

ALASKA LEGISLATURE SPECIAL COMMITTEE/SUBJECT FILE 8672
1996 SCOMM 77: SENATE SPEC. COMM. EXXON VALDEZ OIL SPILL. 1991

213

APPENDIX C

Selected Beach Elevation Profiles

Beach profiles were surveyed routinely by measuring elevation changes along transects oriented approximately perpendicular to the shoreline. Measurements were collected usually every 2 m across the beach to the waterline. In most instances, the Emery pole-and-horizon method (Emery 1961) was used to obtain elevation data (Photographs B-3 and B-13, on pages B-2 and B-5). Quality control of the data was achieved by closing the profile; that is, after surveying the transect, the line was resurveyed back to the first point on the profile. Closing errors were normally a few centimeters at most. Fieldwork was timed to coincide with low tides so that most of the intertidal zone at the beach could be surveyed. The graphs contained in this appendix are all plotted on the same height and distance scales, except for sites AK-3 and AK-5. Note the elevation and distance axes are not at the same scale. Elevations are expressed with respect to a local relative datum assumed to be the mean lower low water (MLLW), which is the mean of the lower of the two semi-diurnal tides.

Figure C-1a
Elevation Profile/AP-1, Transect 8

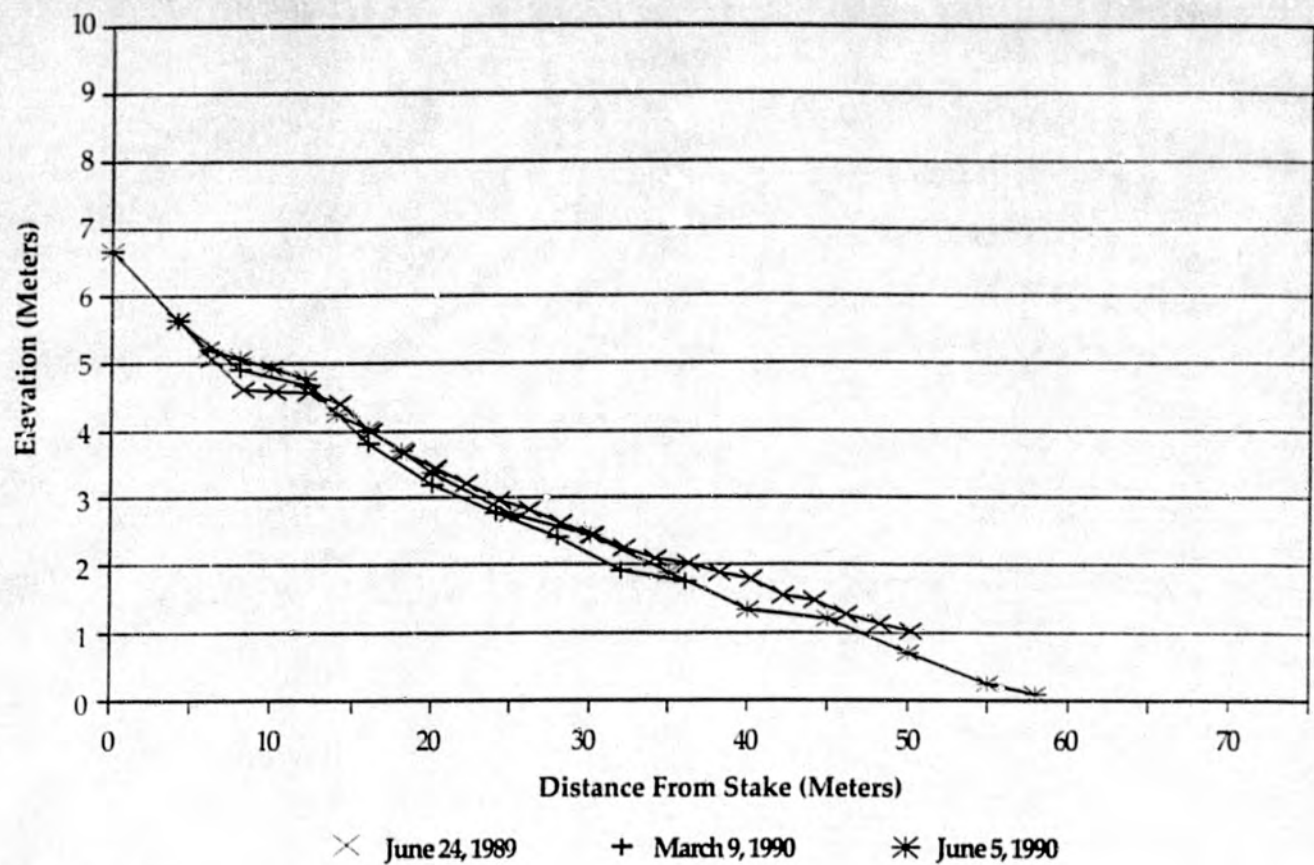


Figure C-1b
Elevation Profile/AP-1, Transect 10

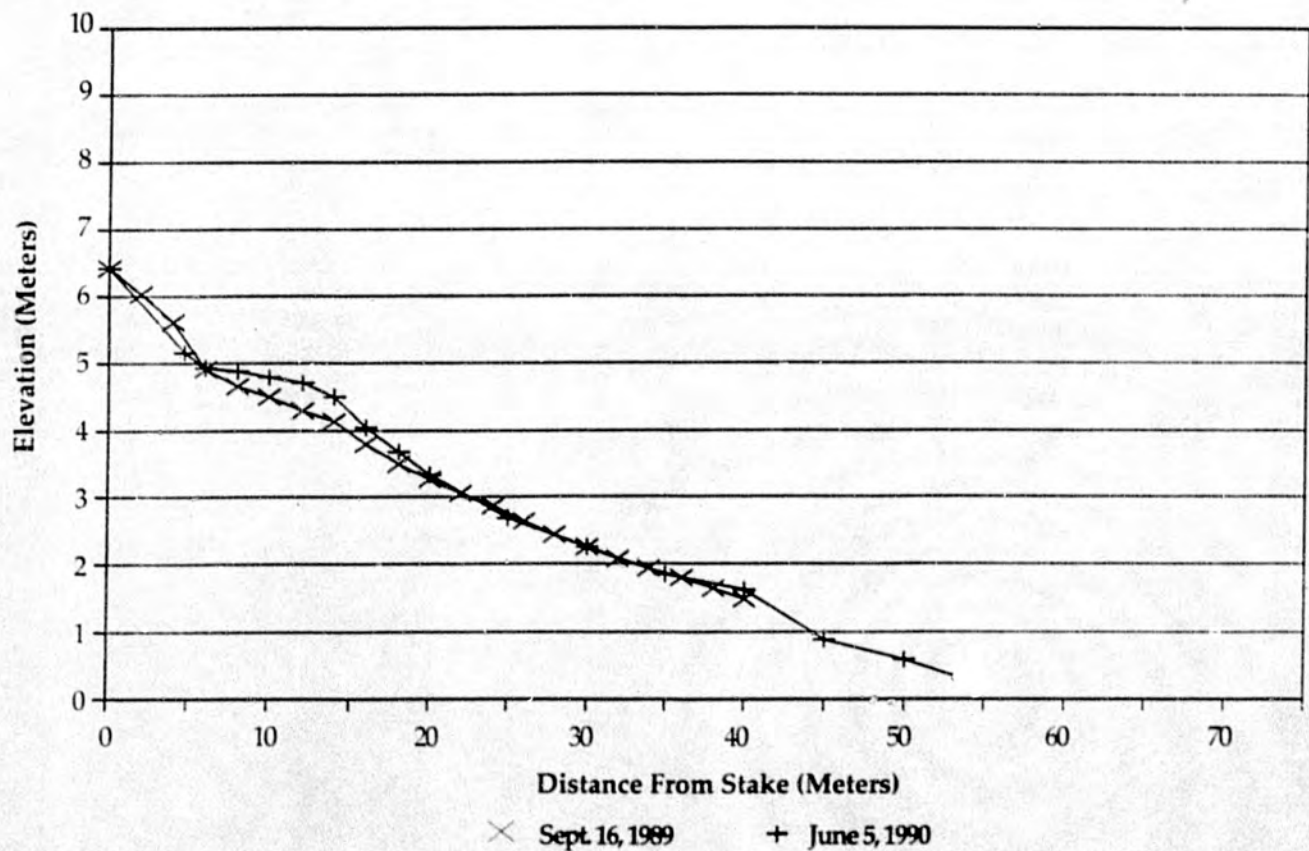


Figure C-2
Elevation Profile/AP-10, Transect 5

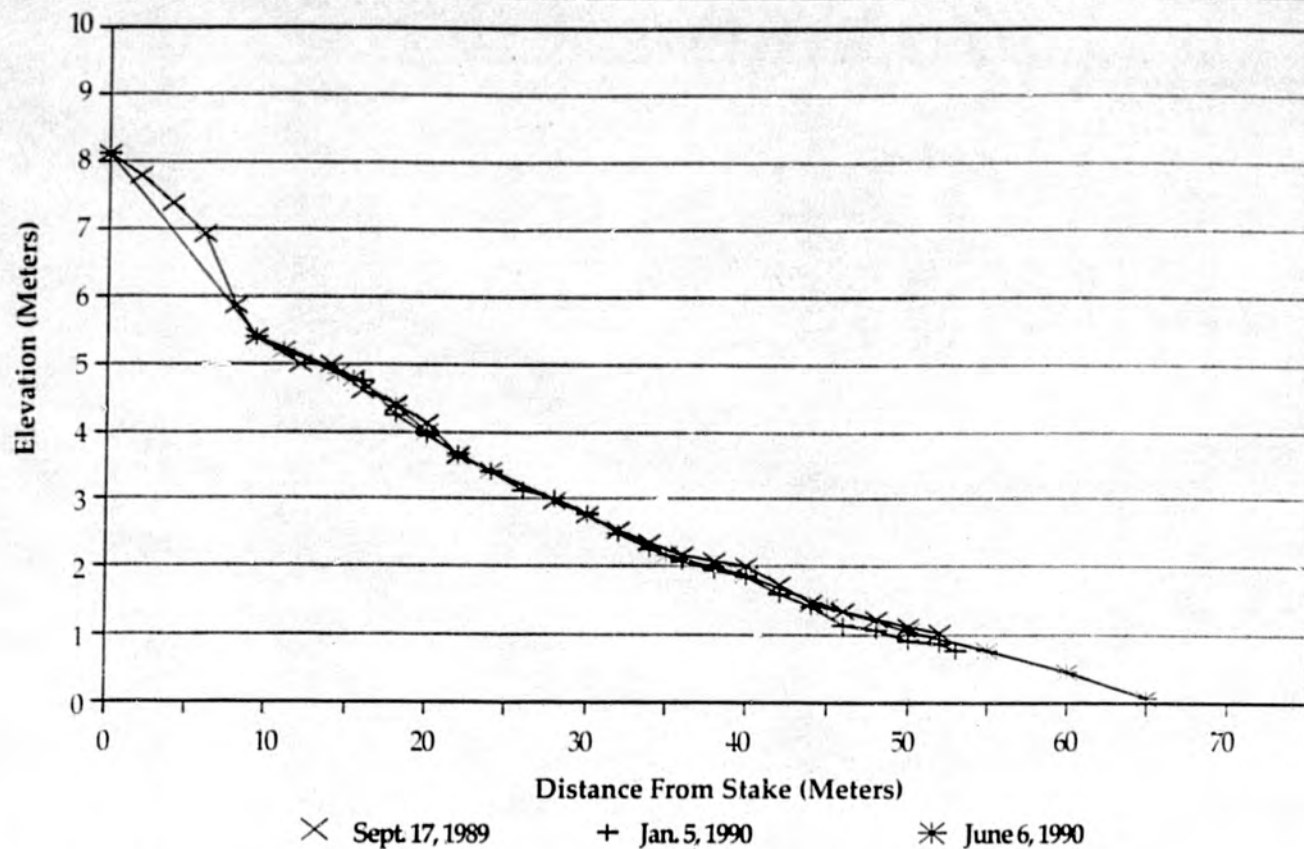


Figure C-3
Elevation Profile/AP-16, Transect 3

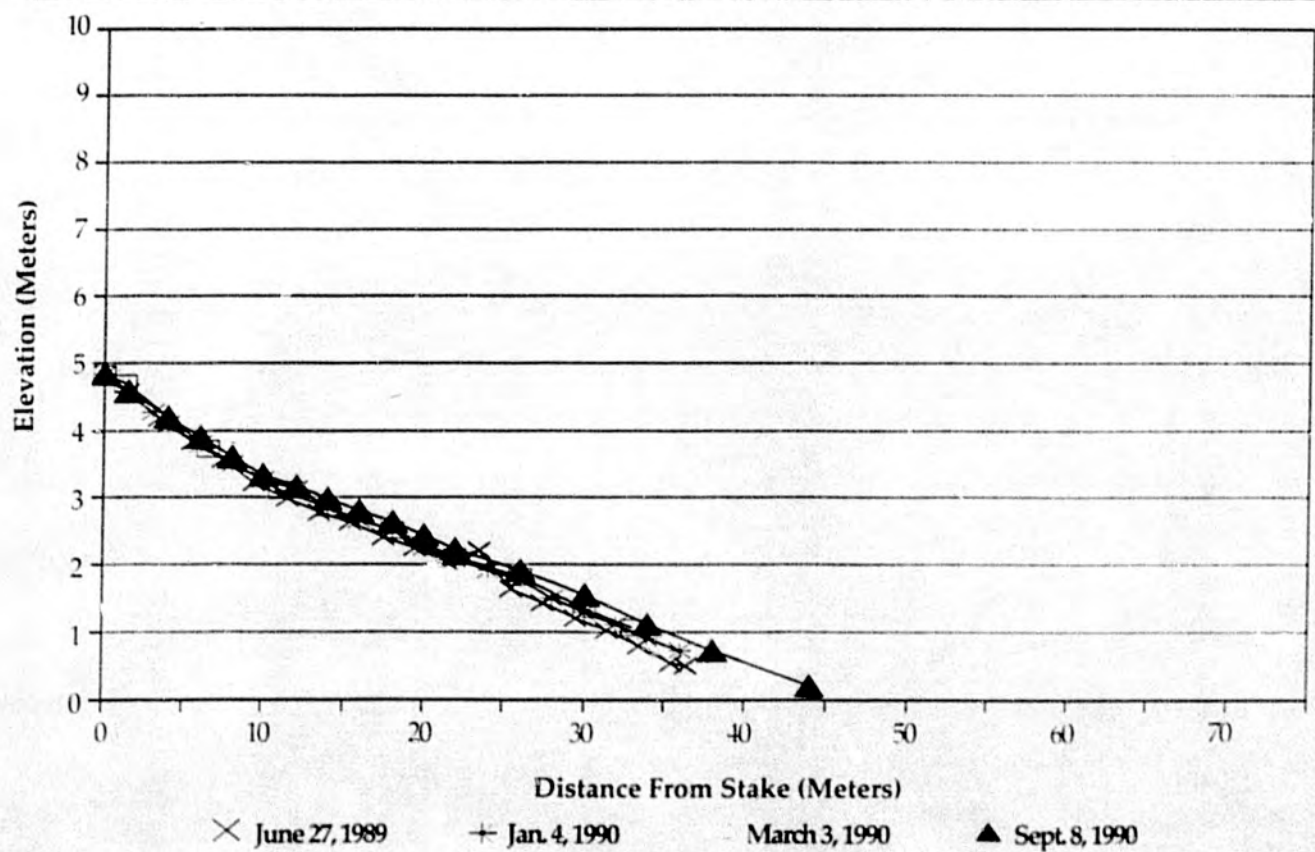


Figure C-4
Elevation Profile/AH-3, Transect 2

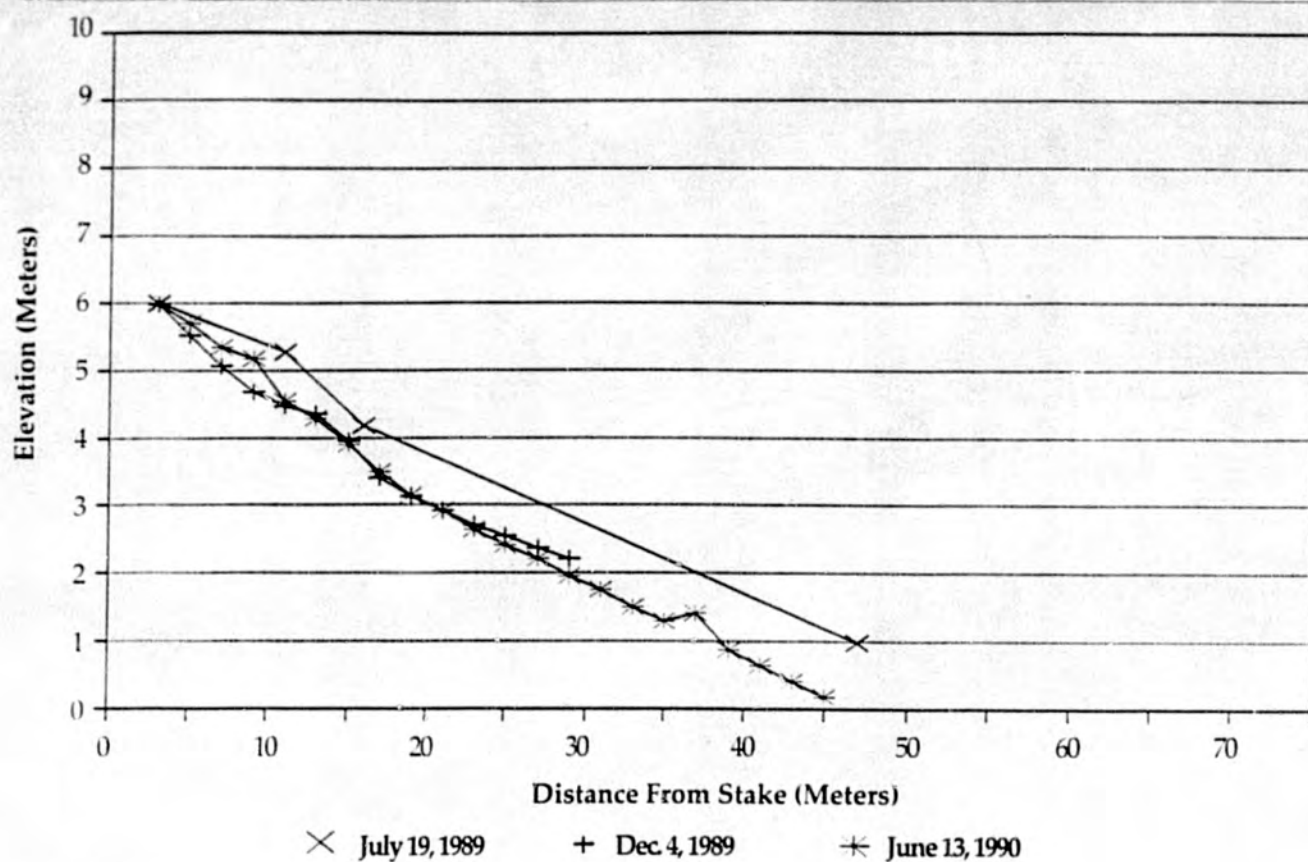


Figure C-5a
Elevation Profile/AK-2, Transect 3

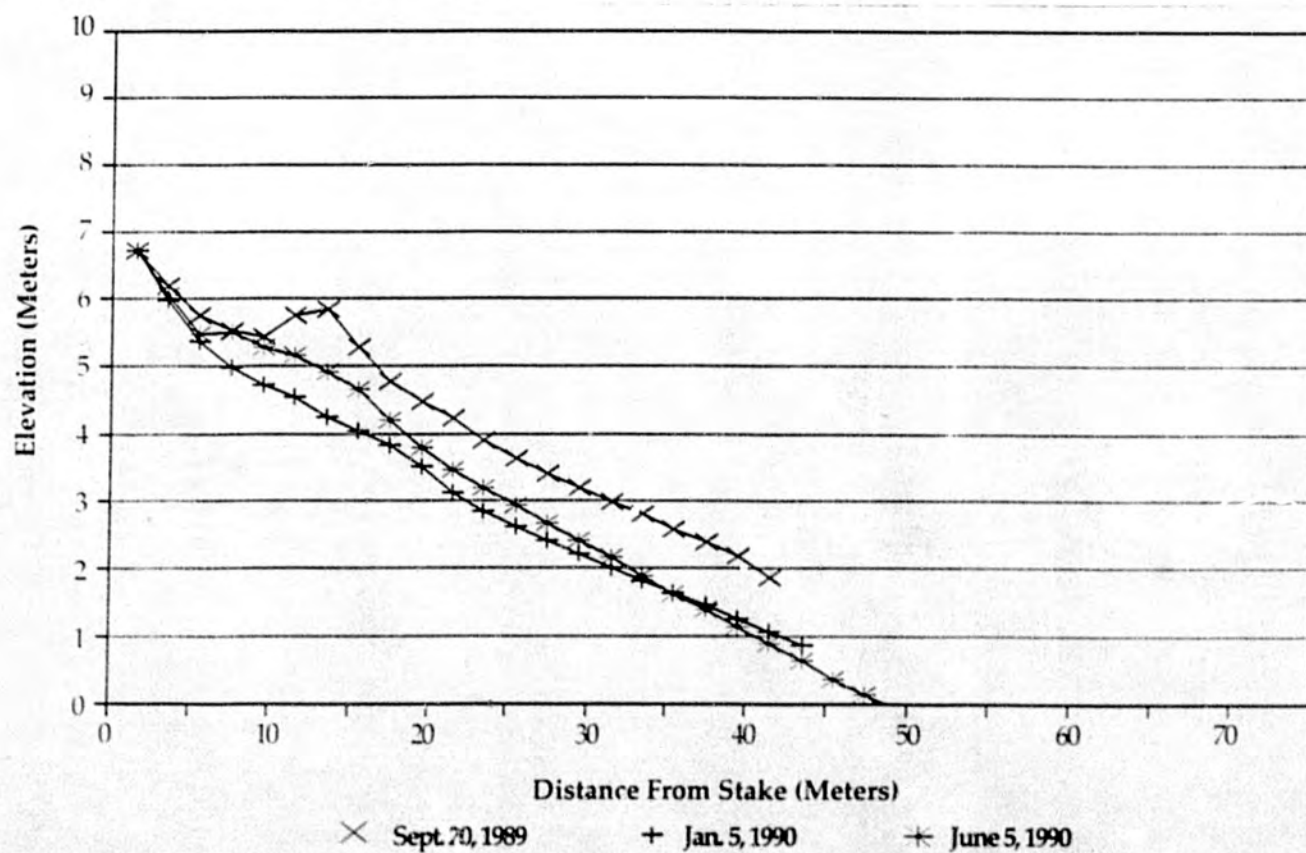


Figure C-5b
Elevation Profile/AK-2, Transect 7

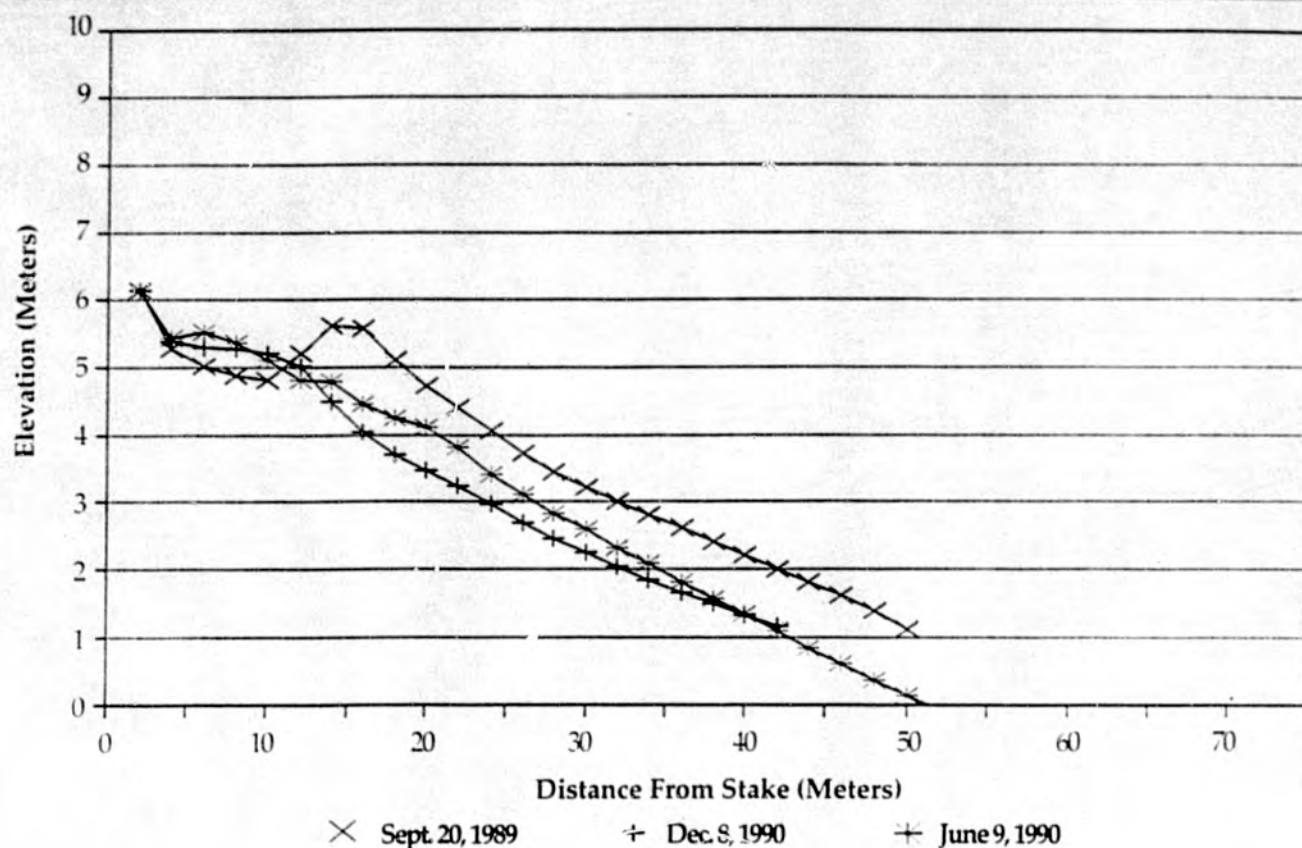


Figure C-6
Elevation Profile/AK-3, Transect 8

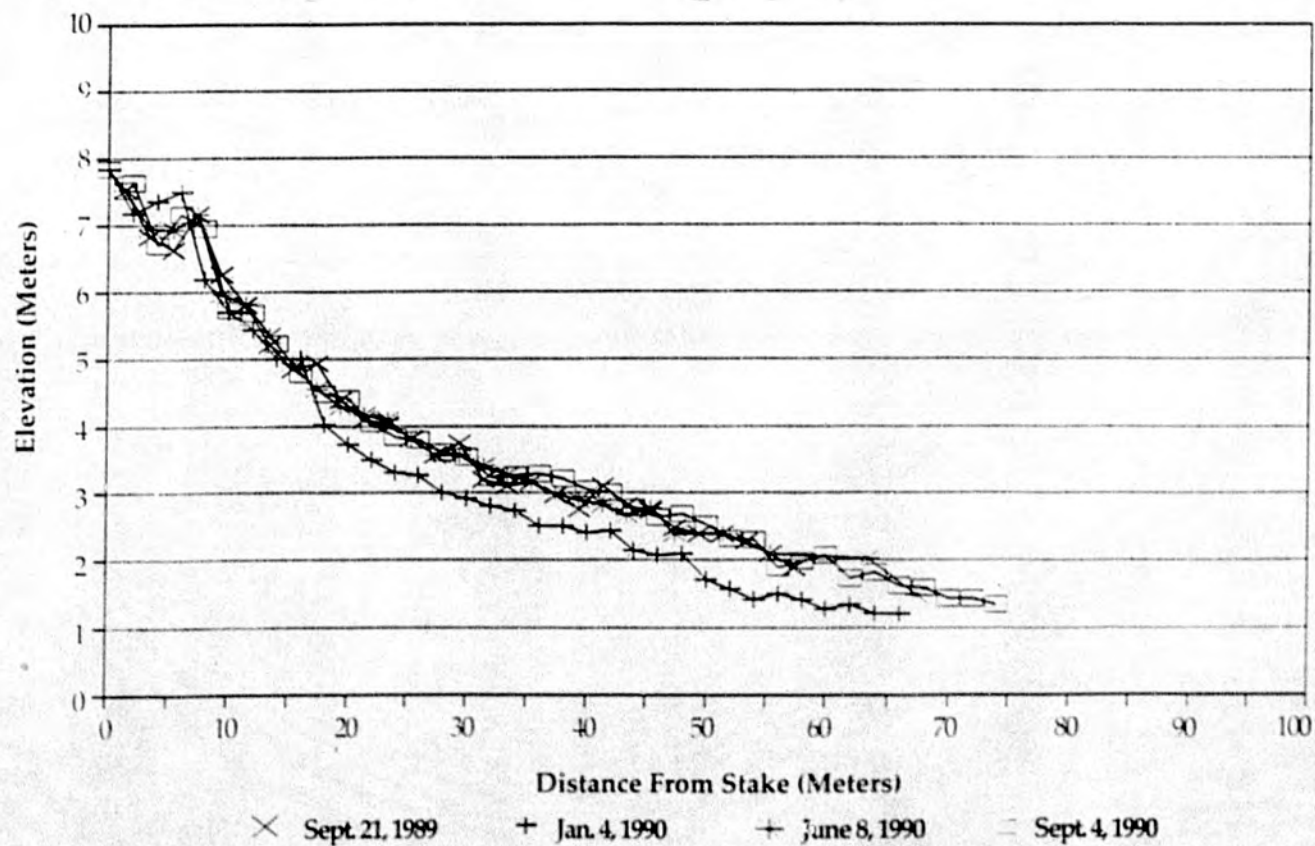


Figure C-7
Elevation Profile/AK-5, Transect 6

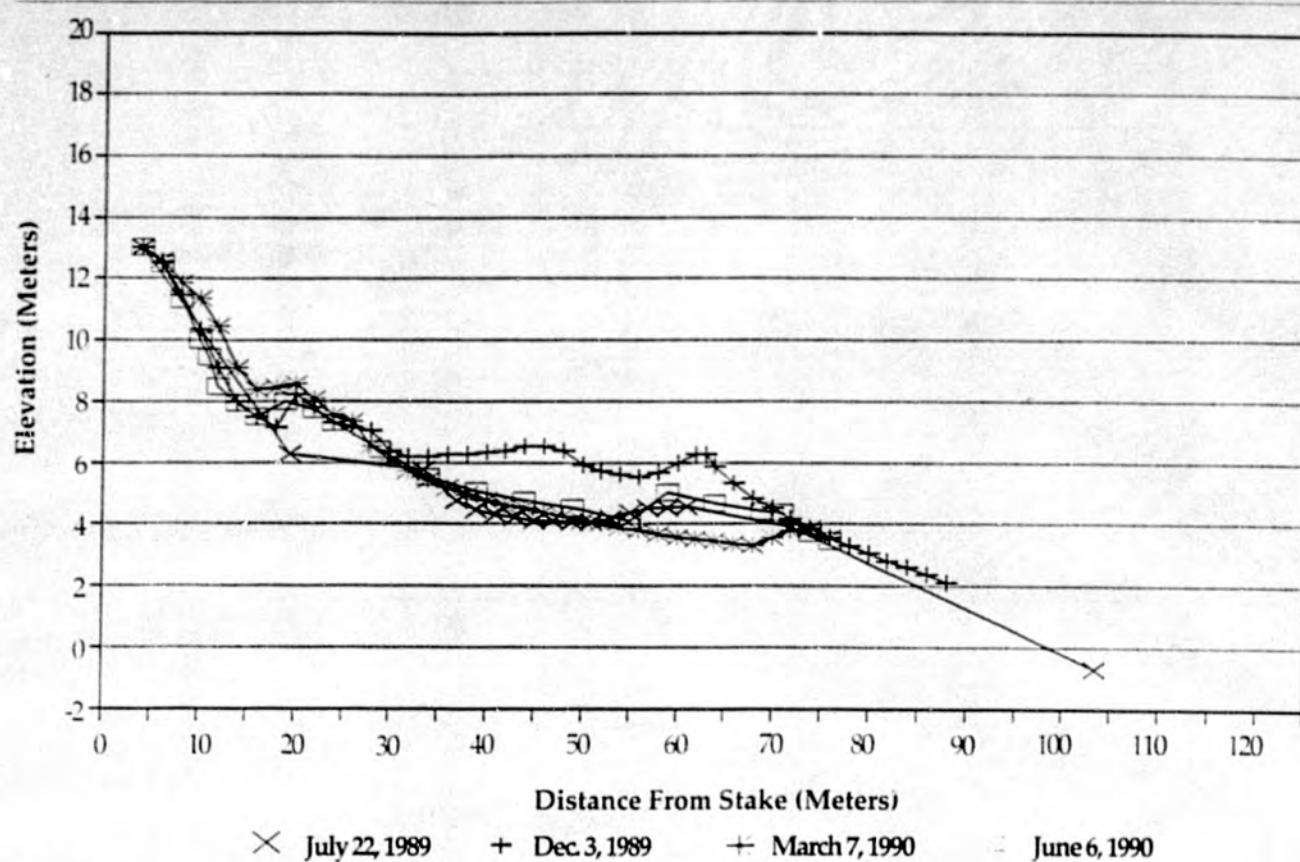
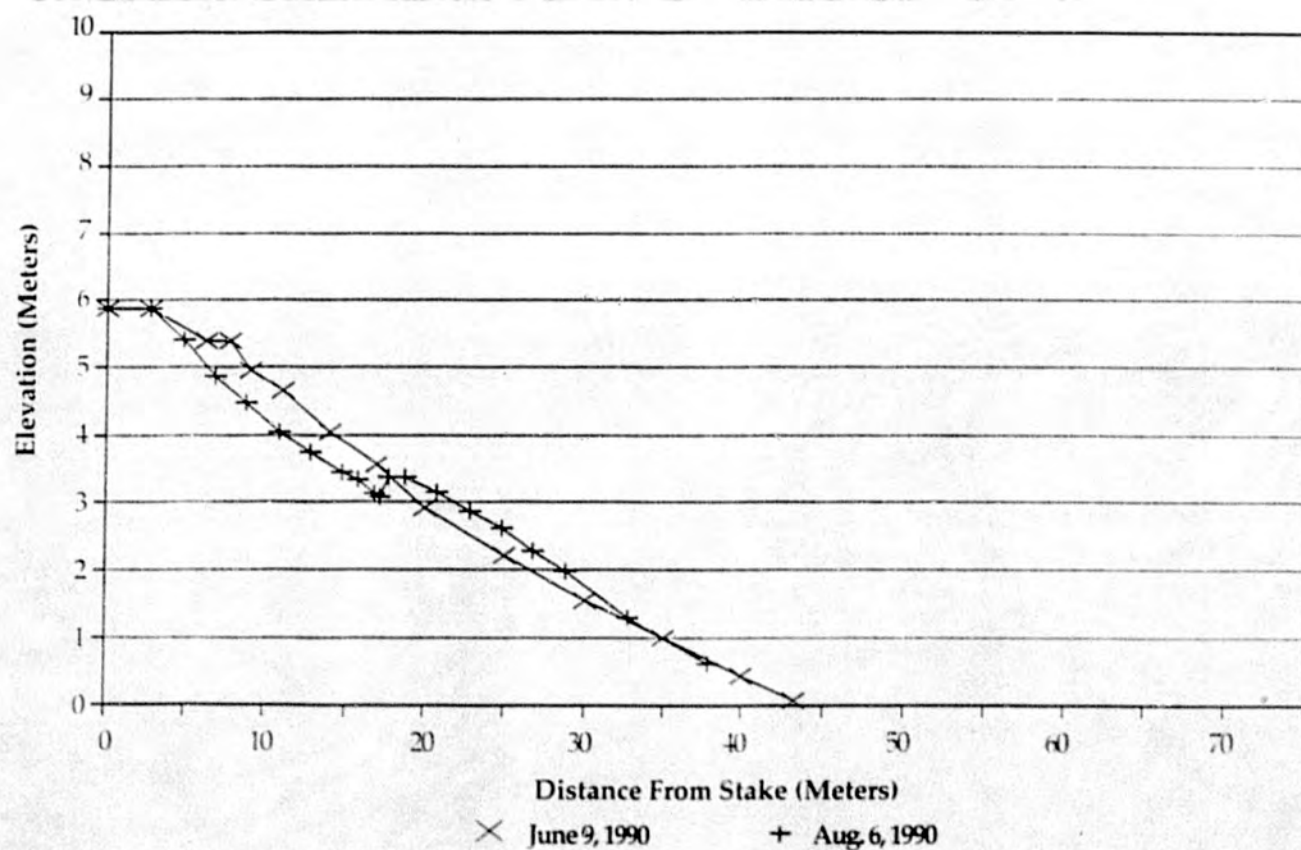


Figure C-8
Pre- and Post-Berm Relocation Profiles/AP-13W, Transect 26



APPENDIX D

Surface Oil Cover Data

This appendix provides data on the observed changes in surface oil cover for each of the primary surveyed sites. All survey dates are given in Table D-1 and the "equivalent oiled area" values in Table D-2, both on the next two pages. The "percent oiled area" values (the equivalent oiled area divided by the total oiled area) for each beach are presented in Table 6, on page 21. Site locations are indicated on the maps in Appendix A.

Maps indicating changes in surface oil cover are shown for selected sites discussed in the text. Surface oil cover data were collected along the transects shown as numbered solid lines crossing the beaches. In cases where data were not collected during a given survey, the transect lines are dashed. Surface oil cover is expressed as a percent of the total observed beach surface and is interpolated between transects. Field observations of surface oil cover were made to the nearest 5 percent, and these values have been grouped into five categories on the maps for illustration purposes. The shoreline at each site is approximated by the mean high water (MHW) line.

Table D-1
Oil Cover Survey Dates

SITE	1989							1990			
AP-1	-	6/24	8/29	9/16	10/15	11/10	12/4	-	3/9	6/5	9/2
AP-2	-	6/23	8/29	9/20	10/14		12/4	1/2		6/5	9/3
AP-3	5/17	7/6	8/28	9/21	-	11/11	-	-		-	-
AP-4	-	-	8/22	9/15	10/15		12/4	1/9	3/1	6/10	9/3
AP-5	5/15	7/6	8/23	-	10/19		12/3	-	3/2	6/6	-
