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SHORELINE SURVEYS AT THE *EXXON VALDEZ* OIL SPILL: THE STATE OF ALASKA RESPONSE

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ABSTRACT: *The state of Alaska needs information on the shoreline impacts of the* Exxon Valdez *incident to determine the linear extent of affected shoreline and the degree of oil penetration into the beach versus surface coverage, to assist the shoreline treatment effort, and to monitor oil persistence.*

Three principal methods were used to obtain data. Low-altitude helicopter surveys were made repeatedly during the first months of the incident to define shoreline impacts as heavy, moderate, light, and "no observed oiling." A total of 140 ground stations in Prince William Sound, and over 60 stations in the Kenai and Kodiak areas, were set up to make specific measurements of surface coverage, oil penetration, and oil thickness along a topographic profile. An extensive (more than 1,400 km) walking survey was mounted after the 1989 treatment season to determine the extent of oil remaining and to guide the 1990 cleanup effort. More than 160 km of shoreline remained moderately to heavily oiled in the three regions at the end of 1989. Collected data were entered into the Alaska Department of Environmental Conservation geographic information system to enable map production, database queries, and report creation. On an as-needed basis, data derived from these surveys were presented to the state on-scene coordinator, other state and federal agencies, and the cleanup operation.

The *Exxon Valdez* ran onto Bligh Reef during the night of March 24, 1989, rapidly spilling over 10.8 million gallons of Prudhoe Bay crude oil into the waters of Prince William Sound. Slicks and sheens from the *Exxon Valdez* were subsequently observed covering more than 28,000 km^2 of water surface (Figure 1), and oiled approximately 1,700 km of shoreline. Within hours after notification, the state of Alaska recognized the need for shoreline surveys to track the oil. These surveys began on March 26, 1989, and continued through 1990, concentrating on areas where significant *Exxon Valdez* oil remained. Surveys planned for 1991 will concentrate on chronic problem areas.

This report focuses on the program conducted by the Alaska Department of Environmental Conservation (ADEC), the designated State of Alaska organization responsible for responding to the oil spill and protecting state resources. An overview of the results of the various components of the ADEC program are discussed. Other investigators working on monitoring shoreline oiling at sites within the area affected by the *Exxon Valdez* spill include Owens and Teal under Exxon sponsorship, and ATI/CSA and Michel and colleagues under NOAA sponsorship.[1, 12, 15] Nauman summarizes the shoreline treatment techniques applied by Exxon.[11]

Purpose of surveys. The shoreline program was undertaken to provide specific field information to the spill response effort, including the following:

- The location of oil concentrations along the shoreline
- Scientific data on subsurface contamination in the beach and natural removal rates
- A basis for monitoring long-term changes in oil levels on the shore
- The effectiveness of the shoreline treatment process
- The effectiveness of various cleanup techniques proposed during the response effort, including chemical beach cleaners and berm relocation

Setting. The *Exxon Valdez* spill site is composed of a variety of shoreline types, most influenced by recent tectonic activity particularly evident in the form of bedrock cliffs. Beaches of coarse sand and gravel or gravel, cobble, and boulder dominate much of the shoreline and are commonly separated by bedrock outcrops. Only a few affected sites, mainly on the Alaska Peninsula, are composed of sand. Affected marshes and tidal flats are equally rare.

The mean and spring tidal ranges for Prince William Sound and the Kenai area are approximately 4 m and 5.5 m. The Kodiak/Alaska Peninsula area shows a range about 0.5 m greater. Cordova, adjacent to Prince William Sound, has monthly mean air temperatures range from −5° C in January to 12° C during July. In Kodiak, monthly mean air temperatures range form approximately −1° C in January to 13° C in August, according to the University of Alaska[3, 5] Arctic Environmental Information Data Center. During the period 1973 to 1987, seawater temperatures averaged 7.3° C with a monthly mean ranging from 4.1° C in March to 11.8° C in September for Prince William Sound and the adjacent shelf and basin.[16]

Survey methods

The methods for this program were developed through investigations of several other major oil spills dating back to 1975. References include Gundlach and colleagues's 1978 study of the *Urquiola* spill; Gundlach and colleagues's 1982 study of the *Metula* spill; Gundlach and Hayes's 1978 study of the *Amoco Cadiz* spill; and Gundlach and colleagues's 1981 study of the Ixtoc I blowout.[7-10]

The assessment program consisted of overflights and ground surveys

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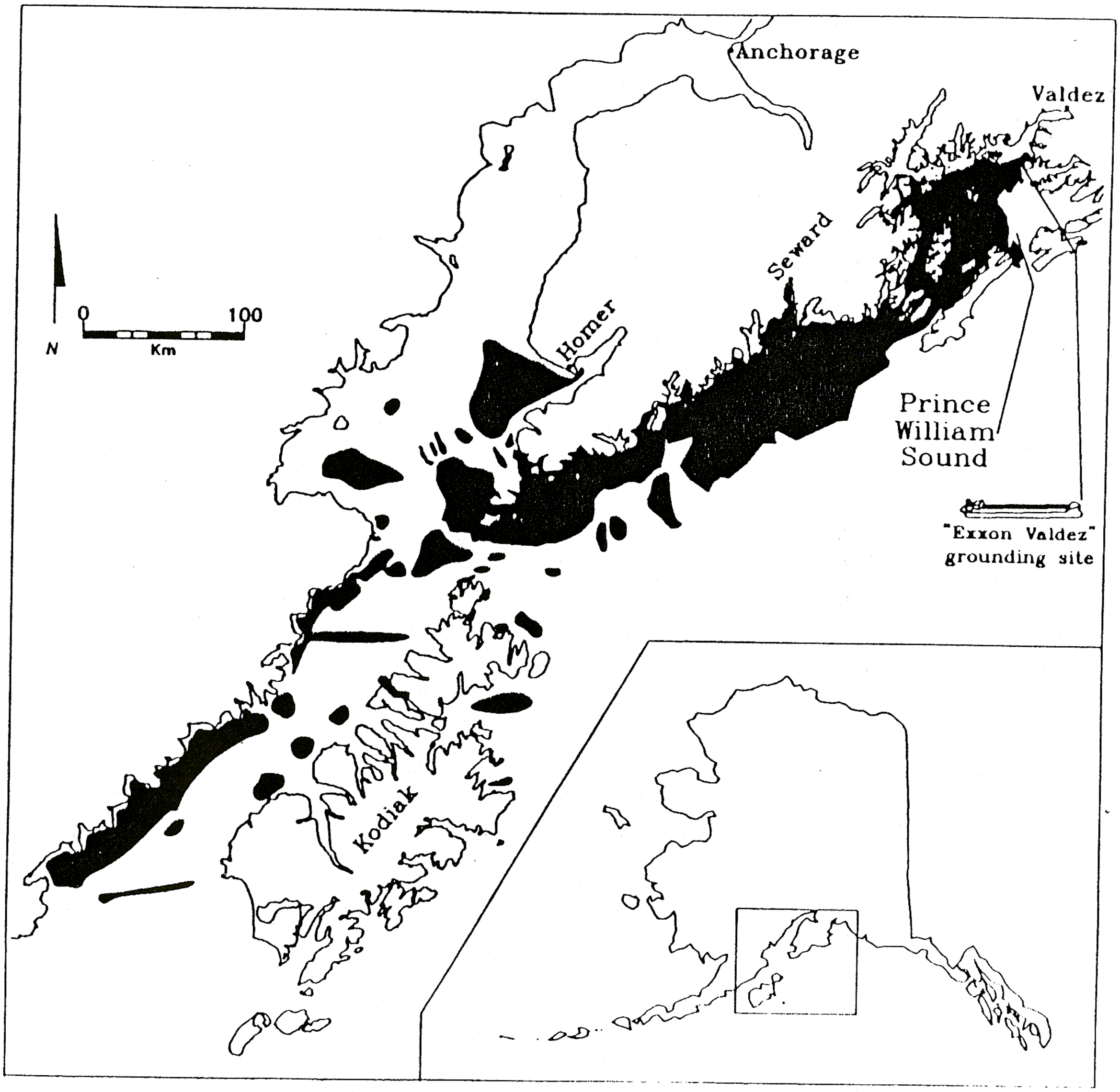

