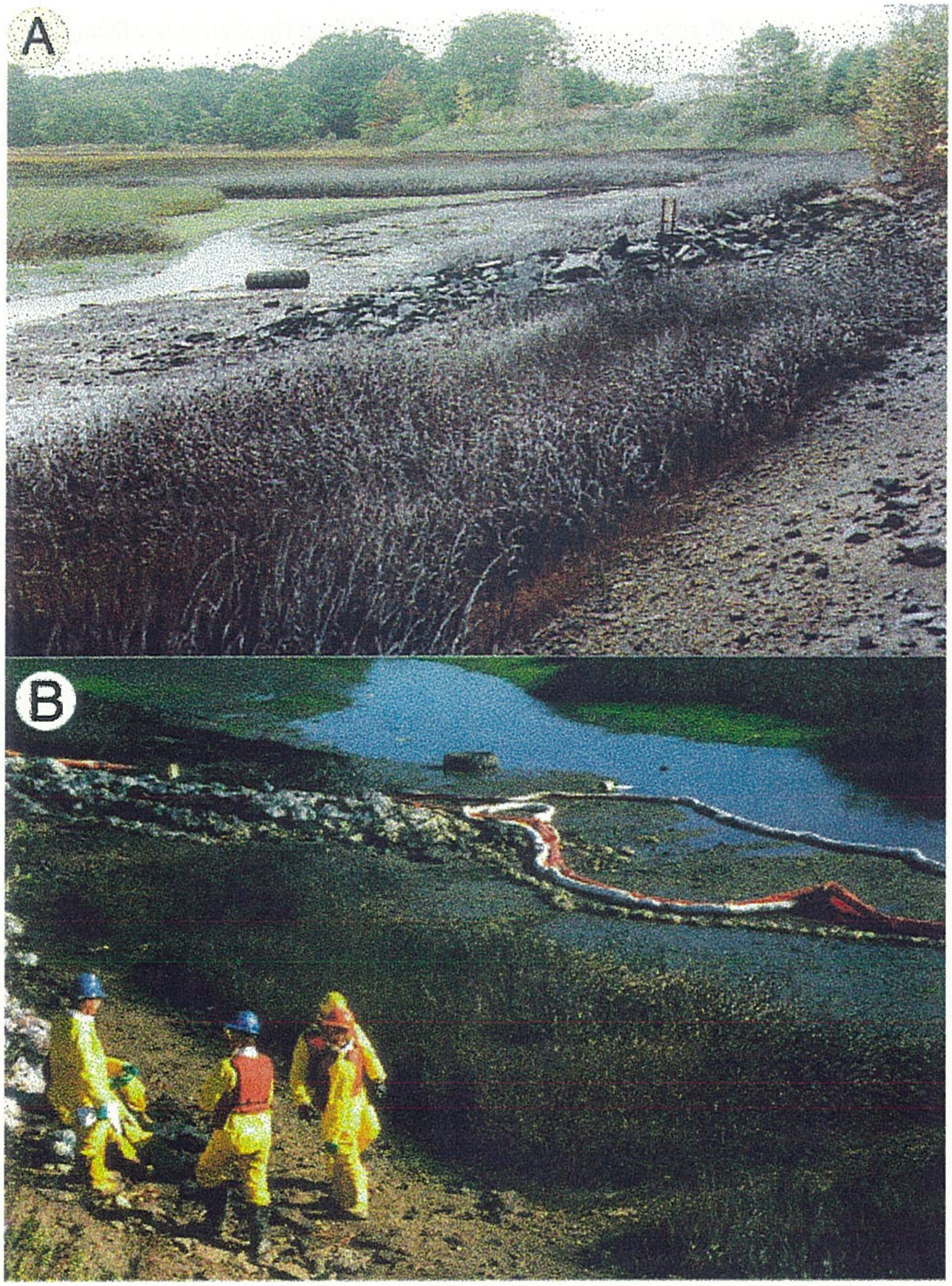

Figure 4. *Corexit 9580 test site in the heavily oiled marsh at Thompson Point.*
A. *September 29, 1996, before any treatment was attempted.*
B. *October 6, 1996, the day following Corexit 9580 application and flushing. Vegetation is visibly cleaner. Note the constant position of the riprap and tire.*

***Figure 4** (continued)*
C. October 7, 1996. Close-up of marsh vegetation two days after Corexit 9580 application. Note that about half of the oil has been removed from the treated vegetation surface. The undersides show little or no removal.

oil was apparently not as adhesive to the substrate as before. To address the issue of how much oil should have been released from the vegetation, samples of marsh vegetation (moderately and heavily oiled) were collected for quantification of the amount of oil present. The chemical results confirmed the observed effectiveness: the difference between two composite samples, a control and post-treatment, was 50%.

- Adjacent water did cloud up, although it was not clear how much was suspended sediment from flushing of the substrate versus dispersed oil. Water samples collected adjacent to the treated area where a cloudy plume was clearly visible showed little visual evidence of suspended oil.
- No evidence of oil persistence in the sediments or increased penetration in the substrate at the treated site. However, when the intertidal area downstream of the treated site was observed the next morning at low tide, there was a significant increase in the amount of oil that could be resuspended by disturbing the sediments underwater. Black oil droplets floated to the surface.

The water samples were chemically analyzed, confirming the presence of oil in the water column. Corexit 9580 was clearly identified in the chromatographic trace as being with the bulk oil, suggesting that a major portion of the oil suspended in the water column was present as dispersed oil droplets. The likely mechanism causing dispersion is explained as follows. Corexit 9580 is a hydrocarbon-based solvent with additional surfactants. When applied, the solvent solubilizes the bulk oil, reducing the oil's viscosity. During the rinsing process, water droplets striking an oil-treated (reduced viscosity) surface are easily splattered as tiny droplets. Most of the droplets are large and rapidly float to the surface. Others are very small and remain suspended by the turbulence of the flushing, though it is expected that much of the oil will eventually refloat.