AP-6	-	-	8/21	9/16	10/19		-	1/2	3/2	6/5	9/1
AP-7	-	7/2	8/19	9/20	10/18		-	1/6	3/6	6/12	-
AP-8	-	7/2	8/19	9/20	10/18	11/10	-	1/6	3/6	6/12	9/1
AP-9	-	7/5	8/16	-	-		-	-	3/3	-	-
AP-10	-	7/5	8/16	9/17	10/16		-	1/5	3/3	6/6	9/5
AP-11	5/12	6/17	8/17	9/19	10/17		-	-	3/3	6/13	-
AP-12	5/12	6/17	8/15	9/19	10/20	11/7	12/5	1/7	3/6	6/9	9/9
AP-13E	5/9	6/16	8/14	-	-		12/8	-	3/4	6/8	9/4
AP-13C	5/10	6/16	8/14	-	10/20		12/8	-	3/4	6/8	9/4
AP-13W	5/11	6/17	8/14	-	10/17	11/7	-	1/4-5	3/4	6/9	9/4
AP-14	5/16	6/18	8/14	9/20	-		12/7	1/6	3/7	6/13	9/2
AP-15	-	6/28	8/27	-	-		-	-	3/3	6/7	9/3
AP-16	-	6/27	8/10	9/18	10/19		12/14	1/4	3/3	6/7	9/8
AP-17	-	6/26	8/8	9/18	10/19		12/5	1/5	3/3	6/7	-
AP-18	-	6/26	8/9	9/17	10/16		12/5	1/4	3/3	6/7	9/3
AH-1	-	7/25		9/17	10/17	11/10	12/5	-	3/3	6/11	-
AH-2	-	7/18		9/15	10/17	11/10	12/5	-	3/8	6/11	9/8
AH-3	-	7/19		9/22	10/15	11/8	12/4	1/2	3/3	6/13	-
AH-4	-	7/19		9/16	10/15	11/8	12/4	1/2	3/8	6/12	-
AK-1	-	-	8/4	9/20	10/18	11/13	12/8	1/5	3/3*	6/7	9/2
AK-2	-	7/31		9/20	10/18	11/13	12/8	1/5	3/3	6/9	-
AK-3	-	-	8/1	9/21	10/19	11/15	-	1/4	3/4	6/8	9/4
AK-4	-	-	8/4	9/21	10/19	11/15	-	1/4	3/4	6/8	-
AK-5	-	7/22		-	10/14		12/3	-	3/7	6/6	9/7
AS-1	-	-		-	10/16	11/11	12/7	1/3	3/8*	6/5	9/1

Note: Site AP-13 was subdivided into three sections (East, Central and West) but is considered as a "single" site in most instances.

- Site not visited.

* Site visited but no measurement taken.

Table D-2

Oil Cover Surveys / Equivalent Oiled Area Data (Square Meters)

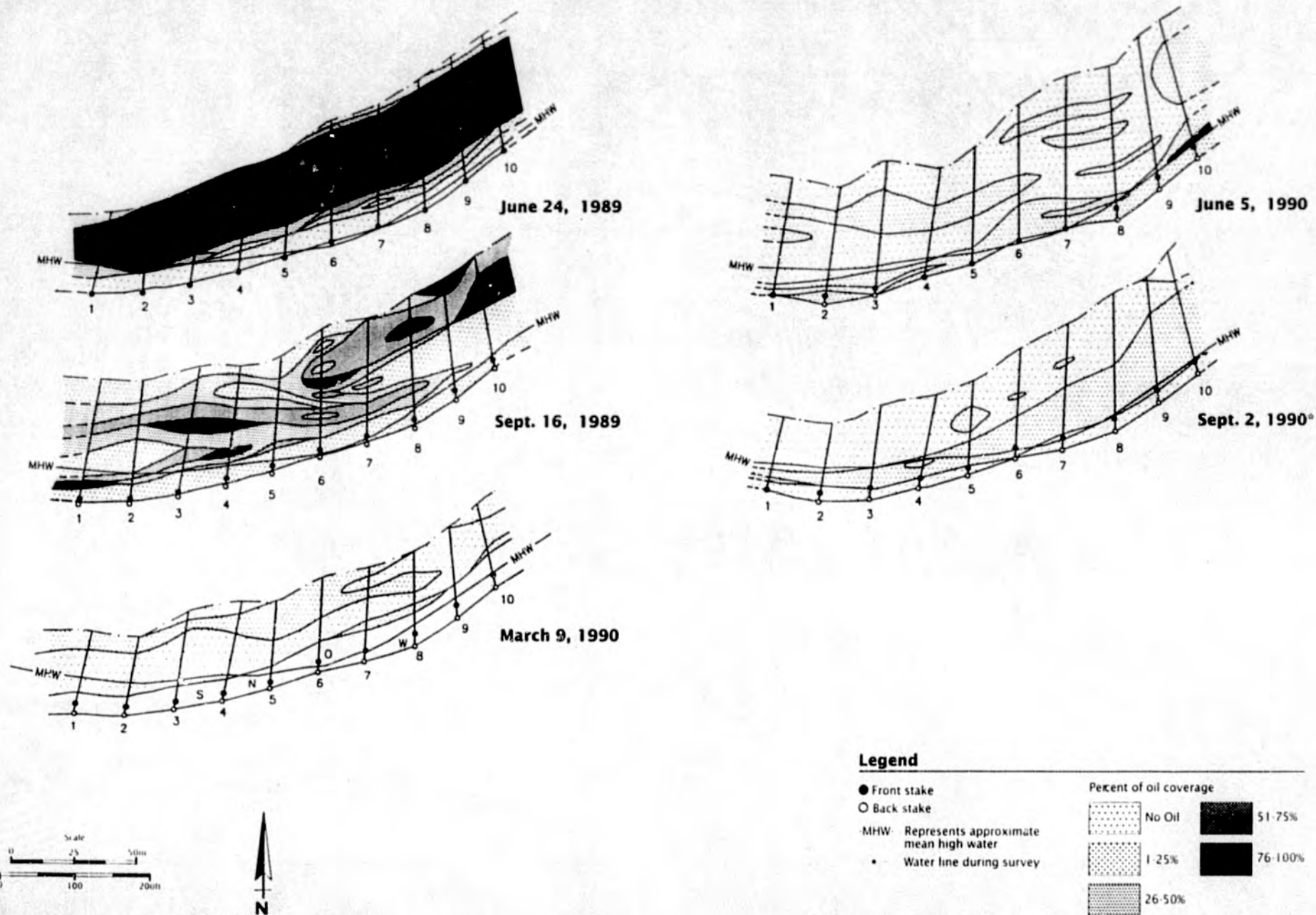
SITE	5/89	6-7/89	8/89	9/89	10/89	11/89	12/89	1/90	3/90	6/90	9/90
AP-1	-	1,565	827	386	357	238	77	-		49	40
AP-2	-	1,073	852	614	644		518	180		181	97
AP-3	204	191	119	119	-		-	-		-	-
AP-4	-	-	507	535	416		387	118		55	27
AP-5	959	364	405	-	67		153	-		38	-
AP-6	-	-	120	124	68		-	48		28	6
AP-7	-	220	183	199	184		-	83		51	-
AP-8	-	962	789	795	285		-	302		134	93
AP-9	-	1,151	1,003	-	-		-	-		-	-
AP-10	-	996	951	877	363		-	438		126	78
AP-11	504	509	477	530	123		-	-		10	-
AP-12	2,037	1,549	1,863	740	455	474	864	496		204	878
AP-13E	1,177	935	818	-	-		368	-	703	81	28
AP-13C	734	872	1,074	-	725		695	-		260	470
AP-13W	536	300	604	-	38		-	3		13	40
AP-14	756	789	596	352	-		311	130		115	10
AP-15	-	605	212	-	-		-	-		19	6
AP-16	-	411	281	228	135		9	30		22	11
AP-17	-	348	179	243	103		34	27		5	-
AP-18	-	690	434	393	98		129	53		49	28
AH-1	-	39		51	0	18	0	-		0	-
AH-2	-	614		918	166	11	110	-		1	22
AH-3	-	0		10	0	0	3	0.4		0	-
AH-4	-	204		192	99	18	3	1.6		1	-
AK-1	-	-	366	317	51		56	66		37	42
AK-2	-	46		16	6		0	0		0	-
AK-3	-	-	175	189	395		-	102		131	67
AK-4	-	-	507	580	43		-	33		17	-
AK-5	-	451		-	283		487	-		27	237
AS-1	-	-		-	360	351	308	330		246	68

Note: Site AP-13 was subdivided into three sections (East, Central and West) but is considered as a "single" site in most instances.

- Site not visited.

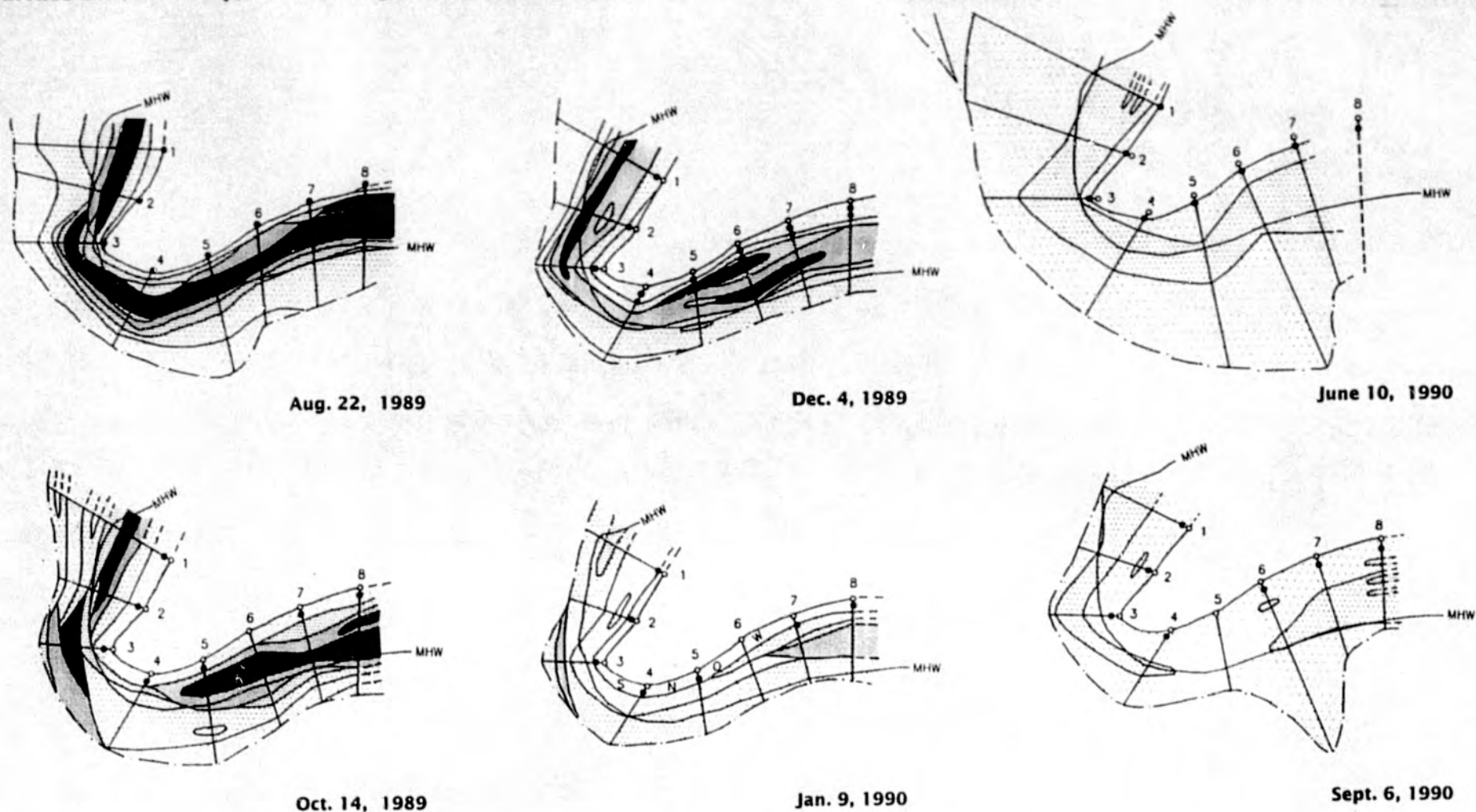
* Site visited but no measurement taken.

Figure D-1
Surface Oil Cover Map/Northeast Smith Island, Site AP-1



*After 1990 berm relocation

Figure D-2
Surface Oil Cover Map/Foul Pass - Ingot Island, Site AP-4



Legend

- Front stake
- Back stake

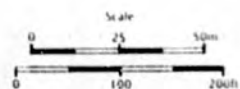
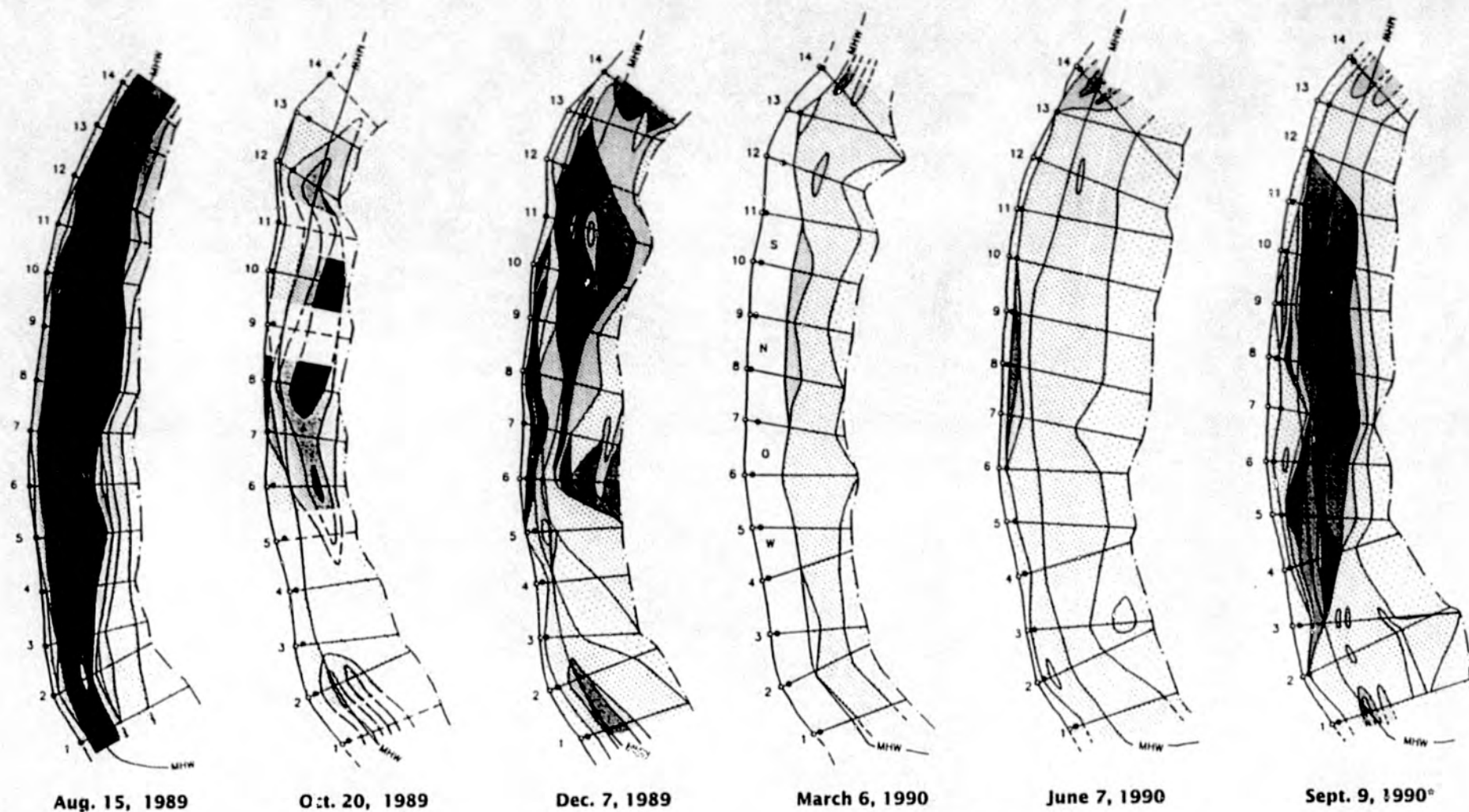
MHW Represents approximate mean high water

--- Water line during survey

Percent of oil coverage

No Oil	51-75%
1-25%	76-100%
26-50%	

Figure D-3
Surface Oil Cover Map/Northeast Latouche Island - North, Site AP-12



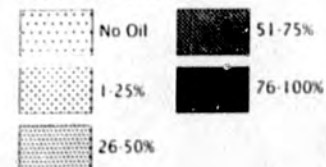
Legend

- Front stake
- Back stake

MHW: Represents approximate mean high water

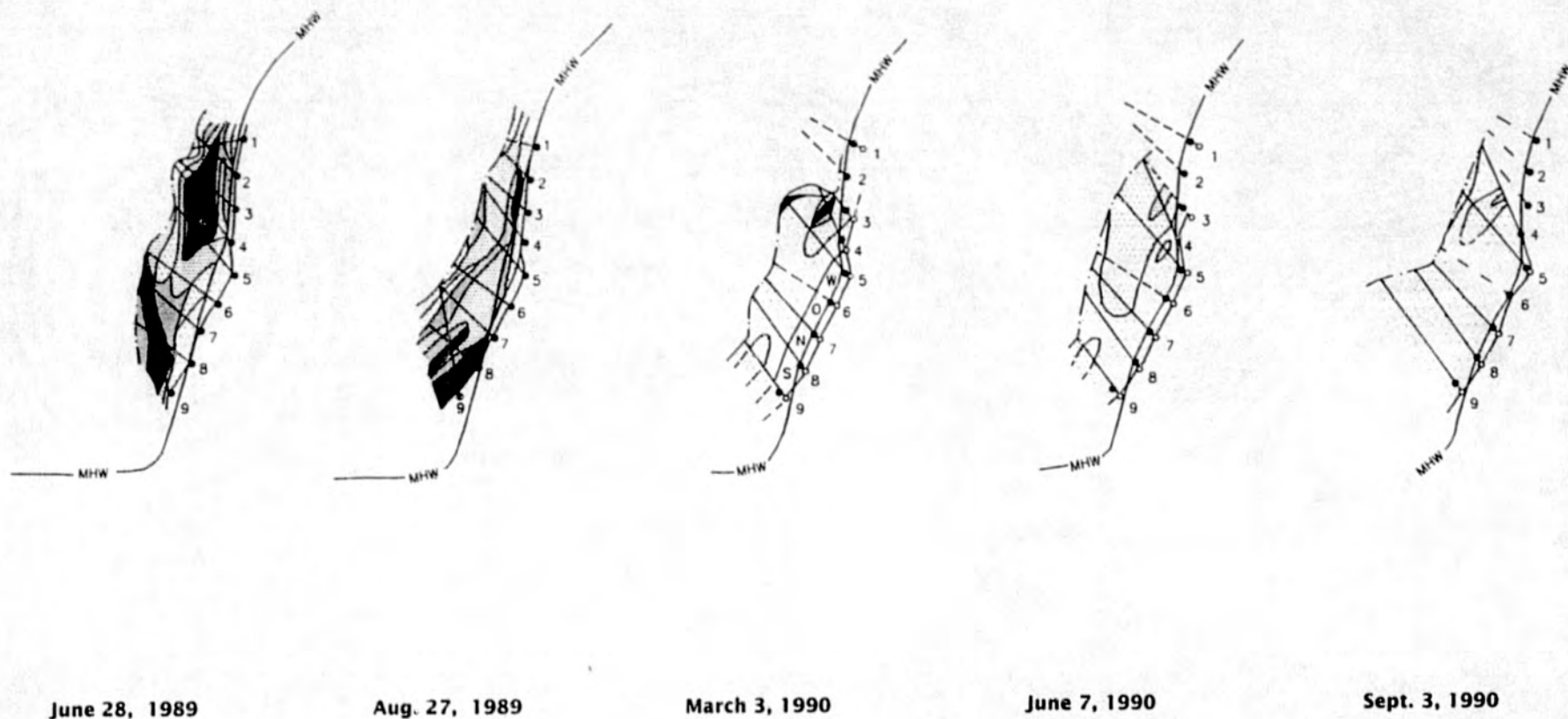
- Water line during survey

Percent of oil coverage



*After 1990 berm relocation.