Figure 1. Location of the *Exxon Valdez* spill site, with the cumulative extent (approximately 28,000 km^2) of observed surface slicks and sheen

to document the position of oil along the shoreline and determine the quantity of resident oil. Field offices were maintained in Valdez, Homer, Seward, and Kodiak to provide information to local communities and to be close to the oil within each region. A description of program methods follows.

Aerial observations. Aerial observations of oil impact began on the third day of the spill. A slow-flying float plane was used during the first two surveys; all others used a helicopter. All surveys were conducted at low tide, approximately two hours on either side of slack low tide, to provide maximum exposure of the oiled intertidal areas. During the overflight, oiling was classified as heavy (a band of oil more than six meters wide or more than 50-percent coverage of the intertidal zone); moderate (a three- to six-meter band of oil or 10- to 50-percent coverage of the intertidal zone); light (a band of oil less than three meters wide or 10-percent coverage of the intertidal zone); or no oil (no observed oiling).

A "very light" category, defined as a band of oil less than one meter wide or less than 1-percent surface coverage, was later added to represent the intermittent oiling by tarballs or mousse commonly found on long stretches of shoreline. This classification scheme was accepted by the United States Coast Guard (USCG) and Exxon and used consistently throughout the spill.

At the beginning of the spill, the base maps consisted of photocopies of 1:63,360-scale U.S. Geological Survey topographic maps. As the spill progressed, we were able to computer-generate maps at greater resolution. All observations were verified by two persons, communicating through the helicopter intercom. Areas where the classification of oiling was difficult were circled or landed at until the issue was resolved. Photographs were taken of the shoreline to document impacts.

Ground surveys. Ground surveys form an integral part of the investigation of oil distribution. More than 200 stations were mentioned within the spill site. Commonly, ground and aerial surveys were conducted during the same low-tide period. Station locations for Prince William Sound and the Kenai Peninsula are indicated in Figures 2 and 3, respectively.

Two types of ground surveys were undertaken. The first entailed a relatively rapid assessment of the site, during which shoreline oiling was described in a field notebook, photographs of the site were taken, and oil thickness and penetration were measured. In some cases, observations of oil coverage at a site were made solely from the air. In the ground survey during the initial oil impacts, oil commonly was very thick and could be easily measured. As time passed, oil became much thinner on the rocks, so that oil less than 1 mm thick could not be directly measured. Oil thickness was then approximated as follows: thick tar able to be scratched off = 1 mm, light tar or coat = 0.5 mm, stain = 0.25 mm, and discontinuous stain or film = 0.1 mm.

