CRUISE REPORT

FOR

THE INITIAL ENVIRONMENTAL SURVEY IN THE

VICINITY OF THE SUNKEN FREIGHTER

PAC BARONESS

December 18, 1987

Performed for

U. S. Department of the Interior
MINERALS MANAGEMENT SERVICE
Pacific OCS Office

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CRUISE REPORT
FOR
THE PAC BARONESS SURVEY
16 - 21 November 1987

1.0 INTRODUCTION

On September 21, 1987, the 564-foot freighter, Pac Baroness, collided in fog with another freighter, the Atlantic Wing, approximately 20 km to the southwest of Point Conception, California. As a result of the collision, the Pac Baroness eventually sank in about 450 to 500 m of water, at a reported location of approximately 34°21.13'N latitude and 120°38.14'W longitude. This site is in the general vicinity of stations sampled during the previous Minerals Management Service (MMS) Phase I Reconnaissance Survey and just to the south of stations that currently are being monitored as part of MMS's ongoing California OCS Phase II Monitoring Program (see Figure 1).

The Pac Baroness was carrying a cargo of 21,000 metric tons of finely powdered (< 200 microns) and concentrated copper ore consisting of refined chalcopyrite, covellite, and native copper, and containing approximately 30% each of copper, sulfur, and iron. The vessel also was carrying approximately 7,500 barrels of intermediate-grade fuel oil and 280 barrels of marine diesel.

The sinking resulted in an initial spill of an estimated 20,000 gal of oil, which created a visible surface slick that could be tracked by aerial overflights for several days. Colored plumes observed at the time of the sinking also suggested that some of the copper ore may have escaped from ruptured bulkheads and hatches in the cargo holds.

The copper ore onboard the Pac Baroness consists principally of relatively insoluble copper sulfide; however, it is possible that dispersion of the material throughout oxygenated surface waters could promote oxidation of the sulfide, leading to increased concentrations of dissolved copper. Both copper (in the oxidized, soluble form) and petroleum hydrocarbons are toxic to marine organisms, even at dilute concentrations.

Battelle Ocean Sciences, through a joint research arrangement with the University of California at Santa Barbara (UCSB), is conducting a limited environmental study in the vicinity of the wreck, to locate the vessel, determine the extent of initial contamination (with a focus on copper and petroleum hydrocarbons) and examine the potential impact on benthic communities of the immediate surrounding area. Battelle also will be using results of this study to evaluate whether potential impacts linked to the sinking of the Pac Baroness will interfere with efforts to detect drilling-related impacts at nearby stations within the Santa Maria Basin, which are being monitored as part of the ongoing MMS California OCS Phase II Monitoring Program. Funding for this study is being provided by the Minerals Management Service, the National Science Foundation, the National Oceanic and Atmospheric Administration, and the Environmental Protection Agency.

An initial environmental survey was conducted in the vicinity of the wreck, from November 17 - 20, 1987. The support vessel for the survey was the M/V Aloha, which is owned and operated by International Underwater Contractors, Inc.

