Exxon Valdez Oil Spill
Restoration Project Final Report

1995 Kodiak Shoreline Oiling Assessment of the *Exxon Valdez* Oil Spill

Restoration Project 95027
Final Report

James C. Gibeaut, Consulting Geologist

Ernest Piper, Project Manager, Alaska Department of Environmental Conservation

Dianne Munson, Principal Surveyor, Alaska Department of Environmental Conservation

Alaska Department of Environmental Conservation
Office of Restoration and Damage Assessment
410 Willoughby Avenue, Suite 105
Juneau, Alaska 99801-1795

April 1996

1995 Kodiak Shoreline Oiling Assessment of the *Exxon Valdez* Oil Spill

Restoration Project 95027
Final Report

Study History: This project was designed to address remaining shoreline oil in the Kodiak region from the *Exxon Valdez* oil spill. The project was in response to public requests to continue monitoring of affected shorelines and to continue cleanup of high-priority sites identified by the public. This project had four objectives that were not necessarily related: (1) monitoring of sites; (2) assessing the changes in subsurface and surface oiling; (3) investigating community complaints; and (4) identifying sites for possible remediation. A data report titled "Data Report for the 1995 Kodiak Shoreline Oiling Assessment of the *Exxon Valdez* Oil Spill"was also completed in 1996 by J. C. Gibeaut, E. Piper, and D. Munson.

Abstract: A shoreline survey team visited 24 sites in the Kodiak archipelago that had shoreline oiling in 1990 and 1991 to determine the persistence of that oiling through the summer of 1995. The survey team concentrated on Shuyak and northwest Afognak Island, selected areas between Sturgeon Head and Chief Cove (Spiridon Bay) on the Shelikof Straight coast of Kodiak Island, and seven sites of community concern near the village of Larson Bay inside Uyak Bay. This survey used shoreline survey methods developed and refined during the *Exxon Valdez* response, and was intended to complement a similar project conducted in Prince William Sound (PWS) in 1993.

Surveyors found no oil at sites south of Chief Cove, trace amounts at Chief Cove, and only widely spaced trace amounts at the sites on Shuyak Island. Traces consisted primarily of tar or asphalt patches less than 5 cm in diameter, with a few small (less than 2 m by 20 m) areas within which friable, weathered surface oil residue and asphalt were scattered. A minor amount of subsurface oil was found in one location. The area of shoreline affected with any amount of oil decreased by 75%within specific locations that were surveyed in 1990 or 1991 and resurveyed in 1995. Hydrocarbon patterns and Carbon isotopic composition of oil samples identified the residual oil as *Exxon Valdez* oil.

Shoreline oil in Kodiak is not persisting as in PWS largely due to the lack of recalcitrant subsurface oil. Kodiak shorelines were initially affected by oil that had been floating for at least seven days. This caused the formation of a mousse (water and oil emulsion) that was significantly more viscous than the oil affecting the shorelines in PWS. This mousse did not penetrate the beach sediments to the extent of what occurred in PWS primarily because of its higher viscosity. Other important reasons for the lack of shoreline oil in the Kodiak region include the patchy distribution of initial oiling and the overall high-wave energy settings of shorelines in the spill's path. These factors allowed the efficient removal of oil by waves and people.

Key Words: *Exxon Valdez*, Prince William Sound, Kodiak, shoreline oiling, oil spill, cleanup

Citation: Gibeaut, J. C., E. Piper, and D. Munson, 1996. 1995 Kodiak Shoreline oiling assessment of the *Exxon Valdez* oil spill, *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 95027), Alaska Department of Environmental Conservation, Juneau, Alaska.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Introduction

The *T/V Exxon Valdez* ran aground a few minutes after midnight on March 24, 1989 and spilled 11 million gallons of Alaska North Slope crude oil into Prince William Sound (PWS), Alaska. By the end of September 1989, an estimated one and one half to five thousand kilometers of shoreline in PWS and the Gulf of Alaska had been contaminated by varying amounts of oil. Since the first summer of the spill, response teams have repeatedly surveyed the shorelines to map the distribution of visible oil in the intertidal and supratidal zones. These shoreline oiling surveys were specifically designed to support the cleanup effort and the information was used to make decisions on the type of treatment, if any, to be performed at particular sites. The surveys, however, also provide data on the effects of cleanup and physical setting on the rate of removal of shoreline oil. The 1995 shoreline survey described in this report continues the time series begun in 1989 and covers 24 shoreline subdivisions in the Kodiak archipelago. In addition to summarizing shoreline oiling conditions in 1995, this report makes comparisons with the 1990, and 1991 surveys. For a site-by-site presentation of the data discussed in this report, the reader should refer to the Data Report for the 1995 Kodiak Shoreline Oiling Assessment of the Exxon Valdez Oil Spill by J. C. Gibeaut, E. Piper, and D. Munson, 1996. The data report may be obtained from the Oil Spill Public Information Center in Anchorage, Alaska (645 G Street Anchorage, AK 99501; 800-478-7745 in Alaska; 800-283-7745 outside Alaska; e-mail address ospic@muskox.alaska.edu).

Objectives

The overall goal of the 1995 shoreline survey was to determine if shorelines in the Kodiak Archipelago had recovered sufficiently to facilitate normal shoreline activities. Specific objectives included the following: (1) survey selected shorelines for oiling to provide current information about the presence or absence of oil that is useful for all injured resources and services; (2) determine if resource uses are affected by oiling or spill-related activities; (3) identify "hot spots" where continued monitoring, and possibly, treatment is necessary; and (4) assess changes in oiling over time, as possible.

Methods

Surveyors used the same techniques as those used during the 1990 and 1991 surveys. Areas of distinct oiling were paced or measured with a tape and visual estimates made of the percentage of cover of oiling and type of oiling within the area. Thirteen oiled-sediment samples were taken from the intertidal portions of the shorelines. The samples were frozen and transported to the National Marine Fisheries Service's Auke Bay Laboratory for analysis using GC/MS techniques. The Auke Bay Laboratory sent a split of each sample to the U.S. Geological Survey at Menlo Park for stable Carbon isotope analysis. The primary objective of the oil analyses was to determine the source of the oil.