The agency representatives who observed the test were asked to provide comments and recommendations for further testing or use. All the agency representatives recommende no further testing or operational use of Corexit 9580 on marsh vegetation. The reasons for this recommendation included:

- Vegetation was not visibly cleaned enough to warrant the risks of introducing more oil into the water column and benthic sediments.
- Apparently a significant amount of the released oil was not immediately recoverable. Some part of the released oil was being introduced into the water column and intertidal sediments during the treatment process.
- Effectiveness of Corexit 9580 was limited, even though the test site represented perhaps the best opera tional conditions in terms of good access on the landward side, where both application and flushing would be more effective.

The biggest concern was the operational feasibility of flushing activities. The Thompson Point site had unusually good land access, and yet there were problems in implementation. With a large tidal range, much of the marsh was inaccessible for all but a few hours around high tide. Sediment disturbance by both foot and boat traffic was unavoidable. With so many implementation problems and decreasing effectiveness as the oil weathered further, it was decided not to pursue use of a shoreline cleaning agent.

Vegetation Cutting

One of the chief concerns of both state and federal wildlife managers was the potential impacts to the arriving migratory birds. As a means of mitigating these potential impacts, state wildlife managers recommended that oiled vegetation be removed by cutting in Thompson Point marsh, which contained most of the heavily oiled vegetation. Much of the vegetation along the main stem of the upper Fore River was already highly erosional, and there was concern that cutting might increase the erosion. Oiling in other marsh areas was not deemed heavy enough to consider cutting.

Based on our experience, we voiced concern about this option. There are well-documented accounts of significant injury to oiled marshes as a result of wholesale, uncontrolled cutting (Zengel and Michel 1996).

We met with wildlife managers to discuss cutting and the following alternatives:

- **Barriers** (the placement of a wire or plastic mesh fence on either side of the small channel within the Thompson Point marsh to exclude birds). This technique was determined to be effective only for water fowl, and would not eliminate or reduce sheen runoff from the marsh. It was also felt that winter ice movement and debris would destroy such fencing.
- **Hazing** (the use of "whistle tape" hazing devices (a thin, luminescent tape that, when tightly strung emits a noise as wind blows across it and flashes in the sunlight)). Although whistle tape has proven somewhat effective in hazing birds in the Midwest, the marsh represented too large an area for practical deployment.
- **Vegetation Coating** (the spraying of a powdery material (e.g., bentonite) was considered to reduce the risk of oil adhering to bird feathers). This method was not entirely withdrawn from consideration, but policy and operational problems prevented its trial. First, it was unclear whether the bentonite might cause particles of oil to sink. If so, the method would be strictly illegal according to the National Contingency Plan and prohibited by state fisheries officials. Second, there was no immediate method of delivery. In the end, heavy rains and flooding in mid-October caused high suspended sediment loads in the Thompson Point marsh area and accomplished the same effect.

It was ultimately agreed that excessive cutting of the marsh could jeopardize the long-term recovery prospects of the area, and thus was rejected. The potential loss of some migratory birds was considered a justifiable trade-off to the loss of habitat. However, it was agreed that an experimental cutting of the marsh would increase knowledge of the technique and better prepare responders for such a decision in the future. The conditions were good, i.e.,

- plants were dormant, greatly increasing the likelihood of vegetation recovery;

- most of the free-floating oil had been removed, thus there was little chance of cut areas becoming re-oiled;
- cutting areas were readily accessible by boats, thus no trampling would occur; and
- there were extensive areas of heavy oiling.

Because the greatest concern for damage in the marsh during such an operation is the traffic of the cutting personnel, it was specified that all cutting operations be conducted from boats deployed at low tide. As the tide rose, personnel using hand-held, gasoline-powered trimmers (weed whackers) cut above a predetermined level (0.3 m off the substrate) and continued as long as possible. In practice, only the top ±25 cm of oiled vegetation were removed. The cutting took place within two 15-m areas, designated by markers placed by the Scientific Support Team (**Figure 5**). The first site was on the river side of the marsh, in a more exposed setting. The second site was approximately 200 m into the marsh and thus more sheltered. The vegetation and degree of oiling were similar on each site. The cut material was retrieved by a second boat and disposed off-site.

In 1997, the cut sites were visited three times: June 11, August 28-29, and November 24. **Figures 6 and 7** are photographs of the cut sites in Thompson Point marsh, shortly after the cut in November 1996 and August 1997 after a full growing season. There were no visual differences between cut and uncut sites.

Figure 5. *Aerial photograph taken on September 30, 1997 showing the location of the two experimental cutting areas in the heavily oiled Thompson Point marsh.*