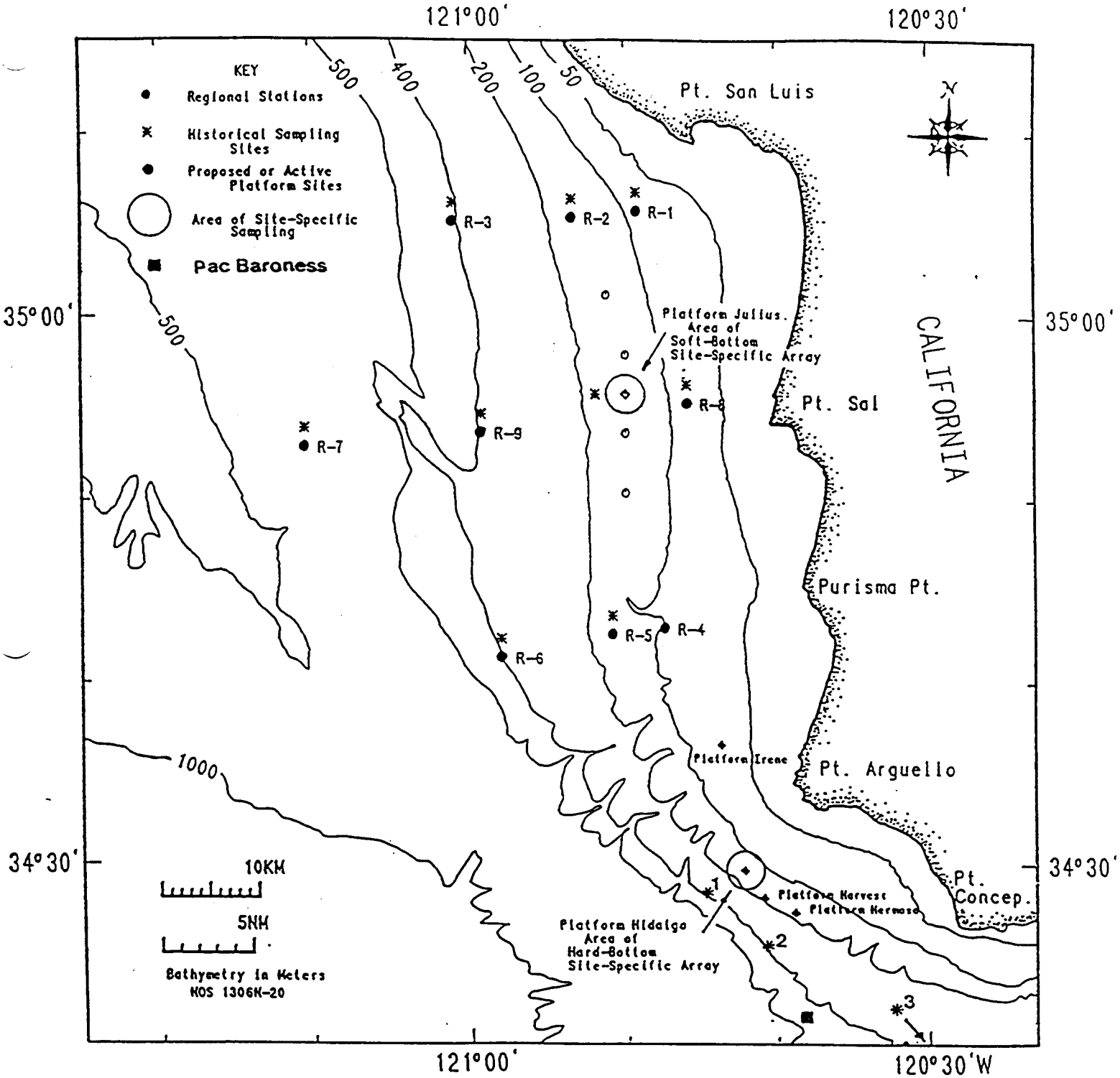

Figure 1.1 Map of Santa Maria Basin area of the California OCS with the position of the sunken vessel Pac Baroness (34°21'N, 120°38'W), station locations for the MMS Phase II Monitoring Program (Regional and Site-Specific Stations), and historical sampling sites from the MMS Phase I Reconnaissance Survey. Note: $*^1$ = MMS Phase I Station 72 (34°28.4'N, 120°44.8'W, Depth 407 m); $*^2$ = MMS Phase I Station 76 (34°25.4'N, 120°41'W, Depth 401 m); $*^3$ = MMS Phase I Station 82 (34°18.7'N, 120°29.5'W, Depth 401 m). Locations of proposed and active platform sites also are shown.

Mobilization and demobilization occurred at Ventura Harbor, California, on November 16 and 21, respectively. The cruise consisted of two legs, separated by an at-sea crew exchange occurring with Island Packers' vessel M/V Jeffrey Arvid at midnight on November 18.

2.0 LEG 1 REPORT
16-18 November 1987

2.1 Objectives

1. Locate the sunken vessel Pac Baroness using side-scan sonar.

2. Examine the vessel with the Recon IV ROV system, and determine overall damage to the hull and sources for potential discharges of copper ore and oil.

3. Photograph and videotape the wreck, surrounding sediments and biota, using the ROV system.

4. Collect sediment and water samples (and possibly biological specimens) in the immediate vicinity (within 200 m) of the wreck.

5. Trawl for animal specimens for body burden analysis of trace metals (especially copper) and possibly hydrocarbons.

2.2 Scientific Personnel

Name	Affiliation
Dr. Bruce Robison	UCSB/MSI
Dr. Stanley Margolis	UCSB/UCD
Dr. Paul Stout	UCSB/MSI
Dr. Bruce Luyendyk	UCSB/Geological Sciences
Dr. Rachel Haymon	UCSB/Geological Sciences
Mr. Kim Reisenbichler	UCSB/MSI
Mr. Eric Doehne	UCS/Geology
Dr. Gary Brewer	Minerals Management Service
Mr. Mike Boyle	USGS Menlo Park
Mr. James Campbell	Battelle Ventura
Mr. Robert Dellaert	Land and Sea Surveys, Inc.
Mr. James Cooley	Land and Sea Surveys, Inc.
6 Crew; 4 ROV Operators	International Underwater Contractors, Inc.

2.3 Activities

11/16/87	0800	Mobilize M/V Aloha for both legs, at Ventura Harbor.
11/17/87	0000	Departed Ventura Harbor.
	0800	Arrived at Pac Baroness site.
	0800-1800	Conducted side-scan searches.
	1800-2400	Performed ROV Dives.