The selection of survey sites relied on what was surveyed in 1990 or 1991 and what local residents suggested may need reassessment. Using the 1990 and 1991 data base, we classified all

104 subdivisions that had available survey data. We ranked the subdivisions into four categories from one being the highest priority for reassessment to four being the lowest priority. In 1995, we actually surveyed 14 rank 1 subdivisions and 3 rank 2 subdivisions. In addition to the above rankings, we considered for survey shorelines cited by the local communities as possibly having residual oil. We surveyed seven of these community-identified sites which had no previous records of cleanup or surveys other than the initial 1989 overflights by the Alaska Department of Environmental Conservation.

Field maps and notes from 1990, 1991, and 1995 were analyzed to yield estimates of the coverage of surface oil. Great care was taken in the field to survey the same locations in 1995 that were noted to have oil during the previous survey. The broad field categories for estimating percent cover of shoreline oil do not allow a quantitative assessment of the amount of change in shoreline oil, particularly for locations with little oil coverage as we found during this survey. We can, however, estimate the change in the shoreline area affected by any amount of oil. Therefore, when estimating trends in oil reduction, we considered only the absence or presence of oil and the area of the shoreline affected. This provides a qualitative measure that is consistent with the techniques used in this and previous surveys. To gain insight into the causes of change in shoreline oiling, we classified each location according to energy level and cleanup activities.

Results

Of the 104 shoreline subdivisions with survey information from 1990 or 1991, 59 had only trace amounts of oiling, and only 31 subdivisions contained locations with enough oil thought to be worth resurveying. In 1995, we surveyed 17 of these subdivisions. Each subdivision had from one to six distinct oiling locations that were generally noted in 1990 or 1991 as having an oil coverage of 1% to 50% over several ten's of meters of shoreline. We surveyed a total of 35 locations among the 17 subdivisions and found that only 14 locations had any oil at all and that the oil in these locations occurred only in trace amounts. The area of shoreline affected with oil decreased by 75% from 1990/91 to 1995. We found no oil at sites south of Chief Cove, trace amounts in Chief Cove, and widely spaced trace amounts at the sites on Shuyak Island. Traces consisted primarily of tar or asphalt patches less than 5 cm in diameter, with a few small (less than 2 m by 20 m) areas within which friable, weathered surface oil residue and asphalt was scattered. Asphalt patches typically had soft interiors and were the result of weathering of 1990/91 deposits of surface oil residue and mousse.

All 13 oiled-sediment samples analyzed with GC/MS techniques had hydrocarbon distribution patterns consistent with moderately to very weathered *Exxon Valdez* oil. In addition, three splits from these samples were analyzed for their Carbon isotopic composition. These three samples had identical δ^{13} Carbon values of -29.3 o/oo relative to the Peedee belemnite standard; this value is consistent with *Exxon Valdez* cargo oil.

Discussion

We had originally planned to survey all of the 31 heaviest oiled subdivisions as we had identified them based on 1990 and 1991 survey data. After visiting several of these subdivisions during our first survey trip and finding very little oil, however, we shortened the survey to 17 subdivisions and the 7 subdivisions identified by the local communities. The shoreline oiling conditions in PWS and the Kodiak region differ in (1) initial and current amount, (2) setting with regard to surface versus subsurface oil, and (3) persistence. Even though the length of shoreline initially affected with any amount of oil was much greater in the Kodiak/Shelikof region than in PWS, the length of shoreline with moderate or heavy oiling was much less. Furthermore, subsurface oil was much less prevalent in the Kodiak Region than in PWS. Based on the 1995 Kodiak survey and a 1993 PWS survey and other observations in PWS in 1994, it also appears to us that the rate of decrease since 1990/91 has been greater in the Kodiak region than in PWS.

The small amount of subsurface oil in the Kodiak region compared to PWS is a primary reason for less persistence of oil in Kodiak. Subsurface oil below the active sediment layer is a major source of residual oil in PWS. The Kodiak shorelines were initially affected by oil that had been floating for at least seven days. This caused the formation of a mousse (water and oil emulsion) that was significantly more viscous than the oil affecting the shorelines in PWS. This mousse did not penetrate the beach sediments to the extent of what occurred in PWS primarily because of its higher viscosity. Other important reasons for the lack of subsurface oil in the Kodiak region include the patchy distribution of oiling and the overall high-wave energy settings of shorelines in the spill's path. These factors allowed the efficient removal of oil by waves and people.

Conclusions

(1) Only trace amounts of shoreline oil remain in the Kodiak region.

(2) Compared to PWS, shoreline oil in the Kodiak region was much less abundant in 1990, and the rate of removal since 1990 has been significant in the Kodiak region and greater than in PWS.

(3) The shoreline oil in Kodiak was initially patchy, emulsified, and in relatively high-wave energy settings compared to PWS. This prevented subsurface penetration of oil and allowed efficient removal by waves and people.

INTRODUCTION

The *T/V Exxon Valdez* ran aground a few minutes after midnight on March 24, 1989 and spilled 11 million gallons of Alaska North Slope crude oil into Prince William Sound (PWS), Alaska (Harrison 1991, Piper 1993). By the end of September 1989, an estimated one and one half to five thousand kilometers of shoreline in PWS and the Gulf of Alasaka had been contaminated by varying amounts of oil (Gundlach et al. 1991, Michel and Hayes 1991) (Fig. 1). Since the first summer of the spill, response teams have repeatedly surveyed the shorelines to map the distribution of visible oil in the intertidal and supratidal zones. These shoreline oiling surveys were specifically designed to support the cleanup effort and the information was used to make decisions on the type of treatment, if any, to be performed at particular sites. The surveys, however, also provide data on the effects of cleanup and physical setting on the rate of removal of shoreline oil. The 1995 shoreline survey described in this report continues the time series begun in 1989 and covers 24 shoreline subdivisions in the Kodiak archipelago (Fig. 2). In addition to summarizing shoreline oiling conditions in 1995, this report makes comparisons with the 1990, and 1991 surveys. For a site-by-site presentation of the data discussed in this report, the reader should refer to the Data Report for the 1995 Kodiak Shoreline Oiling Assessment of the Exxon Valdez Oil Spill (Gibeaut, Piper, and Munson 1996). The data report may be obtained from the Oil Spill Public Information Center in Anchorage, Alaska (645 G Street Anchorage, AK 99501; 800-478-7745 in Alaska; 800-283-7745 outside Alaska; e-mail address ospic@muskox.alaska.edu).