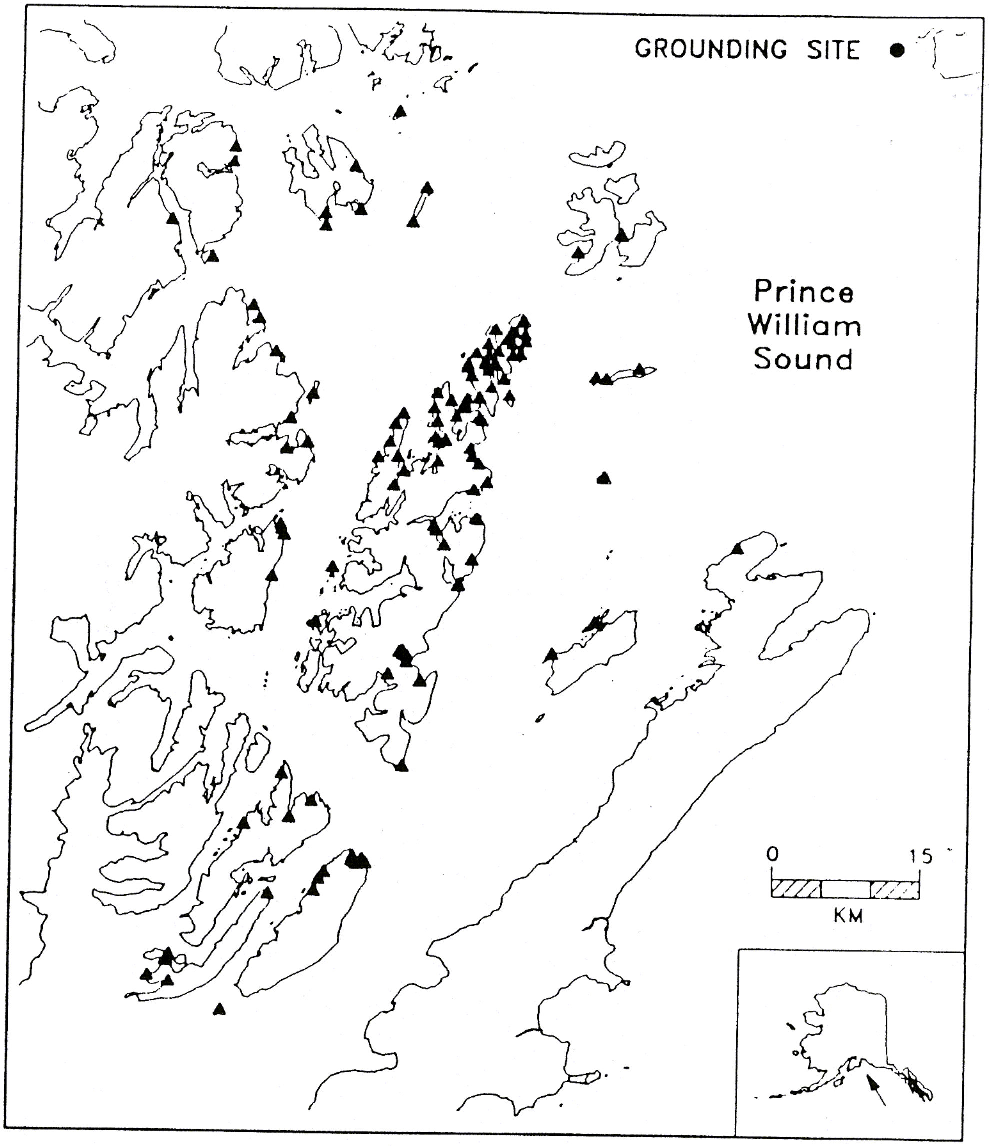

Figure 2. Station locations (filled triangles) in Prince William Sound, with *Exxon Valdez* grounding site indicated

The second survey method used was more intensive and involved running a topographic profile across the intertidal using Emery's method.[6] Along the profile, observations were recorded of surface and subsurface (from pits) oiling, geomorphology, sediment type, and biological characteristics. Intervals of measurement were based on sediment type, beach characteristics (berm, toe of beach, and so on), and oiling. An estimate of oil coverage was made by each member of the survey party, and the estimates were averaged. Data were recorded on a profile sheet, on a sketch sheet, in a field notebook, and in 35-mm photographs taken at a variety of angles to illustrate oil coverage and penetration. A photograph of the site from the departing helicopter was taken to provide a site overview.

Databases and plotting. After the survey, all data were entered into a database (R:base) which cataloged all station information, including observers, samples taken, photographs, and profile data. Profile data were plotted using commercial software called SigmaPlot. The plotting of the profiles with accompanying surface and subsurface oil data serve to verify the accuracy of data entry and provide visual representations of the data. An additional table was used to calculate the volume of oil on the surface and subsurface oiled sediments.

Geographic information system. The system developed by the state of Alaska during the *Exxon Valdez* spill uses available software (GEO/SQL) that integrates AutoCad as the mapping program and R:base as the database to form a geographic information system (GIS).

The ease of use of R:base and the ability to create common entry forms permitted rapid training of field personnel to enter their own data directly. The use of AutoCad as the mapping interface guaranteed the ability to produce maps immediately and as needed. The GEO/SQL linkage permitted queries of the database; for example, it was possible to request a map of all areas heavily oiled and the ground stations present.

The primary information captured and produced included maps indicating surface and shoreline contamination levels, study sites, cleanup areas, and the like; field data on observations, wildlife losses, transects, and biological and chemical sampling; data on segment tracking, including assessments, cleanup work orders, types of treatment, post-treatment evaluations, and the USCG and ADEC sign-offs; and documentation of all field books, graphs, photos, videos, memos, and reports. This portable, DOS-based system is widely applicable in planning and response in other areas.

Fall 1989 survey. At the end of the 1989 season, ADEC organized a field survey (the Fall Walkathon) to determine the extent of residual oil remaining in the spill zone after the Exxon treatment teams had departed. The vast majority of the shoreline in this case was surveyed

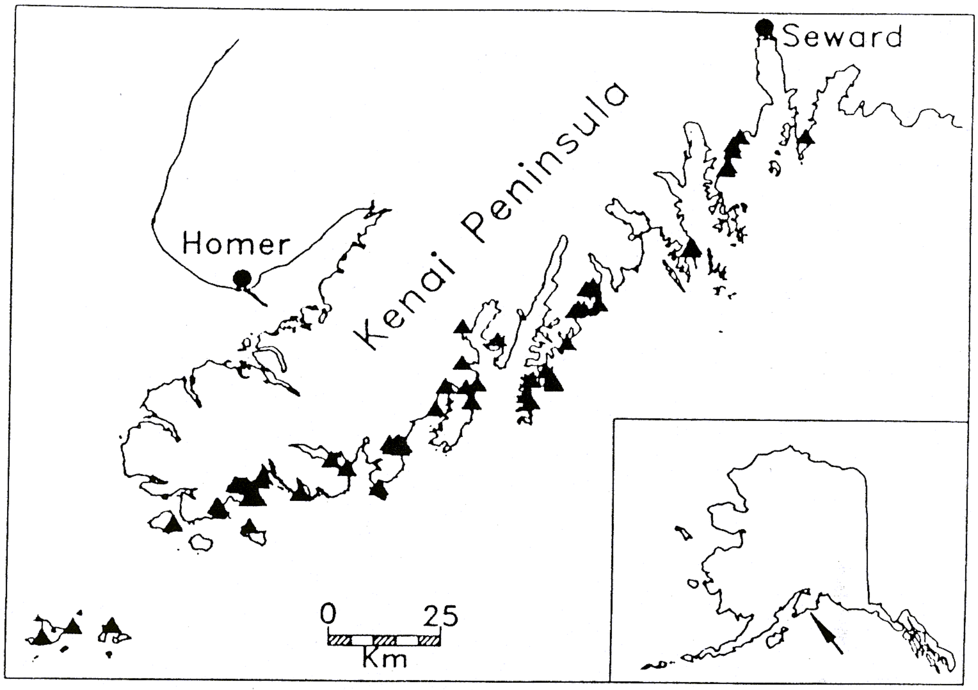

Figure 3. Station locations (filled triangles) in the Kenai Peninsula area, monitored from Seward and Homer

on the ground by physically walking each stretch of shoreline. In the Kenai and Kodiak regions, some areas were surveyed using a low-flying helicopter. Since this survey was ground-based, the "very light" oiling category, indicative of oil stain and tar balls, was added to "heavy," "moderate," and "light" categories described previously.

Fast Assessment Shoreline Survey Team (FASST) survey, winter 1990. The FASST program was the first joint assessment of the shorelines in Prince William Sound and the Gulf of Alaska. This Exxon-sponsored program included representatives of Exxon, ADEC, and the Coast Guard. The project was designed to survey segments that had not been visited by Exxon since the 1989 treatment season, as well as segments that were recognized as being particularly sensitive for cultural or environmental reasons. The teams evaluated the degree of remaining oil impact, as well as the level of improvement. As a result of this cooperative brief survey, the field forms and maps were developed to be used in a full spring shoreline assessment program.