2.3 Activities (Continued)

11/18/87	0000-0100	Continued ROV Dives.
	0100-0700	Operations shutdown.
	0700-1530	Performed ROV Dives.
	1600-1900	Performed side-scan searches.
	1900-2130	Performed grab sampling.
	2130-2400	Crew exchanges at Coho Bay.

2.4 Navigation

Navigation services were provided by Land and Sea Surveys, Inc. The Motorola Miniranger system was the primary navigational aid used for side-scanning and ROV operations on Leg 2.

2.5 Summary

Leg 1 was successful with respect to two of the primary objectives. First, the sunken vessel was located through the use of side-scan sonar and the ship's fathometer. Coordinates of the vessel are:

UTM Zone 10 Coordinates	LORAN-C	Latitude/Longitude
N3804100.9	TDX = 27826.1	34°21.43'N
E717220.2	TDY = 41785.7	120°38.29'W

The ship appears to be resting on its keel in about 430 m of water, and oriented in a north-south direction with the bow pointed to the NNE.

Secondly, side-scan sonar records were successful in revealing that the ship is twisted and fractured into at least three pieces. These same images show a zone of scattered debris within a radius of approximately 150 m of the vessel, and a slightly larger zone of disturbed sediment extending out to a radius of approximately 200 m. Based on these images, it is apparent that cargo and fuel compartments are likely to have been breached, providing a source of escape for the oil and copper ore. Additional attempts were made to inspect the vessel with the ROV; however, equipment failures precluded completion of this work. Therefore, information on the condition of the sunken vessel is limited at this time to the results of the side-scan survey.

The ROV was successful in obtaining some environmental samples during the various dive attempts. Some video footage of ambient sediments and biota was obtained within about 500 to 250 m to the NW of the vessel. A total of 16 water samples also was collected from four different localities within 300 m of the wreck via bottles attached to the ROV.

In addition to the video footage and water samples obtained with the ROV, a small grab sample of sediment was collected within a 150-m range of the vessel. No tissue samples (for analysis of trace metals or hydrocarbons) were collected on Leg 1 (however, as noted in the next section, these samples were collected on the subsequent leg).

3.0 LEG 2 REPORT
19-21 November 1987

3.1 Objectives

1. Collect bottom-sediment samples (with a 0.25-m^2 box corer) at an array of stations near the wreck, and at comparable control stations along the same isobath, to provide a means of examining the extent of initial contamination in reference to trace metals (especially copper) and petroleum hydro-carbons, and the potential biological impact on macroinfaunal communities.

2. Obtain hydrocasts at a limited number of stations (from a subset of the sediment stations) to collect water samples for the analysis of trace metals (especially copper).

3.2 Scientific Personnel

Battelle Ocean Sciences

Dr. Jeffrey Hyland, Program Manager
Mr. Eiji Imamura, Ventura Operations Manager
Mr. James Campbell, Chief Scientist
Ms. Janet Kennedy, Second Scientist
Ms. Heidi DeBra, Technician
Ms. Christie Dolstra, Technician

University of California, Santa Barbara

Dr. Richard Zimmer-Faust
Dr. Paul Stout
Mr. Rich Coffman
Ms. Karen Griffin
Mr. Ben Flowers
Mr. Kim Reisenbichler

U. S. Geological Survey

Mr. Mike Boyle

Moss Landing Marine Laboratory

Mr. Brian Sak

International Underwater Contractors, Inc.

8 Crew Members

3.3 Activities

11/19/87	0000	Crew Exchange.
	0030-0230	Transit to site.
	0230-0400	Grab sampling operations.
	0400-0800	Operations shutdown.
	0800-1000	Continued grab sampling.
	1000-1230	Box coring operations.
	1230-1400	Hydrocast near wreck.
	1400-2400	Box coring operations.
11/20/87	0000-1500	Box coring operations.
	1500-1700	Hydrocast at control site.
	1700-1730	Collection of final box core.
	1800	Departed for Ventura Harbor.
11/21/87	0200	Arrived Ventura Harbor.
	0800-1200	Demobilization

3.4 Navigation

The Northstar 7000 LORAN-C receiver was the primary navigational aid for Leg 2. All station navigation was based on LORAN time delays in the 9940 Group Repetition Internval (GRI) using the X and Y secondary stations, the 27-k and the 41-k lines, respectively. Station positions were established by using a range and bearing method in reference to the Pac Baroness target coordinates.

3.5 Summary

On Leg 2, bottom sediments were collected successfully with a 0.25-m^2 box corer (partitioned into 25 individual 0.01-m^2 subcores) at an array of eight stations (represented by one sample per each station) within a 500-m radius of the vessel and at a control station (represented by three relicate samples) located 8.25 km to the NW (near a historical sampling site). A nominal station design for sediment sampling is shown in Figure 3-1. Subcores from these samples were collected for analysis of petroleum hydrocarbons and trace metals, benthic macroinfauna, sediment grain size, and total organic carbon. In addition, larger animals were collected opportunistically from remaining unused sediment subcores and contained for subsequent analysis of trace metals in tissues.