For two and one half days after the spill the weather was calm. Then for three days, beginning in the afternoon of the third day, winds increased and were sustained at 20 to 25 knots out of the north and northeast. This wind storm rapidly moved and dispersed the oil to the southwest through PWS. Oil first exited PWS through Montague Strait on about March 30, 7 days after the spill (Fig. 1), and small isolated patches of oil continued to exit PWS through at least the end of April (Galt et al. 1991, Wolfe et al. 1994). Galt et al. (1991) used a computer hindcast technique to estimate that by the end of the second week of the spill about 30% of the oil had been lost to weathering processes, 40% was on the beaches of PWS, about 25% of the oil passed out of PWS, and about 5% remained floating in PWS. Only about 10% made it beyond Gore Point, and less than 2% got as far as Shelikof Strait (Fig. 1). Wolfe et al. (1994) estimated that between 2% and 4% was ultimately beached in the Shelikof Strait and Kodiak Island area. They noted, however, that the formation of mousse (a viscous water and oil emulsion with up to 70% water) increased the effective volume of contaminant by about three times.

The oil that exited PWS and eventually contaminated shorelines in the Shelikof Strait and Kodiak Island area was more weathered than the oil in PWS, and it was primarily in the form of mousse and tarballs and dispersed in broken streamers or windrows (Teal 1991, Michel and Hayes 1991, Wolfe et al. 1994). Consequently, the affected shorelines in the Kodiak region were not generally blanketed with fluid, penetrating oil as in PWS but rather with discrete patches of viscous mousse that did not readily penetrate the beach sediments. This type of oiling was more readily removed by tide and wave energy and treatment than the problematic subsurface oil in PWS (Owens and Teal 1990b, Wolfe et al. 1994).

Michel and Hayes (1991) compiled shoreline oiling data collected by ground survey teams during the summer of 1989. These Shoreline Cleanup Assessment Teams (SCAT), contracted by Exxon, found that 115 km of shoreline was initially heavily or moderately oiled and 3,010 km was lightly or very lightly oiled in the Kodiak/Shelikof Strait region[1]. In contrast, about 6-times more shoreline (600 km) was heavily or moderately oiled in PWS, but only 671 km, or about 5-times less shoreline than in the Kodiak/Shelikof region, was lightly or very lightly oiled. The Alaska Department of Environmental Conservation (ADEC) conducted a walking survey of the entire spill area in the fall of 1989 at the end of the first cleanup season, and they found only 2.5 km of shoreline with moderate or heavy oiling in the Kodiak region versus 140 km in PWS (Gundlach et al. 1991). During March and April of 1990, State and Federal Agencies and Exxon jointly

[1] Heavy oiling is defined as a band of oil more than 6-m wide or covering more than 50% of the intertidal zone; moderate oiling is a band of oil 3- to 6-m wide or covering 10% to 50% of the intertidal zone; light oiling is a band of oil 1- to 3-m wide or covering 10% of the intertidal zone; very light oiling is a band of oil less than 1-m wide or covering less than 1% of the intertidal zone.