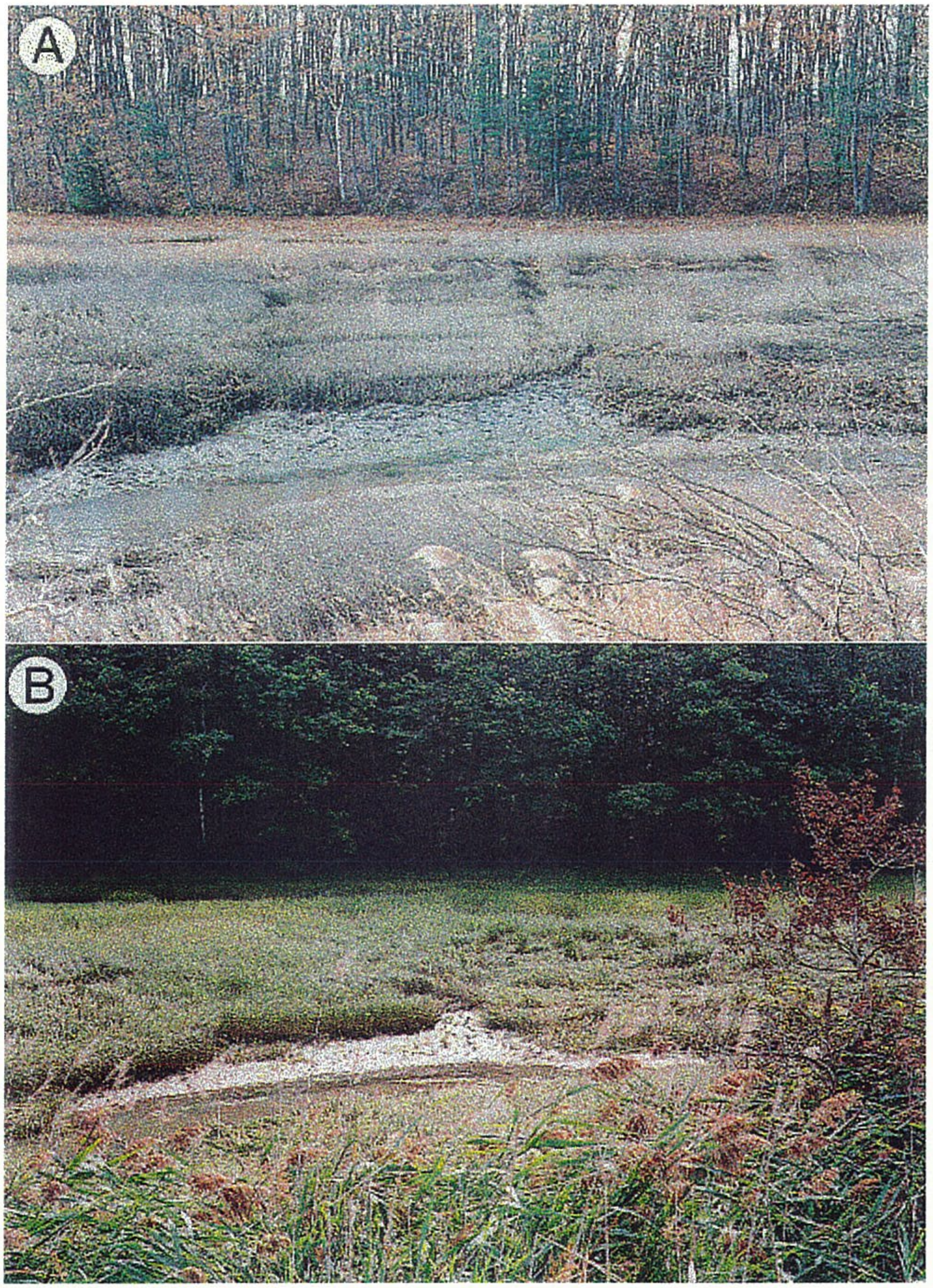

Figure 6. *Photographs of cut marsh site inside Thompson Point.*

A. *November 4, 1996. Note that only the upper part of the vegetation has been cut. The gray color of the marsh is a result of the large flood in mid-October 1996 which caused the shoreline to slump, generating high suspended sediment loads in the creek channel.*

B. *August 28, 1997. There is no visual difference in regrowth of the vegetation between the cut and uncut sites after one full growing season.*

Figure 7. *Photographs of cut marsh site outside Thompson Point.*
A. *October 10, 1996, before cutting. The top one-half of the oiled vegetation was later cut.*
B. *August 28, 1997. There is no visual difference in regrowth of the vegetation between the cut and uncut sites after one full growing season.*

NATURAL REMOVAL PROCESSES

Effects of a Major Flood Event

On October 20-21, 1996 a major storm event resulted in up to 45 cm of rain and flooding along the Fore River, resulting in heavy suspended sediment loads in some areas. Figures 8 and 9 are a series of photographs taken on October 5 and November 5, 1996 before and after the flood event, and again in August 1997. The effects of the flood event were very obvious in the Thompson Point marsh area **(Figure 8)**. Oil on the vegetation was visibly reduced, and the oily residual was much less sticky, covered with a layer of sediment that made it non-adhesive to the touch. There were large slump blocks in the fill along the shoreline, and sections of the marsh had been covered by sediment slumps. However, the effects of the flood event were minimal (visually) for the marshes along the upper Fore River, namely the sites near the Congress Street bridge, the stormwater outfall **(Figure 9)**, and the "2D marsh creek." Oil on the vegetation in these areas was visibly heavier and sticky to the touch.

Table 2 shows the results of chemical analyses for total petroleum hydrocarbons per stem for samples collected before and after the storm event. Assuming an average pre-storm oil content per stem on heavily oiled vegetation of 4.3 grams (average of the two samples from Thompson Point), then 50% of the oil attached to the vegetation had been removed. The chemical results of samples analyzed by LSU, using a different methodology, indicated reductions of about 75% in the amount of oil adhered to vegetation at Thompson Point (Henry 1997) between October 5 and November 8, 1996. The oil remaining on the stems in the Thompson Point marsh also exhibited evidence of biodegradation significantly greater than two samples collected from other sites along the Fore River, namely near the Congress Street bridge and the site east of the combined sewer outfall on the north side of the upper Fore River (see Figure 1 for locations).

Figure 10 shows chromatograms of the normal alkane distribution for oil on the stems of marsh vegetation collected from the Congress Street and Thompson Point sites on November 8, 1996 compared with floating oil collected from the Thompson Point area on September 29, 1996. This floating oil sample is representative of the oil that contaminated much of the marsh vegetation during the spill, composed of a mixture of both types of spilled oil.