Hydrocasts also were obtained on Leg 2 at the control site and one of the nearfield sites, approximately 500 m to the east of the vessel. These water samples will be analyzed for trace metals. Samples were collected at various water depths at each of these two hydrocast stations. A sample replicate collection matrix and a summary of sample positions are shown in Tables 3-1 and 3-2, respectively.

The above work for Leg 2 was completed by approximately 1800 on Friday, November 20, at which time a weather front moved in, bringing unworkable conditions that were predicted to persist through at least the next day. Because of these conditions, the Aloha headed for port at that time, ending the cruise within the originally scheduled four-day period.

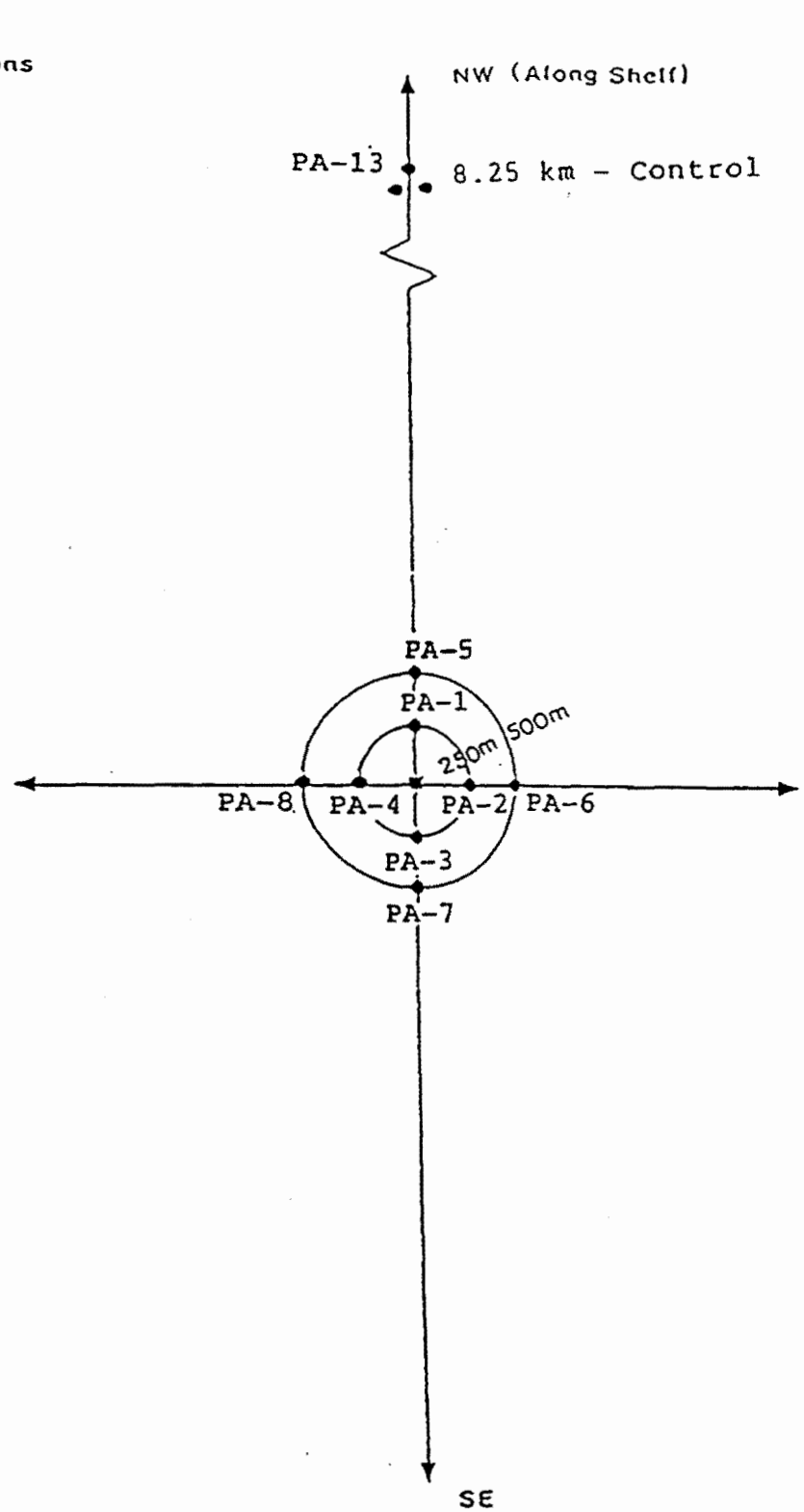

Figure 3-1. Nominal station design for sediment sampling. One sample was collected at each of the stations within a 500-m radius of the wreck. Three replicate samples were collected at the 8.25-km control site. The isobaths within the 500-m radius of the wreck are oriented in a NNE-SSW direction. Approximately 1 km from the wreck, the isobaths are oriented in the NW-SE direction.