Figure D-4
Surface Oil Cover Map/North Evans Island, Site AP-15



Legend

- Front stake
- Back stake
- MHW Represents approximate mean high water
- Water line during survey

Percent of oil coverage

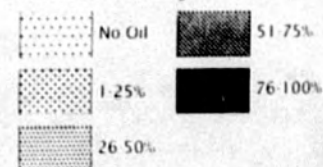
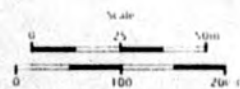
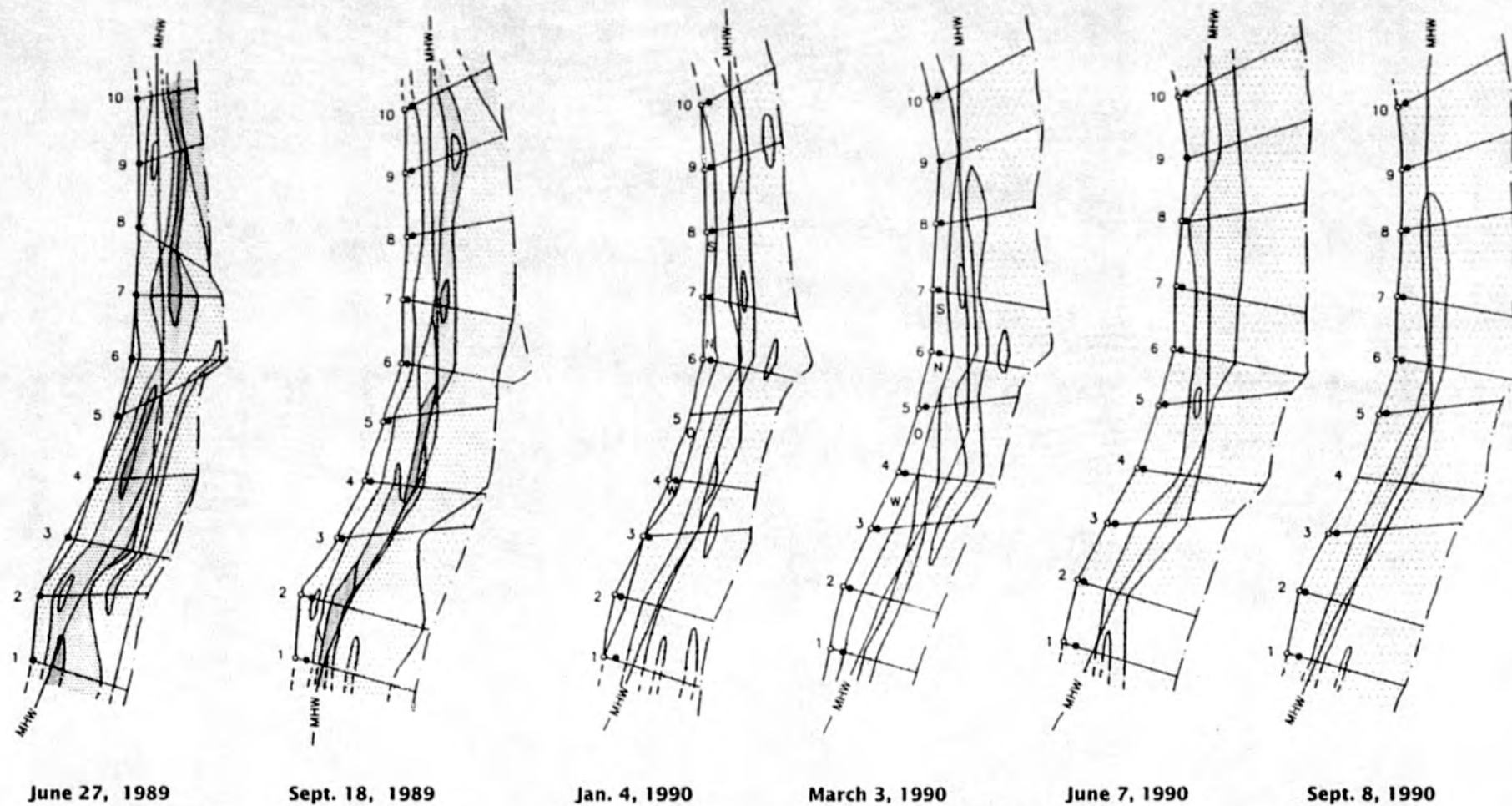


Figure D-5
Surface Oil Cover Map/Southwest Elrington Island - East, Site AP-16



Legend

- Front stake
- Back stake
- MHW Represents approximate mean high water
- Water line during survey

Percent of oil coverage

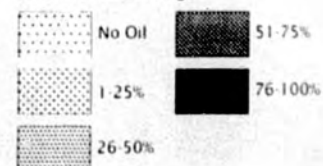
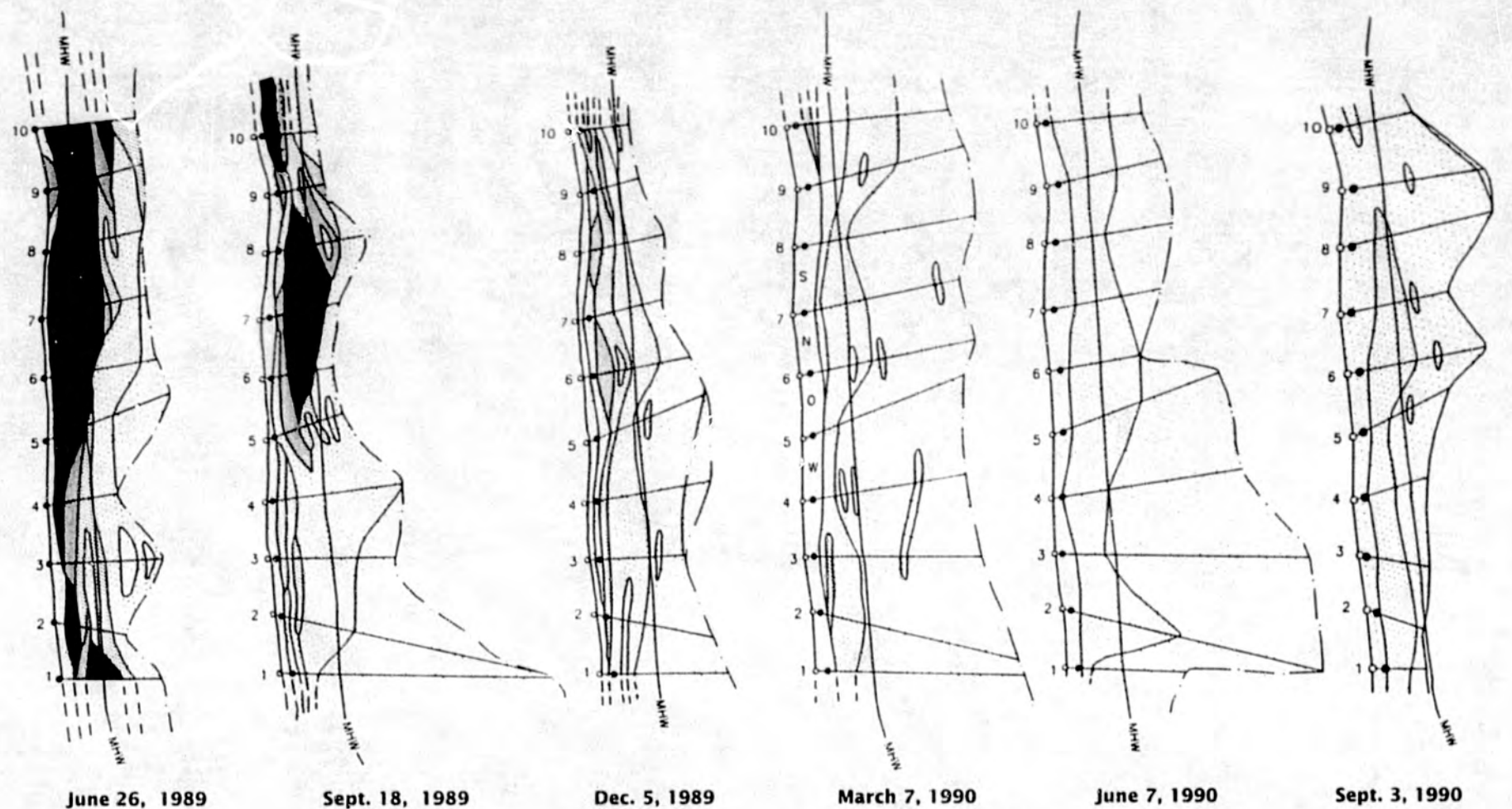


Figure D-6
Surface Oil Cover Map/Southwest Eltrington Island - Southwest, Site AP-18



Legend

- Front stake
- Back stake
- MHW Represents approximate mean high water
- Water line during survey

Percent of oil coverage

No Oil	51-75%
1-25%	76-100%
26-50%	

D-10 Figure D-7
Surface Oil Cover Map/North Windy Bay, Site AH-2

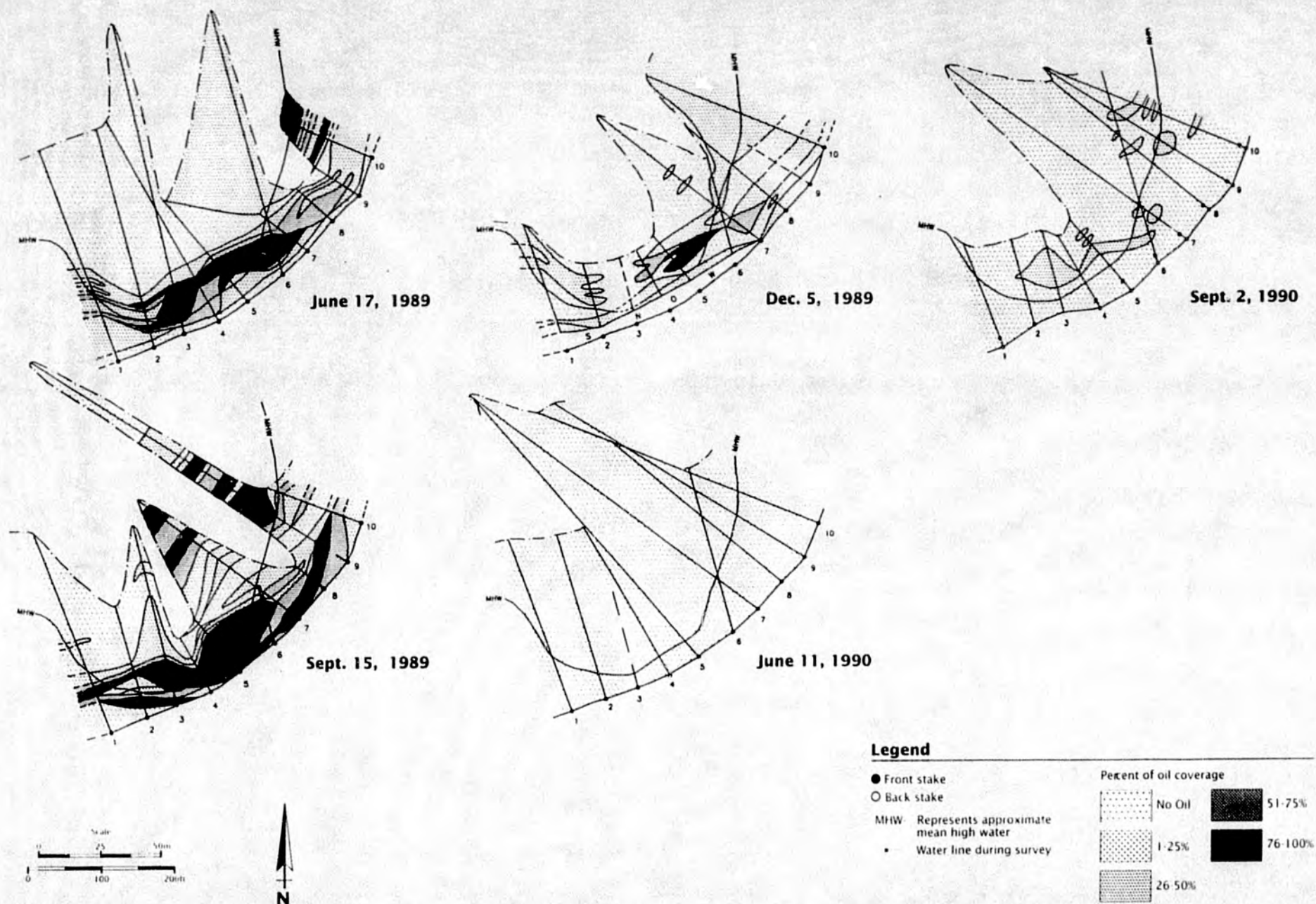
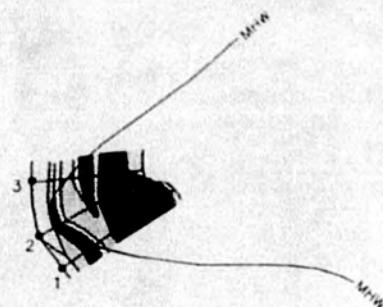
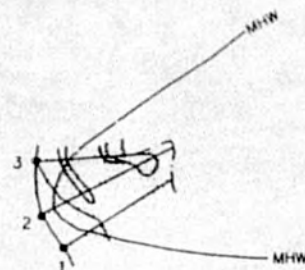


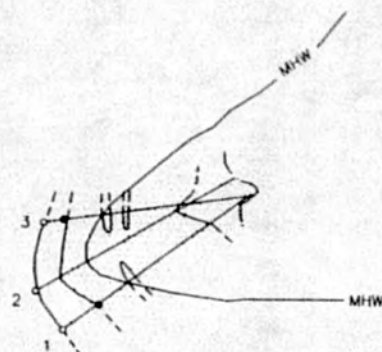
Figure D-8
Surface Oil Cover Map/Perevalnie Point, Site AK-1



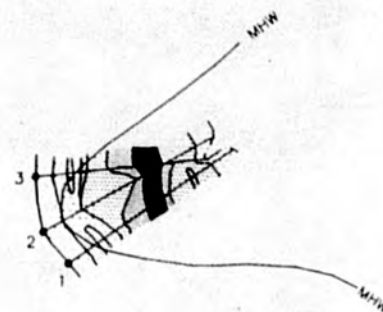
Aug. 4, 1989



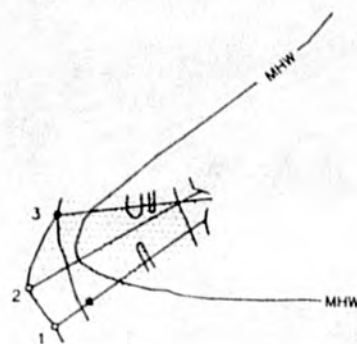
Nov. 13, 1989



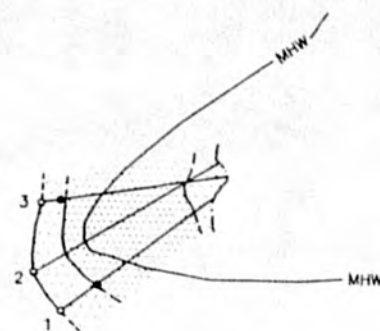
June 7, 1990



Sept. 20, 1989



Jan. 5, 1990

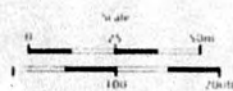
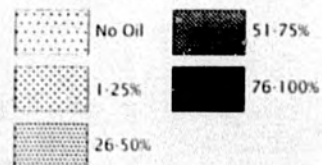


Sept. 2, 1990

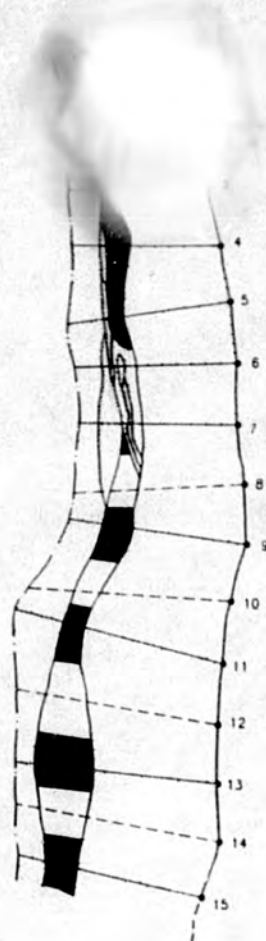
Legend

- Front stake
- Back stake
- MHW: Represents approximate mean high water
- Water line during survey

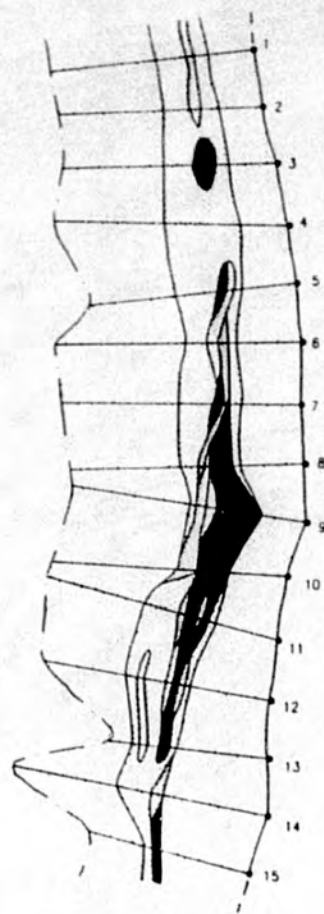
Percent of oil coverage



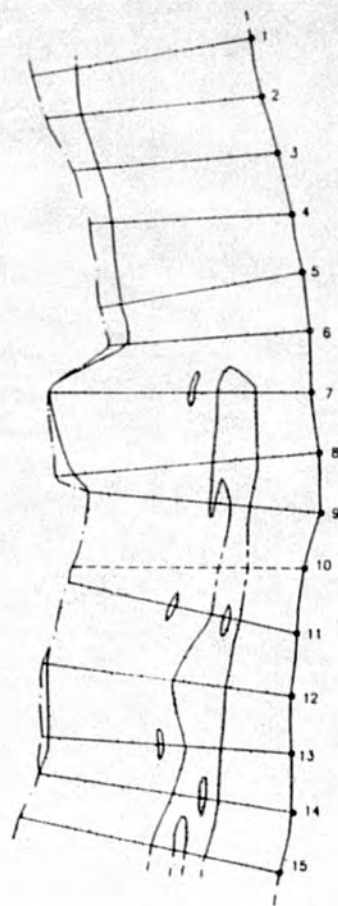
D-12 Figure D-9
Surface Oil Cover Map/Ushagat Island, Site AK-5



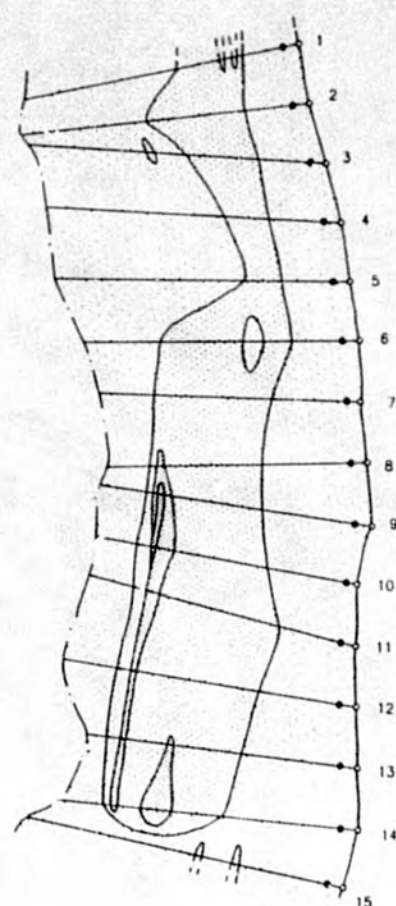
July 24, 1989



Dec. 3, 1989



June 6, 1990



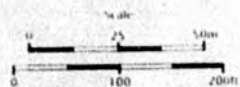
Sept. 7 & 10, 1990*

Legend

- Front stake
- Back stake
- MHW Represents approximate mean high water
- Water line during survey

Percent of oil coverage

No Oil	51-75%
1-25%	76-100%
26-50%	



*After 1990 berm relocation.

APPENDIX E

Seal Island Wind Data

The Seal Island wind data (obtained from the National Oceanic and Atmospheric Administration) provide a picture of winter conditions for the sites in Prince William Sound near the center of the study area (Figure 3, on page 7). The data are not directly affected by the bursts of cold dense air (katabatic winds) that occasionally spill over the coastal mountains during winter. These katabatic winds provide a different wind regime at stations, such as Port Valdez, in the north of the Sound.

Seal Island Wind Data

Wind data for Seal Island are illustrated in Figures E-1a and E-1b, on pages E-4 and E-5. During the winter months (September 1989 to April 1990), the Sound had six major storms and 12 storms of lower intensity (Tables E-1 and E-2, on the next page). The distinction between the two categories is based on wind speed, duration, and the directional consistency of the winds for a sustained period of time.

The major storms were:

Oct. 4-8, 1989:	out of the SE for 5 days
Oct. 15-21, 1989:	out of the SE through NW for 7 days
Nov. 6-10, 1989:	out of the N for 5 days
Nov. 21-23, 1989:	out of the SE for 3 days
Dec. 1-12, 1989:	out of the NE through SE for 12 days
Dec. 27-31, 1989:	out of the SE through NW for 5 days

These storm winds generated waves primarily from eastern directions with a secondary northern component.

The lower intensity storms occurred in the second half of the winter, with three in both January and February 1990. These storms had winds primarily out of the NW to NE and out of the NE to SE (Table E-2, on the next page).

Table E-1
Major Storms

Dates	Maximum Average Wind Speed (km/h)	Peak Wind Speed (km/h)	Direction	Dates of Spring Tides > 4 meters*
Oct. 4-8, 1989	43	88	Southeast-Southwest	-
Oct. 15-21, 1989	60	93	East-Southeast-North-Northwest	Oct. 15-19
Nov. 6-10, 1989	60	85	Northwest-North	Nov. 10
Nov. 21-23, 1989	51	135	East-Southeast	-
Dec. 1-12, 1989	48	111	Northeast-Southeast	Dec. 9-12
Dec. 27-31, 1989	52	111	Southeast-Southwest-Northwest	Dec. 27-30

- Predicted high water levels < 4 m.

* Predicted spring high water levels at Cordova.

Table E-2
Secondary Storms

Dates	Maximum Average Wind Speed (km/h)	Peak Wind Speed (km/h)	Direction	Dates of Spring Tides > 4 meters*
Sept. 23-24, 1989	41	98	Southeast	-
Oct. 25-28, 1989	38	87	Northwest-Southeast	-
Dec. 24-25, 1989	52	111	Southeast-Southwest	-
Jan. 8-11, 1990	37	80	Northwest-East	Jan. 8-11
Jan. 17-19, 1990	31	63	Northwest-North	-
Jan. 29-31, 1990	32	61	North-Northeast	Jan. 29-31
Feb. 5-8, 1990	38	63	North	Feb. 7-8
Feb. 13-14, 1990	39	70	Northeast-South	-
Feb. 26-27, 1990	40	80	West-Northwest	Feb. 26-27
March 6-8, 1990	36	61	Southwest-Northwest	-
March 26-28, 1990	40	82	East	March 26-28
April 3-5, 1990	31	87	West	-

- Predicted high water levels < 4 m.

* Predicted spring high water levels at Cordova.

Figure E-1a
Seal Island Wind Data / September 1989 to June 1990

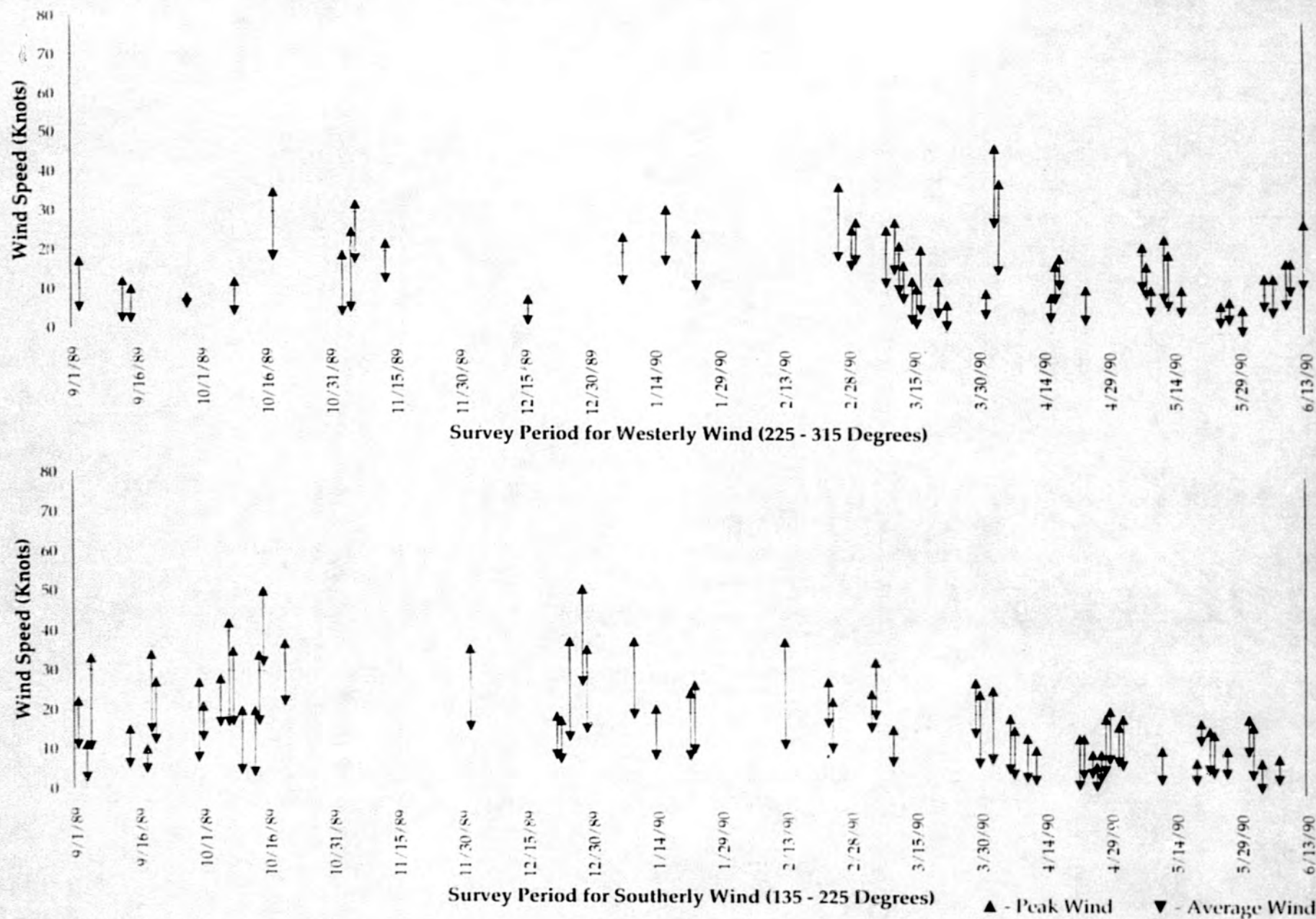
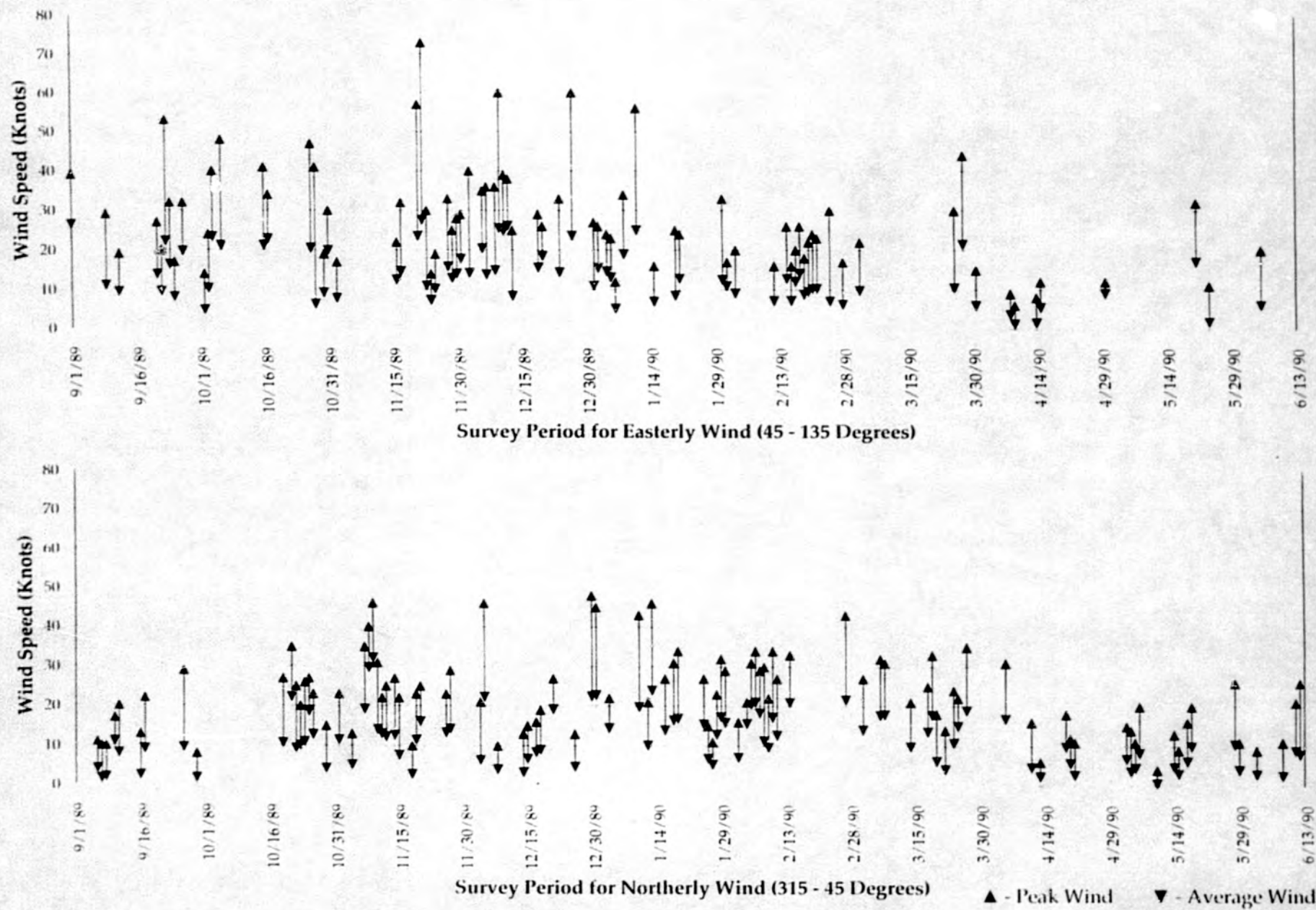


Figure E-1b
Seal Island Wind Data / September 1989 to June 1990



CORRECTION

**THIS DOCUMENT
HAS BEEN REPHOTOGRAPHED
TO ASSURE LEGIBILITY**

Table E-1
Major Storms

Dates	Maximum Average Wind Speed (km/h)	Peak Wind Speed (km/h)	Direction	Dates of Spring Tides > 4 meters*
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Oct. 15-21, 1989	60	93	East-Southeast-North-Northwest	Oct. 15-19
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Nov. 21-23, 1989	51	135	East-Southeast	-
Dec. 1-12, 1989	48	111	Northeast-Southeast	Dec. 9-12
Dec. 27-31, 1989	52	111	Southeast-Southwest-Northwest	Dec. 27-30

- Predicted high water levels < 4 m.

* Predicted spring high water levels at Cordova.

Table E-2
Secondary Storms

Dates	Maximum Average Wind Speed (km/h)	Peak Wind Speed (km/h)	Direction	Dates of Spring Tides > 4 meters*
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Jan. 8-11, 1990	37	80	Northwest-East	Jan. 8-11
Jan. 17-19, 1990	31	63	Northwest-North	-
Jan. 29-31, 1990	32	61	North-Northeast	Jan. 29-31
Feb. 5-8, 1990	38	63	North	Feb. 7-8
Feb. 13-14, 1990	39	70	Northeast-South	-
Feb. 26-27, 1990	40	80	West-Northwest	Feb. 26-27
March 6-8, 1990	36	61	Southeast-Northwest	-
March 26-28, 1990	40	82	East	March 26-28
April 3-5, 1990	31	87	West	-

- Predicted high water levels < 4 m.

* Predicted spring high water levels at Cordova.