Spring Shoreline Assessment Team (SSAT) 1990 survey ADEC field staff participated with Exxon, USCG/NOAA, and land owners and managers in a duplicate ground-based survey of the spill site in the spring of 1990, to provide detailed site information to the treatment team. Methods were similar to those used in the fall, although the field survey form was more detailed. Owens provides copies of the forms used.[14]

Results

Station surveys. More than 1,600 km of shoreline were oiled in Alaska during this spill, with a tremendous diversity in shoreline type, exposure, and degree of oiling. We present results from sites in Prince William Sound that were monitored in detail from the beginning of the spill. Two representative sites are selected for a more detailed discussion to provide an overview of the information obtained.

Several general themes are evident in reviewing the data. First, oil penetrated deeply into many gravel/cobble beaches and was extremely difficult to remove. Treatment reduced the amount of oil within the beaches, but commonly they remained oil-blackened on the surfaces and still contained oil within the sediments. Winter wave activity dramatically reduced the amount of remaining oil at numerous beaches. Several sites, principally in Prince William Sound, remain heavily contaminated after the second year of treatment effort. The profiles in Figure 4 from stations 043 on Latouche Island (Sleepy Bay) and 067 on Smith Island provide examples of these themes.

The Sleepy Bay site represents one of the most persistently oiled areas. Oil remained through the winter of 1989/90. Cleanup techniques used at this beach include sediment movement using heavy machinery, sediment removal, high-pressure hot water flushing, and fertilizer to enhance biodegradation. The site's location adjacent to a salmon stream increased the importance for oil removal. In spite of the effort, oil persisted deep within the beach (as shown by the penetration profiles), and surface coverage was still very high in the early Winter of 1989/90. During the winter, penetration remained similar, and surface coverage dropped only a small amount. Figure 5 summarizes the surface oil coverage (m^2) and oiled sediment volume (m^3) for all measurements at the station. The total oiled volume rose over the winter due to deep penetration along the foreshore, whereas the surface oil coverage dropped by more than 50 percent, from 21 m^2 to 9 m^2 of oiled sediment along a 1-m-wide band of shoreline. The 1990 treatment program consisted of manual removal, bioremediation, and the use of heavy machinery to expose the buried oiled sediment to wave action and self-cleansing.

The Smith Island station was extensively treated during May 1989 and August 1989, using high-pressure flushing by hoses and a high-volume deluge system. Fertilizer was added to enhance biodegradation. In spite of this effort, the site remained heavily oiled after cleanup was terminated in September 1989. Figure 4 compares transect data from August 1989 to March 1990, indicating a dramatic drop in the amount of surface and subsurface oil, attributable to the wave conditions generated during the winter of 1989/90. A time sequence of surface and subsurface oil data is presented in Figure 5, illustrating the decline over the winter months. Oil, however, did remain along a minor portion of the upper berm and in a protected pocket to the east of the profile. The treatment activity in 1990 relocated the oiled berm gravels onto the upper beach (as discussed later).

Most oiled shorelines fall into the range illustrated by these two situations. Figures 6 and 7 present the data for 14 stations summarized for surface and subsurface oil and plotted in terms of percentage change. The first value measured at the station, during months 7 to 9, is always set to 100. These figures indicate that neither surface nor subsurface oiling (oiled sediment volume, not total oil content) changed substantially until the winter of 1989/90, that both subsurface

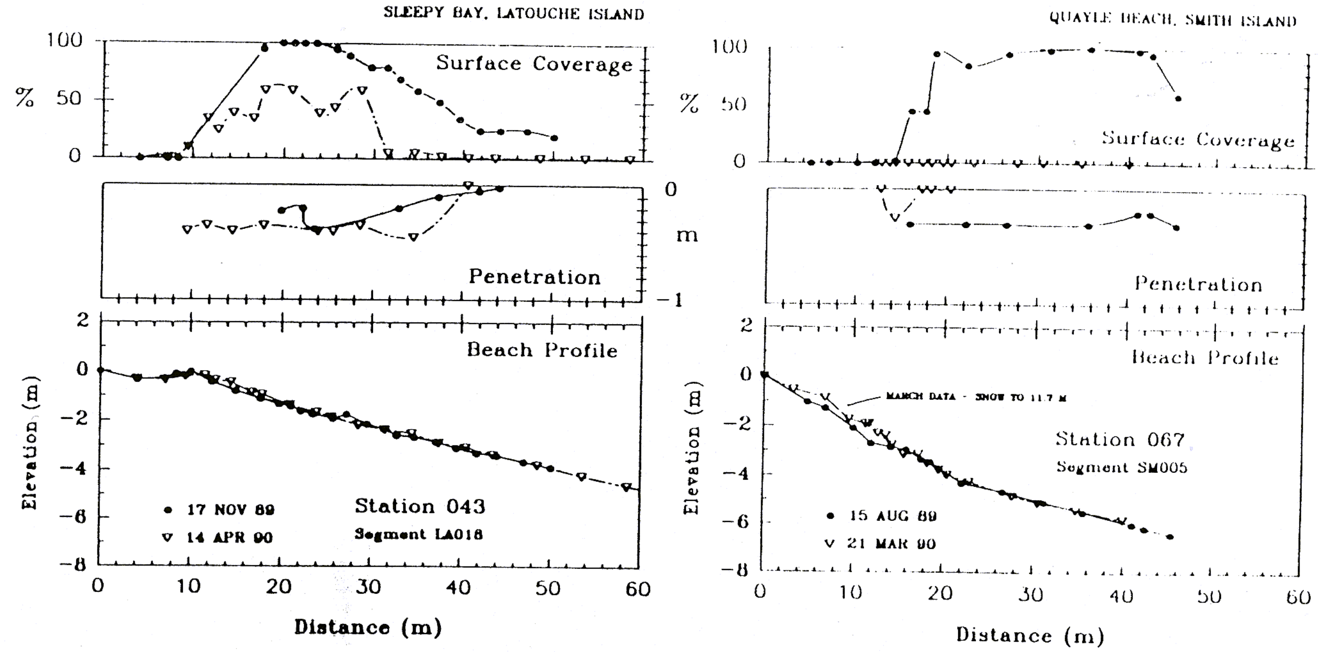

Figure 4. Transect plots for stations 043 (Latouche Island) and 067 (Smith Island), indicating topographic profiles, oil penetration, and surface oil coverage from pre- and post-winter 1989/90