TABLE 3-1. SAMPLE REPLICATE COLLECTION MATRIX FOR PAC BARONESS SURVEY, LEG 2

Station	Macrofauna 0-10cm	Meiofauna	Trace Metals 0-2cm	Trace Metals Profile Core	Trace Metals in Animal Tissues	Hydrocarbons 0-2cm	Hydrocarbons 2-10cm	Grain Size	TOC	Hydrography
PA-1	1		1	1	1	1	1	1	1	
PA-2	1	1	1		1	1		1	1	
PA-3	1		1	1	1	1		1	1	
PA-4	1		1		1	1		1	1	
PA-5	1		1		1	1		1	1	
PA-6	1		1		1	1		1	1	1
PA-7	1		1	1	1	1	1	1	1	
PA-8	1	1	1		1	1		1	1	
PA-13	3	1	3	2	3	3	1	3	3	1
TOTAL NUMBER OF SAMPLES	11	3	11	5	11	11	3	11	11	2
Sample Custody	Battelle Ventura	UCSB	UCSB	UCSB	UCSB	Battelle Duxbury	Battelle Duxbury	UCSB	Battelle Ventura	UCSB

TABLE 3-2. SUMMARY OF SAMPLE POSITIONS ON PAC BARONESS SURVEY 1, LEG 2 (M/V Aloha)

Station	Date and Time (PST)	Sample	Northstar 7000 Latitude Longitude	LORAN Time Delays	Range(M) Bearing(deg) To Wreck	Depth (M)	Comments
PAC BARONESS Reference Coordinates			34°21.53'N 120°38.24'W	27826.1 41785.5			Established via Side Scan Survey.
PA-1	20 Nov 87 0353	Box Core 1	34°21.64'N 120°38.24'W	27826.3 41786.0	300M/200°	423	First attempt unacceptable. Penetration to 20cm. Sediment layers very soft, high water content. Oil visible on sediment surface. Disturbed surfaces.
PA-2	19 Nov 87 1604	Box Core 1	34°21.43'N 120°38.11'W	27826.6 41784.6	300M/296°	428	First attempt unacceptable due to over penetration. Good sample, penetration to 17cm. Oil present in sediments.
PA-3	20 Nov 87 0527	Box Core 1	34°21.41'N 120°38.35'W	27825.9 41785.3	175M/030°	432	Penetration to 20cm. Oil present in samples.
PA-4	19 Nov 87 1834	Box Core 1	34°21.55'N 120°38.44'W	27825.6 41786.3	290M/117°	436	Penetration to 25cm. Samples contained oil, paint chips, and heart urchins.

TABLE 3-2. SUMMARY OF SAMPLE POSITIONS ON PAC BARONESS SURVEY 1, LEG 2 (M/V Aloha) (Continued)

Station	Date and Time (PST)	Sample	Northstar 7000 Latitude Longitude	LORAN Time Delays	Range(M) Bearing(deg) To Wreck	Depth (M)	Comments
PA-5	19 Nov 87 2333	Box Core 1	34°21.68'N 120°38.30'W	27826.0 41786.4	350M/170°	410	Penetration to 20cm. Oil present in sediments. Sample collected off-station, unable to re-sample due to time constraints.
PA-6	19 Nov 87 1054	Box Core 1	34°21.35'N 120°38.00'W	27826.9 41783.8	540M/307°	421	Penetration >25cm. Sediments very silty, oil present. Sample photographed during sieving. Sample collected off-station, unable to resample due to time constraints.
PA-6	19 Nov 87 1317	Hydrocast	34°21.35'N 120°37.98'W	27826.9 41783.7	550M/310°	421	Eleven bottles on cast.
PA-7	20 Nov 87 0811	Box Core 1	34°21.26'N 120°38.40'W	27825.7 41784.9	750M/037°	435	Variable penetration; 15-23cm. Coarse-grained sediments. Oil and paint chips in sediment.
PA-8	19 Nov 87 2102	Box Core 1	34°21.65'N 120°38.62'W	27825.1 41787.5	625M/125°	432	Penetration to 17cm. Coarse-grained sediment. Oil and paint chips in sediment.