Figure E-1a
Seal Island Wind Data / September 1989 to June 1990

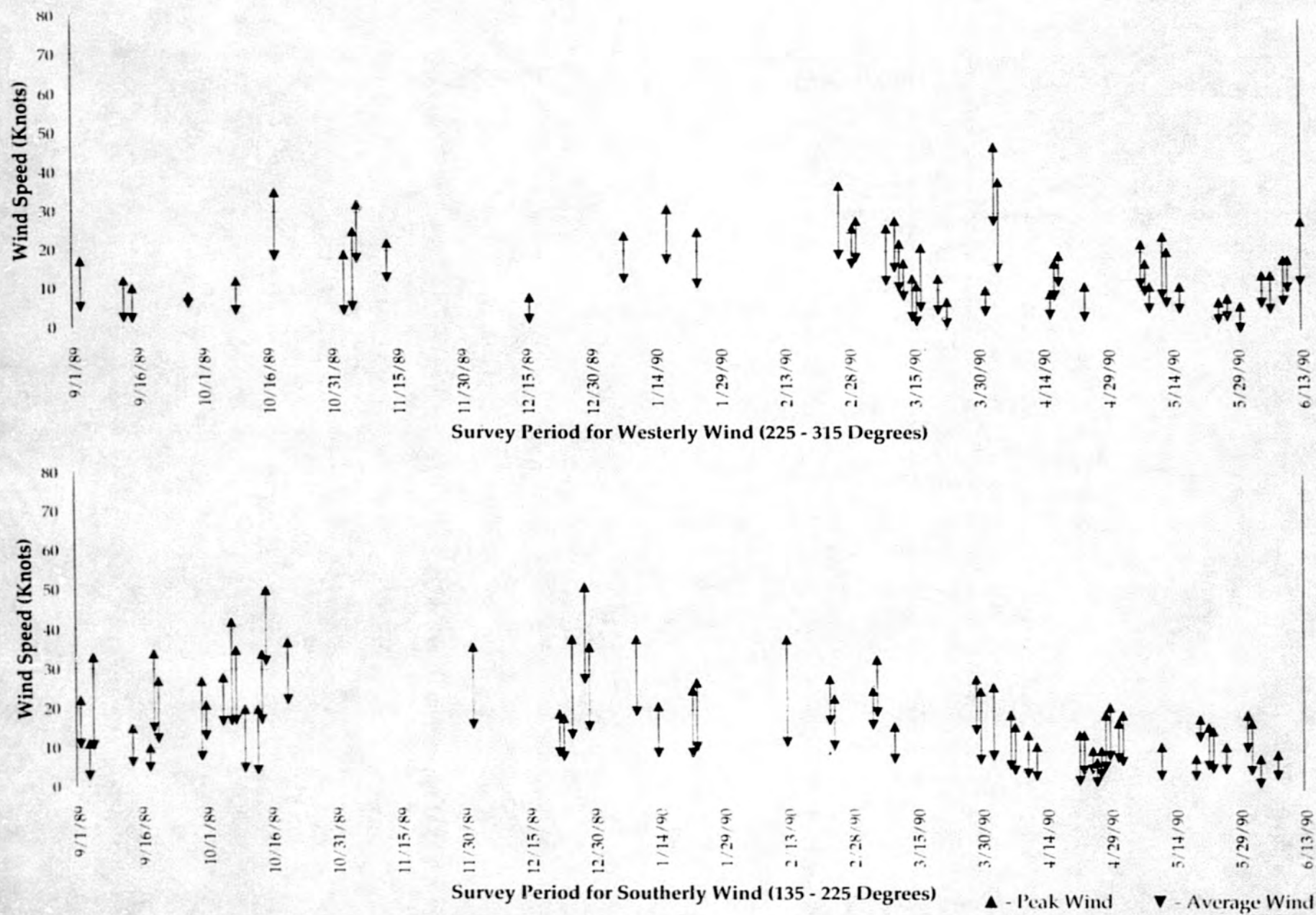
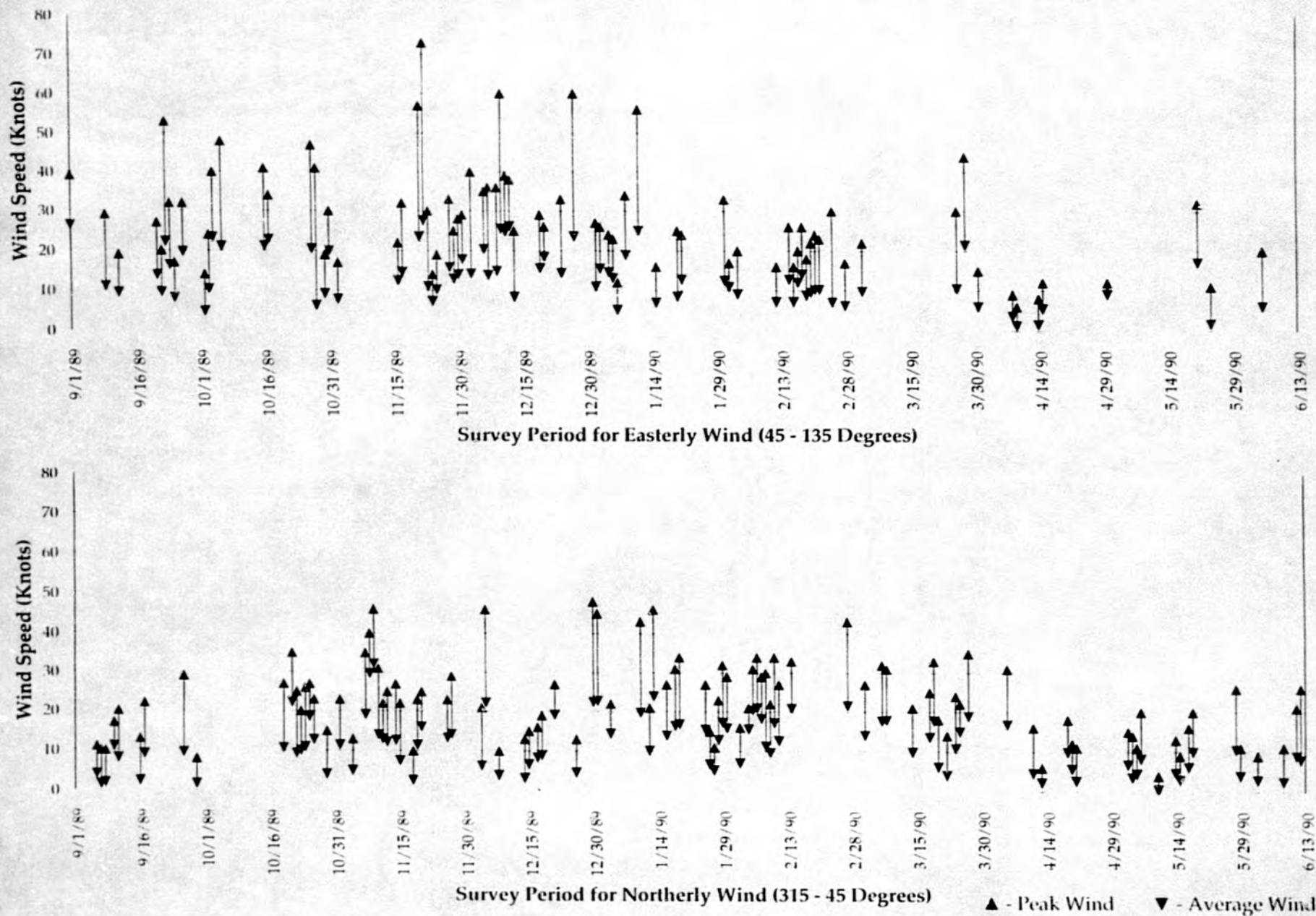


Figure E-1b

Seal Island Wind Data / September 1989 to June 1990



APPENDIX F

Winter Breaker Height Data

Time-lapse photography surveys provided a nearly continuous record of coastal processes and beach changes at five sites in the Sound during daylight hours from mid-November 1989 to mid-April 1990. In addition to three long-term monitoring sites, two other sites (Bay of Isles and Chenega Island) were added to the time-lapse photography surveys. As a group, they represent the various wave-energy environments in the Sound.

Photographs from the Sleepy Bay site appear on pages F-11 and F-12. They represent some of the observed variations at this exposed location.

Winter Breaker Height Data

One component of the image analysis involved an estimate of breaker height. Data from this analysis are summarized as a series of figures (F-1 through F-5) that show the averaged daily breaker height and, at three of the five sites, illustrate when predicted high tides at Cordova exceeded 4 m (Table F-1).

Table F-1
Predicted Spring Tides at Cordova

Periods of Predicted High Tides ≥ 4.0 meters	Highest Predicted Water Level (in meters)
Sept. 14 - 20, 1989	4.6
Oct. 13 - 19, 1989	4.8
Oct. 29 - Nov. 1, 1989	4.1
Nov. 10 - 17, 1989	4.9
Nov. 27 - 30, 1989	4.2
Dec. 9 - 16, 1989	4.7
Dec. 27 - 30, 1989	4.2
Jan. 7 - 13, 1990	4.5
Jan. 26 - 28, 1990	4.2
Feb. 7 - 10, 1990	4.2
Feb. 24 - March 3, 1990	4.3
March 26 - 31, 1990	4.5
April 24 - 29, 1990	4.6
May 25 - 28, 1990	4.6
June 19 - 26, 1990	4.5

At the Sleepy Bay site (AP-13W), breaker heights exceeded 1 m on 12 different occasions between Nov. 11, 1989 and April 12, 1990. Seven of these events were related to storms between Nov. 24, 1989 and Jan. 10, 1990. The large breakers at Sleepy Bay (Figure F-1, on page F-4) on Dec. 12 coincided with a major storm (Table E-1, on page E-3) and spring high tides of 4.4 m (Photographs F-3a and F-3b, on page F-12). The Jan. 10 storm (Table E-2, on page E-3) coincided with predicted high tidal elevations of 4.2 m (Photographs F-2a, b and c, on page F-11). Significant changes were recorded on this beach during these storms, as illustrated in the accompanying photographs, and storms that coincided with high spring tides clearly were capable of reworking the backshore storm berms.

In contrast to Sleepy Bay, the data from northeast Smith Island (AP-1) show that higher breaker heights were concentrated from Dec. 30, 1989 through Feb. 6, 1990 (Figure F-2, on page F-5). The only storm event with breakers greater than 1 m that coincided with spring tides occurred Jan. 8-9, 1990. The difference in observed breaker height data between these two

exposed sites is a function of location within the Sound and the local character of the fetch area. Although winds measured at Seal Island were strongest in the first half of the winter, the shift in the prevailing direction of storm winds from the east toward the north after December caused a decrease in overall wave-energy levels at Sleepy Bay and an increase at northeast Smith Island.

At the sheltered Foul Pass location (AP-4), the average breaker heights exceeded 0.5 m on three occasions (Nov. 22; Dec. 2; and Jan. 11). For a considerable portion of the observation period, wave heights were less than 0.25 m (Figure F-3, on page F-6).

The Chenega Island site presents an example of a further reduction in shoreline wave-energy levels because breaker heights did not reach 0.5 m, exceeded 0.25 m on only one occasion, and were observed to be 0.25 m on five occasions (Figure F-4, on page F-7).

Although there are some long gaps in the time-lapse record for the very sheltered Bay of Isles site (Figure F-5, on page F-8), this location is an example of shoreline processes at the very lowest end of the wave-energy spectrum. No wave heights greater than 0.25 m were observed throughout the observation period.

The summary of the breaker heights over the observation periods (Table F-2) illustrates the difference in wave-energy levels between the five study sites, which are located on Figure F-6, on page F-9.

Table F-2
Summary Of Breaker Height Observations/Days of Estimated Breaker Heights

	Height (meters)						Total Days
	>1.00	0.50 -1.00	0.25 -0.50	<0.25	Calm	No Data	
Northeast Smith Island (AP-1)	11	26	76	38	2	0	153
Sleepy Bay (AP-13W)	12	20	78	43	0	0	153
Foul Pass, Ingot Island (AP-4)	0	3	21	49	81	0	154
Chenega Island	0	0	6	58	87	2	153
Bay of Isles	0	0	0	31	52	48	131

Figure F-1

Estimated Breaker Heights for AP-13W, Sleepy Bay/Time Lapse Video Survey (11/11/89 - 4/12/90)

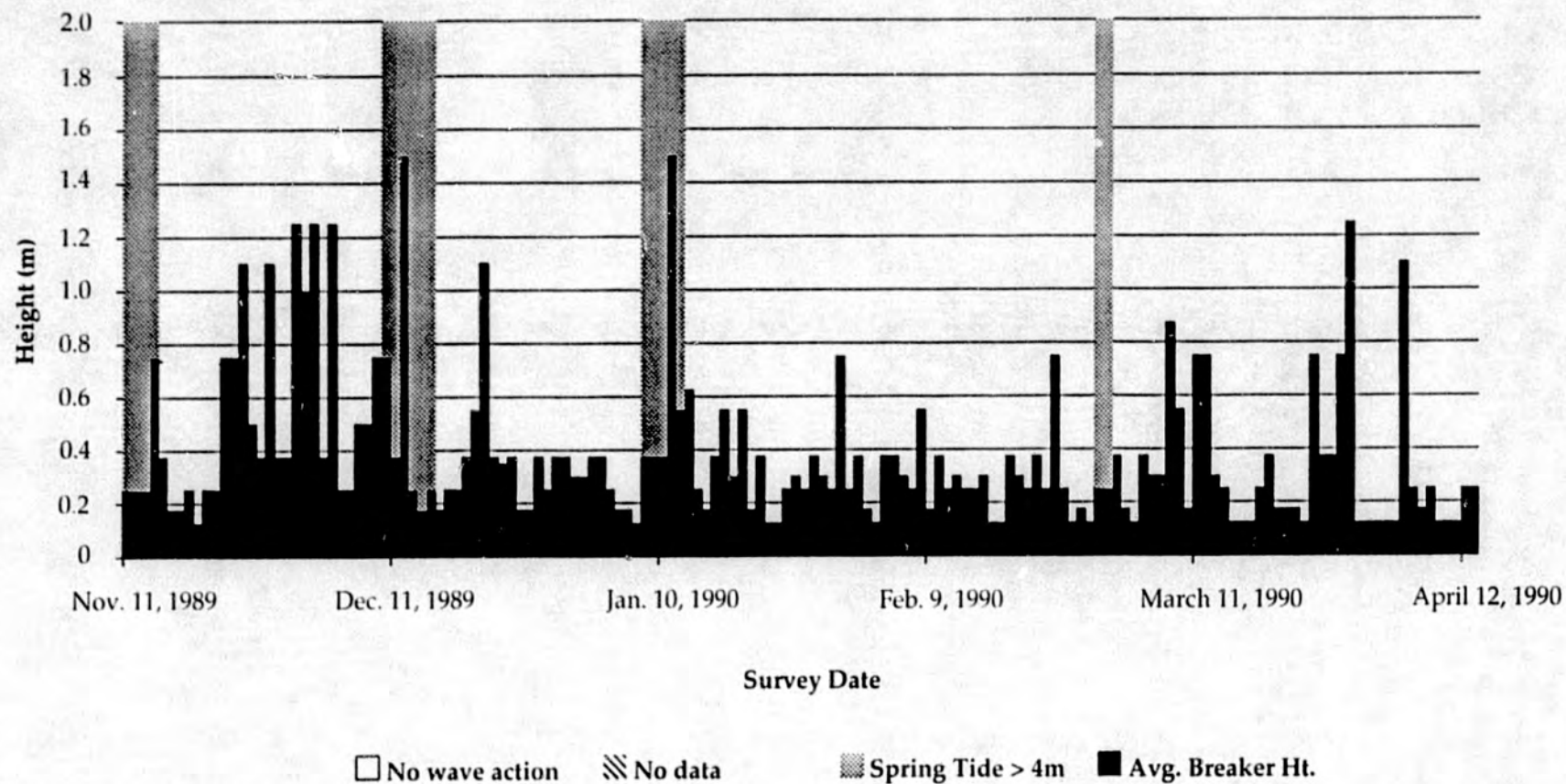


Figure F-2

Estimated Breaker Heights for AP-1, Northeast Smith Island/Time Lapse Video Survey (11/12/89 - 4/11/90)

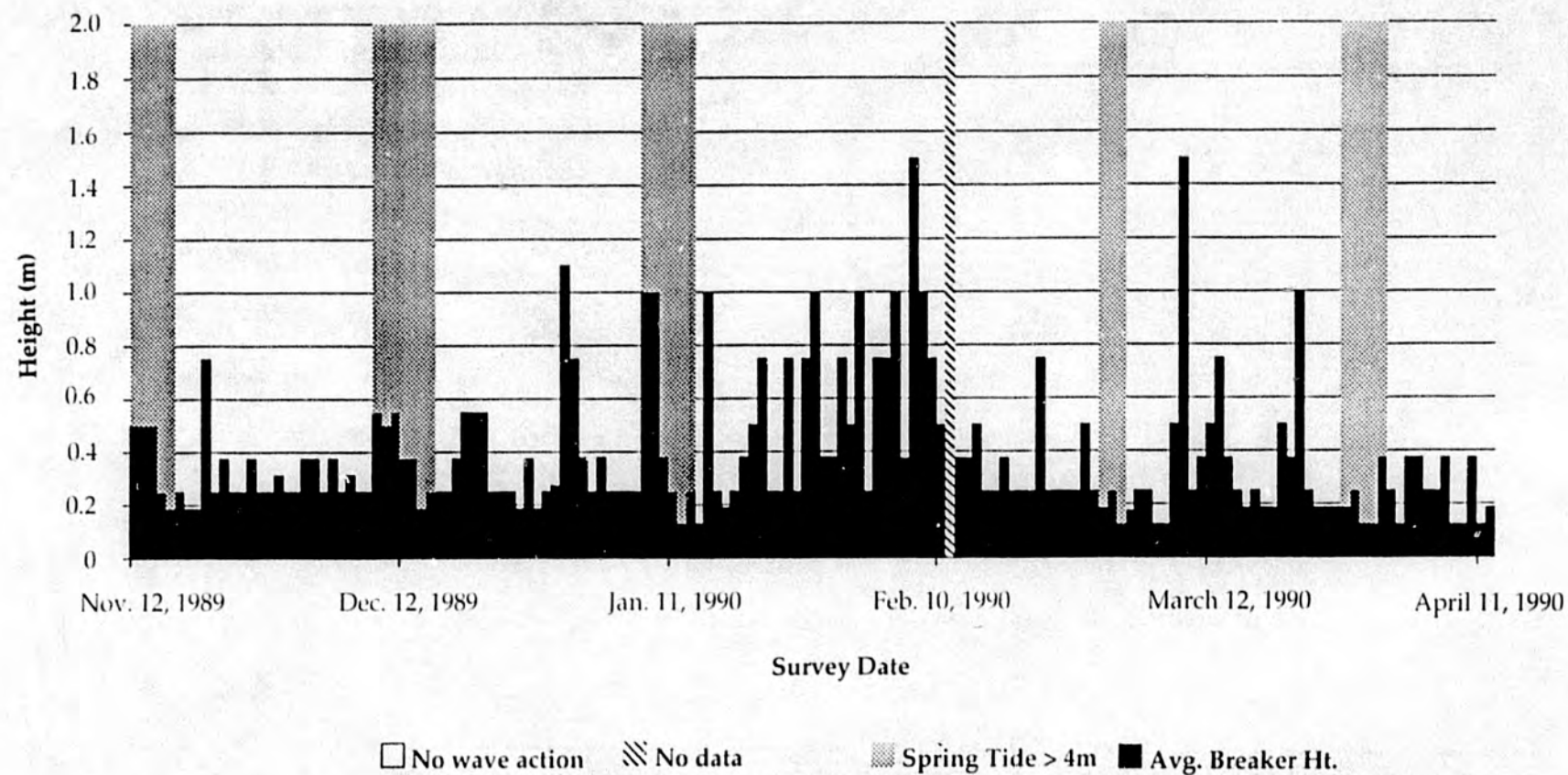


Figure F-3

Estimated Breaker Heights for AP-4, Foul Pass, Ingot Island/Time Lapse Video Survey (11/9/89 - 4/8/90)

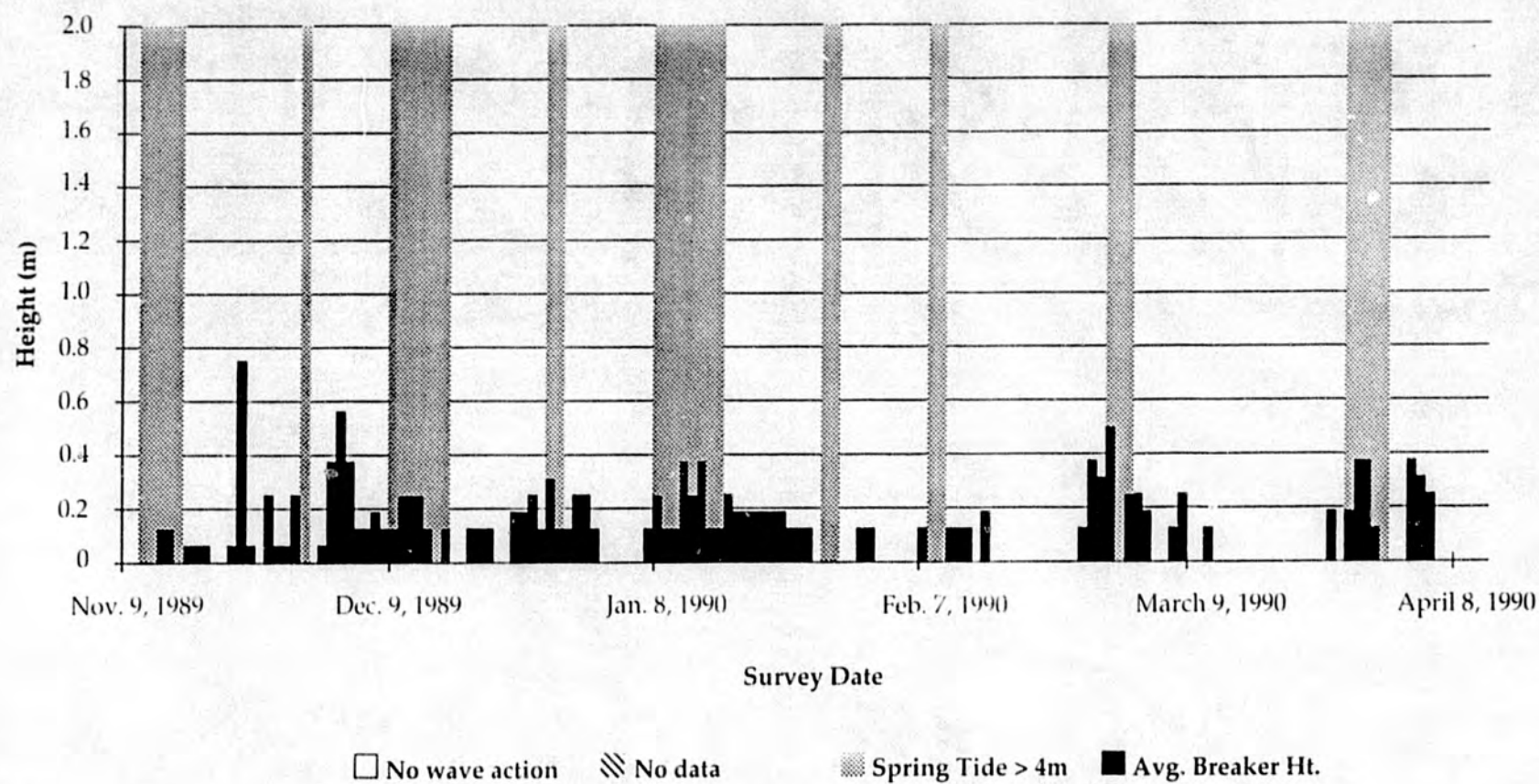


Figure F-4

Estimated Breaker Heights for Chenega Island/Time Lapse Video Survey (12/10/89 - 5/9/90)

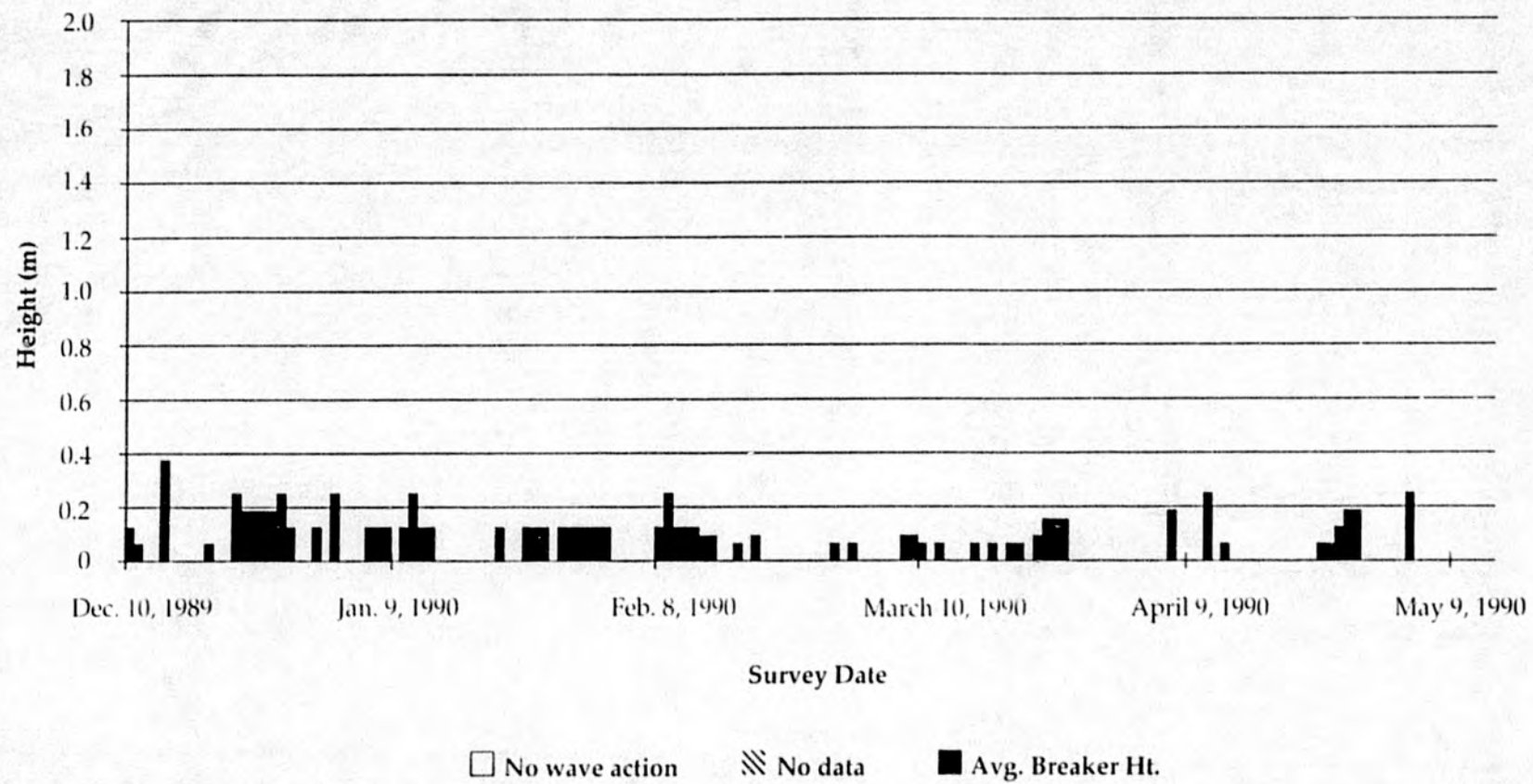


Figure F-5

Estimated Breaker Heights for Bay of Isles (Short Arm)/Time Lapse Video Survey (12/4/89 - 4/3/90)

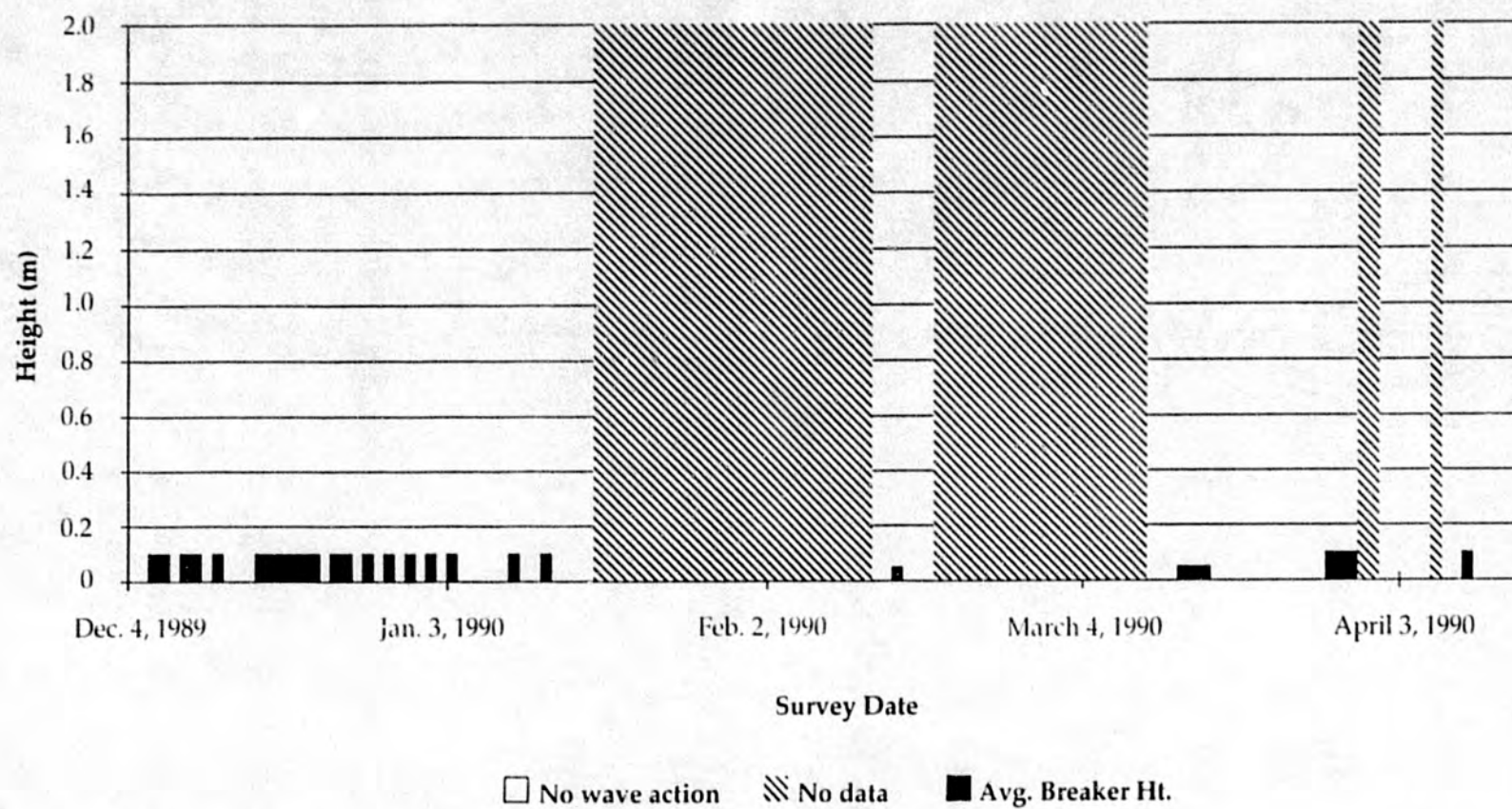
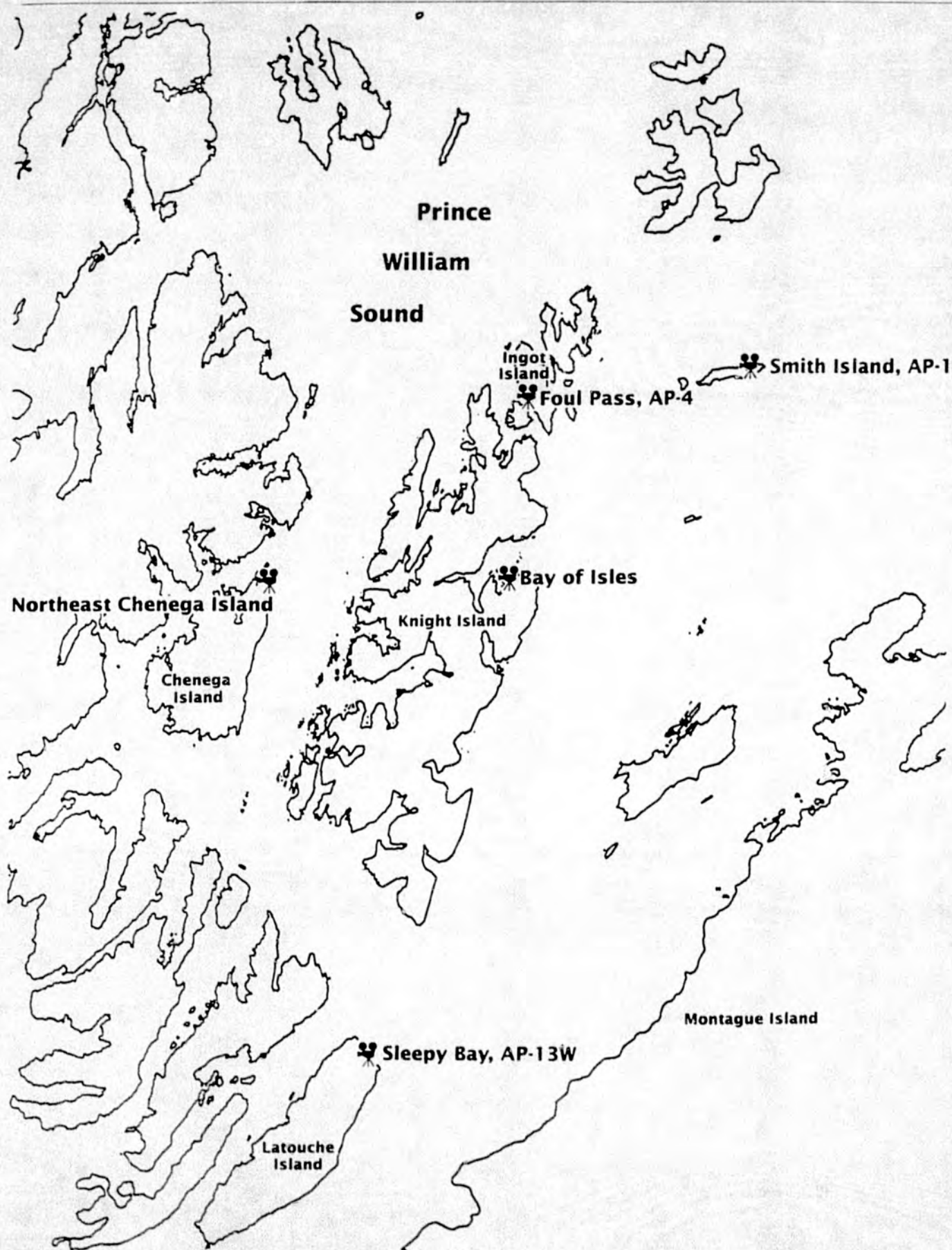


Figure F-6
Time-Lapse Camera Site Locations in Prince William Sound



F-1– Tides and breakers (0.5 meter high) produced a steep beach face with a well-sorted pebble berm ridge at site AP-13W in Sleepy Bay (Nov. 14, 1989). All photographs in this section were taken at the same site.