Table 2. *Grams of oil per stem of vegetation on* S. alterniflora *from the Fore River at selected sites before and after the major storm event on October 20-21, 1996.*

Site	October 5	November 8
Long Creek (moderately oiled)	1.4	-
Thompson Point (heavily oiled)	4.1	1.8
Thompson Point (heavily oiled)	4.6	2.6

Figure 8. *Photographs of heavily oiled marsh at Thompson Point.*
A. *October 4, 1996. The entire above-ground vegetation is heavily oiled.*
B. *November 4, 1996. Note the effect of the high suspended sediments on the oil coating the vegetation.*

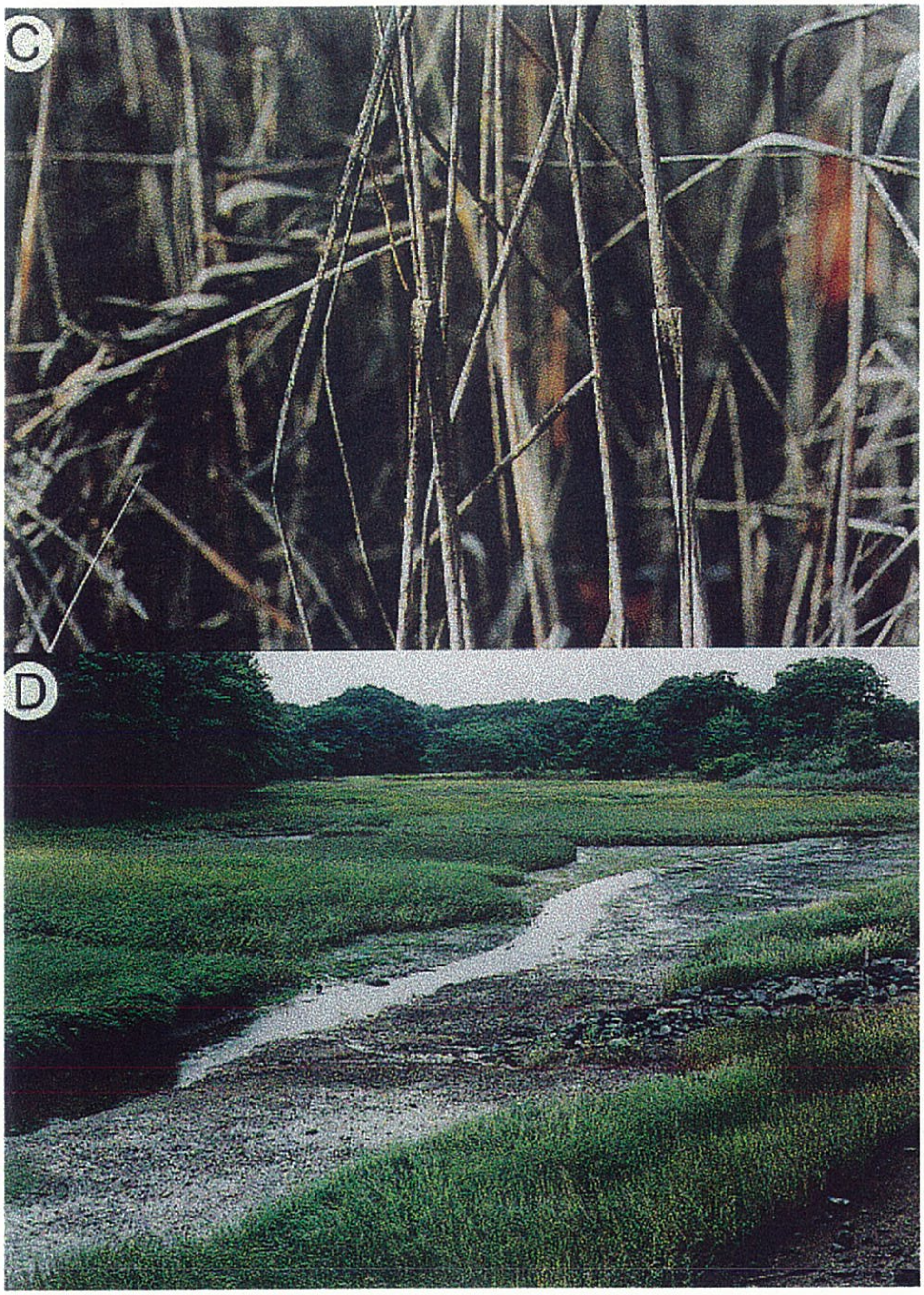

***Figure 8** (continued)*

C. November 4, 1996. Close-up of oil/sediment coating on the vegetation. Compare with Figure 9C.

D. August 28, 1997. Vegetation appears healthy. Spotty, light sheens observed on the water and tidal flat surface.

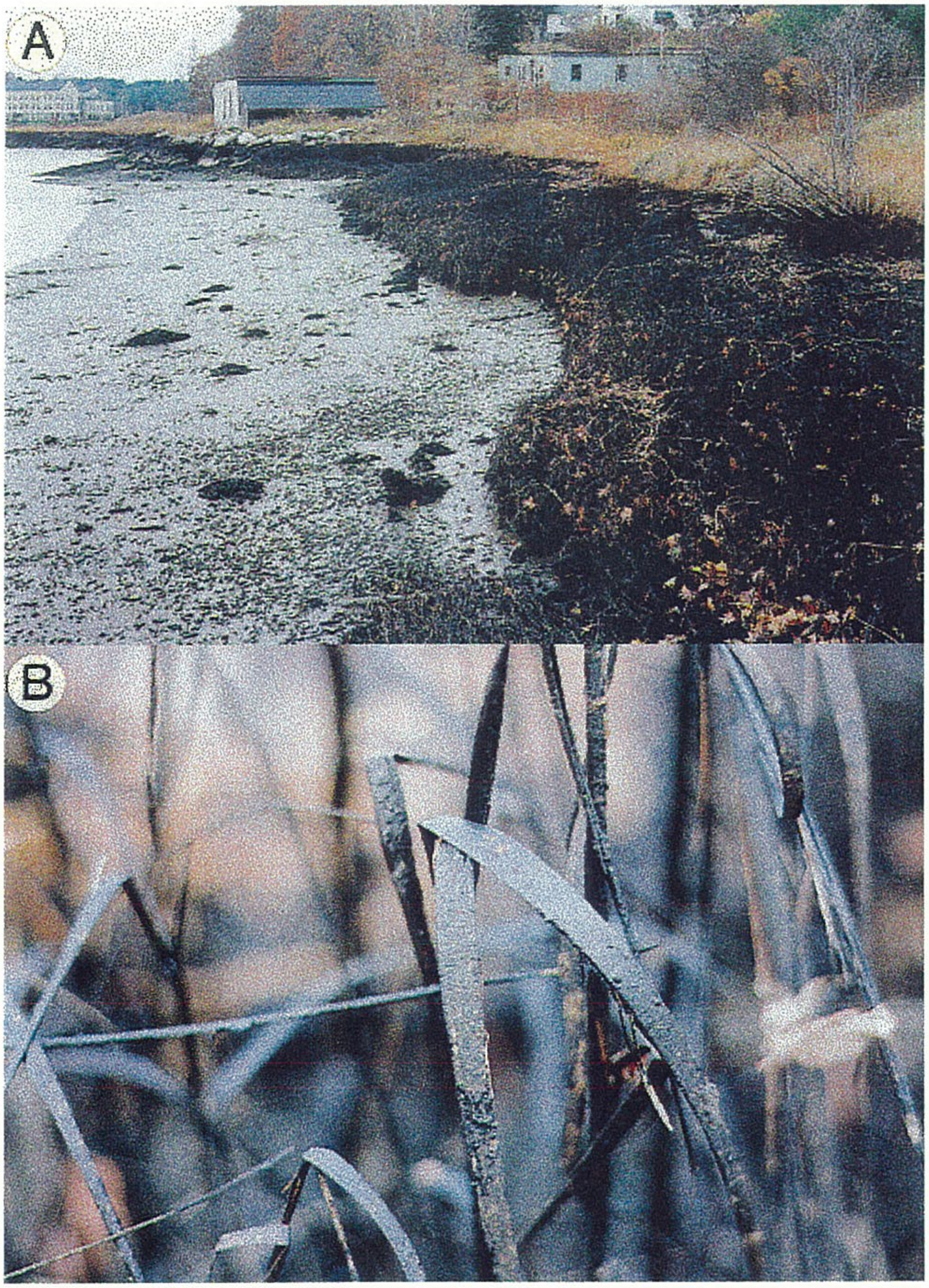

Figure 9. *Photographs of heavily oiled marsh along the upper Fore River.*
***A.** November 5, 1996. Storm had little effect on the oil coating in this area.*
***B.** November 4, 1996. Close-up of oil coating on the vegetation. Compare with Figure 8C.*

Figure 9 *(continued)*
C. August 28, 1997. Vegetation appears healthy.

Clearly, both samples collected on November 8 exhibited compositional changes due to environmental weathering. All hydrocarbons less than nC-13 were essentially lost through evaporation. Hydrocarbons between nC-13 and nC-21 were reduced by a combination of evaporation and biodegradation. **Figure 11** is the