TABLE 3-2. SUMMARY OF SAMPLE POSITIONS ON PAC BARONESS SURVEY 1, LEG 2 (M/V Aloha) (Continued)

Station	Date and Time (PST)	Sample	Northstar 7000 Latitude Longitude	LORAN Time Delays	Range(M) Bearing(deg) To Wreck	Depth (M)	Comments
PA-13	20 Nov 87 1244	Box Core 1	34°25.01'N 120°41.51'W	27816.9 41813.4	8.25KM/143°	432	Penetration to 20cm. No oil in sediment. Wind increased to 25 kts.
PA-13	20 Nov 87 1411	Box Core 2	34°25.03'N 120°41.57'W	27816.7 41813.7	8.25KM/143°	432	Good penetration. Amphipods on sediment surfaces.
PA-13	20 Nov 87 1730	Box Core 3	34°25.02'N 120°41.66'W	27816.4 41814.0	8.25KM/143°	432	Variable penetration 13-23cm. Echinoids and shrimp in samples. Sampling conditions marginal due to increased wind and seas.
PA-13	20 Nov 87 1625	Hydrocast	34°24.70'N 120°41.77'W	27816.1 41813.0	7.65KM/143°	432	Wind 25-30 kts. Station keeping difficult. Five bottles on cast.

Some very interesting preliminary observations were noted from samples collected on Leg 2. Some of the more significant observations are as follows:

- Visible quantities of oil were found in all sediment samples collected within 500 m of the vessel; these levels were not seen in any of the replicated control samples collected 8.25 km to the NW.

- The oil seen in sediments did not resemble seep oil; rather, it looked more like the type of fuel oil that was contained on the Pac Baroness.

- The oily sediments within 500 m of the vessel tended to form into small "beads," which created relatively large volumes of material retained on the 300-micron sieves in comparison to control samples.

- Live animals were noted in all samples; however, there appeared to be a higher abundance of amphipods in control samples relative to the samples collected near the sunken vessel (amphipod crustaceans are known as being highly sensitive to oil toxicity).

These preliminary observations made at the time of sample collection must be confirmed analytically before reaching conclusions regarding fate and effects of contaminants linked to the Pac Baroness. These necessary laboratory analyses are proceeding at this time. Battelle is performing the analysis of hydrocarbons in sediments and analysis of macroinfaunal samples, as identified in the Revised Technical Proposal for the Pac Baroness Survey, submitted to MMS on November 4, 1987. Scientists at UCSB also are proceeding with the analysis of copper and other trace metals in samples of water, sediment, and animal tissues. Preliminary results of this latter work at UCSB reveal that excessive amounts of copper ore are present in the same sediments that contained visible levels of oil (Stan Margolis, personal communication). These joint results suggest that the same process(es) are responsible for the initial mixing of both the oil and copper into the ambient sediments.

A follow-up cruise is scheduled for mid-January to complete the ROV survey of the sunken vessel and to obtain additional nearfield samples of sediment, water, and biota. Use of the research vessel and ROV for this cruise will be made available at no cost to the program as a result of a contribution from International Underwater Contractors, Inc.

Initial Environmental Effects of the *Pac Baroness* Oil and Copper Spill: Results of Hydrocarbon and Macrofaunal Analyses

May 25, 1988

by

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Report prepared for the Minerals Management Service (Pacific OCS Office, 1340 West Sixth Street, Los Angeles, CA 90017) and the Environmental Protection Agency (Region 9, Water Management Division, 215 Fremont Street, San Francisco, CA 94105) under MMS Contract No. 14-12-0001-30262.

ABSTRACT

A study was conducted to investigate initial environmental effects of an offshore oil and copper spill resulting from the sinking of the freighter Pac Baroness. The location of this spill was approximately 20 km SW of Point Conception, California, at a water depth of 430 m. Gas chromatography (GC) and mass spectrometry (MS) were used to examine the distribution and levels of hydrocarbons in surficial sediments, and to compare the patterns of hydrocarbons in the sediments to those of a source-oil sample obtained from the vessel. Potential impacts of the spill on macroinfauna were also evaluated by examining changes in community structure and composition, and in abundances of component species, based on comparison between control and wreck-site samples. Results of the chemical analyses show that sediment samples collected in the vicinity of the Pac Baroness contain elevated levels of hydrocarbons that clearly originate from the oil on board the sunken vessel. Furthermore, statistical and various other mathematical comparisons of the macroinfaunal data reveal distinct biological effects of the spill within the immediate surrounding area of the vessel, at water depths of 410 to 436 m. Among these effects are significant reductions in mean number of species, mean number of individuals (all species combined), dominance structure, abundances of several component species (half of which are dominants within the community) and the combined abundance of sensitive amphipod species. These initial levels of contamination and associated environmental effects are unique in consideration of the extreme water depth within which the spill incident occurred.

1.0 INTRODUCTION

On September 21, 1987, the 564-foot freighter Pac Baroness collided in fog with another vessel, the Atlantic Wing, approximately 20 km southwest of Point Conception, California. As a result of the collision, the Pac Baroness eventually sank in 430 m of water, at a latitude of 34°21.43'N and longitude of 120°38.29'W. This site is located just to the south of stations that currently are being studied by a team of scientists from Battelle and other research organizations as part of an offshore environmental monitoring program designed to assess potential long-term, cumulative impacts of oil and gas development and production along the California Outer Continental Shelf (Hyland and Neff, 1988) (Figure 1).