F-1

F-2a– A sequence of three photographs taken on the same day illustrates the tremendous energy of storm waves available to rework a beach. This photograph shows a 2-meter-high plunging breaker (Jan. 10, 1990).



F-2a

F-2b– Spring tides, combined with a storm surge and wave action, reworked backshore sediment and drift debris (Jan. 10, 1990).



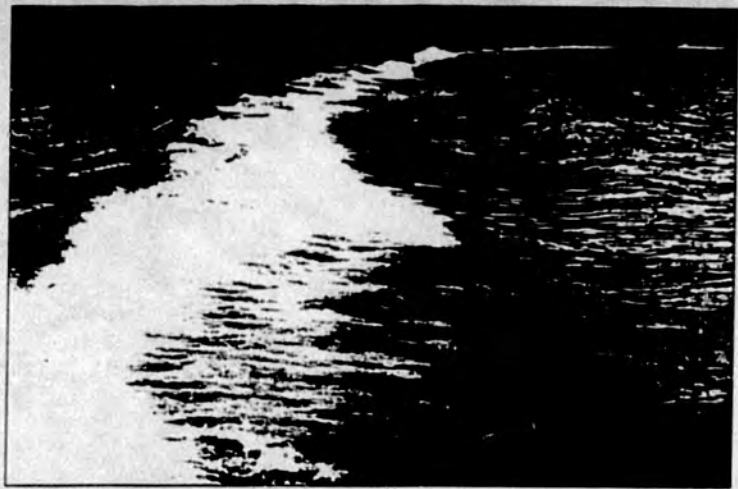
F-2b

F-2c– As the tide ebbed, drift debris and sediments were redistributed across the beachface (Jan. 10, 1990).



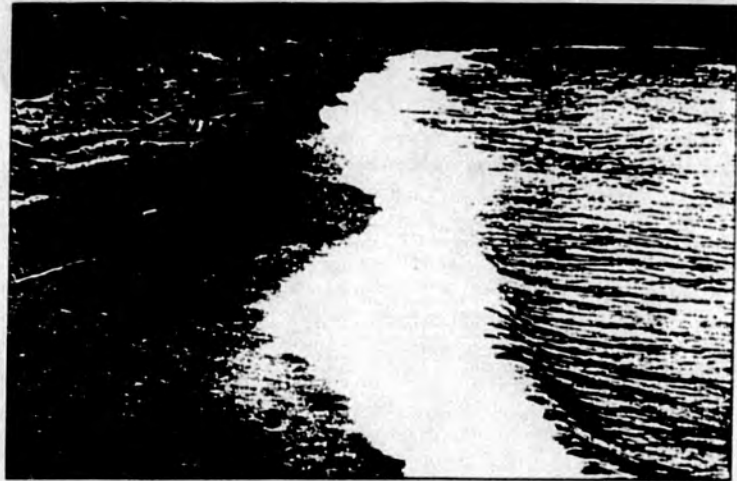
F-2c

F-3a- Wave action during spring tides is capable of reaching the backshore, reworking the highest portions of the beach (Dec. 12, 1989).



F-3a

F-3b- A 1-meter-high plunging breaker reworked the upper beachface (Dec. 12, 1989).



F-3b

F-4- The beachface was built outward with the change from erosive to constructive wave energy of late winter. The breaker forming at the shoreline was typical during late winter. Deer appeared in a number of photographs taken during middle and late winter (Feb. 26, 1990).



F-4

F-5- Constructive wave action continued to build up the beachface. The presence of several swash ridges indicated continual reworking and redistribution of beach sediments (March 21, 1990).



F-5

APPENDIX G

Summary of Biological Results

The intertidal ecology monitoring program focused on a selected core group of species, including acorn barnacles, blue mussels, limpets, littorinid snails, rockweed, and green algae. Because of their abundance the species were selected to represent key trophic groups common to this region. A permanent cross-shore transect was sampled regularly at each of 26 monitoring sites since September 1989. In February-April 1990, the program was expanded to include six non-oiled reference sites to provide information on natural patterns of recruitment, distribution and abundance. In June and September 1990, an additional 16 sites were examined. Gradual expansion of the program to 48 sites increased the range of typical habitats and oiling conditions to better evaluate the status of intertidal communities in the region.

In the summary, diagrams of the results (Figures G-1 through G-7, on the following pages) are arrayed according to the wave-energy environment, with sheltered sites to the left (AP-4, AP-6, AP-18, AH-2 and AK-1), followed by moderately exposed energy sites (AP-16 and AK-3), and with exposed sites to the right (AP-1, AP-2, AP-8, AP-10 and AP-12).

Summary of Biological Results

The rocky intertidal zones of the region support a modest diversity of marine plants and animals that interact directly and indirectly to form complex communities that vary greatly in response to the harsh environmental conditions. As a result of biological and environmental variability, a mosaic of intertidal communities in different stages of development can be found on similar shoreline types at any time within the region.

Key Organisms

A core group of organisms generally characterizes the rocky intertidal communities of the region. These plants and animals are relatively conspicuous and occur over a wide range of shoreline types and wave-energy exposures. The principal feature of the supratidal zone, which is above most wave action but receives sea spray, is a band of black lichen, which is often confused with stranded oil by untrained observers. The upper intertidal zone is often barren or is sparsely populated by a few species that are more common lower on the shore. The mid- and low-intertidal zones are characterized by acorn barnacles, littorinid snails, limpets, and rockweed (a brown algae). These organisms may be replaced, in part, by blue mussels or by a variety of brown, green, and red algae. The lower tidal zones are also variably populated by larger animals, including grazers (chitons), scavengers (crabs), and predators (anemones, whelks, starfish, sculpins, and gunnels). In addition, numerous small and inconspicuous species are present in the intertidal communities.

Zonation

The most obvious feature of intertidal communities on the rocky shores of the region is the pattern of zonation that characterizes the distributions of all organisms. Upper limits of species distributions are set by the tolerance of each organism to physical conditions, such as temperature, no ultraviolet light, and wave energy; whereas, lower limits of distributions are set by biological interactions, including competition for space and predation. Thus, zonation results from the heavy mortality of larvae or juveniles that settled too high in the intertidal zone and were desiccated, or settled too low and were eaten; those organisms that remain, therefore, occur in bands within which physical and biological conditions are more suitable for sustained growth.

Intertidal Habitats

The species and abundance of intertidal organisms likely to be found on a section of coast depend primarily on the shoreline type, and character and mobility of the sediments. Exposed beaches consisting of smaller sediments rarely support a well-developed intertidal community

because the sedentary organisms are frequently scoured from the substrate by waves and mobile sediments. The only organisms that can survive are those that can burrow rapidly and deeply in sands, or that can scuttle through small spaces between pebbles or cobbles. On exposed bedrock or boulder shores, the substrate is stable, but the organisms must be able to hold on to the rock to withstand pounding by breaking waves. Intertidal communities are sometimes well-developed on moderately exposed to sheltered shores, where the sediments are less commonly disturbed by waves.

Life Histories

The intertidal organisms of this cold temperate region have developed life history strategies that maximize growth and reproductive potential. The high nutrient content of coastal waters and longer days during the warmer spring and summer months enable species to rapidly replenish populations devastated by winter storms and freezing temperatures. These life history strategies may involve the production of very large numbers of small eggs that are broadcast into the water where they hatch into planktonic larvae and are dispersed along the coast to recolonize available intertidal shores. Species with this type of reproductive pattern are least susceptible to an oil spill because of the vast numbers of eggs and larvae produced and their wide dispersal in the plankton. Other organisms produce a fewer number of large, yolk-filled eggs, so the young hatch at an advanced stage of development with improved chances of survival; the eggs are attached to sheltered surfaces of lower intertidal sediments and are brooded by a parent in some species. Species with this reproductive pattern could be more susceptible to stranded oil but fortunately in this instance oil was rarely deposited in the lower intertidal zone.

Variability

Random mortality of intertidal organisms because of predation or battering by logs, or mass mortality resulting from regionwide freezing temperatures, commonly results in the local removal of organisms from rock surfaces. These bare patches are rapidly colonized by bacteria, algal spores and invertebrate larvae, which are present in the plankton at the time. They compete for available space and initiate the process of marine community succession. The organisms that eventually come to dominate the space may be different from those there previously because they were able to recruit to the area first or were able to displace the initial occupants. As a result of temporal and spatial variation or mortality and recolonization, similar intertidal shores are populated by a mosaic of communities in various stages of development.

Field Studies

Stranded oil adversely affected intertidal biota on most monitored sites. In assessing the extent of effect, as well as the recovery of organisms from the spill, it is important to note that on the majority of sites oil was stranded on the upper half of the intertidal zone, where the diversity and abundance of organisms is typically lower.

Furthermore, this portion of the shore is more frequently exposed by tides, so organisms in this habitat are more susceptible to daily, seasonal and annual environmental extremes, resulting in great variation in their numbers and distribution. Thus, differences in the distributions and abundances of organisms between oiled and non-oiled reference sites were small and difficult to detect unless a particular organism was especially sensitive to oil pollution or a beach was very heavily and persistently oiled.

The upper limit of distribution and average abundance of key intertidal organisms on oiled study sites surveyed in September 1989 and 1990 are compared in Figures G-1 to G-7, on pages G-7 to G-13, to illustrate the extent of recovery that occurred during the year. The graphs also compare these biological characteristics of the oiled sites and non-oiled reference sites in September 1990 as a basis for assessing the extent of recovery to normal conditions. Since oil was usually stranded on the upper shores, a temporary reduction in the upper limit of biological distributions may have occurred. Persistent oiling and treatment efforts may also have had a more pervasive effect on organisms; this effect may be reflected in reduced average abundances on a site. The upper limits of distribution are in meters above mean low water. Limited time available for surveys of each site necessitated using simple observational methods to score abundances of key organisms that were often too numerous to count within 1-meter-wide transects that extended the width of a beach. Littorinid snails and limpets were scored on a geometric scale from 0 (absent) to 10 (more than 6,000 per m²). Rockweed (*Fucus*) abundance was scored as percent cover of the sediments. Cover of barnacles and mussels was scored from 0 to 10 on a normal scale of distribution.

Discussion of Results

Because oil was stranded only on the upper shore of the great majority of beaches, reduction in the upper limit of distribution of key organisms might have been expected. However, comparison of survey results on the same site between September 1989 and September 1990 reveals that the upper limit of distribution for juvenile and adult barnacles, mussels, rockweed, and littorinid snails was very similar on most study sites. The species distributions also were comparable with those observed on non-oiled reference sites in September 1990. Barnacle spat commonly settle higher on the shore than the larval or juvenile life stages of other key organisms; on the majority of study sites, spat settled somewhat lower on

shore in September 1990 than they had the previous September. Comparison of spat distributions on oiled and non-oiled sites in September 1990 revealed no consistent tendency for spat to have settled higher on the shores of control sites (Figure G-1, on page G-7).

Limpets appear to have been the most adversely affected of the key organisms. On the vast majority of the sites surveyed in September 1989, limpets were not observed or were present in very low abundance (Figure G-6, on page G-12). During spring 1990, limpets migrated up the shore and juveniles recruited, so by September 1990 populations on most oiled sites were similar in distribution and abundance to those of non-oiled sites. However, there remained a few sites where limpets were not as abundant.

The abundances of the ubiquitous littorinid snails and juvenile and adult barnacles on the majority of oiled sites were generally comparable with, if not greater than, those of non-oiled sites by September 1990. The abundances of littorinids at this time were almost uniformly higher on oiled sites than they had been the previous September (Figure G-7, on page G-13). With few exceptions, abundance was similar to or higher on oiled sites when compared with non-oiled sites in September 1990. Similarly, the older life stages of barnacles on oiled sites were usually more abundant in September 1990 than they were at the outset of this study. With the exception of a few sites that were heavily and persistently oiled, barnacle abundances on oiled sites in September 1990 were comparable with those of non-oiled sites (Figure G-2, on page G-8).

Although mussel distribution on oiled sites exhibited little change during the period of investigation, their average abundance had increased on most sites by September 1990 (Figure G-3, on page G-9). On the remaining sites, abundance was usually low and had not changed much since September 1989. One of the Foul Passage sites (AP-4; transect 5) stands out as an exception because mussel abundance was consistently high from September 1989 through June 1990, and then declined about 60 percent by September 1990. Large amounts of crushed mussel shells were observed at this time, indicating that foot traffic had possibly resulted in significant mussel mortality. Predatory whelks were abundant on this beach and had killed great numbers of mussels, as evident from intact shells with drill holes, but predation was not responsible for the magnitude of the observed decline in mussels. For example, the abundant mussel population on the set-aside site in East Herring Bay was also plagued by dense whelks but had increased nearly six-fold by September 1990.

Rockweed was a conspicuous component of the intertidal communities of most sheltered beaches but was generally much less abundant and ephemeral on exposed sites (Figure G-4, on page G-10). The upper limit of distribution of juvenile and adult plants was usually comparable in the

two September surveys or had declined somewhat by September 1990. Average abundance of these plants on oiled sites was, for the most part, comparable in 1989 and 1990, although abundances on some of the higher energy sites had increased considerably. One exception occurred in east Herring Bay (AP-6) where average abundance had declined 18 percent by September 1990 because of the loss of most plants in one quadrat during the summer. Even so, the distribution and abundance of *Fucus* on this and other sheltered oiled sites were comparable to or greater than these on a non-oiled reference site in September 1990; on exposed beaches, the results of such comparisons were more variable.

Recruits are usually not very abundant in healthy, dense *Fucus* beds because older plants occupy and shade most suitable substrate. Thus, it is not surprising that the abundance of recruits was usually greater on sheltered oiled sites in September 1989 than during the next September (Figure G-5, on page G-11). This was probably a result of increased availability of space when the canopy of mature plants was reduced by oiling and cleanup activity. This effect was still in evidence on sheltered oiled beaches in September 1990 when recruit abundances were usually much higher than on the non-oiled reference site. The abundances of rockweed recruits on exposed sites were much more variable; recruitment often occurs on these sites, but survival is low (as evident from the low abundance of older plants) because of wave scour of the sediments.

Conclusions

Overall, the abundances and distribution of key organisms on most oiled sites in September 1990 usually were not substantially different from those observed on non-oiled reference sites. Nevertheless, the intertidal biota on a few oiled sites had apparently not completely recovered in that time. These sites had been very heavily oiled over much of the intertidal zone and had not received extensive cleanup in summer 1989. The northwest Smith Island site (AP-2) is an example; the upper limit of distribution and abundance of nearly all key organisms declined during the year, so they were restricted to the lower intertidal zone, which is below 0.4 m above mean low water (MLW). These types of sites received extensive treatment in summer 1990, and thus by summer 1991, it is anticipated that the intertidal biota on virtually all study sites will have recovered to such an extent that the communities will be indistinguishable from those on non-oiled shores in the region.

Figure G-1a

Barnacle Spat Comparisons/

Between September 1989 and September 1990 on Selected Oiled Sites

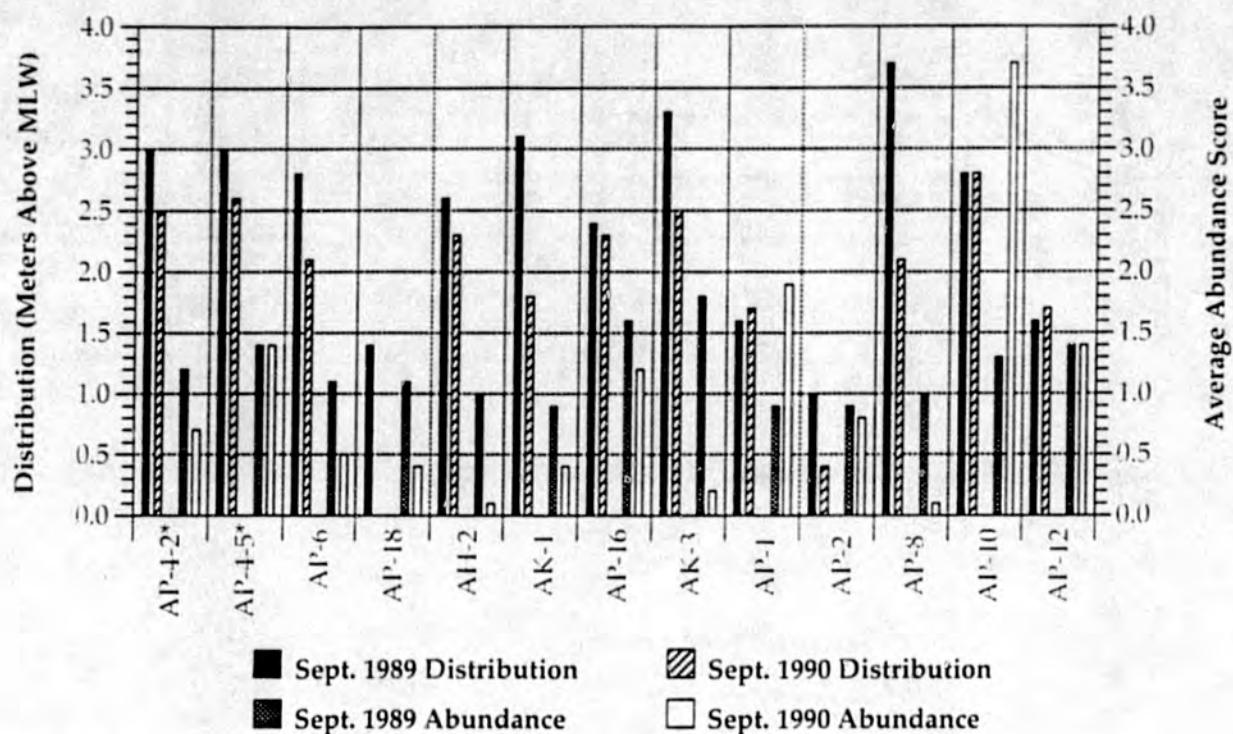
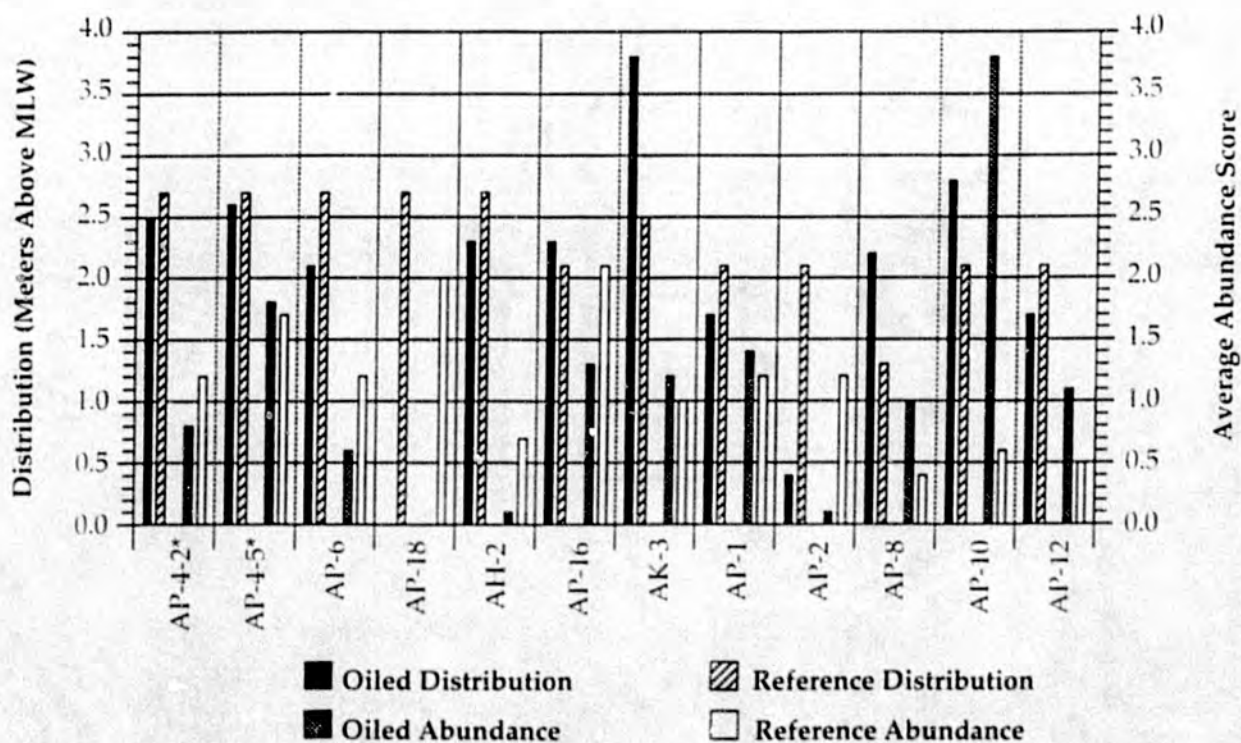


Figure G-1b

Barnacle Spat Comparisons/

Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

Figure G-2a
Juvenile and Adult Barnacle Comparisons/
 Between September 1989 and September 1990 on Selected Oiled Sites

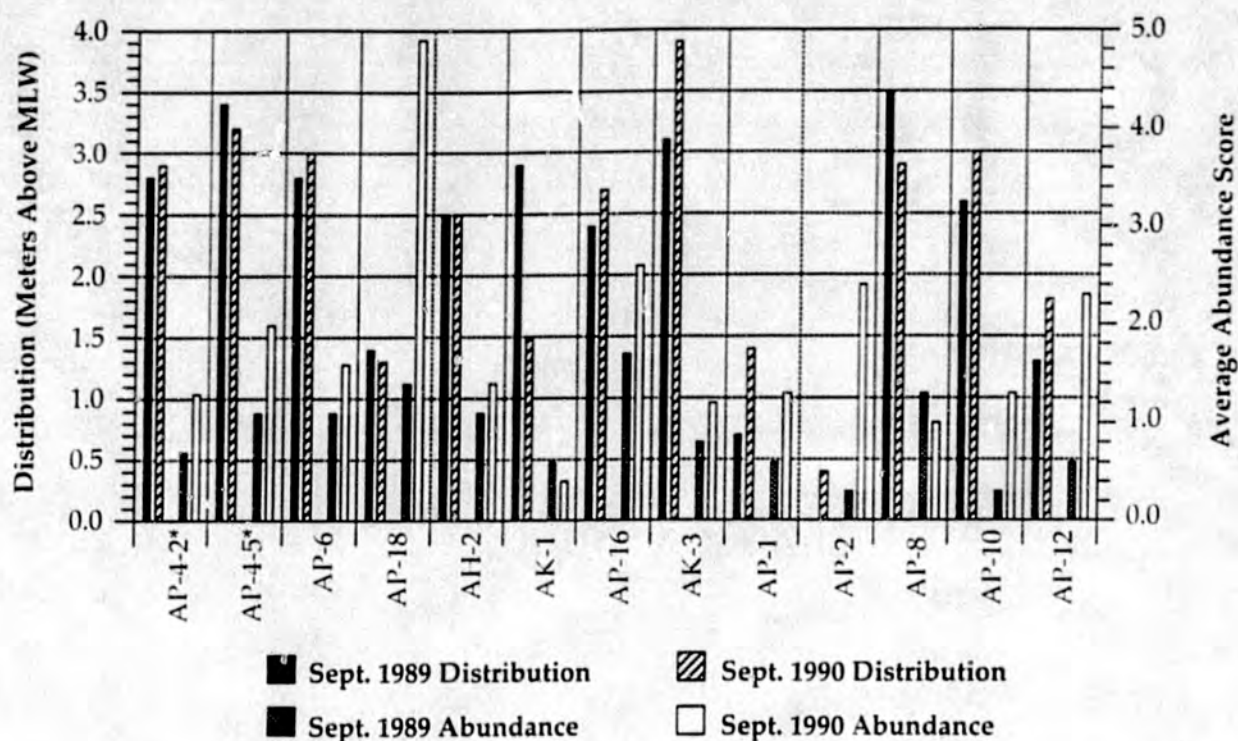
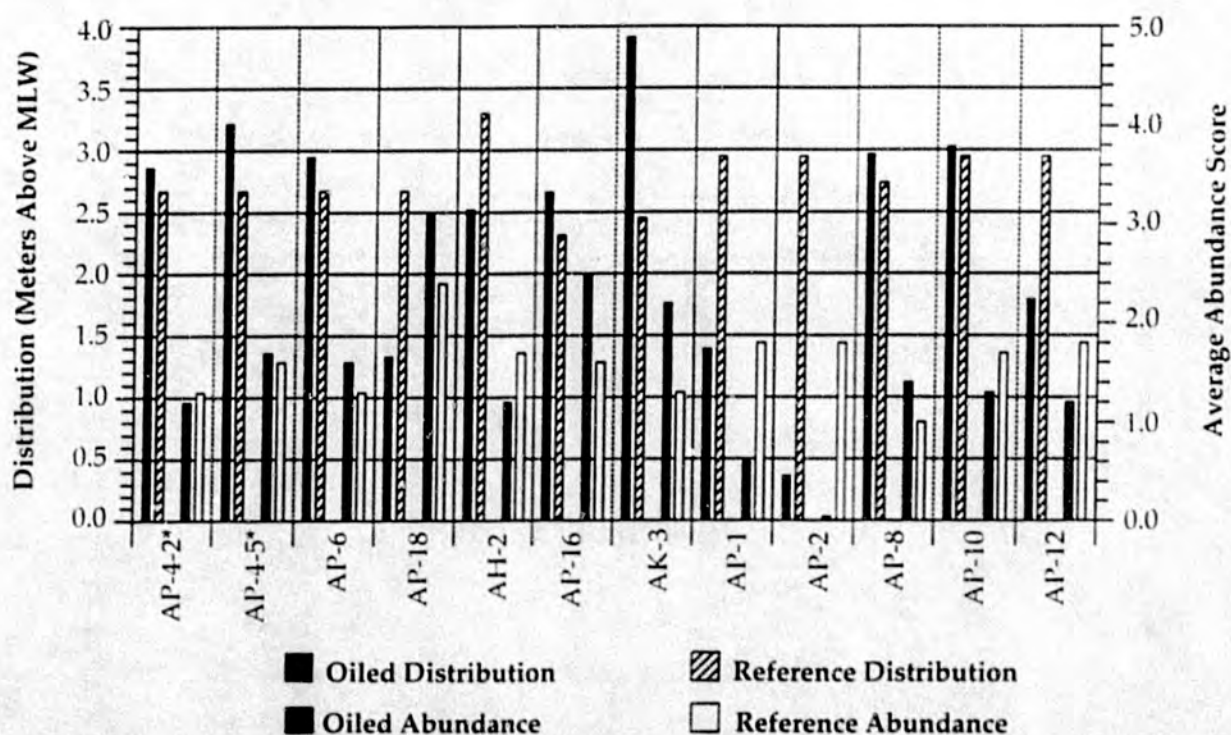


Figure G-2b
Juvenile and Adult Barnacle Comparisons/
 Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