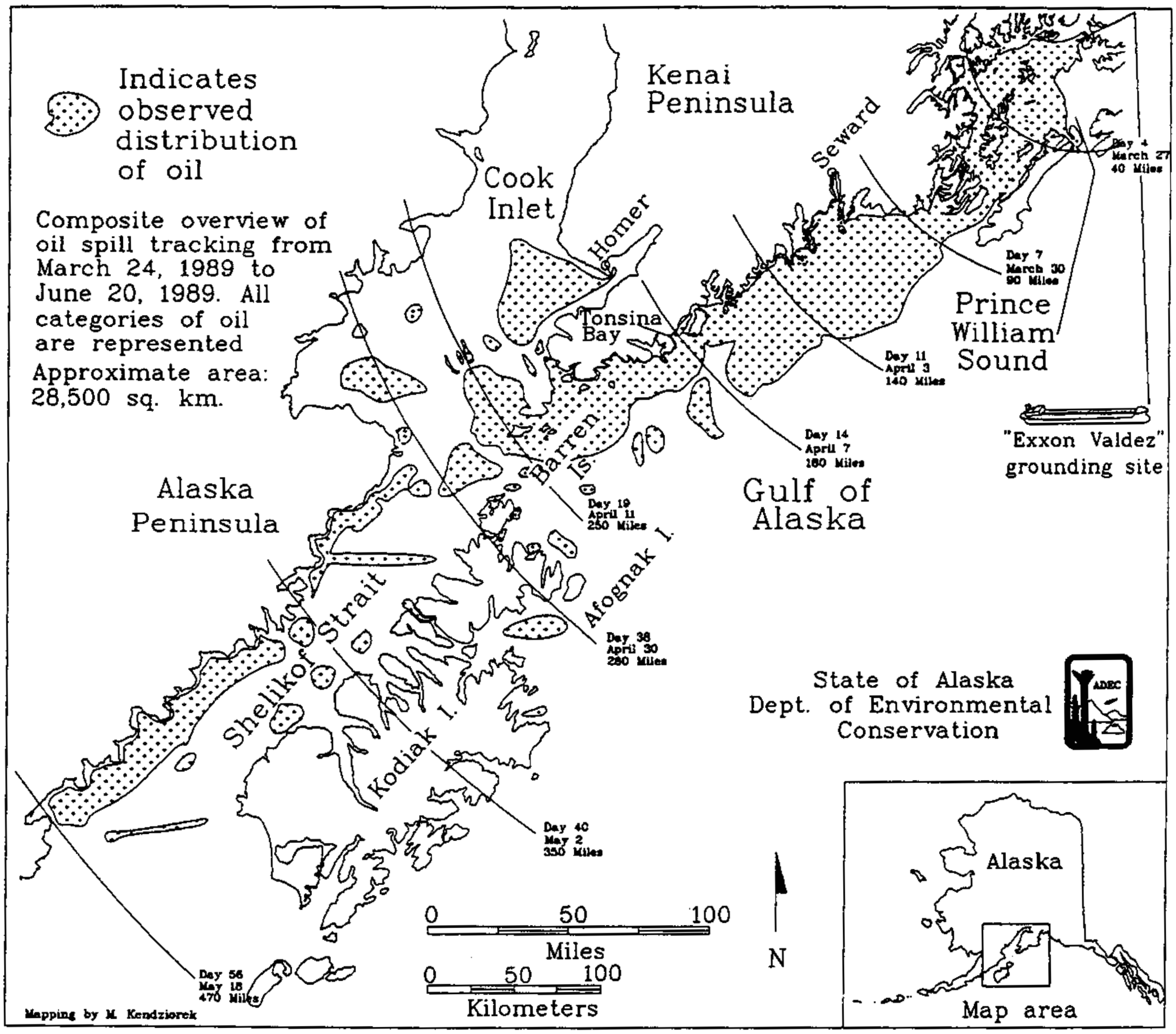

Fig. 1.- Composite overview of oil on water from March 24, 1989 to June 20, 1989.

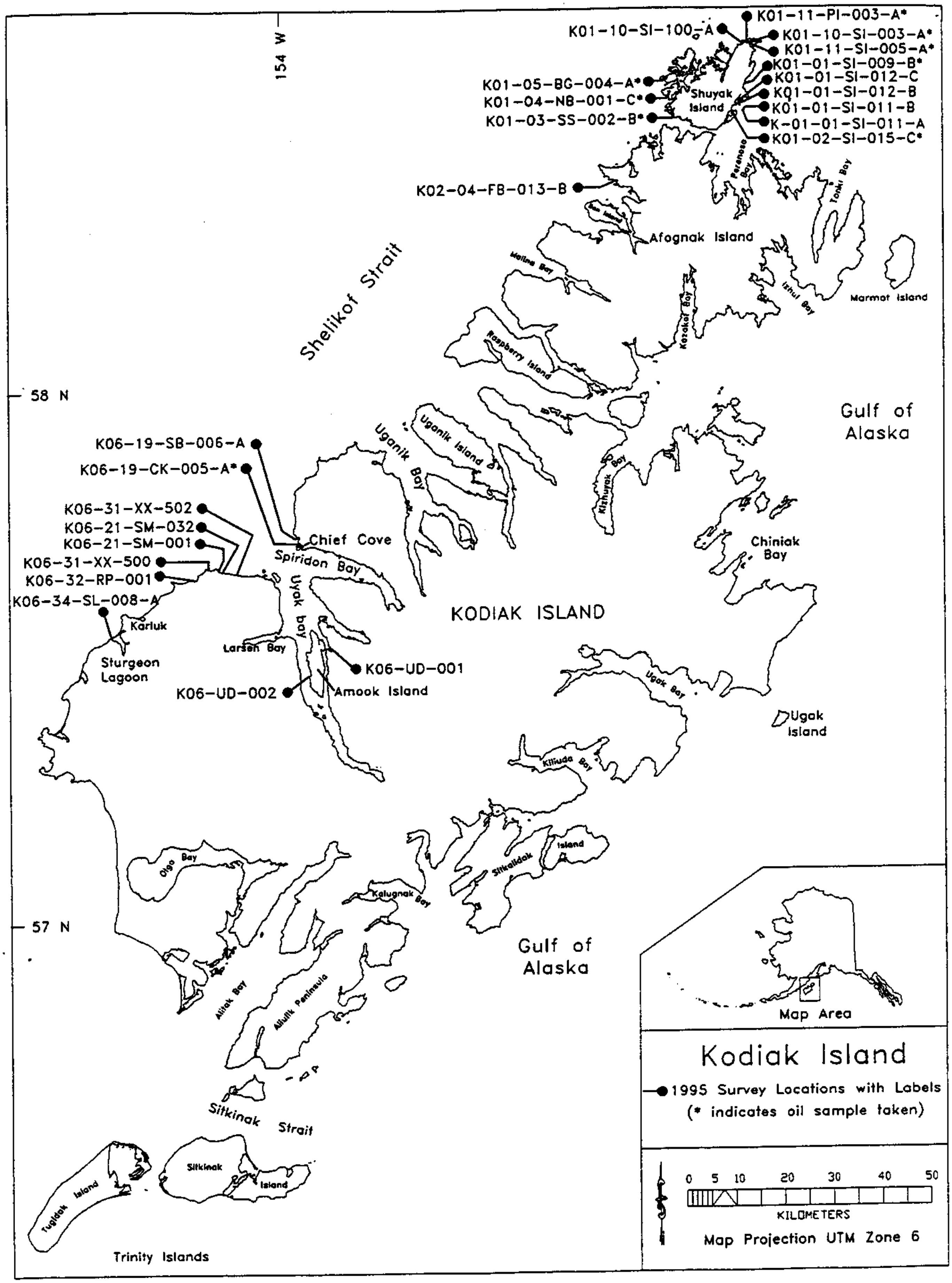

Fig. 2.- Locations of 1995 survey sites in the Kodiak region.

conducted ground surveys throughout the spill area during the Spring Shoreline Assessment Program (SSAP) (Owens and Teal 1990a). A comparison of these data with the 1989 data shows that all surface oil in PWS had reduced by 67% and that surface oil in the Kodiak/Shelikof Strait region had reduced by 97%. Thus, by 1990, there was more shoreline with surface oil in PWS than in the Kodiak/Shelikof Strait region. More significantly, however, was the large amount of subsurface oil remaining in PWS versus outside of PWS (Gibeaut et al. 1995, 1996). The removal of shoreline oil is attributed to both cleanup and natural processes, particularly high-wave energy in the region outside of PWS.