The Pac Baroness was carrying a cargo of 21,000 metric tons of a finely powdered copper concentrate of which approximately 71% was comprised of chalcopyrite ($CuFeS_2$); the remainder consisted primarily of chalcocite (Cu_2S), covellite (CuS_2), and trace amounts of native metallic copper (Dames and Moore, 1987). The vessel also was carrying a combined volume of 378,943 gal of fuel and lubricating oils, consisting of 339,360 gal of intermediate-grade fuel oil (approximately equivalent to No. 4 fuel oil), 29,568 gal of marine diesel (with a consistency between No. 2 and No. 3 fuel oil), and 10,015 gal of lubricating oil (U.S. Coast Guard, personal communication).

The sinking of the vessel resulted in an initial spill of an estimated 20,000 gal of oil, which created a visible surface slick that was tracked by Coast Guard aerial overflights for several days. Colored plumes of powder noted by observers present at the time of the sinking also indicated that some of the copper ore had escaped into the water column from ruptured bulkheads and hatches in the vessel's cargo holds. There was further belief that if the vessel broke apart as it made contact with the sea floor, then both the oil and copper ore could become mixed directly into bottom sediments.

The copper ore on board the Pac Baroness consisted principally of relatively insoluble copper sulfide; however, it is possible that contact of the material with dissolved oxygen present in the sea water would promote oxidation of the sulfide, eventually leading to increased concentrations of dissolved copper. Both copper (in the oxidized, soluble form) and petroleum hydrocarbons can be toxic to marine organisms, even at dilute concentrations. Also, coating of organisms with oil could result in death from the physical effects of entanglement and smothering.

Because of the possible transport of these contaminants through the marine ecosystem and resulting biological effects, Battelle Ocean Sciences and the University of California at Santa Barbara (UCSB) received funds to conduct a preliminary, environmental investigation of the Pac Baroness incident. Objectives of this joint study were to locate the sunken vessel, examine the extent of initial contamination (with a focus on copper and petroleum hydrocarbons) and determine the potential impact on benthic communities of the immediate surrounding area. An additional important objective, with respect to Battelle's portion of the study, was to evaluate whether potential impacts linked to the sinking of the Pac Baroness would interfere with efforts to detect drilling-related impacts at nearby stations within the Santa Maria Basin, which are being monitored as part of the ongoing California OCS Phase II Monitoring Program (sponsored by the Minerals Management Service).