same chromatographic comparison as Figure 10 but for the retention time range of 26-32 minutes, highlighting the relative abundance of the normal hydrocarbons nC-17 and nC-18 and the isoprenoids pristane and phytane. Loss of the normal hydrocarbons at an accelerated rate to the coupled isoprenoids is a strong indicator of biodegradation. Both samples collected in November exhibit evidence of biodegradation. Clearly, the Thompson Point marsh sample exhibited evidence of biodegradation significantly greater than the samples collected from the outer Fore River at the same time. The fine sediment coating in the vegetation at the Thompson Point marsh likely increased biodegradation of the oil attached to the vegetation.

Figure 12 is a plot of the polynuclear aromatic hydrocarbons (PAHs) in the reference oil (the floating oil sample collected on September 29) and the three oiled marsh samples collected on November 8. **Table 3** shows the key to the PAH abbreviations used in **Figure 12**. All the samples collected on November 8 exhibited changes due to environmental weathering. Changes in the PAH profile were dominated by evaporative loss. The PAH profiles for the three samples collected in November 1996 were similar, indicating no enhanced degradation of the PAHs in samples from Thompson Point compared with the other marsh areas. PAHs are more difficult to degrade; thus by the time of the November 8 sampling, enhanced degradation was evident only in the readily degraded alkanes, and not the PAHs.