More site-specific but more rigorous field studies also illustrated the decline of shoreline oiling. Exxon established 18 detailed, multi-transect study sites in PWS and 10 in the Gulf of Alaska outside of PWS and including the Kodiak region (Owens and Teal 1990b). Owens and Teal (1990b) found that surface oiling at the study sites outside of PWS decreased from an average of 15% cover in the summer of 1989 to less than 1% in March of 1990. In contrast, their PWS sites had 39% surface oil cover in 1989 and decreased to 4% cover by March, 1990. They also stated that the sites outside of PWS showed similar or even faster rates of surface oil reduction than those in PWS. ADEC established and tracked 14 detailed single transect study sites in the Kodiak/Shelikof Strait region and tracked them from 1989 to 1991 (Endres, Pavia, and Lane 1992). ADEC's results regarding the amount of oil and rate of oil reduction were similar to Exxon's.

Results from this study show that in 1995 there were still locations with surface oil in the Kodiak region. Surface oil occurred only in trace amounts, however, and of the 35 specific locations that we revisited in 1995, only 14 had any oil remaining. Data from this study and reanalyzed data from the 1990 and 1991 surveys show that subsurface oil was not abundant relative to PWS in 1990 and 1991 and that subsurface oil in 1995 was almost non existent in the Kodiak region. Oil reduction from 1990/91 to 1995 was significant in the Kodiak region and is attributed to both natural processes and manual removal and raking in 1990.

OBJECTIVES

The overall goal of the 1995 shoreline survey was to determine if shorelines in the Kodiak Archipelago had recovered sufficiently to facilitate normal shoreline activities. Specific objectives included the following: (1) survey selected shorelines for oiling to provide current information about the presence or absence of oil that is useful for all injured resources and services; (2) determine if resource uses are affected by oiling or spill-related activities; (3) identify "hot spots" where continued monitoring, and possibly, treatment is necessary; and (4) assess changes in oiling over time, as possible.

METHODS

Field Surveys

Surveyors used the same techniques as those used during the 1990 and 1991 surveys as best explained in the 1991 MAYSAP survey manual (Exxon Corporation 1991). Surveyors dug pits in the beaches and turned over cobbles and boulders to reveal hidden oil. After the beaches were dug and a general reconnaissance made, workers then documented the oil distribution on field sketch maps. Areas of distinct oiling were paced or measured with a tape and visual estimates made of the percentage of cover of oiling within the area. Shorelines were visited within two hours of low tide and always when the tide level was lower than plus two meters. At one site we reoccupied an established transect oriented perpendicular to the shoreline on the north side of Shuyak Island that had been last measured in 1991 (K01-10-SI-003-A, Fig. 2).

Field oiling classifications regarding types of surface oil and percent coverage are consistent with previous surveys (Exxon Corporation 1991), and they are presented in Table 1. Subsurface oiling classifications (Exxon Corporation 1991) are also consistent (Table 1). These classifications were designed for the consistent collection of qualitative field data and are now in wide use (Owens and Taylor 1993). The categories are broad and reflect the limitations of qualitative observations in areas of complicated geology and oiling conditions. Survey team members worked together to inter-calibrate their judgments on oiling classifications and percent coverage estimates. All survey work was done as a team with constant interaction between surveyors. All surveyors had worked on the spill since 1989, and they are experienced observers of shoreline oiling.

Field forms for this survey are the same as those used in 1991 and 1992 (Exxon Corporation, 1991; Owens and Taylor, 1993). To further maintain consistency with the earlier surveys, the shoreline sketch maps from the most recent survey were used in the field and amended with 1995 data. Photographs that documented typical oiling conditions and overall setting of each site were also taken and are included in the data report (Gibeaut, Piper, and Munson 1996).

Thirteen oiled-sediment samples were taken from the intertidal portions of the shorelines. The samples were frozen and transported to the National Marine Fisheries Service's Auke Bay Laboratory for analysis using GC/MS techniques. The Auke Bay Laboratory sent a split of each sample to the U.S. Geological Survey at Menlo Park for stable Carbon isotope analysis. The primary objective of the oil analyses was to determine the source of the oil.

Survey Site Selection

The selection of survey sites relied on what was surveyed in 1990 or 1991 and what local residents suggested may need reassessment. Each previous year's survey was based primarily on the most recent oiling information available for each site. An interagency group, which included Exxon, compared data and negotiated the final survey list. The primary criteria for selecting a site for survey in 1990 and 1991 was whether the last recorded oiling data suggested that more cleanup might be needed and possible. Some sites that may contain oil in 1995, therefore, may have been dropped from earlier year's survey lists because of a lack of a treatment method for the site or a lack of willingness to treat a site by the agencies and Exxon.

Using the 1990 and 1991 data base, we classified all 104 subdivisions that had available survey data. We ranked the subdivisions into four categories from one being the highest priority

Table 1: Field Oiling Classifications

Surface Oil Types	Abbreviation	Definition
asphalt pavement	AP	Heavily oiled beach sediments held cohesively together.
Mousse/pooled oil	MS	Any oil/water emulsion with a thickness of more than 1 cm.
tar balls, patties, tar patties	TB	Small, distinct oil deposits lying on top of the beach surface; possibly binding debris but typically not sediments
surface oil residue	SOR	Significantly oil coated beach sediments in the top 5 cm; sediments do not form a cohesive layer; may be described as heavy or light.
Cover	CV	Oil more than 1 mm to 1 cm thick.
Coat	CT	Oil more than 0.1 mm to less than or equal to 1 mm thick; can be easily scratched off with fingernail.
Stain	ST	Oil less than or equal to 0.1 mm thick; cannot be easily scratched off with fingernail.
Film or sheen	FL	Transparent or translucent film or sheen.
Oiled debris	DB	Any oiled debris or cleanup material stranded on a shore.