Figure G-3a

Mussel Comparisons/

Between September 1989 and September 1990 on Selected Oiled Sites

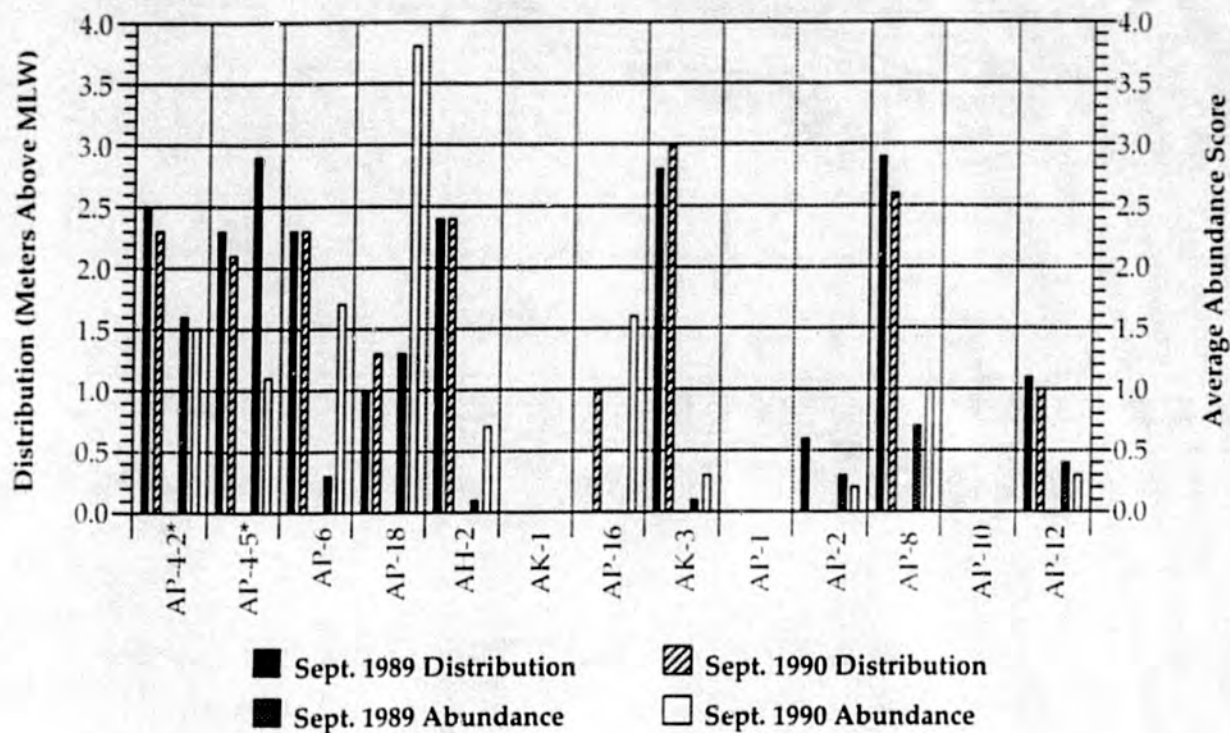
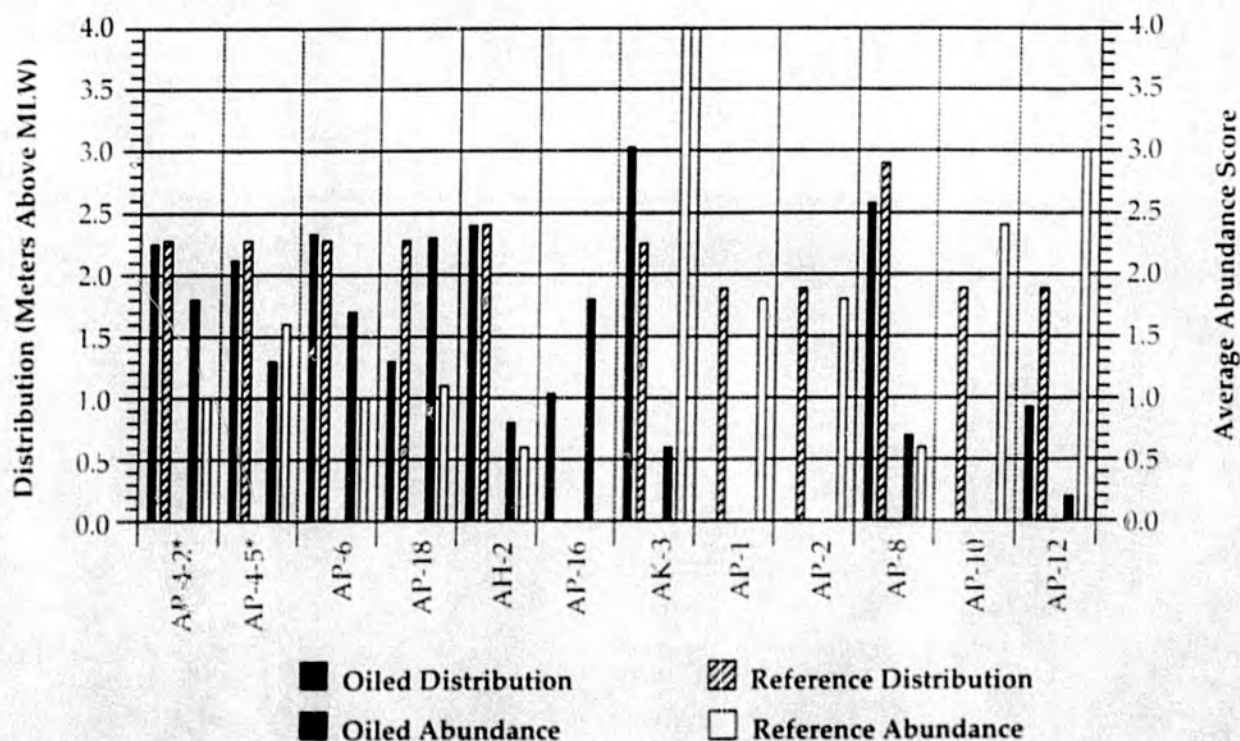


Figure G-3b

Mussel Comparisons/

Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

Figure G-3
Juv

**Comparisons/
September 1989 and September 1990 on Selected Oiled Sites**

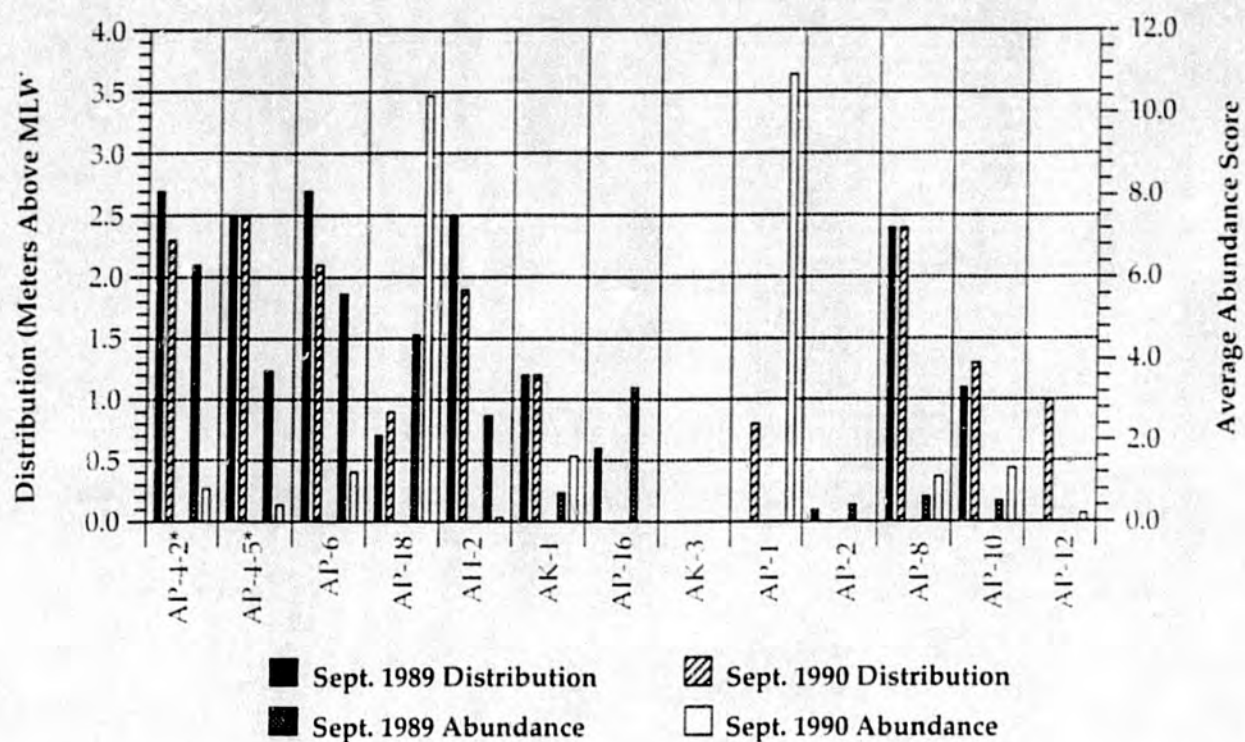
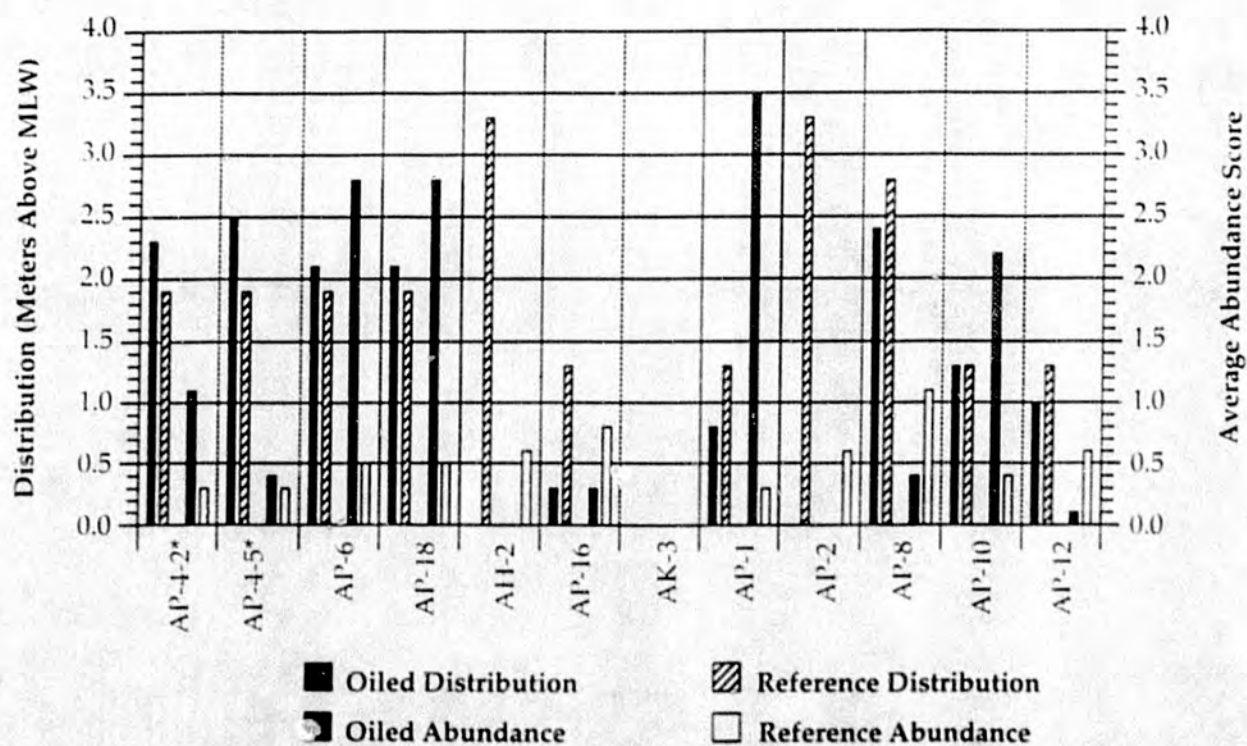


Figure G-4b
Fucus Recruit Comparisons/
Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

Figure G-5a

Juvenile and Adult Fucus Comparisons/

Between September 1989 and September 1990 on Selected Oiled Sites

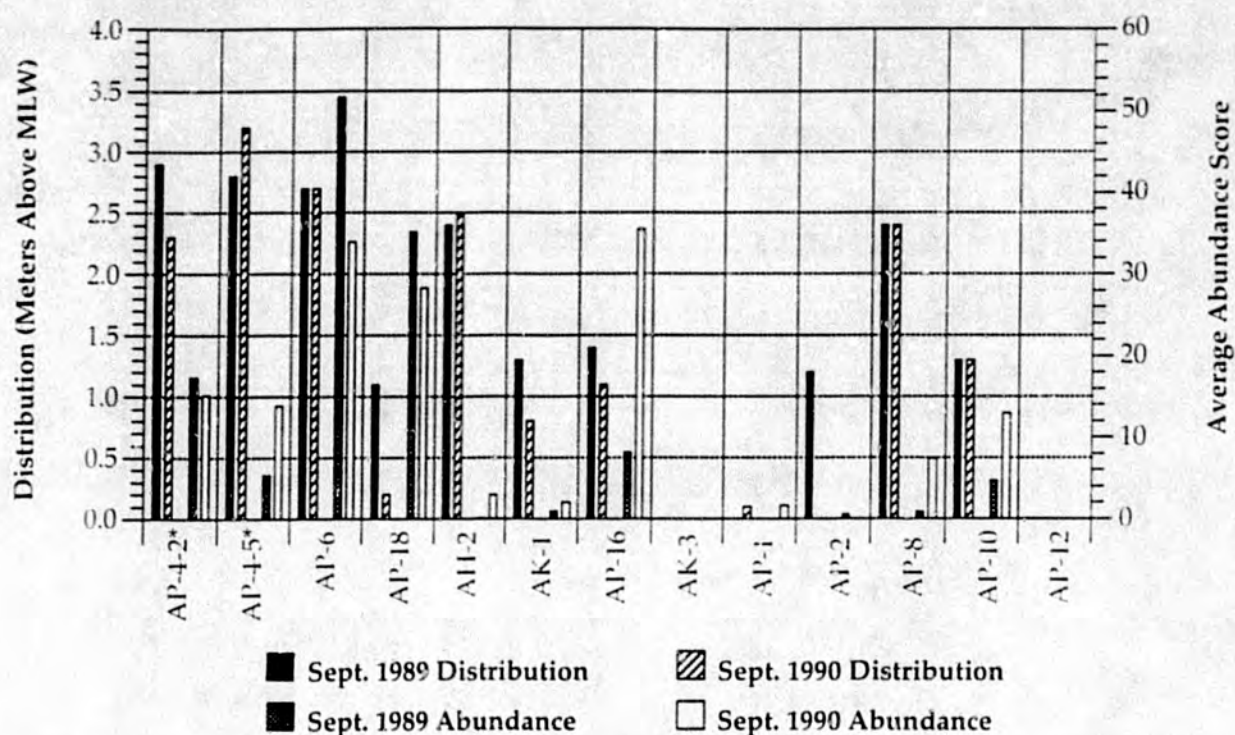
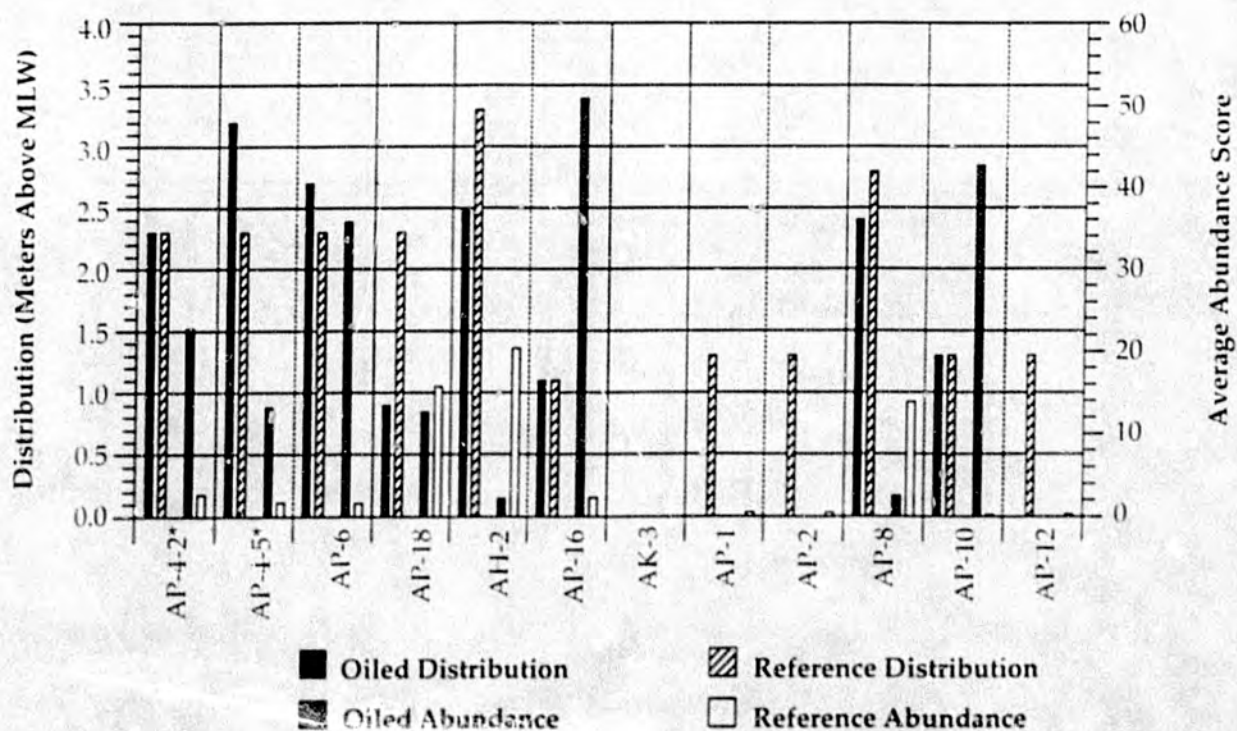


Figure G-5b

Juvenile and Adult Fucus Comparisons/

Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number

Figure G-6a

Limpet Comparisons/

Between September 1989 and September 1990 on Selected Oiled Sites

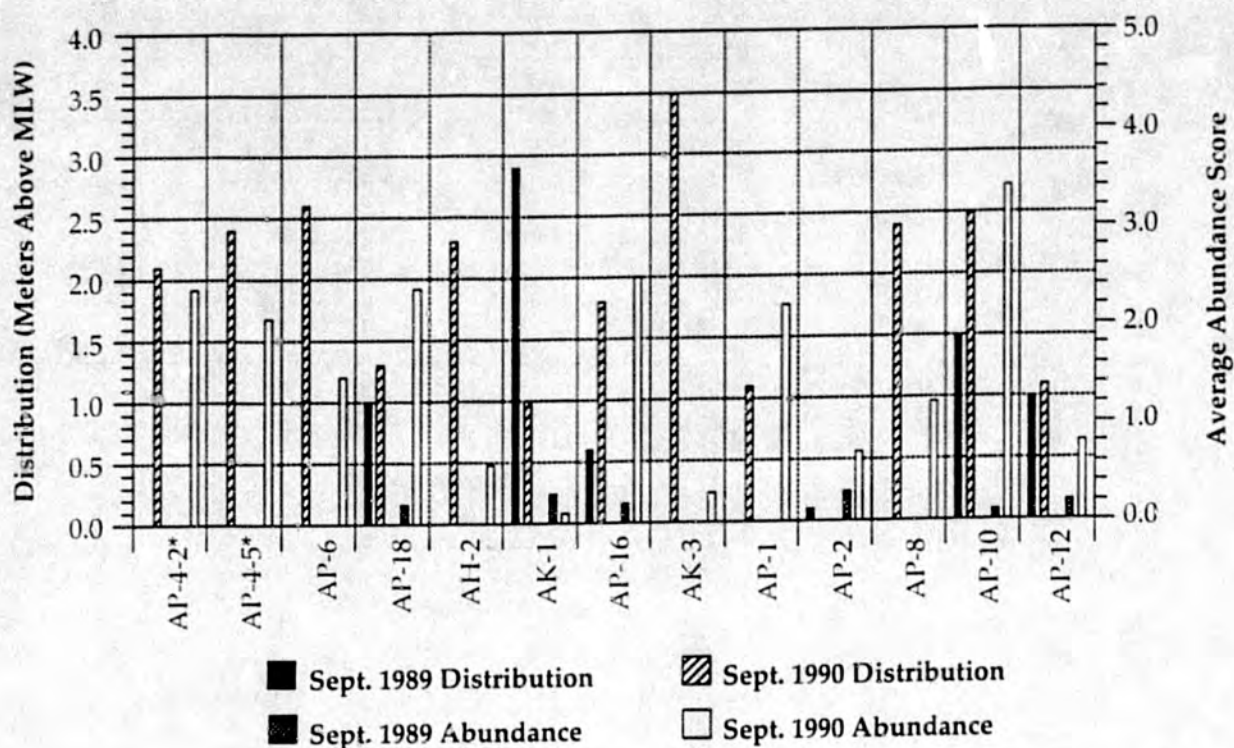
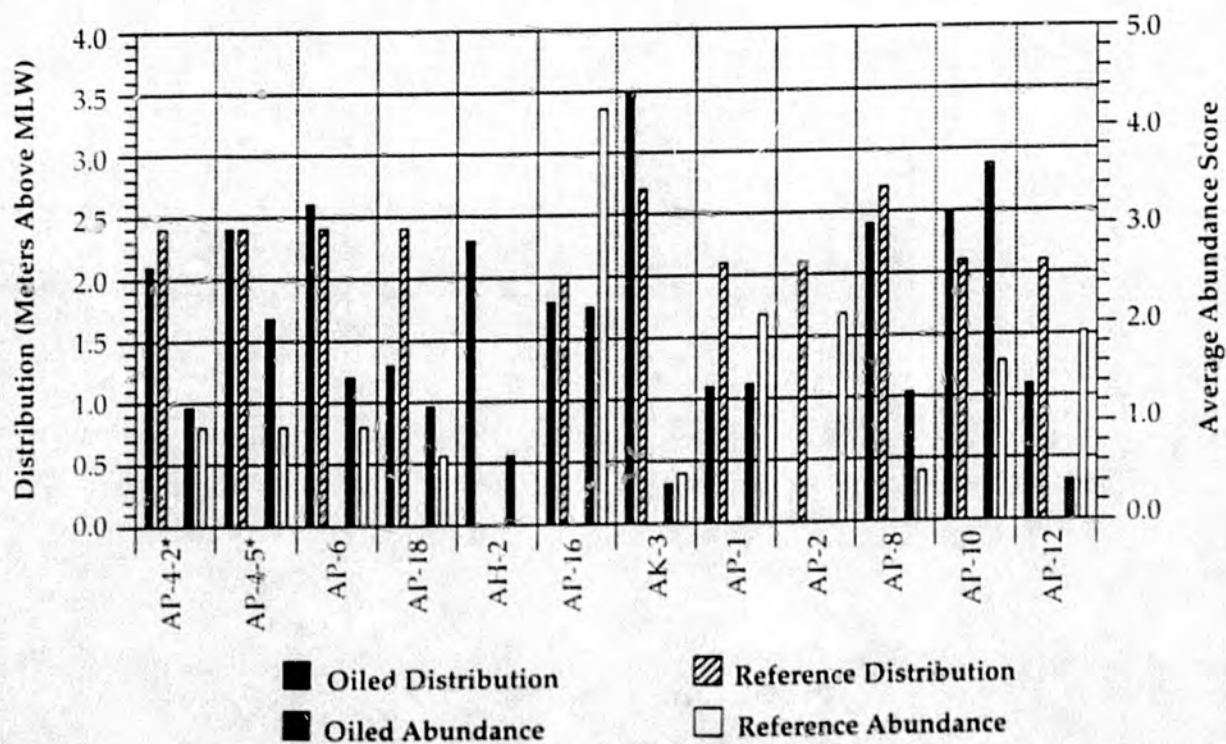


Figure G-6b

Limpet Comparisons/

Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

Figure G-7a
Littorinid Snail Comparisons/
 Between September 1989 and September 1990 on Selected Oiled Sites

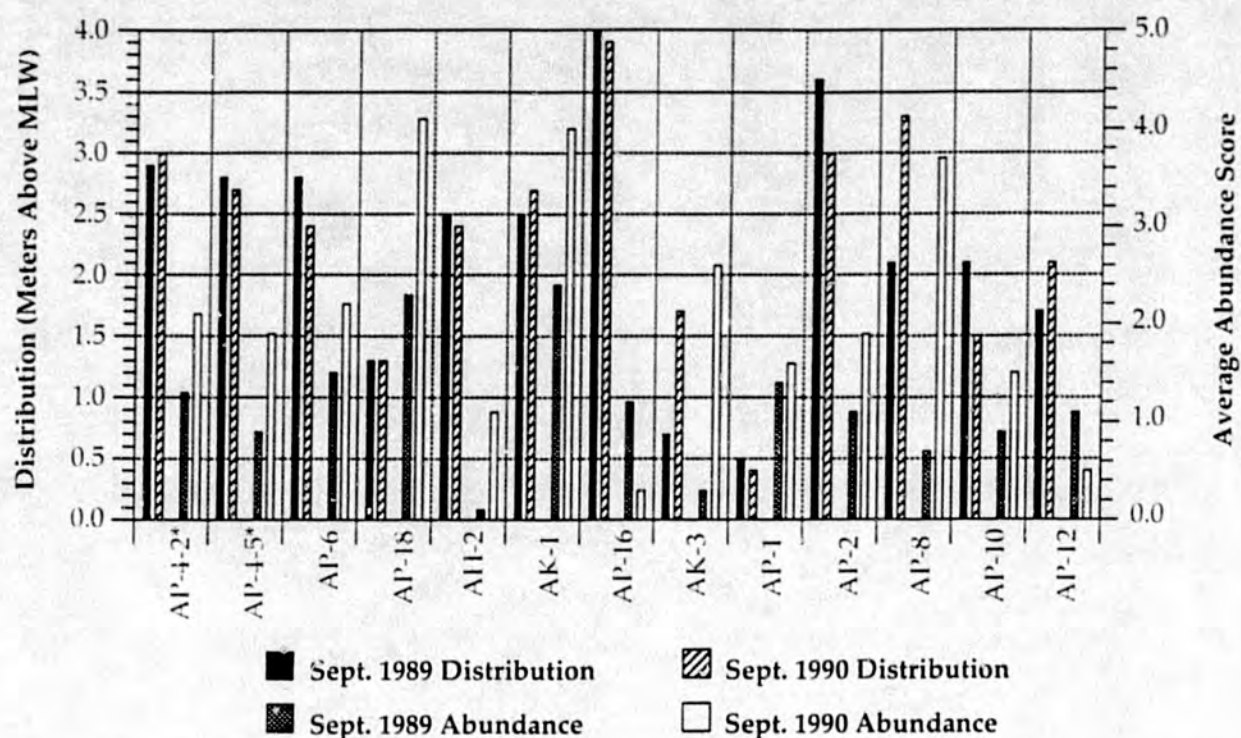
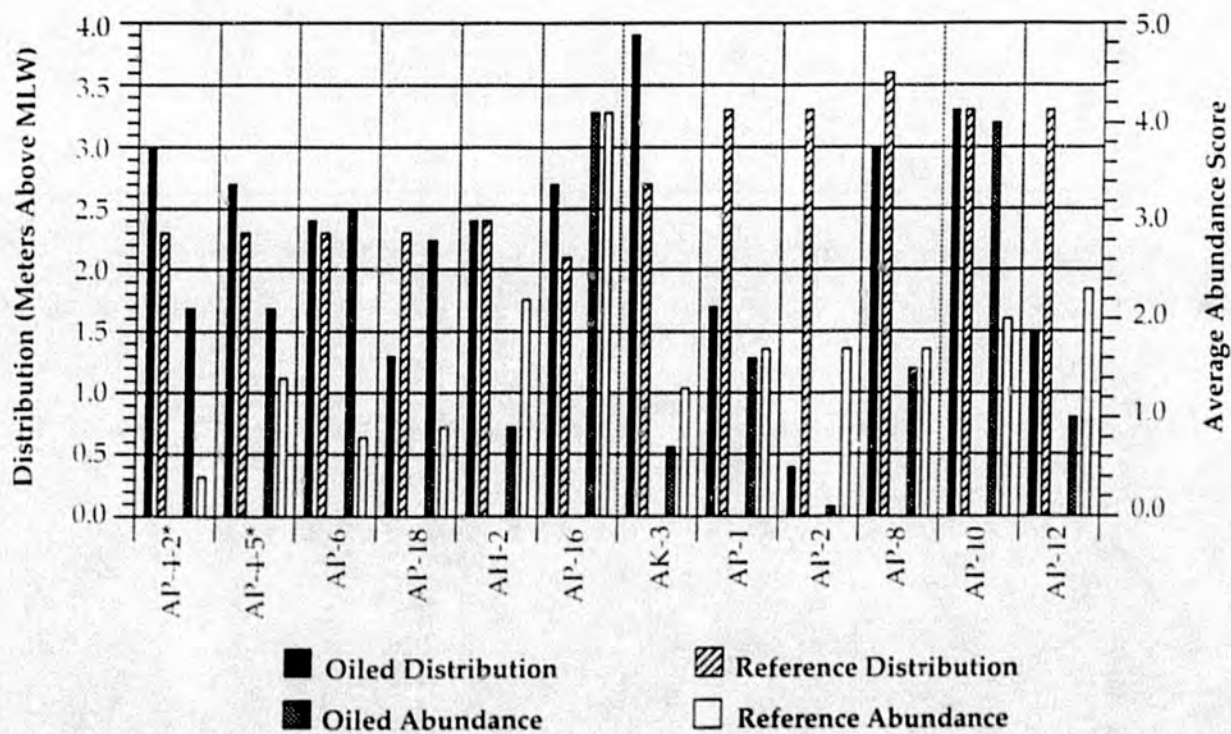


Figure G-7b
Littorinid Snail Comparisons/
 Between Oiled and Non-Oiled Reference Sites in September 1990



*Last number at AP-4 refers to transect number.

WOODWARD- CLYDE

About the Firm

Woodward-Clyde is an international consulting firm that has achieved prominence in environmental, geotechnical, and waste management services. Founded in 1950, the firm has grown to more than 50 offices and over 2,000 employees worldwide. *Engineering News-Record* has listed the firm as one of the top 50 U.S. design firms since that listing began in 1965.

Woodward-Clyde, with headquarters in Denver, is recognized internationally as a leader in the field of oil spill cleanup and research. Staff members have accumulated practical experience through participation in or observation of more than 100 oil spills worldwide.

Woodward-Clyde's professional experience in the marine and coastal environments has been brought together in its Coastal Science and Engineering Center to provide an interactive approach to biological, chemical, and physical studies. The center provides a forum for professional staff to bring state-of-the-art technology and innovative solutions to problems. The scientists and engineers of the center have considerable international as well as Alaskan experience.

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This report should be referenced as follows: Owens, E.H., 1991. "Changes in Shoreline Oiling Conditions 1-1/2 Years After the 1989 Prince William Sound Spill." Unpublished report. Woodward-Clyde, Seattle. Washington. 52 pages and appendixes.

Assessing the Risk to Pacific Herring from Offshore Gas and
Oil Development in the Southeastern Bering Sea

by

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ABSTRACT

The U.S. Department of the Interior (USDOI) began the presale process for conducting an offshore gas and oil lease sale in the southeastern Bering Sea (North Aleutian Basin) during 1973. Due in part to potential environmental effects from gas and oil operations, an offshore gas and oil lease sale--Sale 92, North Aleutian Basin--was not held in this area until October 1988. As a result of this sale, 23 leases were issued for gas and oil exploration. The USDOI's Minerals Management Service (MMS) has spent approximately \$235 million to gather information needed to identify resources potentially at risk from offshore gas and oil exploration and development. The MMS is continuing to support studies concerning these resources and is focusing on species of specific concern near areas currently under lease.

During the prelease process for Sale 92, concern was expressed about the potential effects of gas and oil activities on Pacific salmon (all five species), Pacific herring (*Clupea harengus pallasi*), and king crab (*Paralithodes camtschatica*).

Gas and oil activities or accidents that have the greatest potential for affecting these species are chronic or acute discharges of pollutants, such as oil and associated fluids. Studies conducted for MMS and others indicate that early life stages of these species are vulnerable to spilled oil and other pollutants. The "Window of Maximum Vulnerability" (WMV) is considered to be that period when the early life stages are most sensitive to pollutants, e.g., spilled oil. Studies results show that the WMV for Pacific herring in the southeast Bering Sea falls between May and July, when early life stages are found in shallow coastal waters. A numerical simulation conducted for MMS by the National Marine Fisheries Service and a synthesis report (Thorsteinson, 1984) evaluating the potential effects of spilled oil on offshore fisheries resources indicated that even during the WMV, gas and oil activities pose minimal threat to offshore fisheries resources. This report also concluded that an offshore oil spill poses a minimal threat to herring stocks spawning in Port Moller, Alaska. The findings are consistent with findings that the Exxon Valdez oil spill had no measurable effect on herring eggs and larvae in Prince William Sound, Alaska.

INTRODUCTION

The U.S. Department of the Interior (USDOI), Minerals Management Service (MMS), began leasing submerged lands on the Outer Continental Shelf (OCS) off Alaska for gas and oil exploration in April 1976 with OCS Lease Sale 39 in the northeastern Gulf of Alaska. Since then, MMS has conducted 14 OCS lease sales and leased 3.2 million hectares, and industry has drilled some 67 exploration wells in Federal waters offshore Alaska. Oil in economically producible quantities has been found under State waters in Cook Inlet and under Federal and State waters in the Beaufort Sea--some 6 wells as of May 1990 have been classified as producible in the Federal OCS portion of the Beaufort Sea near Prudhoe Bay.