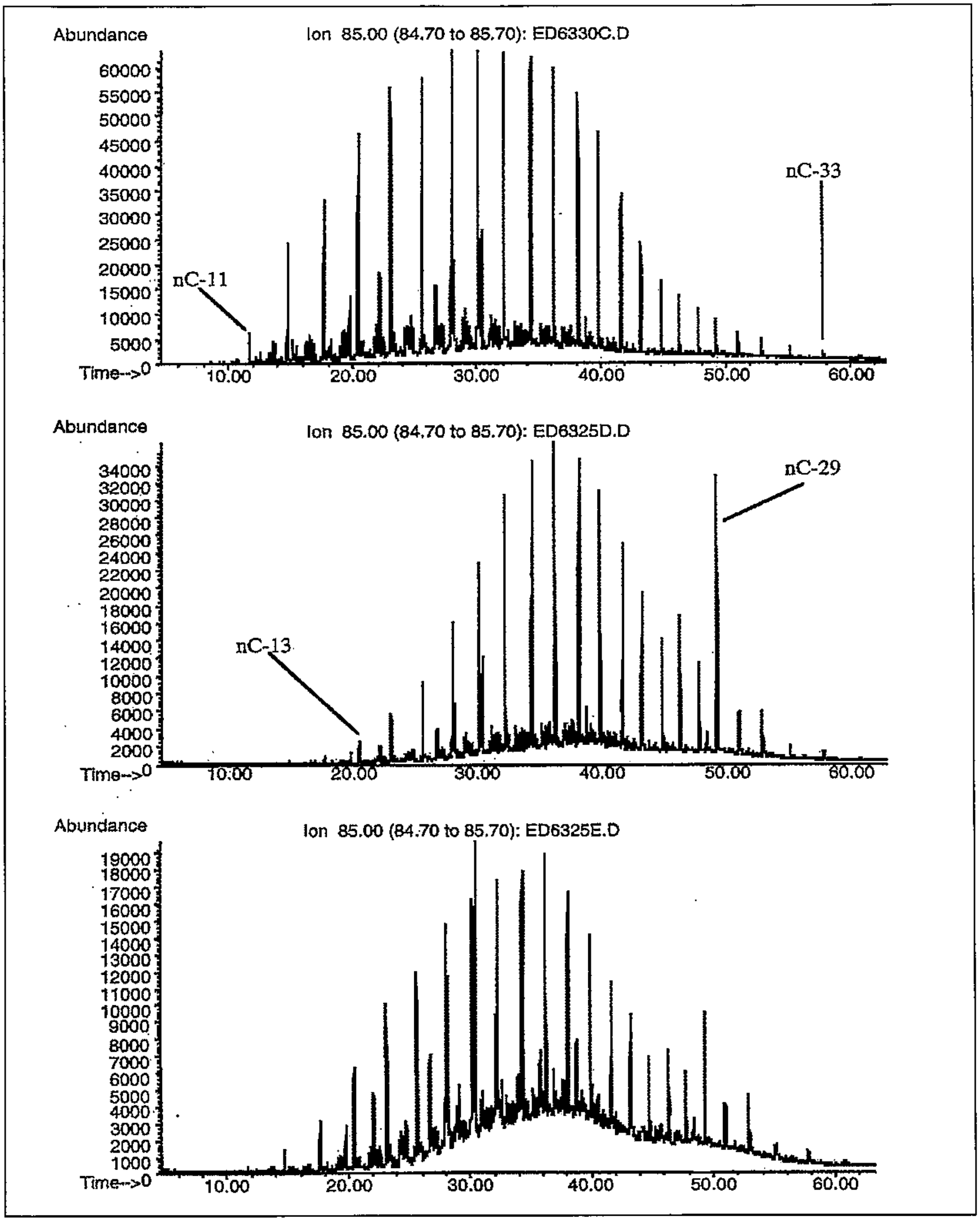

Figure 10. *Chromatographic comparison of the normal alkane distribution (m/e 85) for:* ***(top)*** *Floating oil collected from Thompson Point marsh on September 29, 1996, representative of the oil that contaminated the marshes of the Fore River;* ***(middle)*** *Oiled marsh vegetation collected east of Congress St. on November 8, 1996;* ***(lower)*** *Oiled marsh vegetation collected from Thompson Point marsh on November 8, 1996, which shows more weathering than the oil in other marsh areas.*

Table 3. Key to PAH abbreviations used in Figure 12.

Abbreviation	PAH Name	Abbreviation	PAH Name
N	Naphthalene	PY	Pyrene
F	Fluorene	CH	Chrysene
D	Dibenzothiophene	BF	Benzo[b,k]fluoranthene
P	Phenanthrene	BeP	Benzo[e]pyrene
ANT	Anthracene	PER	Perylene
NB	Naphthobenzothiophene	IPY	Indeno[1,2,3-cd]pyrene
FA	Fluoranthene	DIB	Dibenz[a,h]anthracene
BA	Benzo[a]anthracene	BNZ	Benzo[ghi]perylene
BaP	Benzo[a]pyrene	C1-4	Alkylated PAH homolog

Vegetation Recovery After One Growing Season

The marsh surveys of the upper Fore River were repeated in late August 1997. As shown in the 1997 photographs in Figures 6B, 7B, 8D, and 9C, most of the vegetation appeared healthy. Stem density and height measures showed either no differences or slight increases in oil contamination between 1996 and 1997 at all sites, based on statistical analysis of parameters for stem density and height among stations over time and degree of oiling categories (NOAA 1997b). In fact, slight increases were observed for the sites with light oiling. However, the wetland areas between Thompson Point and the Congress Street bridge showed evidence of continued impacts to the vegetation. There were scattered open patches in the marsh where much of the *S. alterniflora* vegetation had died and not regrown from the roots **(Figure 13)**. These dead patches of *S. alterniflora* were apparently concentrated at about mean high water. The outer fringe of vegetation was always intact, as shown in Figure 13. The broken-off, dead stems of *S. alterniflora* from the previous year's growth were still visible **(Figure 14)**. Sediments in the dead patches generally appeared to have higher levels of oil contamination than in adjacent areas, although samples collected for chemical analysis have not been analyzed. In some areas, droplets of black oil were released when the sediments in the dead patches were disturbed. No such release of oil droplets was observed in any of the wetland areas with full vegetation recovery. During the August 1997 survey, 96 dead patches were identified.

There were also patches of dead *S. patens* along the upper Fore River. The stems remained in place as brown patches of vegetation. In some areas, there was visible oil contamination in the dead patches, although in most areas there were no obvious differences between the dead patches of *S. patens* and adjacent live areas. **Figure 15** shows the sharp edge of one of the brown, dead patches of *S. patens*. The areas of all the dead patches were measured and are totaled in **Table 4** (NOAA 1997b).

Table 4. Survey of areal extent of dead patches of vegetation.

	Percent live vegetation in patches							
	<10%		10-50%		50-90%		>90%	
	ft²	acres	ft²	acres	ft²	acres	ft²	acres
Spartina alterniflora	3,420	0.08	5,088	0.12	1,127	0.03	0	0
Spartina patens	3,307	0.08	2,756	0.06	6,546	0.15	1,528	0.04
Sedges	150	0.003	150	0.003	2,040	0.05	0	0
Total	6,877	0.16	7,994	0.18	9,713	0.22	1,528	0.04