Surface Oil Distribution Classes	Abbreviation	Definition	Value for Calculations
continuous	C	Area or band with 91% to 100% oil coverage.	96%
broken	B	Area or band with 51% to 90% coverage.	70%
patchy	P	Area or band with 11% to 50% coverage.	30%
splash	S	Area or band with 1% to 10% coverage.	6%
trace	T	Area or band with less than 1% coverage.	0.5%

Subsurface Oil Types	Abbreviation	Definition	Weighting Value
oil pore	OP	Pore spaces are completely filled with oil resulting in oil oozing out of sediments - water cannot penetrate OP zone.	5
heavy oil residue	HOR	Pore spaces partially filled with oil residue but not generally flowing out of sediments.	4
medium oil residue	MOR	Heavily coated sediments; pore spaces are not filled with oil - pore spaces may be filled with water.	3
light oil residue	LOR	Sediments lightly coated with oil.	2
oil film	OF	Continuous layer of sheen or film on sediments - water may bead on sediments.	1
trace	TR	Discontinuous film; spots of oil on sediments; an odor or tackiness with no visible evidence of oil.	0.1

for reassessment to four being the lowest priority. The ranks had the following characteristics: rank 1, those sites with significant oil as noted on the 1990 or 1991 survey data; rank 2, not as much oil as recorded for rank 1 sites but one of the surveyors wrote that it should be resurveyed; rank 3, the time and cost involved in surveying it compared to the amount of oil expected was considered high; and rank 4, those areas with minimal oil. There were 20 subdivisions ranked priority 1, 11 with rank 2, 13 with rank 3, and 59 with rank 4. In 1995, we surveyed 14 rank 1 subdivisions and 3 rank 2 subdivisions (Fig. 2). In addition to the above rankings, we considered for survey shorelines cited by the local communities as possibly having residual oil. We surveyed seven of these community-identified sites which had no previous records of cleanup or surveys other than the initial 1989 overflights by ADEC.

Data Analysis

Field maps and notes from 1990, 1991, and 1995 were analyzed to yield estimates of the coverage of surface oil. For the most useful and accurate comparisons, oiling was compared on a location-specific level. During the years of cleanup operations, a hierarchy of shoreline designations developed. A shoreline "segment" is the broadest designation and may include a piece of shoreline several kilometers in length. Depending on the history of the cleanup and oiling a "segment" may be divided into "subsegments" or "subdivisions". More specific locations within a subsegment are generally referred to as "beaches" or "sites". Beaches and sites within a subsegment are usually separated by geomorphic boundaries such as headlands or by stretches of shoreline that do not contain oil or were not surveyed. Contiguous areas of oiling within beaches and sites are here referred to as "locations". "Locations" generally contain a consistent type of oiling or sediment type and are the spatial level at which this survey and analysis were targeted.

Great care was taken in the field to survey the same locations in 1995 that were noted to have oil during the previous survey. The broad field categories for estimating percent cover of shoreline oil do not allow a quantitative assessment of the amount of change in shoreline oil, particularly for locations with little oil coverage as we found during this survey. We can, however, estimate the change in the shoreline area affected by any amount of oil. Therefore, when estimating trends in oil reduction, we considered only the absence or presence of oil and the area of the shoreline affected. This provides a qualitative measure that is consistent with the techniques used in this and previous surveys.

To gain insight into the causes of change in shoreline oiling, we considered the energy level and cleanup activities. Each location was classified as either high, moderate, or low energy. Energy for this study refers to the relative wave heights and storm occurrence and duration expected to affect the shoreline. Relative energy classification is determined by the fetch, shoreline orientation, biological character, and sedimentological characteristics such as sediment rounding and the presence or absence of storm berms. Energy level was assigned on the "location" level, and in some areas varying energy levels may have been assigned to locations in the same sites depending on local wave shadow effects. Cleanup information was also investigated on the "location" level. Data sources for treatment activity in 1990 and 1991 included the signed, Federal On-Scene Coordinator work orders, ADEC Daily Shoreline Assessments that were completed by the state monitor for each day treatment occurred at a site, and supplementary State, Federal, and Exxon surveys and memos describing treatments. Treatment for this report refers to removal or tilling and not bioremediation.

RESULTS

Of the 104 shoreline subdivisions with survey information from 1990 or 1991, 59 had only trace amounts of oiling, and only 31 subdivisions contained locations with enough oil thought to be worth resurveying. In 1995, we surveyed 17 of these subdivisions. Each subdivision had from one to six distinct oiling locations that were generally noted in 1990 or 1991 as having a patchy or sporadic coverage (Table 1) over several ten's of meters of shoreline. We surveyed a total of 35 locations among the 17 subdivisions and found that only 14 locations had any oil at all and that the oil in these locations occurred only in trace amounts. We found no oil at sites south of Chief Cove, trace amounts at Chief Cove (subdivision K06-19-CK-005-A), and widely spaced trace amounts at the sites on Shuyak Island (Fig. 2). Traces consisted primarily of tar or asphalt patches less than 5 cm in diameter, with a few small (less than 2 m by 20 m) areas within which friable, weathered surface oil residue and asphalt were scattered. Asphalt patches typically had soft interiors. In 1990 and 1991, 37% of the affected oiled shoreline included coat and cover types of oil, but in 1995, no coat or cover was discovered. Commonly, mousse and surface oil residue present in 1990 or 1991 turned to asphalt by 1995. Three locations where this conversion completely occurred are on the south shore of Shuyak Island in Shuyak Harbor (K01-03-SS-002-B), on the west shore of Shuyak Island in Big Bay (K01-05-BG-004-A), and on the north shore of Shuyak Island in Perevalnie Passage (K01-11-SI-005-A) (Fig. 2).