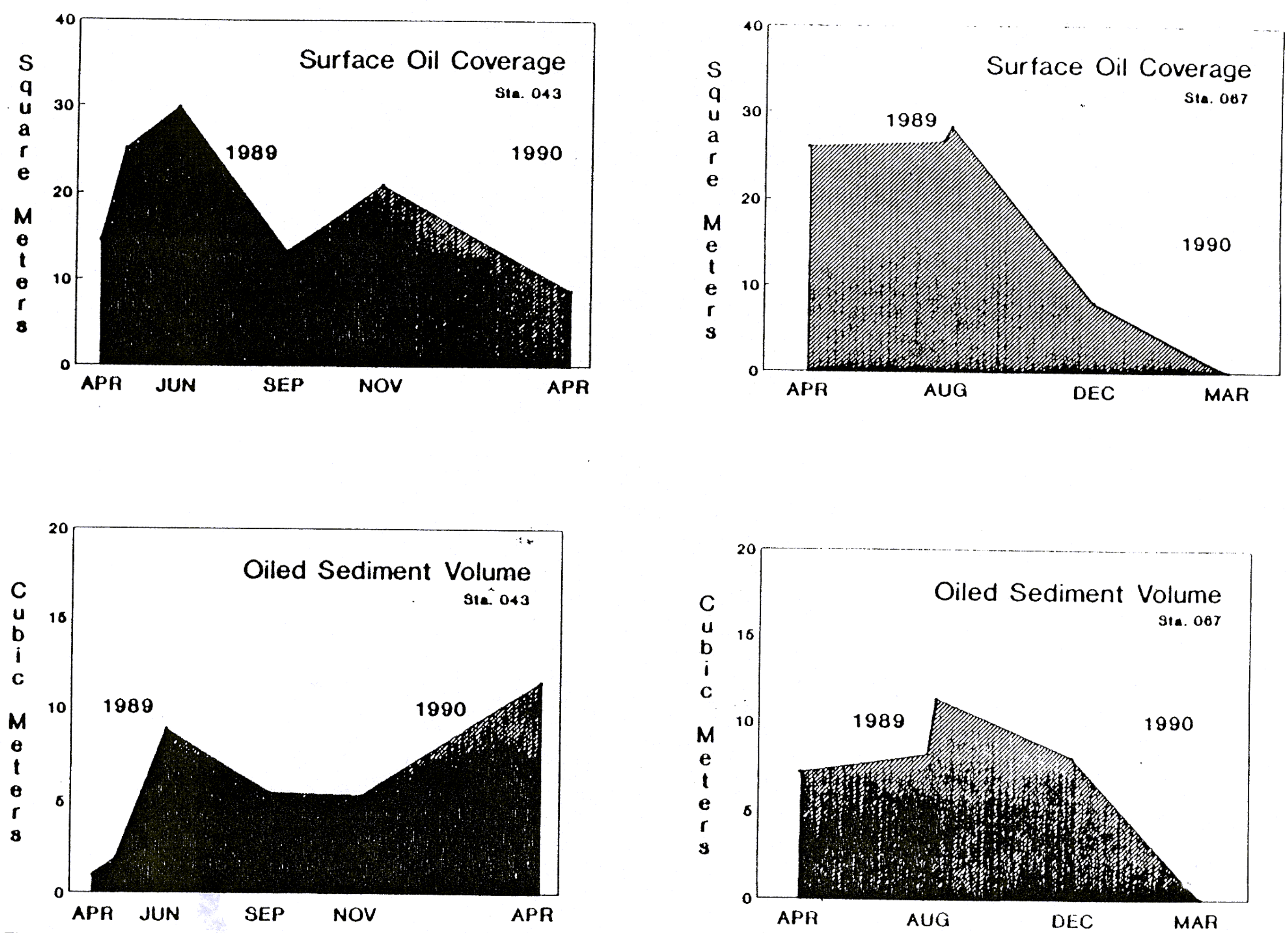

Figure 5. Surface oil coverage in square meters and oiled sediment volume, as measured along a one-meter-wide profile for stations 043 (Latouche Island) and 067 (Smith Island), observed from April 1989 to March 1990

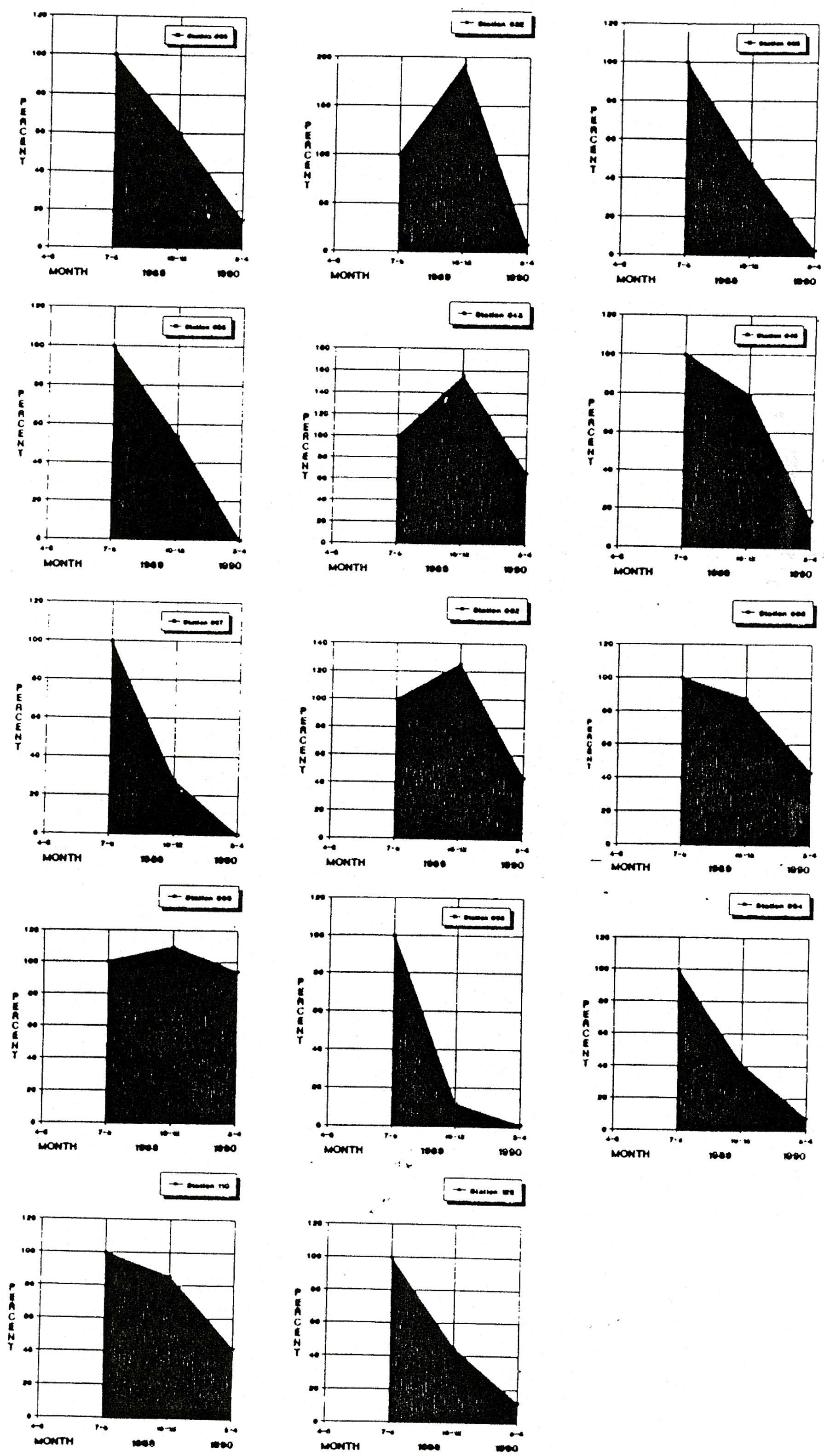

Figure 6. Change in surface oil coverage for 14 stations, measured in months 7–9 (July to September 1989), 10–12 (October to December 1989), and 3–4 (March to April 1990)—The first observation value is set to 100 percent. Values for the following months are divided by the first observation value, expressed as a percentage