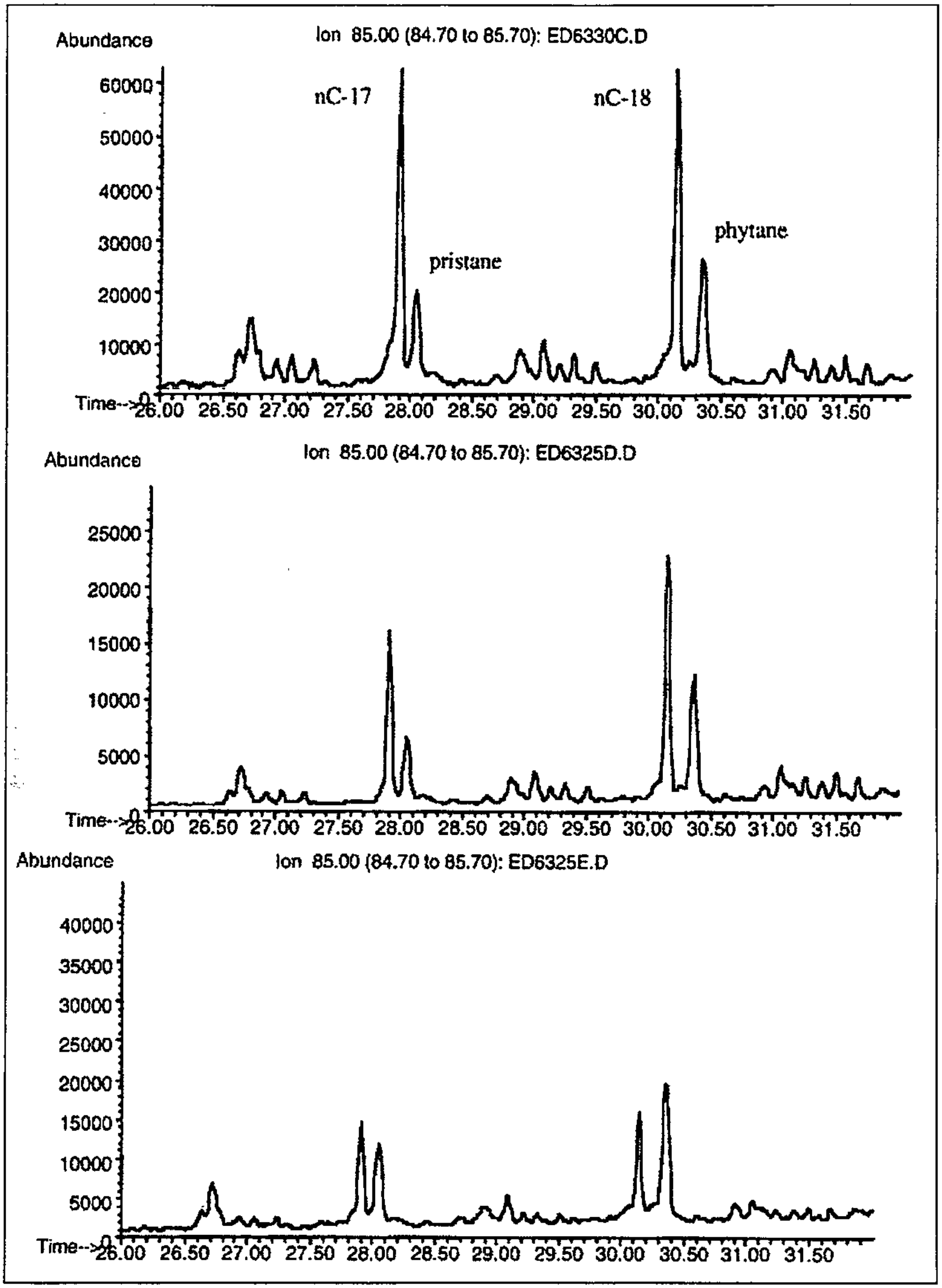

Figure 11. *Chromatographic comparison of the relative abundance of normal hydrocarbons nC-17 and nC-18 and the isoprenoids pristane and phytane.*