Table 2 presents the area of the intertidal shoreline with any amount of oil for the locations surveyed in both 1990/91 and 1995. Most of the area surveyed was in moderate-energy and treated locations. The area of shoreline affected with oil decreased by 75% from 1990/91 to 1995. Oil in high-energy locations completely disappeared. The values in table 2 do not account for reductions in percent coverage of oil that undoubtedly occurred but are not measurable. At some of these locations, we actually counted only 10 to 30 splotches of tar and asphalt a few centimeters in size along 10's to several hundreds of meters of shoreline. Therefore, the amount of oil reduction indicated by the values in table 2 are minimal estimates. The greater improvement in affected area for non treated versus treated locations is caused by not accounting for reductions in percent cover and because more heavily oiled areas in 1990 and 1991 were targeted for treatment. That is non treated locations had less oil than treated locations in 1990 or 1991 even after treatment occurred. All sites that we surveyed because of community concern were in the Uyak Bay area and none of them had oil.

Only two subdivisions among the 17 we surveyed in 1995 were noted with subsurface oil in 1990. A location along Sturgeon Lagoon (subdivision K06-34-SL-008-A , Fig. 2) contained mousse that had penetrated 10 cm into the gravel in 1990. No cleanup occurred here, but by 1995 all oil had disappeared. On the north side of Shuyak Island in Perevalnie Passage (subdivision K01-10-SI-003-A, Fig. 2) one location measuring about 30 m alongshore had mousse beneath boulders in the lower intertidal and medium oil residue buried across the mid intertidal. Apparently no substantial subsurface cleanup occurred here since 1990. At this location in 1995, we found no subsurface oil in the lower intertidal and only one pit with a light oil residue in the mid intertidal. Natural processes were effective in removing subsurface oil at these two locations.

Table 2: Area of Shoreline Affected with Oil (square meters)

	1990/91	1995	change	%change
all treated (26 locations)	11930	3355	-8575	-72
all not treated (9 locations)	1722	18	-1704	-99
low energy (12 locations)	4684	1214	-3470	-74
moderate energy (16 locations)	6314	2159	-4155	-66
high energy (7 locations)	2654	1	-2653	-100
all locations (35 locations)	13652	3373	-10279	-75

All 13 oiled-sediment samples (Fig. 2) analyzed with GC/MS techniques had hydrocarbon distribution patterns consistent with moderately to very weathered *Exxon Valdez* oil (Jeff Short, personal communication, 13 October 1995, Supervisory Research Chemist, National Marine Fisheries Service, Auke Bay, Alaska Laboratory). In addition, three splits from these samples (two from Shuyak Island and one from Chief Cove in Spiridon Bay on Kodiak Island) were analyzed for their Carbon isotopic composition. These three samples had identical δ^{13} Carbon values of -29.3 o/oo relative to the Peedee belemnite standard (Paul Carlson, personal communication, U.S. Geological Survey). Kvenvolden et al. (1993, 1995) showed that *Exxon Valdez* cargo oil also had an average δ^{13} value of -29.3 o/oo ±0.1 o/oo. They used δ^{13} values of whole-oil residues from PWS shorelines to distinguish *Exxon Valdez* oil from oil that apparently resulted from an asphalt spill caused by the March 27, 1964 earthquake. Thus the δ^{13} values determined for this survey do not contradict an *Exxon Valdez* source of the oil.

DISCUSSION

We had originally planned to survey all of the 31 heaviest oiled subdivisions as we had identified them based on 1990 and 1991 survey data. After visiting several of these subdivisions during our first survey trip and finding very little oil, we decided to survey as much as the weather would allow in three, week-long or shorter trips and to obtain representative surveys across the geographic area from Shuyak Island on the north to Sturgeon Lagoon on the south. We think that the 17 subdivisions we surveyed are representative of the 31 originally listed subdivisions and that the oiling observations and trends we observed are representative of the entire Kodiak archipelago. Furthermore, the absence of oil at the seven subdivisions we surveyed in response to community concern, but for which we had no prior oiling records since the initial 1989 ADEC over flights, indicates that our oiling records are adequate.

The shoreline oiling conditions in PWS and the Kodiak region differ in (1) initial and current amount, (2) setting with regard to surface versus subsurface oil, and (3) persistence. Even though the length of shoreline initially affected with any amount of oil was much greater in the Kodiak/Shelikof Strait region than in PWS, the length of shoreline with moderate or heavy oiling was much less (Gundlach et al 1991, Michel and Hayes 1991). Furthermore, subsurface oil was much less prevalent in the Kodiak Region than in PWS. The 1990 interagency spring survey considered in this report was the first reliable and comprehensive, ground survey of the oiled area, and this survey showed relatively small amounts of oiling in the Kodiak region compared to PWS and little subsurface oil. Based on the 1995 Kodiak survey and the 1993 PWS survey (Gibeaut et al. 1995, Gibeaut and Piper 1995, 1996) and other observations in PWS in 1994, it also appears to us that the rate of decrease since 1990/91 has been greater in the Kodiak region than in PWS. We make this assessment based mostly on our qualitative judgments and experiences as observers of *Exxon Valdez* shoreline oiling since 1989 because the numbers generated by these types of surveys are too coarse for quantitative comparisons.