MMS began preparing for an gas and oil leasing program in the southeastern Bering Sea in 1974, with the first lease sale (Sale 51) scheduled for October 1977 (USDOI, MMS, 1985a). After several delays and sale cancellations, 23 leases from Sale 92 were let in 1988 (Fig. 1). Exploration of these tracts has been suspended pending court review (USDOI, MMS, 1990a).

In addition to recognizing legal mandates guiding the Department's activities, Departmental managers are aware that the harvest of marine resources--primarily fish (Pacific salmon, Pacific herring, and walleye pollock) and crab (king and Tanner crabs)--plays an important part in cultural and commercial activities within Alaska. They, therefore, have directed considerable resources to assessing potential conflicts between traditional uses of these resources and the exploration for gas and oil resources.

In 1973, MMS initiated the Environmental Studies Program (ESP) to support the OCS oil- and gas-leasing program off Alaska. The purpose of the ESP is to develop information needed to assess and mitigate potential effects that proposed gas and oil leasing and development might have on the human, marine, and nearshore environments. Since its inception, the ESP has conducted some 521 environmental studies in Alaska at a cost of over \$235 million (1973-1990). Over half of these studies have focused on fisheries-oceanography issues. Information

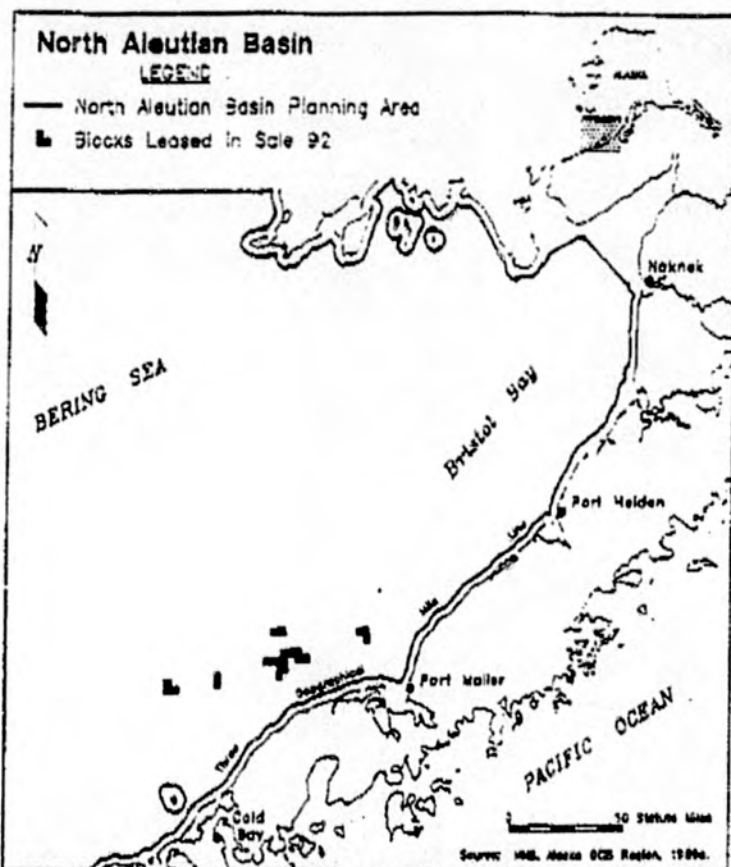


Figure 1. North Aleutian Basin Planning Area.

acquired through this program is in the forefront of subarctic and arctic research and is used to support offshore leasing and management decisions.

Fisheries resources in the Bering Sea have been exploited for well over a century, with annual harvests exceeding 1.2 million metric tons (mt) during the past decade. Walleye pollock, flounders, and Pacific cod account for the majority of this harvest. Other important fisheries include salmon, Pacific herring, and crab (king and snow). With the exception of the salmon and Pacific herring fisheries, most fisheries occur offshore, well away from the coast. The salmon and Pacific herring fisheries occur near shore and in estuaries in Bristol Bay and along the Alaska Peninsula.

In 1975, MMS funded the Alaska Department of Fish and Game (ADF&G) to conduct a resource-assessment survey of Pacific herring and other fishes spawning in coastal waters of the eastern Bering Sea (Barton, 1972) from Cape Charikof on Unimak Island to the Seward Peninsula (Barton, 1972). Annually,

ADF&G conducts areal surveys throughout the region to estimate spawning-herring biomass. In addition to the spawning surveys discussed above, MMS has supported several projects to synthesize available environmental information concerning the southeastern Bering Sea and to develop information pursuant to potential gas and oil in the region. These projects have included a synthesis of environmental information (Thorsteinson, 1984); a forage-fish workshop (USDOL, MMS, 1987); a monograph of eastern Bering Sea resources (Hood and Calder, 1981); an open-file geologic report (USDOL, MMS, 1983a); an exploration and development report (USDOL, MMS, 1985b); Environmental Impact Statements (EIS's) for gas and oil lease sales (USDOL, MMS, 1982a,b; 1983a,b; and 1985a,c,d); a study of the fish use of inshore habitats (Isakson, 1986); and an environmental characterization of the nearshore zone (LGL, 1987).

PROBLEM STATEMENT

Pacific herring, because of their general life history, are considered to be at considerable risk from spilled oil. This perceived risk was well stated by Rice et al., 1988, when they suggested that the spawning strategy of herring made them particularly vulnerable to the effects of an oil spill because spawning adults and their maturing gonads could be exposed to spilled oil, and the spawned eggs and larvae would be subjected to an oil-contaminated environment.

Background

MMS is charged with managing the exploration for and development of offshore gas and oil resources in an environmentally sound manner. To accomplish this goal, MMS evaluates the potential environmental effects of gas and oil exploration and development on marine resources. MMS has, for example, evaluated the potential effects from offshore gas and oil activities on eastern Bering Sea Pacific herring in EIS's prepared for each of the five gas and oil lease sales in the Bering Sea (USDOL, MMS, 1982a,b; 1983a,b; and 1985a,b,d). Evaluations contained in these documents were based, in part, on results from studies that simulated the potential effects of spilled oil on fisheries resources in the southeastern Bering Sea (Laevastu and Fukuhara, 1984, and Thorsteinson, 1984).

These evaluations and simulations concluded that spilled oil would have minimal or no measurable effect on offshore fisheries resources, including Pacific herring. However, because site-specific information on many of the fisheries resources in coastal waters was not available, the simulations were unable to evaluate the potential effects of an offshore oil spill on certain coastal resources, e.g., herring eggs and larvae.

Following the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, MMS funded a study to determine the potential effects that spilled oil may have had on Pacific herring eggs and larvae. Developing eggs and larvae were collected from areas that appeared to have been heavily oiled as a result of the oil spill and compared with samples collected from areas that were not exposed to the spilled oil. Results from these studies indicate that the oil spill had no measurable effect on herring eggs and larvae in Prince William Sound in 1989 (McGurk, 1990a,b).

Status of Gas and Oil Exploration

The tracts that currently are under lease for possible gas and oil exploration are offshore of and upstream from Port Moller, Alaska. This estuary supports a large spawning stock of herring that may be at risk from an offshore oil spill.

This report provides an evaluation of the risk to the herring resources in Port Moller from an offshore oil spill and builds on information developed by numerous other authors.

PORT MOLLER--PHYSICAL ENVIRONMENT



Figure 2. The Port Moller Estuary (McGurk, 1990).

The Port Moller estuary (lat. 56° N, long. 160° 35' W.) is located on the north side of the Alaska Peninsula (Fig. 1). The largest (878 square kilometers [km²]) coastal estuary in the southeastern Bering Sea, it consists of Nelson Lagoon, Mud Bay, Herendeen Bay, and Moller Bay (Fig. 2). The estuary is shallow, 4 to 17 meters (m), and is characterized by extensive shallow mud flats drained by narrow dendritic drainage channels. Herendeen Bay, however, is deeper (> 100 m) and is connected to the remainder of the estuary by the relatively narrow and shallow (< 30 m) Johnson Channel. Tidal range within the estuary is about 3 m, and current velocities in the

channels can exceed 140 centimeters per second (cm/s).

Circulation of water into and through the Port Moller complex has been described by Greengrove, 1990, as being dominated by tidal forces and major regional storm events. During each tidal cycle, marine water tends to enter on the west of the estuary and exit on the east side, and there is a net discharge from the estuary of about 13 cm/s. Waters within the estuary tend to be well mixed; however, waters in Herendeen Bay may become stratified during periods of low winds.

Prevailing winds are from the southeast and average 8.9 knots. Summer temperatures range from 6 to 18 °C, and winter temperatures range from 6 to -20 °C (Brower, 1988). Although sea ice seldom extends as far south and west as Port Moller, the estuary freezes over each winter.

The Eastern Bering Sea is separated into three hydrographic regions--the outer shelf, the middle shelf, and the coastal region--which are separated by the shelf-break front, the middle front, and the inner front, respectively. Coastal circulation during the ice-free period generally is east along the Alaska Peninsula and to the northeast along the inner-front boundary (Fig. 3). The mean flow past Port Moller appears to be northeastward along the Alaska Peninsula with a velocity of about 2 to 5 centimeters per second (cm/s). Circulation along the coast is dominated by tidal currents (Schumacher and Kinder, 1983). Only about 3 percent of the kinetic energy within the coastal region is associated with weather events.

The Port Moller biota is dominated by large stands of eelgrass (*Zostera marina*) and rockweed (*Fucus distichus*). The area is an important staging area for water-

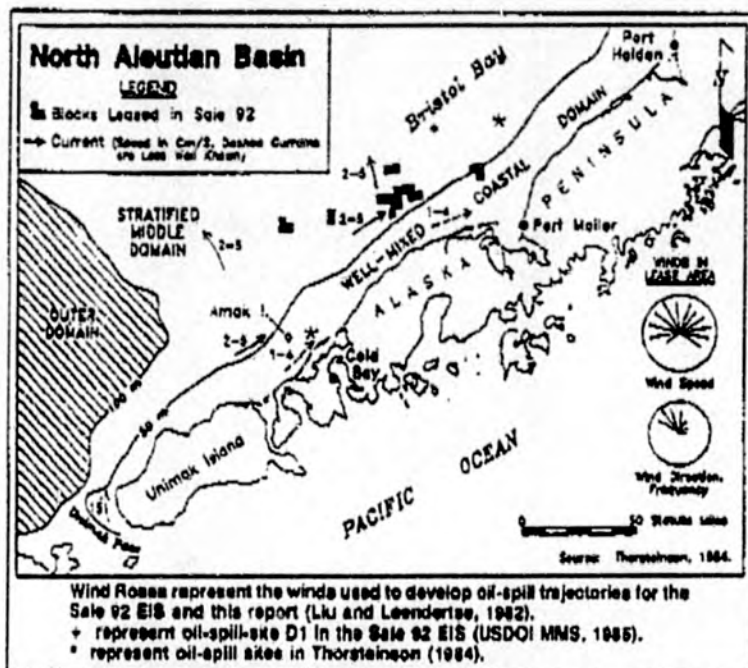


Figure 3. Prevailing coastal circulation during typical summer conditions. Redrawn from Thorsteinson (1984).

fowl and supports spawning populations of Pacific herring (*Clupea harengus pallasii*) and red and blue king crab (*Paralithodes camtschatica* and *P. platypus*, respectively).

BIOLOGICAL NOTES

Pacific herring are found throughout the eastern Bering Sea at various times of the year. Fish appear to overwinter in the central Bering Sea (Thorsteinson, 1984, and Funk, 1987) and return to coastal spawning sites in late spring-early summer (Wespestad and Barton, 1981). Figure 4 shows the relative abundance and timing of herring spawning in the eastern Bering Sea. Wespestad and Barton (1981) estimated that the eastern Bering Sea herring biomass ranges from 0.374 to 2.75 million metric tons (mt). Results from aerial surveys in 1978 indicated that the coastal spawning biomass for the eastern Bering Sea was 432 to 864 thousand mt. Laevastu (1985) used biomass estimates of 1,409 and 1,121 (kg/km²) for juvenile and adult herring, respectively, occurring in Port Moller when conducting his analysis. A recent study by McGurk (In Press) suggests that the minimum herring biomass spawning in Port Moller during the 1989 spawning period ranged from 1,784 mt (based on aerial surveys) to 1,788 to 2,241 mt (based on larval abundance).

Spawning occurs subtidally (McGurk, 1989) on marine vegetation (eelgrass and rockweed) throughout Moller and Herendeen Bays (Fig. 5) between early May and

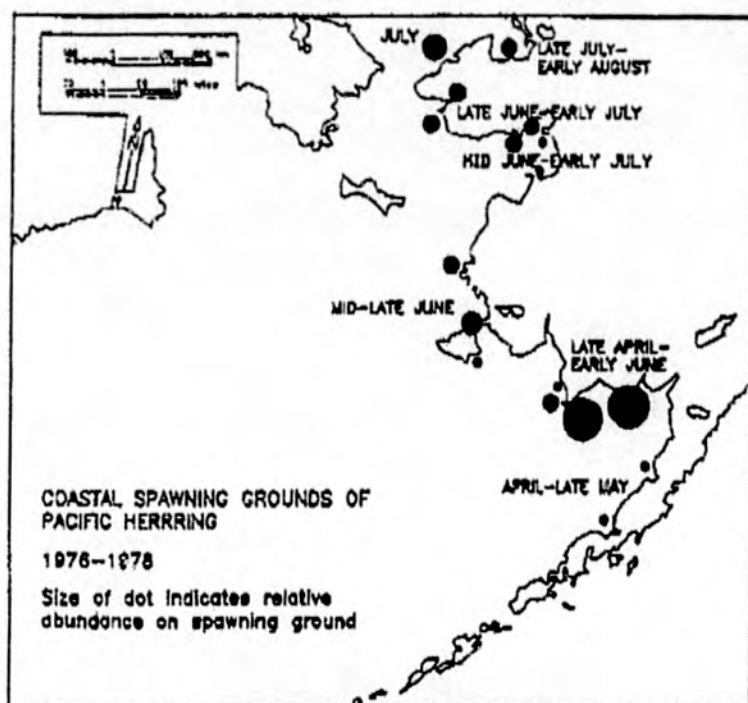


Figure 4. Distribution, spawning time, and relative abundance of Pacific herring in the eastern Bering Sea. Redrawn from Wespestad and Barton (1981).

late June. Winter-ice scour removes most of the intertidal vegetation in Port Moller. High-water turbidity within the Port Moller complex and poor weather conditions in the region make spawning surveys, both aerial and shipboard, difficult. As a result, shoals of pre- and postspawning adults are seldom seen for more than one or two tidal cycles, and clouds of milt in the water indicating active spawning are seldom observed. To date, efforts to collect developing herring eggs spawned within the estuary have not been successful (McGurk, 1990, pers. commun.). Therefore, the actual spawning beds have not been mapped, and the extent of potential spawning beds has been determined only by estimating the areal extent (using aerial photos of the area) of marine vegetation in areas where herring larvae have been collected.

Three cohorts of herring eggs hatched in Port Moller between May 10 and June 30, 1989 (McGurk, 1989). Initial observations indicate that three cohorts also hatched during the same time period in 1990 and that yolk-sac larvae that were collected in July suggested the existence of a fourth cohort (McGurk, 1990, pers. commun.); these data are currently being analyzed. Herring larvae collected in Moller Bay appear to grow faster than those collected from Herendeen Bay; this may be related to the warmer water temperatures observed in Moller Bay (Fig. 6) (McGurk, 1989).

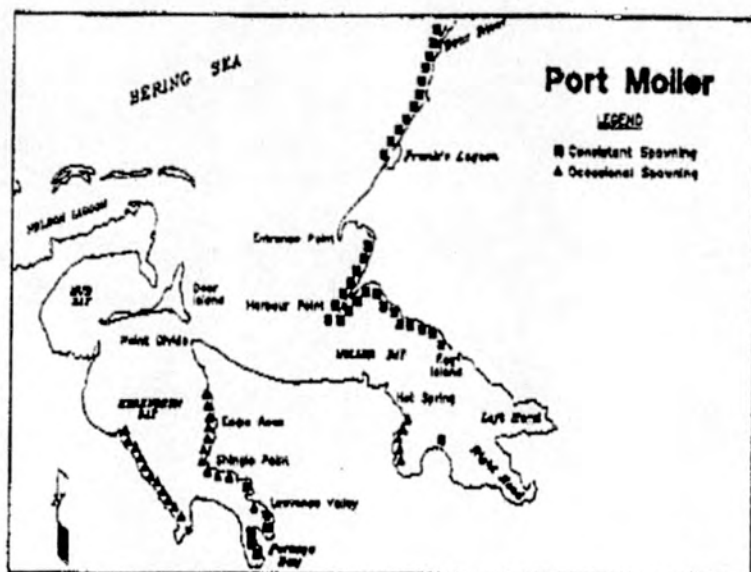


Figure 5. Distribution of herring spawning locations in Port Moller, Alaska. Redrawn from McGurk (1989).

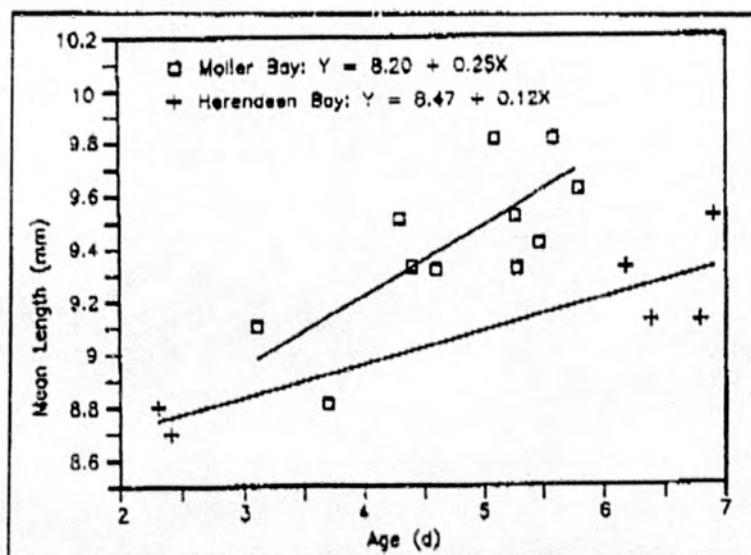


Figure 6. Growth Rates for Pacific herring larvae collected from Herendeen and Moller Bays, Port Moller, Alaska, in 1989 (McGurk, 1989).

Herring larvae undergo diurnal vertical migrations, apparently following their prey field (McGurk, 1989a). The younger larvae are found primarily in the top 15 m of the water column, whereas older, larger larvae have been found as deep as 35 m. At night, smaller larvae tend to be most abundant in the 5 m of the water column and the larger larvae in the top 25 m (McGurk, 1990, pers. commun.). Robertson, 1988, reported that herring larvae in British Columbia waters tended to be most common at depths between 5 and 10 m. The vertical distribution of larvae in the Port Moller estuary (McGurk, 1990, pers. commun.) is controlled in part by the degree of stratification or mixing within the water column. Off Harbor Point, a well-mixed area, larvae were collected throughout the water column, 0 to 25 m, whereas in Herendeen Bay—an area of limited vertical mixing—few larvae were captured below 15 m (larger larvae were found at the deeper depths). McGurk found herring larvae to be most abundant near the eelgrass beds off Right Head in Moller Bay and south of Bluff Point in Herendeen Bay. Other studies suggest that the herring will begin schooling and move out of the estuary as the season progresses, possibly by September.

RISK ASSESSMENT

The probability of an oil spill affecting a significant portion of the herring population or spawning and rearing habitat is expressed by the relationships presented in Table 1. The effects (P_{effect}) that spilled oil may have on Pacific herring resources

Table 1. Information needed to evaluate the potential effects of an oil spill on herring resources in Port Moller, Alaska.

$P_{\text{effect}} = P_{\text{threat}} \times P_{\text{transport}} \times Q_{\text{amount}} \times Q_{\text{rate}} \times T_{\text{toxicity}} \times R_{\text{resource}}$ where	
P_{threat}	$P_{\text{spill}} \times P_{\text{WMV}}$
$P_{\text{transport}}$	$T_{\text{to shore}} \times T_{\text{PM}}$
Q_{amount}	$Q_{\text{floating}} \times Q_{\text{in water column}} \times Q_{\text{in bottom sediments}}$
Q_{rate}	$C_{\text{concentration}} \times D_{\text{time}}$
T_{toxicity}	$H_{\text{downing}} = H_{\text{rearing}} \times B_{\text{biomass}}$
R_{resource}	
P_{effect}	Probability of a significant effect on herring resources and habitats in Port Moller, Alaska.
P_{threat}	Probability of an oil-spill event occurring during the window of maximum vulnerability (WMV).
P_{spill}	Probability of a spill event occurring.
P_{WMV}	Probability of a spill event occurring during the WMV.
$P_{\text{transport}}$	Probability of oil spilled on or near tracts currently under lease for oil and gas exploration being transported by winds and currents into Port Moller.
$T_{\text{to shore}}$	Probability of being transported to shore.
T_{PM}	Probability of being transported into Port Moller.
Q_{amount}	The amount of oil spilled.
Q_{rate}	The rate of spilled oil, that portion that is floating or stranded, that is dispersed and dissolved in the water column, and that is deposited in bottom sediments.
Q_{floating}	The portion of oil floating or stranded.
$Q_{\text{in water column}}$	The portion of oil dispersed and dissolved in the water column.
$Q_{\text{in bottom sediments}}$	The portion of the oil incorporated into the bottom sediments.
T_{toxicity}	The concentration of hydrocarbons and duration of exposure to the hydrocarbons needed to have a lethal or sublethal effect on herring.
$C_{\text{concentration}}$	The concentration of hydrocarbons on the surface, floating or stranded, in the water column, and in bottom sediments.
D_{time}	The duration of exposure to concentrations of hydrocarbons.
R_{resource}	The resources and habitat at risk from an oil spill.
H_{downing}	Area of potential downing habitat in the Port Moller estuary.
H_{rearing}	Area of potential rearing habitat in the Port Moller estuary.
B_{biomass}	Biomass of herring spawning within the Port Moller estuary.

in Port Moller are related to the probability of a spill occurring (P_{spill}); the joint probability that spilled oil will reach the coast and also will enter the Port Moller estuary ($P_{\text{transport}}$); the amount of oil spilled (O_{amount}); the time required for the spilled oil to reach the resource at risk (O_{time}); the toxicity (T_{toxicity}) of the oil when it reaches the resource at risk (toxicity is a function of the amount of hydrocarbons dissolved or suspended in the water column ($O_{\text{concentration}}$)); the duration of exposure to oil (O_{duration}); and the herring's sensitivity to specific hydrocarbon compounds; and the resource at risk (R_{resource}), which in this evaluation include the spawning habitat (H_{spawning}), rearing habitat (H_{rearing}), and biomass of herring spawning in Port Moller (B_{biomass}). Other possible effects, i.e., bioaccumulation, reduction of prey density, etc., are considered minor (Varanasi and Malins, 1977; Cimato, 1980; and USDOI, MMS, 1990b) and are not considered in this evaluation.

Table II. The probability of an oil-spill event occurring during the WMV.

	Probability
Oil-Spill Event	57%
Oil Spill Occurring During WMV	19%
The WMV is 3 months long (May to July)	
Source: USDOI, MMS, 1985a.	

P_{spill} (Table II). The probability (P_{spill}) of an oil-spill event occurring as a result of gas and oil leasing in the area was evaluated in the Sale 92 EIS and also in the Environmental Assessment (EA) (USDOI, MMS, 1985a and 1985b) and the North Aleutian Basin Synthesis Report (Thorsteinson, 1984). The Sale 92 EA estimated that under the offshore-loading scenario, the most likely number of 1,000 barrels (bbl) or greater oil spills occurring

is less than one; for spills greater than 100,000 bbl, the most likely number is 0. The probability of one or more spills of 1,000 and 100,000 bbl occurring is 57 percent and 7 percent, respectively.

The WMV for herring spawning in Port Moller is assumed to be 3 months, May through July, based on the time that spawning herring, spawned eggs, and larvae are most vulnerable to spilled oil. Information needed to determine the most probable season during which an oil spill is most likely to occur is not available. However, the author assumes that the probability (P_{WMV}) is related to the proportion of the year that is identified as the WMV (Table II).

Table III. Transport probability.

Probability of Spilled Oil Contacting the Coast Within 30 Days	
1,000-barrel spill	27%
100,000-barrel spill	2%
Probability of Spilled Oil Contacting Port Moller Within 30 Days	8%
Probability of Spilled Oil Contacting Coast (Port Moller) Within 4 Days	13%
Probability that Spilled Oil Will Enter Port Moller (Thorsteinson, 1984)	20%
Source: Liu and Leendertse, 1982; Thorsteinson, 1984; and USDOI, MMS, 1985a.	

$P_{\text{transport}}$ Table III indicates that the probability of a 1,000-bbl oil spill occurring and contacting the coast within 30 days is 27 percent. For a spill of over 100,000 bbl, the probability of coastal contact is 2 percent. There is a 6-percent probability of the spilled oil contacting the Port Moller area within 30 days following a 1,000-bbl spill. Figure 7 shows the simulated trajectories for an oil spill occurring at release point D-1 (near the area currently under

lease) under summer (June-August) conditions (Liu and Leendertse, 1982). These trajectories indicate that the most likely path for spilled oil will be toward the east along the Alaska Peninsula. The trajectory analysis also indicated that sustained onshore winds (13% probability) could drive the oil onshore within 100 hours.

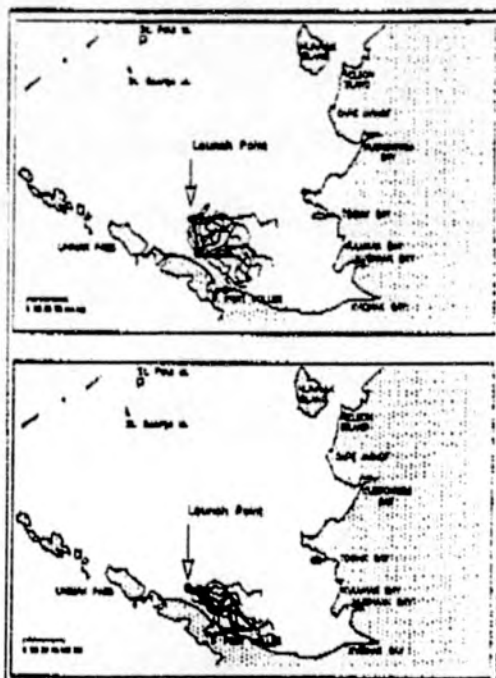


Figure 7. Simulated 30-day trajectories for oil spilled from launch points near tracts currently under lease (Liu and Leendertse, 1982). Redrawn from Thorsteinson, 1984.

conditions, wind, air temperature, water temperature, etc., and the specific composition of the spilled oil. Figure 8 summarizes the weathering process or partitioning of spilled Prudhoe Bay crude oil under subarctic conditions. Within the first 24 hours following a spill, 11 percent of the oil—mostly the volatile, highly toxic compounds—will have evaporated; 4 percent will have dispersed into the water column as small droplets; 1 percent will have dissolved; and the remainder, 84 percent, will be present on the surface as a slick or water-in-oil mousse. By the fourth day following the spill, only some 70 percent of the oil will remain on the surface (Thorsteinson, 1984). Under prevailing June wind conditions, the spilled oil will not persist as a contiguous slick but will form streaks or windrows, thereby increasing the area covered by the spilled oil (a 10,000-bbl spill may cover about 18 km²).

By the 10th day following a spill, approximately 55 percent of the oil will remain on the surface as floating or stranded oil (O_{floating}). Once floating oil reaches the coast, it tends to be blown and washed ashore, where some will be incorporated into the beach sediments and the remainder will be remobilized during high tides and storm events. Twenty eight percent of the oil will be dispersed or dissolved in the water column ($O_{\text{in water column}}$), and a small fraction (1%) of the oil will have become incorporated in bottom sediments ($O_{\text{in bottom sediments}}$).

Participants in the 1982 synthesis meeting chose to assume that 20 percent of the oil that reached the coast would enter Izembek Lagoon. Since similar conditions prevail off Cape Seniavin (Port Moller), they assumed similar probabilities for spilled oil reaching the coast in this area.

Oil amount: The median-size spill for OCS platforms and pipelines is 7,000 and 6,000 bbl, respectively, and 9,000 and 11,500 bbl for U.S. and Alaskan tankers, respectively (LaBelle, 1990). Using similar statistics, participants in the North Aleutian Basin Synthesis Meeting in March 1982 decided to evaluate the potential effects of a 10,000-bbl spill (2,000 bbl spilled per day for 5 days) on regional resources.

Oil fate: The rate of oil weathering is dependent on environmental

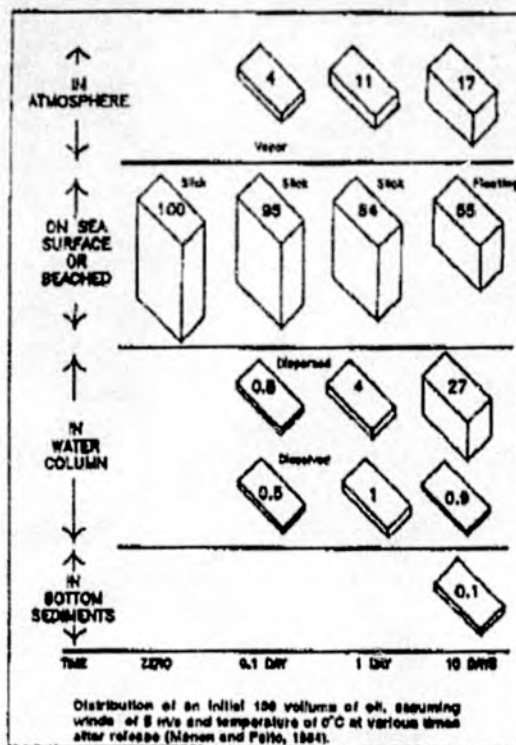


Figure 8. Speculative mass balance for Prudhoe Bay crude oil (USDOL, MMS, 1985a).

The Sale 92 EIS (USDOL, MMS, 1985a) reported that lethal effects on larvae and eggs were observed at concentrations of 0.1 to 1.0 ppm and that sublethal effects were observed at 0.01 to 1.0 ppm (Table IV).

Results from oil-effects studies are difficult to compare because of the differing experimental and analytical methods employed (Neff, 1990). More contemporary studies are exposing organisms to the water-soluble fraction (WSF) of crude oil (only a small fraction of the crude oil is soluble). The parameters used by Neff, 1990, are similar to WSF parameters used by other authors.

Rice et al., 1986 (Table V), concluded that larvae are the most sensitive life stage, and they were killed by lower

concentrations and shorter exposures than eggs or adults.

Table IV. Marine-organism sensitivity to seawater-soluble-petroleum fractions.

Concentration	Effect	Life stage
1-100 ppm	lethal	adult
0.1-1.00 ppm	lethal	larvae, some eggs
0.01-1.0 ppm	sublethal	adult, larvae

Sources: Moore and Dwyer, 1974; Thorsteinson, 1984; USDOL, MMS, 1985a; and Laevastu et al., 1985.