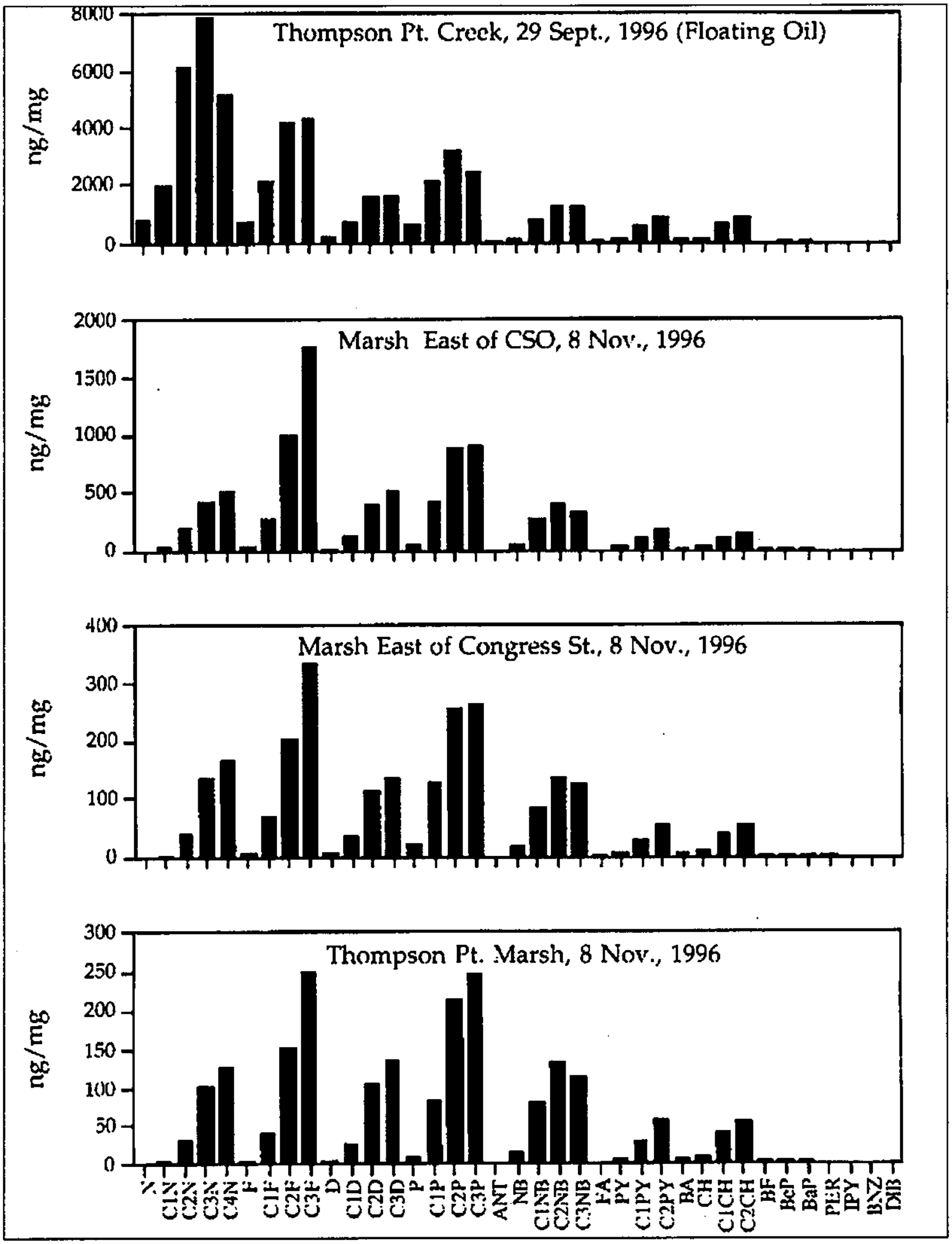

Figure 12. *PAH profile comparison of slightly weathered oil from the Julie N on September 29, and samples of oiled Spartina alterniflora collected 40 days later on November 8. Note that the PAH patterns for all marsh vegetation samples were similar in their weathering stage. See Table 3 for the key to the PAH abbreviations.*

***Figure 13**. Photographs taken August 29, 1997 of dead patches in S. alterniflora marsh west of Thompson Point. Note that the outer fringe remains healthy.*

Figure 14. *Close-up photograph of dead patches in S. alterniflora vegetation showing the dead stems, August 28, 1997.*

Figure 15. *Patch of dead S. patens on the north side of the upper Fore River, August 28, 1997. Although the stems remain in place, the vegetation is dead. Note the sharp contrast between live and dead vegetation.*

SUMMARY/LESSONS LEARNED

There are very few effective cleanup options for oiled marshes that do not pose serious risks of causing more harm to the habitat. During the *Julie N* oil spill, we tried three specific cleanup techniques, with limited effectiveness.

Ambient-Water Flushing

For the first day or two after the spill, the oil coating on the vegetation could be removed by low-pressure, ambient-water flushing. However, after the first sunny day, the oil rapidly weathered to a sticky coating that could not be removed by gentle flushing. After evaporation of the more solvent-like components from the No. 2 fuel oil/ IFO 380 mix and limited photo-oxidation, what remained was a heavy, sticky residue on the vegetation.

Shoreline Cleaning Agents

Application of Corexit 9580 removed about 50% of the oil where the chemical was in direct contact with the oil coating. It was generally not possible to apply the chemical to the undersides of the vegetation, particularly where the vegetation was heavily oiled and formed dense mats of collapsed stems. It was also very difficult to work in the marsh without trampling the vegetation. Ideally, cleanup crews would have ready access to the back side of the marsh, where the water flushing would direct the oil out of the marsh and toward recovery devices. However, few marsh sites are likely to have such a setting. There was no obvious impact to the vegetation where Corexit 9580 was used. The plants were already dormant, and the above-ground vegetation was starting to die back.

For large tidal ranges, water is in the marsh for only a short time which makes it very difficult to conduct effective cleaning with flushing techniques. Although mid-day high tides would be most effective, this still limits operations to about four hours of actual flushing per day. Therefore, only small treatment areas could be attempted.

There is a significant learning curve to the proper application of shoreline cleaning chemicals and subsequent flushing. This kind of cleanup operation is not commonly used, particularly in marshes. Thus, responders should allow time for crews to learn from their mistakes and figure out how to handle site-specific constraints. Close monitoring by trained staff is necessary to protect the marsh from further damage during cleanup.

Because of these problems, shoreline cleaning agents are likely to be used in marshes only to treat small areas, where removal of oil from the vegetation is deemed necessary to protect important users of the marsh and as an alternative to cutting. However, the use of cleaning agents is further limited by the fact that their effectiveness decreases as oil weathering increases.

Vegetation Cutting

The very limited cutting (less than one-half of the vegetation in 15-m wide swaths) conducted from boats had no visually detectable impact on vegetation recovery after one growing season. Perhaps key to this result was the lack of any sediment disturbance or mixing of oil into the sediments during the cutting operation. There was very little sediment contamination of the two sites as a result of the initial oil stranding in the marsh. Apparently, the parts of the marsh which exhibited die-back one year after the spill had more oil residues in the sediments than adjacent areas.

Natural Recovery

The fourth cleanup technique used in the oiled marshes at the *Julie N* spill was the one most commonly used at spills, namely natural recovery. Even the most heavily oiled marshes showed impressive recovery after one growing season. Out of 12 acres of heavily oiled vegetation, only 0.6 acres, or 5%, exhibited some die-off. These die-off areas occurred as isolated patches with potentially good rates of revegetation from adjacent plants once the sediments lost their toxicity.

It is interesting to note that none of the dead patches occurred inside Thompson Point marshæwhere the effects of the high suspended sediments from the storm were visually strikingæwith about a 50% reduction in the amount of oil on the vegetation stems. However, there may have been differences in how the oil stranded on the substrate in the Thompson Point marsh compared with the Fore River shoreline. Obviously, the flood event (and sedimentation) reduced the potential for oiling of wildlife using the marsh. The lack of obvious negative impacts to the marsh habitat from the deposition of sediment on the oiled vegetation may lend support to the experimental use of vegetation coating or "dusting" when protection of wildlife using the marsh is a high priority, perhaps as an alternative to vegetation cutting.

A final lesson learned at the *Julie N* oil spill is the importance of experimenting with new cleanup techniques, particularly when few other options are available. In fact, small trials of new techniques in limited areas at actual spill sites are often the only way that these techniques can be tested.

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