The small amount of subsurface oil in the Kodiak region compared to PWS is a primary reason for less persistence of oil in Kodiak. Subsurface oil below the active sediment layer is a major source of residual oil in PWS (Gibeaut and Piper 1995, 1996). The Kodiak shorelines were initially affected by oil that had been floating for at least seven days. This caused the formation of a mousse (water and oil emulsion) that was significantly more viscous than the oil affecting the shorelines in PWS. This mousse did not penetrate the beach sediments to the extent of what occurred in PWS primarily because of its higher viscosity. Other important reasons for less residual shoreline oil in Kodiak than in PWS include the patchy distribution of oiling in Kodiak compared to PWS where entire bays were covered and reoiled during the tidal cycle effectively "pumping" oil into the beach sediments. Also the oiled portion of the Kodiak region does not include as many low-energy bays as PWS; the higher-wave energy in the Kodiak region prevented deposition of oil and rapidly cleaned shorelines compared to PWS.

CONCLUSIONS

(1) Only trace amounts of shoreline oil remain in the Kodiak region.

(2) Compared to PWS, shoreline oil in the Kodiak region was much less abundant in 1990, and the rate of removal since 1990 has been significant in the Kodiak region and greater than in PWS.

(3) The shoreline oil in Kodiak was initially patchy, emulsified, and in relatively high-wave energy settings compared to PWS. This prevented subsurface penetration of oil and allowed efficient removal by waves and people.

LITERATURE CITED

Endres, P. J., E. A. Pavia, and W. H. Lane, 1992. Evaluation of oil impacted shoreline in the Kodiak/Alaska Peninsula regions final report 1989-1991. Oil Spill Response Center, Alaska Department of Environmental Conservation, Anchorage Alaska, 128 p.

Exxon Corporation, 1991. MAYSAP survey, May shoreline assessment program. Exxon USA, Anchorage, Alaska.

Galt, J. A., G. Y. Watabayashi, D. L. Payton, and J. C. Petersen, 1991. Trajectory analysis for the *Exxon Valdez*: Hindcast study. Proceedings, 1991 International Oil Spill Conference, American Petroleum Institute, Washington, D. C., p. 629-634.

Gibeaut, J. C., E. Piper, D. Munson, J. Matthews, M. Profita, and C. Crosby, 1994. 1993 Shoreline assessment data report: volume 1 (introduction and ground surveys AE005A through EV036A), volume 2 (ground surveys EV037A through KN136A), volume 3 (ground surveys KN209A through LA015D), volume 4 (ground surveys LA015E through TB004A), volume 5 (transect surveys), *Exxon Valdez* Oil Spill Restoration Project (Restoration Project 93038), Alaska Department of Environmental Conservation, Juneau, Alaska.

Gibeaut, J. C., E. Piper, and D. Munson, 1996. Data report for the 1995 Kodiak shoreline oiling assessment of the *Exxon Valdez* oil spill. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 95027), Alaska Department of Environmental Conservation, Juneau, Alaska.

Gibeaut , J. C., E. Piper,1996. 1993 Shoreline oiling assessment of the Exxon Valdez oil spill - out for review. *Exxon Valdez* Oil Spill Restoration Project Final Report (Restoration Project 93038), Alaska Department of Environmental Conservation, Juneau, Alaska.

Gibeaut, J. C. and E. Piper, 1995. Shoreline oil from Exxon Valdez: change from 1991 to 1993, Proceedings, 1995 International Oil Spill Conference, American Petroleum Institute, Washington, D. C..p. 972-973.

Gundlach, E., E. A. Pavia, C. Robinson, and J. C. Gibeaut, 1991. Shoreline surveys at the *Exxon Valdez* oil spill: the State of Alaska response. Proceedings, 1991 International Oil Spill Conference, American Petroleum Institute, Washington, D. C., p. 519-529.

Harrison, O. R. 1991. An overview of the *Exxon Valdez* oil spill. Proceedings, 1991 International Oil Spill Conference, American Petroleum Institute, Washington, D.C., p.313-319.

Kvenvolden, K. A., P. R. Carlson, C. N. Threlkeld, and A. Warden, 1993. Possible connection between two Alaskan catastrophes occurring 25 yr apart (1964 and 1989). Geology, vol. 21, p. 813-816.

Kvenvolden, K. A., F. D. Hostettler, P. R. Carlson, J. B. Rapp, C. N. Threlkeld, and A. Warden, 1995. Ubiquitous tar balls with a California-source signature on the shorelines of Prince William Sound, Alaska. Environ. Sci. Technol., vol. 29, p. 2684-2694.

Michel, J., and M. O. Hayes, 1991. Geomorphological controls on the persistence of shoreline contamination from the *Exxon Valdez* oil spill. National Oceanic and Atmospheric Administration, Seattle, Washington 306 pp.

Owens, E., and A. Teal, 1990a. Shoreline cleanup following the *Exxon Valdez* oil spill: Field data collection within the S.C.A.T. program. Proceedings of the Thirteenth Arctic and Marine Oil Spill Program Technical Seminar, Edmonton, Alberta, p. 411-421.

Owens, E., and A. Teal, 1990b. A Brief overview and initial results from the winter shoreline monitoring program following the *Exxon Valdez* incident. Proceedings of the Thirteenth Arctic and Marine Oil Spill Program Technical Seminar, Edmonton, Alberta, p. 451-470.

Owens, E. H., and E. Taylor, 1993. A proposed standardization of terms and definitions for shoreline oiling assessment. Proceedings of the 1993 Arctic and Marine Oil Spill Programme (AMOP), Technical Seminar, Calgary, Alberta.

Piper, E., 1993. The *Exxon Valdez* oil spill final report, State of Alaska response. Alaska Department of Environmental Conservation, Juneau, Alaska, 184pp.

Teal, A. R., 1991. Shoreline cleanup – reconnaissance, evaluation, and planning following the valdez oil spill. Proceedings, 1991 International Oil Spill Conference, American Petroleum Institute, Washington, D.C., p. 149-152.

Wolfe, D. A., M. J. Hameedi, J. A. Galt, G. Watabayashi, J. Short, C. O'Claire, S. Rice, J. Michel, J. R. Payne, J. Braddock, S. Hanna, and D. Sale, 1994. The fate of the oil spilled from the Exxon Valdez. Environ. Sci. Technol., vol. 28, no. 13, p. 561A-568A.