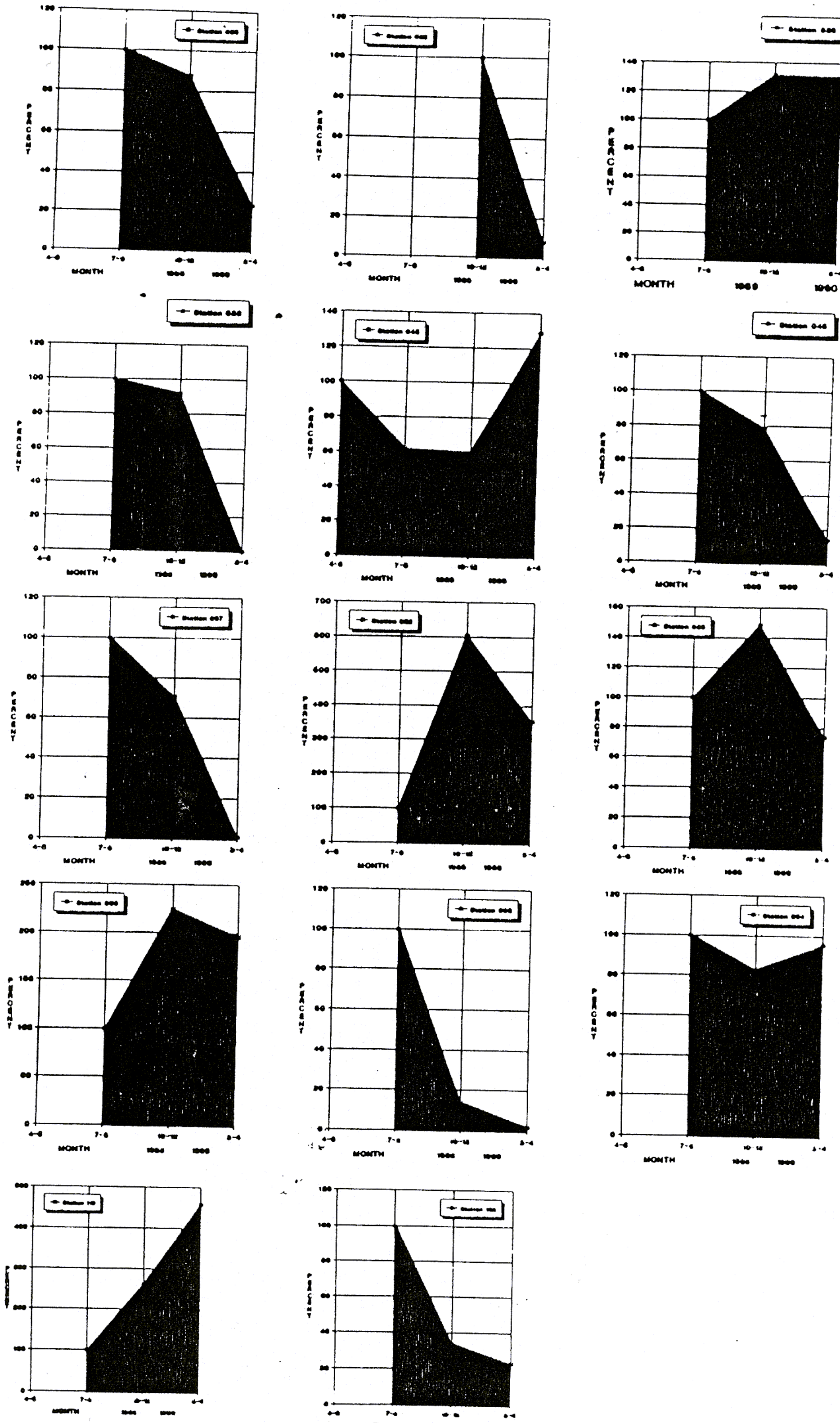

Figure 7. Change in the volume of subsurface oiled sediment for 14 stations measured in months 7–9 (July to September 1989), 10–12 (October to December 1989), and 3–4 (March to April 1990)—The first observation value is set to 100 percent. Values for the following months are divided by the first observation value, expressed as a percentage.

and surface oiling fell substantially over the winter months, and that surface coverage fell more than the volume of subsurface oiled sediment. Pre-winter and post-winter data from all 21 stations are totaled and compared in Table 1. Surface oil coverage fell to 19 percent of its initial value, while the volume of surface oiled sediment fell to 59 percent of its initial level. Owens and Teal noted a decrease to 10 percent of the original surface oiling for 111 transects measured at 18 localities, comparing July/August 1989 to March 1990.[15] Michel and colleagues noted decreases of surface oiling to about 20 percent for exposed beaches, to 60 percent for intermediate exposed shorelines, and to 50 percent for sheltered shorelines, as measured from September 1989 to March 1990.[12]

Evaluation of treatment processes. The shoreline survey teams also provided the state on-scene coordinator with field data to evaluate the effectiveness of various treatment processes. Tasks included running topographic profiles before and after the use of heavy equipment to manipulate heavily oiled sediment at a salmon stream in Sleepy Day, the evaluation of high-pressure, high-temperature flush techniques (omni-booms) of varying durations, and the use of several chemical shoreline treating agents including BP1100X and Corexit 9580.

The Corexit test site of August 1989 was located on the north shore of Smith Island. Profiles measuring surface and subsurface oil were measured before and after application (five days apart) Oil was found to have penetrated deeply into into the site (more than 60 cm). The survey after application found a much reduced surface coverage (from approximately 90 percent to 20 percent), significant oil thickness reduction (from 1-2 mm to 0.25 mm, a stain). The depth of upper subsurface oiling was reduced down to approximately 15 cm, with no significant change below this depth. The tendency of a chemical agent to mobilize oil deeper in the sediments depends on the extent and consistency of the subsurface oil and the shoreline composition and morphology. In this case, Corexit did not penetrate into the heavily oiled, finer sediments at depth, so this oil remained in place and inhibited the deeper transport of oil. The use of all chemical agents, including Corexit 9580, was ultimately not approved by the federal on-scene coordinator because the increased efficiency over accepted mechanical means to remove the oil was not proved.