The adhesion of oil droplets on developing herring eggs appeared to result in an increase in the occurrence of larval deformities, suggesting that developing eggs with adhering oil droplets may be exposed to higher concentrations for a longer period of time than those exposed to low levels (<4.7 ppm) of WSF (Pearson, 1985).

Laevastu et al., 1985, surveyed the oil-effects literature and concluded that for marine eggs and larvae, mortalities and serious sublethal

effects can be observed at WSF concentrations of 100 parts per billion (ppb).

Concentration (Table VI). This variable can be divided into three components, floating oil, i.e., on the sea surface or stranded; oil in the water column as dispersed and dissolved oil; and oil in bottom sediments.

Table V. Results of herring-oil challenge experiments conducted by Rice et al., 1986.

Lifestage	Duration	Concentration	Result
Prespawn Adult	2 days	2.3 ppm	LC ₅₀
	12 days	2.3 ppm	LC ₅₀
Eggs in Adult	12 days	1.8 ppm	Normal Hatching
Eggs	2 days	6.3 ppm	Normal Hatching
	12 days	1.8 ppm	LC ₅₀
Yolk-sac Larvae	<6 hours	6.8 ppm	Survived
	16-164 hours	2.8-2.3 ppm	LC ₅₀
Larvae	7 days	1.8 ppm	LC ₅₀
	21 days	0.96 ppm	LC ₅₀
	7 days	0.3 ppm	Growth Reduced
	NA	NA	Growth Rates Not Reduced by a Diet of Oil-Contaminated Prey

An oil slick is broken into discontinuous patches by wind and wave action. The area covered by the oil patches is much greater (10-100 times) than the area covered by the initial oil slick. In the experiment conducted by Payne et al., 1984, Prudhoe Bay crude oil formed a stable emulsion within 48 hours under simulated wind conditions of 2 m/s.

Table VI. Maximum area affected by a 10,000-barrel oil spill, assuming that 100 percent of the oil remains on the surface, in the water column, or deposited in bottom sediments.

Floating Oil Slick, Contiguous ¹	16 km ²
Floating Oil Slick, Noncontiguous ¹	18 km ²
Oil in Water Column ²	548 km ²
Oil in Bottom Sediments ³	2,730 km ²

¹ A contiguous slick 1 mm in thickness.

² A water-in-oil emulsion dispersed to 100 times the initial size.

³ Oil in the water column (dispersed and dissolved) at a concentration of 0.1 ppm, 5 m thick.

⁴ Oil in bottom sediments at a concentration of 8.1 ppm.

Figure 9 indicates that the concentration of petroleum hydrocarbons in the water column reaches a maximum within the first 24 hours following a spill. The concentration then decreases rapidly over the next 12 days. After 9 days, the concentrations of hydrocarbons in the water column will decrease to less than 0.1 ppm.

Observations made following the Exxon Valdez oil spill showed that the concentrations of volatile aromatic

hydrocarbons (VOA) in the water column had returned to near background levels, 0.20 ppb (Fig. 10), within a month. Continued weathering of the oil and flushing of water from Prince William Sound were considered important factors in reducing the concentration of VOA in the water column.

Table VII. Estimated time that herring eggs and larvae could be exposed to concentrations of hydrocarbons exceeding 0.1 ppm.

Source	Duration (Days)
Floating Oil	0 (<1)
Oil in Water Column	5
Oil in Sediments	> 1-Year

Sources: Payne, 1984; Threlkington, 1984; and Holt, 1990.

Table VII provides an estimation of the length of time that herring eggs and larvae could be exposed to levels of hydrocarbons exceeding 0.1 ppm.

Herring eggs can be directly affected by contact with floating/stranded oil (smothering of eggs), dispersed or dissolved oil (toxic effects), and oil in bottom sediments.

Few if any herring eggs spawned in Port Moller will be exposed to floating oil because they are deposited subtidally, on marine vegetation. Exposure to floating oil is further reduced because floating oil tends to become stranded high in the littoral zone during high tides and storm surges, where it is incorporated in beach sediments. The oil, however, may persist as pancakes or tarballs for over a year and could expose to floating oil a portion of two year-classes of herring spawning in Port Moller.

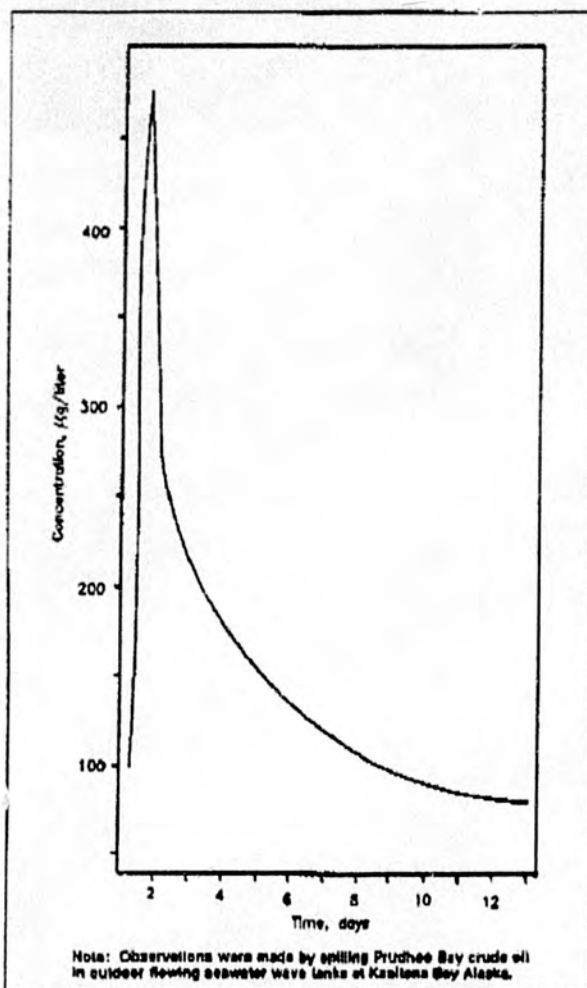


Figure 9. Observed concentrations of petroleum hydrocarbons in a moving water column under a slick of crude oil (Payne et al., 1984).

is weathered and contains low levels of VOA's and PAH's. The residence time for significant amounts of sedimented oil in offshore areas appears to be about a year. Inside the Port Moller estuary, residence times are expected to be shorter in shallow areas because of the comparatively higher energy and approaching a year in deeper areas because of comparatively lower energy levels (Thorsteinson, 1984).

R_{resources} Estimates of herring resources at risk in Port Moller are presented in Table VIII.

The length of time that eggs and larvae could be exposed to concentrations of dispersed and dissolved oil is a function of the oil-weathering and -flushing rate for Port Moller. Neff, 1990, observed a similar process in Prince William Sound when within 30 days following the spill, the concentration of toxic compounds returned to background or near-background levels. Therefore, the duration of exposure to maximum levels of hydrocarbons in Port Moller is expected to be less than 30 days. Observations by Payne, 1984, suggest that the concentration of hydrocarbons in the water column will decrease to less than 0.1 ppm within 9 days following a spill.

Oil that is incorporated in bottom sediments

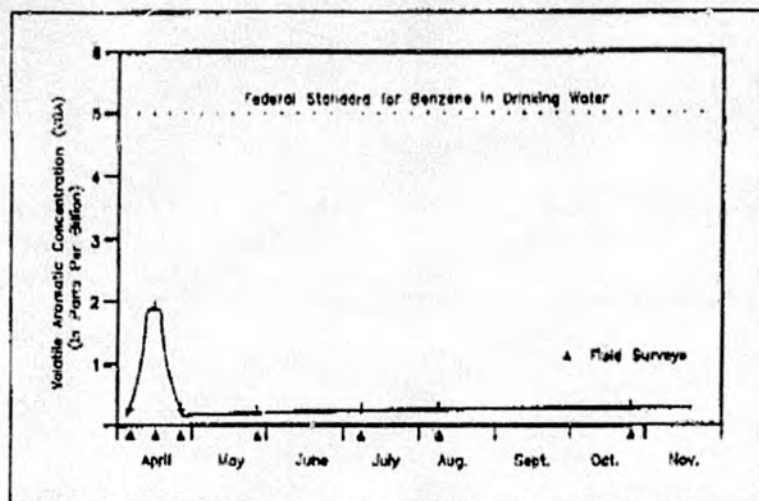


Figure 10. Average volatile aromatic concentrations from primary sites in Prince William Sound (Neff, 1990).

Table VIII. Potential spawning and rearing habitat and spawning biomass that could be affected.

Spawning Habitat ($H_{spawning}$) (Estimated Spawning Habitat)	24 km ²
Rearing Habitat ($H_{rearing}$) (Estimated Area of Moller and Herendeen Bays)	438 km ²
Estimates Herring Spawning Biomass	
Based on 1988 aerial survey	1,764 mt
Based on larval abundance	1,764 to 2,241 mt

Sources: McGurk, 1989b, and McGurk, In Press.

$H_{spawning}$: Information provided by McGurk, 1989, was used to estimate the aerial extent of eelgrass and rockweed beds (24 km²) in Moller and Herendeen Bays that have been associated with spawning herring in the past (Table VIII).

$H_{rearing}$: Specific information on the amount of optimum rearing habitat for herring larvae in the Port Moller estuary is not

available. However, information provided by McGurk, 1989, indicates that larvae tend to concentrate in Moller and Herendeen Bays. Therefore, these bays are considered prime rearing habitat. These two bays cover over half of the estuary, or about 438 km² (Table VIII).

Biomass. Estimates of the biomass of herring spawning in the Port Moller estuary range from 1,764 to 2,530 (Laevastu, 1985) and 1,768 to 2,241 (McGurk, In Press). The adults have been observed throughout the estuary (Table VIII).

OIL-SPILL ASSUMPTIONS

Table IX lists the assumptions used in analyzing the potential risk to spawning Pacific herring and herring eggs and larvae in Port Moller, Alaska, from an offshore oil spill. This evaluation is based on the assumption that a median-sized oil spill will occur during the WMV and that it will occur on or near tracts currently under lease by MMS for oil and exploration (Fig. 1). The joint probability (Table II) of a median-sized oil spill occurring and that it would occur during the WMV were not factored into this analysis.

Table IX. Oil-spill-evaluation assumptions.

P _{event}	
P _{oil spill}	1 Spill
P _{WMLV}	18%
P _{transport}	
P _{to coast}	13%
P _{into estuary}	20%
Q _{amount}	10,000 bbl
Q _{floating}	7,000 bbl
Q _{in water column}	2,800 bbl
Q _{in bottom sediments}	100 bbl
Q _{concentration}	
Q _{floating}	1 mm thick x 100 (dispersion rate)
Q _{in water column}	0.1 ppm to a depth of 5 m
Q _{in bottom sediments}	0.1 ppm per m ²
Q _{size (partitioning)}	
Q _{floating}	11.2 km ²
Q _{in water column}	153 km ²
Q _{in bottom sediments}	27 km ²
D _{disposal}	30-Day Maximum
D _{floating}	8-Days
D _{in water column}	5-Days
D _{in bottom sediments}	0-Days
H _{spawning}	24 km ²
H _{rearing}	438 km ²
B _{omass}	1,784 mt

It is assumed that there is a 13-percent probability that oil could reach the coast within 4 days and that the probability of oil entering Port Moller is 20 percent (Table IV).

A 10,000-bbl oil spill was assumed to be representative of the median-sized oil spills occurring on the OCS and is similar in size to a spill evaluated in the North Aleutian synthesis report (Table V). Based on information provided in Figure 5, 70 percent (7,000 bbl) of the oil would be floating or stranded after 4 days. After 10 days, 28 percent (2,800 bbl) would be dispersed or dissolved in the water column and 1 percent (100 bbl) would reside in bottom sediments.

Assuming that northeasterly winds prevailed for at least 4 days following the spill, 13

percent (1,300 bbl) of the oil could reach the coast. Of this amount, 70 percent or 910 bbl of the oil could be floating (based on 4 days of weathering), 28 percent or 384 bbl of the oil could be dispersed and dissolved in the water column (based on 10 days of weathering), and 1 percent or 130 bbl could be in bottom sediments (based on 10 days of weathering). The 4- and 10-day partitioning estimates were used to provide conservative estimates of the size of the areas that could be affected by an offshore oil spill.

For the purpose of this analysis, the area directly affected by floating oil was estimated by assuming that the oil spread to a uniform thickness of 1 mm and that the oil was dispersed into patches or windrows affecting an area about 100 times the undispersed size of the oil slick. The author assumes that the majority of the floating oil that enters Port Moller will be in the form of a stable water-in-oil emulsion and that it will become stranded along the high-tide line, where it will become incorporated in the beach sediments to slowly release petroleum hydrocarbons into the marine environment. Because the amount of oil that could be released into the estuary is assumed to be negligible, considering the weathered state of the oil and the amount that could be involved, it is not considered in this analysis.

The critical, i.e., lethal, concentration of oil in the water column and bottom sediments was assumed to be 0.1 ppm (Table V). To provide a conservative estimate of potential effects, oil dispersed and dissolved in the water column was assumed to be concentrated within the top 5 m. McGurk (1990, pers. commun.) observed concentrations of young herring larvae in this depth strata at night. Port Moller herring resources that could be affected by an oil spill were divided into three life stages: pre-spawning adults, spawned eggs, and larvae. The maximum

period of time that pre-spawning herring adults, spawned eggs, and larvae could be exposed to concentrations of oil exceeding 0.1 ppm is assumed to be about 30 days (Figs. 9 and 10). Since herring eggs in Port Moller are deposited subtidally and larvae do not reside on the surface, it is assumed that the duration of their exposure to floating crude oil would be minimal (0). Figure 9 indicates that pre-spawning adults, eggs, and larvae could be exposed to 0.1-ppm levels of dispersed and dissolved hydrocarbons for up to 9 days following an oil spill. Since in this analysis spilled oil would take about 4 days to reach Port Moller, the expected duration of exposure of fish, eggs, and larvae to oil in the water column would be shortened to about 5 days. Adult and larvae herring are not associated with bottom sediments; therefore, their exposure is assumed to be minimal (0). Since herring eggs are deposited primarily on marine vegetation and not on bottom sediments, their exposure to oiled sediments is also assumed to be minimal (0). However, a small but unknown portion of the eggs may be deposited on bottom substrate during the mass spawning process and, therefore, could be exposed to contaminated sediments.

The portion of the herring resources considered to be at risk from an offshore oil spill was assumed to be that portion of the habitat occupied by pre-spawning adults, eggs, and larvae. A conservative biomass estimate (1,784 mt) of pre-spawning adult herring in Port Moller was used in this analysis. The habitat occupied by the pre-spawning adults is expected to be similar to that used by the larvae (438 km²). The aerial extent of potential spawning and rearing habitat was used to estimate the portion of spawned herring eggs and larvae that could be exposed to spilled oil. The estimate of spawning habitat available was based on

an estimate of the aerial extent of marine vegetation (24 km²) in areas where large numbers of herring larvae were collected and where spawning had been observed in the past. The extent of rearing habitat was based on the observation that most herring larvae were observed in Moller and Herendeen Bays; and because the bays account for about half of the area of the Port Moller estuary, the rearing habitat was estimated to include about half of the estuary, or about 438 km².

RESULTS

Table X presents a summary of the potential effects that could result from a 10,000-bbl oil spill offshore, off of and upstream from Port Moller.

Assuming that northeasterly winds prevailed for at least 4 days following the spill, 13

Table X. Potential effects of a 10,000-barrel crude-oil spill on herring resources in Port Moller, Alaska.

P event	
P oil spill	67%
P WMLV	19%
P transport	
P to coast	13%
P into estuary	20%
O amount entering Port Moller	280 bbl
O floating	182 bbl
O in water column	73 bbl
O in bottom sediments	3 bbl
O fate	
O floating	9.8 km ²
O in water column	4 km ²
O in bottom sediments	1 km ²
D exposure	30-Day Maximum
D floating	0 Days
D in water column	8 Days
D in bottom sediments	0 Days
H spawning	24 km ²
Potential portion of spawning habitat affected	17%
H rearing	438 km ²
Potential portion of rearing habitat affected	1%
B biomass	1,784 mt
Potential portion of spawning biomass affected	1%

* Based on the assumption that the spilled oil will reach Port Moller within 10 days and that it will have reached a stable water-in-oil emulsion by the fourth day.

percent (1,300 bbl) of the oil could reach the coast. Of this amount, 20 percent (260 bbl) would enter the Port Moller estuary. Of this 20 percent, 70 percent (182 bbl) of the oil would be floating, 26 percent (73 bbl) would be in the water column, and 1 percent (3 bbl) would be in the sediments. Floating oil could cover an area of about 0.5 km², oil dispersed and dissolved in the water column could affect an area of about 4 km², and 1 km² of bottom sediments could be affected. The duration of exposure of the herring resources to floating oil and oiled sediments was assumed to be zero, and exposure to oil in the water column was expected to be about 5 days. The analysis also indicates that approximately 17 percent of the spawning habitat and 1 percent of the rearing habitat could be exposed to critical levels of oil in the water column.

DISCUSSION

While it is possible that large quantities of oil from an offshore oil spill could enter the Port Moller estuary and could affect herring resources, results of this analysis suggest that if an oil spill occurred on or near offshore areas currently under lease for gas and oil exploration in the southeastern Bering Sea during the period when herring resources were most vulnerable to the potential effects from spilled oil, the probability of a significant effect to these resources is quite low. The primary variables that reduce the probability of a significant effect to the herring resources are distance and time.

The distance separating the spill site and the resource at risk determines the minimum time required for the spilled oil to reach the resource in question. This in turn determines the maximum amount and condition of the oil that could reach the resource at risk. The condition and amount of oil reaching the resource determines the toxicity of the oil and the portion of the resource that could be exposed to toxic levels of spilled oil.

The probability of an offshore oil spill having a significant effect on herring resources in Port Moller is probably less than that described in this analysis because the analysis did not consider the probability that the spill would occur during the WMV, that dispersed and dissolved oil would be distributed throughout the mixed layer rather than just the top 5 m, and that there are multiple herring spawnings each year.

Considering the oceanographic dynamics of the estuary, all of the herring resources in the estuary could be exposed to varying concentrations of dissolved and dispersed oil in the water column for varying periods of time. Observed concentrations of hydrocarbons seldom would approach 0.1 ppm and would generally be much less. Therefore, the observation that specific portions of the resources could be exposed to 0.1 ppm for up to 5 days is considered to be a worst-case possibility.

Results from studies of herring eggs and larvae conducted following the Exxon Valdez oil spill indicated that the presence of spilled oil had no measurable effect on hatching success, occurrence of abnormal larvae, or larval growth and mortality rates (McGurk, 1990a,b). These results suggest that the developing eggs and resulting larvae were exposed to levels of dissolved and dispersed oil less than that needed to elicit an acute response, i.e., death, deformity, or reduced growth rates.

Although results from histopathological studies conducted following the Exxon Valdez oil spill have not been released, it appears that even though fishes

examined exhibited no overt response to the presence of spilled oil, hydrocarbons metabolites in liver bile and elevated levels of mixed function oxidases (MFO) were detected (anonymous comments made during discussions following the presentation of this paper). Therefore, even though hydrocarbons could be present in Port Moller following an oil spill at levels too low to elicit an acute response, sublethal effects could be observed for an extended period of time. Sublethal amounts of hydrocarbons could leach into the estuary from crude oil stranded in the littoral zone or be resuspended from bottom sediments during storm events. The presence of sublethal concentrations of hydrocarbons could probably be detected as elevated levels of hydrocarbons metabolites in liver bile and MFO enzymes. The long term effects from exposure to sublethal concentrations of hydrocarbons is unknown. However, the observation that spawning populations of Pacific herring are found in areas where chronic hydrocarbon pollution is endemic, i.e., San Francisco Bay, Puget Sound, etc., suggests that herring populations are able to tolerate exposure to sublethal concentrations of hydrocarbons that exceed those expected to occur in Port Moller following an offshore oil spill.

The study upon which much of the information used in this analysis is based was developed through the MMS-funded study, "Fisheries Oceanography of the Southern Bering Sea and North Aleutian Basin: Relationship of Larval Dispersion and Mortality of Herring Larvae to Environmental Conditions in the Port Moller Estuary," by Michael McGurk of Triton Environmental Consultants Ltd., Sidney, British Columbia (McGurk, 1990c).

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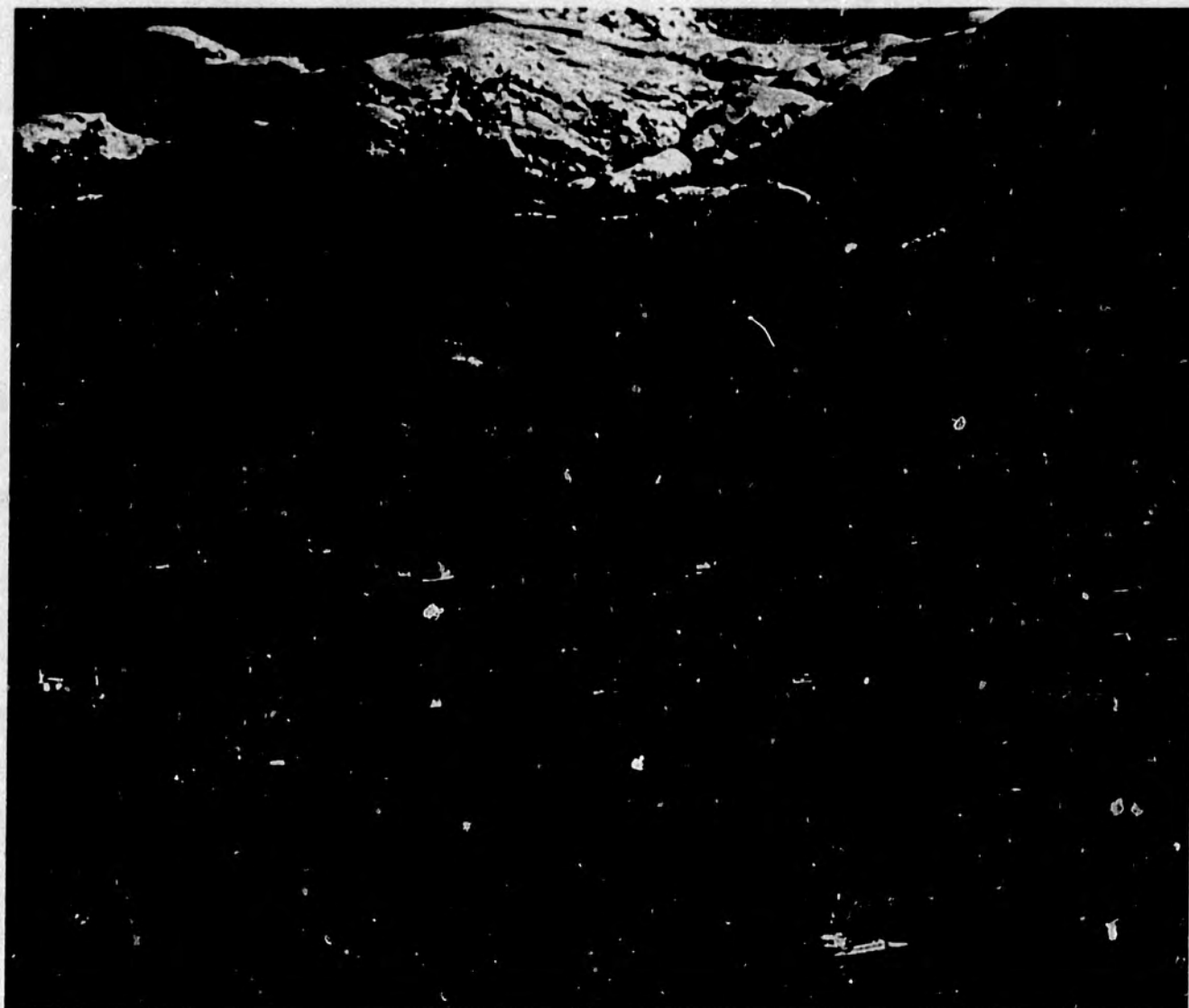
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Alaskan Fisheries

Two Years After the Spill



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February 1991

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PREFACE

This background paper responds to concerns that the 1989 *Exxon Valdez* spill might have damaged Alaska's fisheries, which are vital to the area's economy and lifestyle. It describes the robust condition of Prince William Sound fisheries and future prospects for seafood harvesting in Alaska. It does not include results of any of the research that has been conducted in Prince William Sound since the spill, but relies on the 1989 and 1990 commercial fishing results, the thousands of previously published scientific studies of oil in the sea, and the history of fishing after major spills in other regions.

The four authors all have extensive experience with Alaska's fisheries:

William F. Royce, Ph.D., Professor Emeritus of Fisheries in the College of Ocean and Fishery Sciences of the University of Washington in Seattle and retired executive of the U.S. National Marine Fisheries Service. For many years, he has studied fisheries management and the fish species of Alaska.

Thomas R. Schroeder, a fisheries consultant based in Homer, Alaska. He recently retired from the Alaska Department of Fish and Game, where he served as commercial fisheries management biologist for part of the area affected by the oil spill.

A.A. "Ole" Olsen, an Anchorage fisheries consultant and former fisherman, bush pilot and manager of seafood-processing plants throughout Alaska. In 1989 and 1990, he reviewed results of scientific studies (which he helped conduct) of the area's fish stocks with Alaskan villagers who rely on fish for subsistence. In addition, he participated in 1990 fishery-related spill cleanup activities.

William J. Allender, a former commercial fisherman and owner/operator of a sport fishing business based in Cordova Harbor in Prince William Sound. In 1989, he participated in Exxon's wildlife rescue programs. In 1990, as a consultant to Exxon, he worked with the Alaska Department of Fish and Game to help ensure the safe operation of Prince William Sound fisheries.

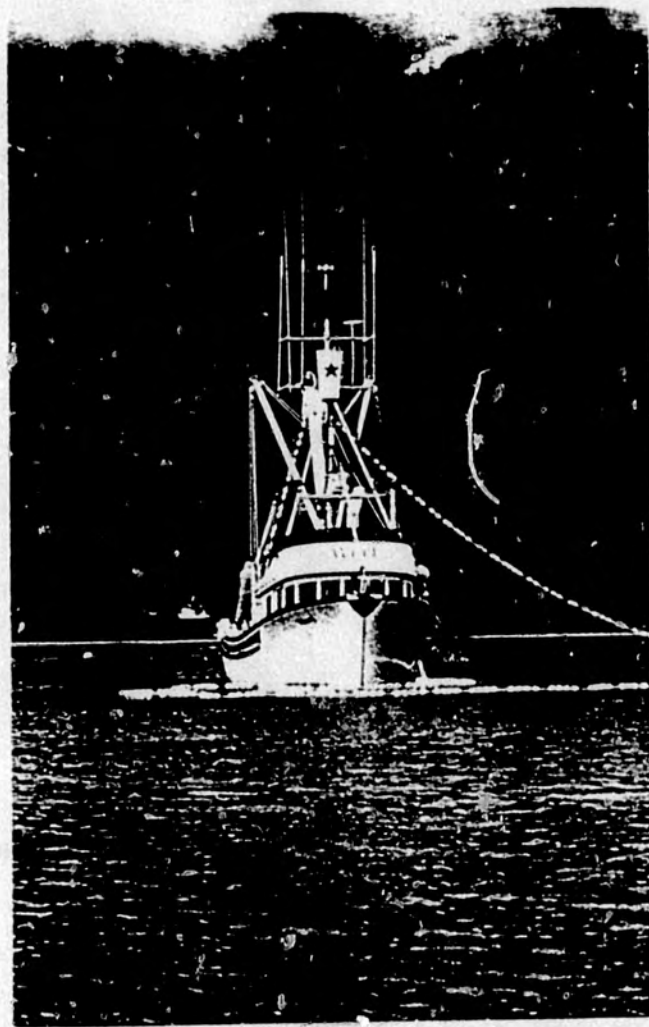


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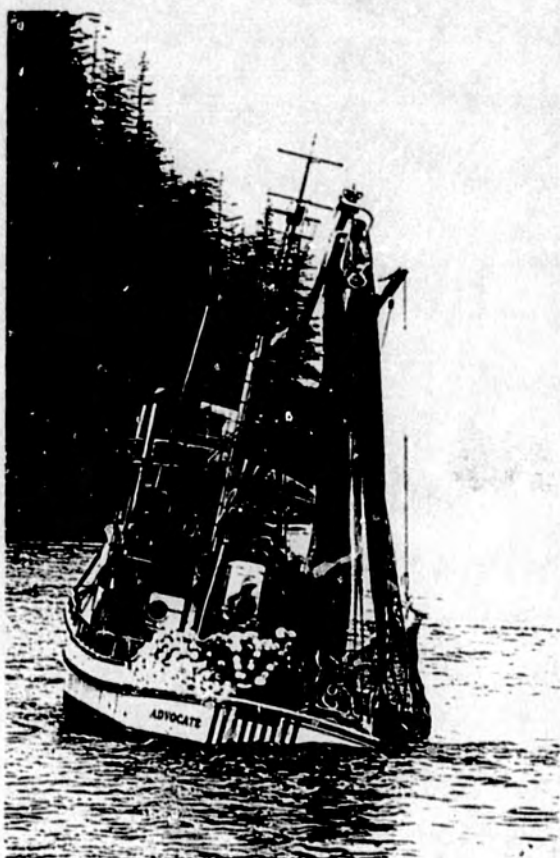
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*In 1990, fishermen caught
44.2 million pink salmon
in Prince William Sound,
far eclipsing the previous
record of 29.2 million fish.*

1

SUMMARY AND CONCLUSIONS

In March 1989, the tanker *Exxon Valdez* struck a submerged reef off Bligh Island in Alaska's Prince William Sound, spilling about 11 million gallons of North Slope crude oil onto the waters. As the slick spread, anxiety also spread among the local commercial and sport fishing industries. Many fishermen worried whether the spill had ruined their livelihoods forever.

Within a year and a half, however, the commercial and sport fishing industries could move beyond the pessimism following the spill. During the 1990 season, commercial fishermen in Prince William Sound enjoyed record-breaking catches. In April, purse seiners netted 8,300 tons of herring — more than the entire year's "harvest quota" — in just 20 minutes, though the season typically lasts several hours. Then, over the summer, fishermen caught 44.2 million pink salmon, far eclipsing the previous record of 29.2 million fish.

The ample stocks of herring and pink salmon were significant to the sport and commercial fishermen for several reasons. Economically, the area's fishermen have traditionally harvested both pinks and herring in large numbers, and they rely on them for a major portion of their income. Biologically, the two species are considered more vulnerable to adverse effects of the oil than other species. The record-breaking harvests therefore have positive implications for less vulnerable species, including such favorites as halibut and king and coho salmon.

In spite of the accident, the sport and commercial fishing industries fared better in 1989 than originally anticipated. State officials concluded that sport fishermen would avoid oiled areas, and they did not restrict sport fishing in any way. Alaskan officials did close many of the spill area's prime commercial fisheries following the spill in order to eliminate any risk of marketing fish contaminated by oil-fouled nets or other gear. Although this action did force many fishermen to abandon their traditional fishing grounds, the total 1989 pink salmon harvest in Prince William Sound was still the fourth highest on record,