Fall 1989 Walkathon. The walking survey of beaches, undertaken after treatment stopped in the fall, illustrated the degree to which oil remained after all treatment by Exxon and its contractors had ended. In particular, it revealed significant oiling within the upper berm areas of many beaches, including protected pockets even along exposed rocky shores, and a substantial amount of oil beneath the surface. Table 2 presents the results of the survey for all areas. In the fall of 1989, more than 160 km of shoreline remained moderately or heavily oiled, of which more than 140 km were located within Prince William Sound. In total, 79 km remained moderately oiled and 165 km lightly oiled. The "very light" category contained over 450 km. Figure 8 shows the shorelines with moderate or heavy oiling as determined by the survey teams in Prince William Sound. Four reports were issued detailing the results of the study, with tables and over a thousand detailed maps.[2-5]

Spring 1990 survey. Using the Fall Walkathon as a basis, Exxon sponsored a spring survey using similar methods. In this case, surveys focused on areas where light, moderate, and heavy oil had previously been noted. The field team was composed of Exxon state, federal, and landowner representatives. A work order was created for each section of shoreline needing additional treatment.

Table 1. Average and volume of subsurface oiled sediment (cubic meters) and surface oil coverage (square meters), pre-winter and post-winter 1989/90, for profiles 1 meter wide measured at 21 stations

	Oiled sediment volume (m^3/m)				Surface oil coverage (m^2/m)			
	1989 months 4–12	%	1990 months 3–4	%	1989 months 4–12	%	1990 months 3–4	%
Total (21 stations)	75.9	100	44.7	59	396.4	100	75.7	19
Average	9.8	100	6.0	61	49.5	100	8.0	16
Standard deviation	6.3		6.7		14.3		8.2	

Table 2. Lengths of oiled shorelines in all regions, as determined by the ADEC fall walking surveys and joint spring assessment survey (SSAT)

Region	Oiling Level	Fall 1989 (km)	Spring 1990 (km)	Net Change	Percent Change
Prince William Sound	Heavy	75.6	20.8	− 54.8	− 72.5
	Moderate	64.4	45.9	− 18.5	− 28.7
	Light	131.9	79.8	− 52.1	− 39.5
	Very light	308.9	273.4	− 35.5	− 11.5
	Total surveyed	1,160.0	1,107.0	− 53.0	− 4.6
Kenai	Heavy	9.7	2.6	− 7.1	− 73.2
	Moderate	12.9	7.7	− 5.2	− 40.3
	Light	24.1	15.8	− 8.3	− 34.4
	Very light	82.9	84.9	+ 1.9	+ 2.3
	Total surveyed	129.5	400.0	+270.5	+208.8
Kodiak	Heavy	0.55	0.56	− 0.07	− 12.7
	Moderate	1.9	5.1	− 3.2	+168.4
	Light	8.3	6.8	− 1.5	− 18.1
	Very light	66.3	94.9	+ 28.6	+ 43.1
	Total surveyed	156.2	451.9	+295.7	+189.3
All regions	Heavy	85.8	24.0	− 62.0	− 72.3
	Moderate	78.9	58.7	− 20.2	− 25.6
	Light	164.8	102.4	− 62.4	− 37.9
	Very light	458.1	452.5	− 5.6	− 1.2
	Total surveyed	1,446.1	1,958.9	+512.8	+ 35.5

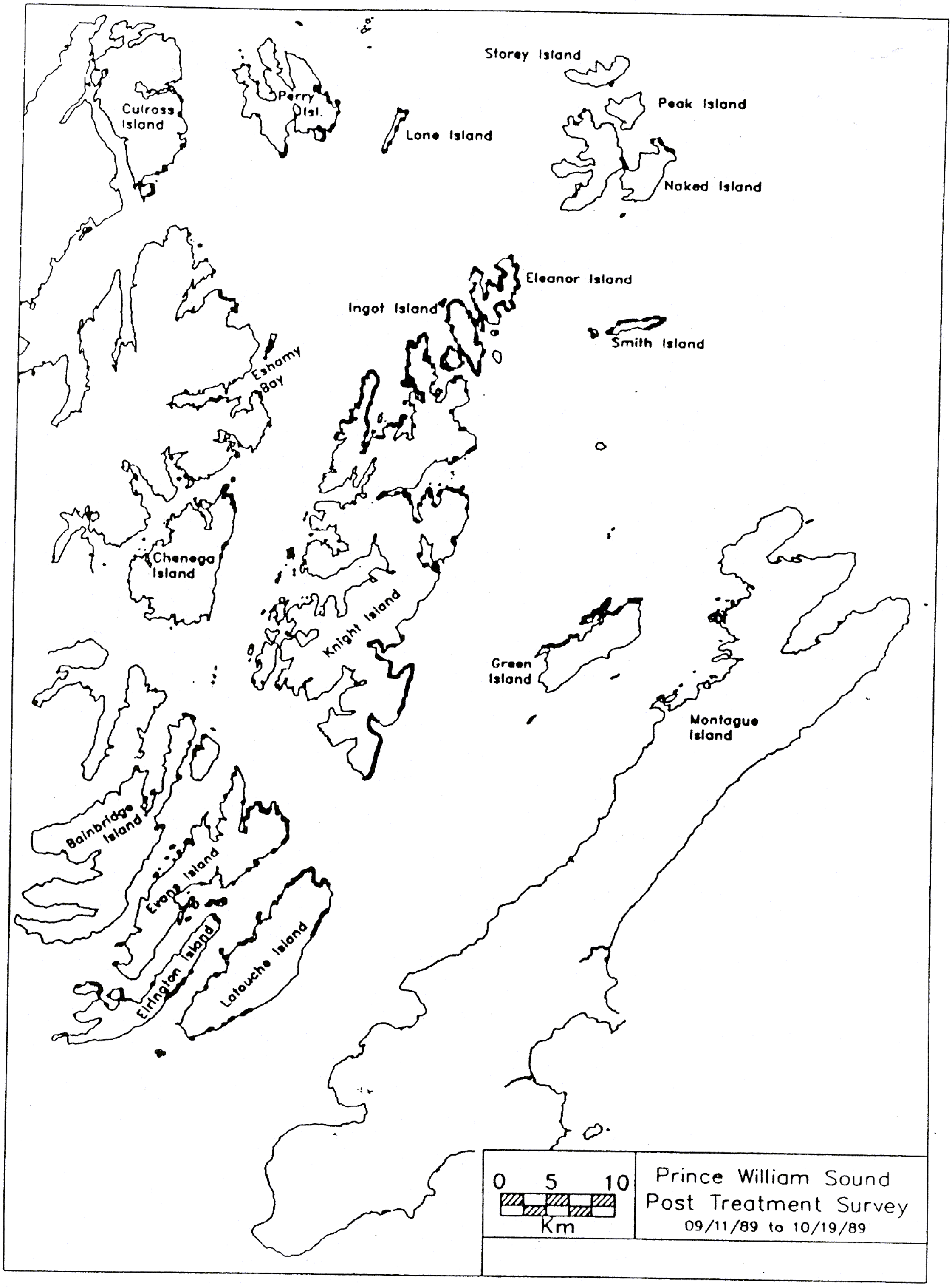

Figure 8. Locations of moderate or heavy oiling found in the Fall of 1989 by the ADEC shoreline surveys

Results of the spring survey are compared to those of the fall survey in Table 2. There was a 73-percent reduction in the length of heavily oiled shorelines in Prince William Sound (to 21 km) and the Kenai region (to 2.6 km). The length of heavily oiled shorelines in Kodiak remained the same, at less than 1 km. Moderately oiled shorelines decreased 28 percent and 40 percent for the Prince William and Kenai areas, respectively. In the Kodiak region, additional moderately oiled areas were found, increasing the amount oiled to 5.1 km. The extent of light oiling decreased roughly 20 to 40 percent for all areas. In total, the amount of light, moderate,and heavy oiling decreased 25 to 72 percent for all areas.

1990 berm relocation. The spring 1990 survey found substantial oil residing in the back berm areas of about 20 sites that could not be treated by manual pickup or through the use of fertilizer to enhance biodegradation. These sites include the following segment designations: CU-10A, EL-107C, EL-109A, KN-113, KN-122, KN-209,

KN-408A, LA-15B, LA-15C, LA-19, LA-20A, PR-02A, PR-04A, PR-16A, SM-05B, SM-06A, SM-06B, SM-06C, and US-010. The Treatment Advisory Group, representing state, federal, Exxon, and land manager interests, recommended that these sediments be reworked and moved onto the active beach face, to be naturally reworked and cleansed by wave and tidal action, as suggested by fall/spring comparisons. As needed, the oiled sediment was treated with high-pressure (low-volume) sprays to remove oil more quickly at some sites. In most cases, snare boom was anchored across the intertidal zone to collect oil as it was released, and to provide physical agitation as the boom was moved across the beach face during tidal changes. In addition, sorbent boom was placed a short distance offshore to collect sheens leaving the beach. A similar process of sediment movement was used during the *Amoco Cadiz* oil spill with the sediment becoming free of oil and returning to its natural position on the beach with no erosion evident.[10] However, where the sediment in France was placed below the active beach face, sediment did not return to its original position, causing criticism of the cleanup effort for years after the spill. For this reason, it was advised that all oily gravel moved at the *Exxon Valdez* site be restricted to the upper portion of the beach (usually the upper third, approximately at the level of the neap berm) to ensure the return of the cleansed gravel.

Oily gravel from the upper berm was moved beginning in July 1990. Profiles before and after movement from Smith Island and Sleepy Bay (Figure 9) show the zone of gravel movement. These sites will be surveyed in the future to monitor beach recovery.

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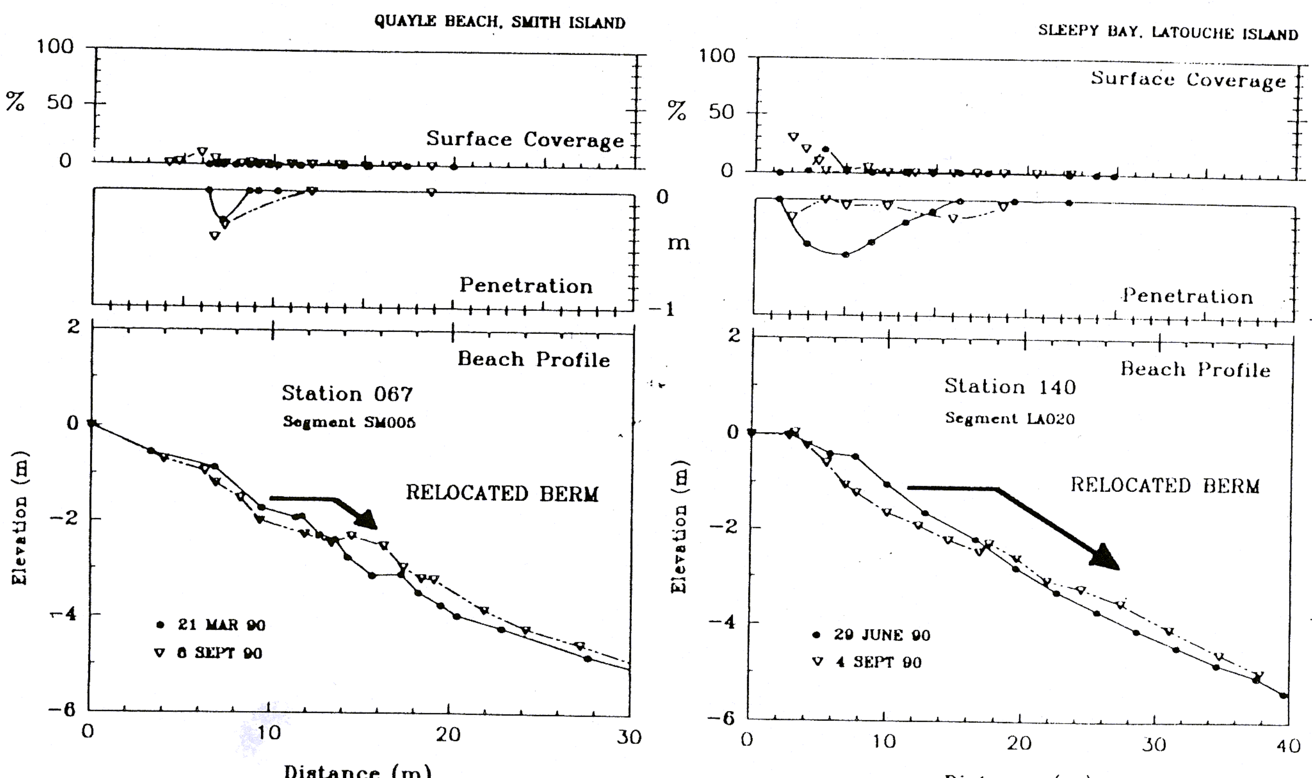

Figure 9. Comparative profiles from stations 067 (Smith Island) and 140 (Sleepy Bay, Latouche Island) before and after berm relocation, indicating sediment removal from the upper beach and deposition into the beach face

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