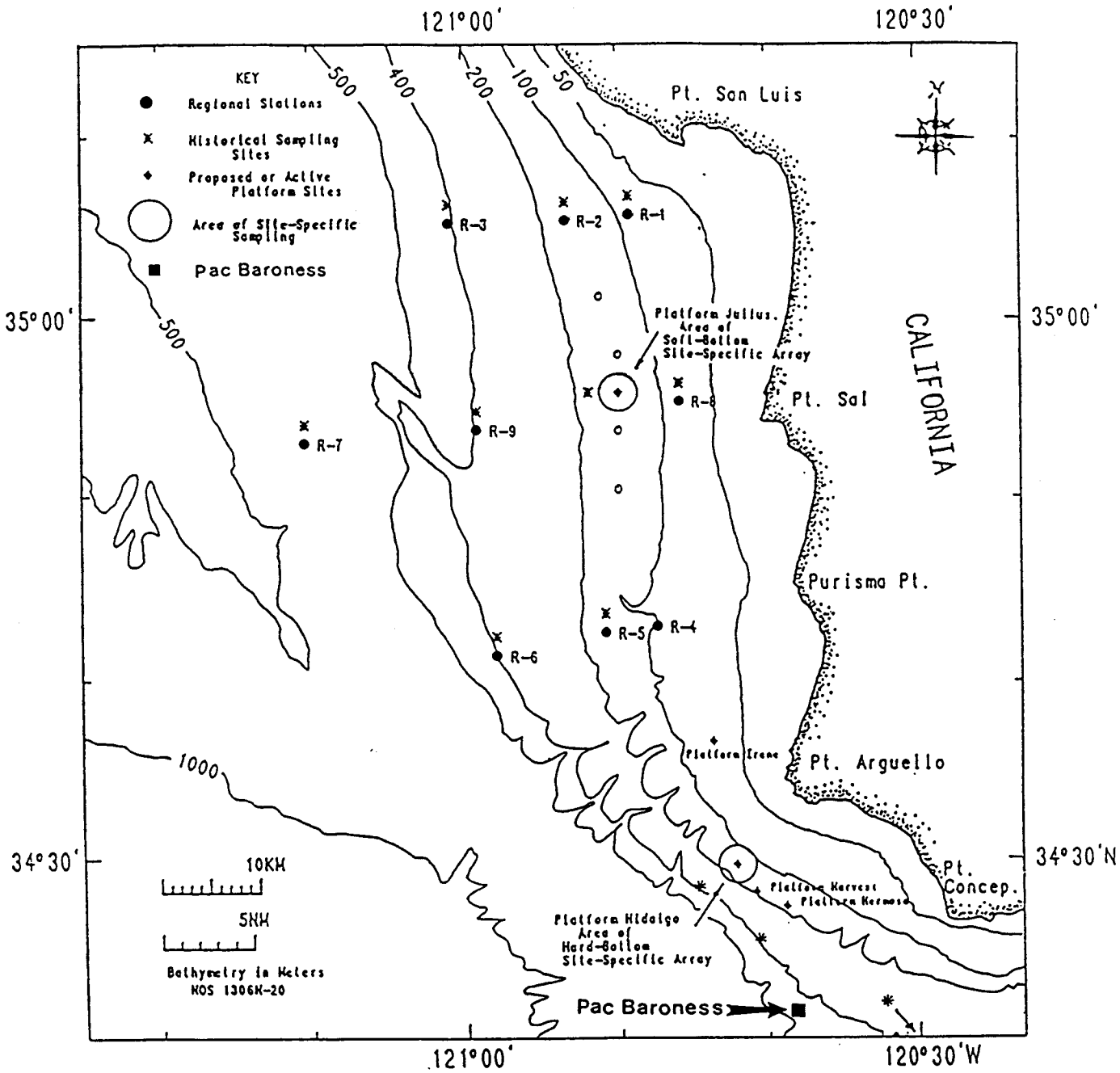


Figure 1. Map of Santa Maria Basin area of the California OCS with the position of the sunken vessel Pac Baroness (34°21.43'N, 120°38.29'W), and station locations for the MMS Phase II Monitoring Program (Regional and Site-Specific Stations). Locations of proposed and active platform sites and historical sampling sites from the MMS Phase I Reconnaissance Survey are also shown.

The current report presents results of hydrocarbon and macrofaunal analyses performed by Battelle Ocean Sciences. Additional work relating to the analysis of copper in water, sediments, and biota is being performed by UCSB and will be reported elsewhere in the literature.

2.0 METHODS

2.1 LOCATION AND DESCRIPTION OF THE SUNKEN VESSEL

An initial field survey consisting of two legs was conducted in the vicinity of the wreck from November 17-20, 1987 on the research vessel M/V Aloha, operated by International Underwater Contractors, Inc. (IUC). The first leg was devoted to locating and describing the condition of the sunken vessel; the second leg was devoted to obtaining environmental samples for biological and chemical analyses. The details of this initial survey are summarized in a separate cruise report (Hyland *et al.*, 1987).

Location of the *Pac Baroness* was accomplished through use of side-scan sonar (operated by the U. S. Geological Survey) and the research vessel's fathometer. Coordinates of the sunken vessel, obtained with a LORAN Northstar 7000 navigation system, are 34°21.43'N and 120°38.29'W; LORAN C time delays are TDX = 27826.1 and TDY = 41785.7. UTM Zone-10 coordinates, obtained with a Motorola Miniranger system, are N3804100.9 and E717220.2; Miniranger navigation was provided by Land and Sea Surveys, Inc.

The side-scan images indicate that the *Pac Baroness* is resting on its keel in about 430 m of water and is oriented in a north-south direction with the bow pointed to the SSW. The ship appears to be twisted and fractured into three pieces. These same images also show a zone of scattered debris within a radius of approximately 200 m. Based on these images, it was apparent at the time of sampling that cargo and fuel compartments were likely to have been breached, providing a source of escape for the oil and copper ore. This scenario was confirmed subsequently by the appearance of visible quantities of oil in sediments collected on the second leg of the November cruise and by results of a photographic inspection of the vessel and surrounding area, performed with a remotely operated vehicle (ROV) during a follow-up cruise conducted by UCSB and IUC from January 12-15, 1988. Video footage and still photographs obtained on this follow-up cruise provided direct evidence of the presence of the fractured vessel, of ruptured cargo holds, and of a disturbed sediment zone surrounding the vessel. Details of this follow-up ROV survey are summarized in a separate cruise report (Margolis, 1988).

2.2 SAMPLING LOCATIONS AND METHODS

Bottom sediments for chemical and macrofaunal analyses were collected on the second leg of the November, 1987 cruise, at an array of eight stations (represented by one sample per each station) within a 500-m radius of the wreck and at a control station (represented by three replicate samples) located at the same depth 8.25 km to the NW. Figure 2 illustrates the station sampling-design and relative position of each station to the wreck site. Table 1 lists the exact location (latitude, longitude, and depth) of each sample.

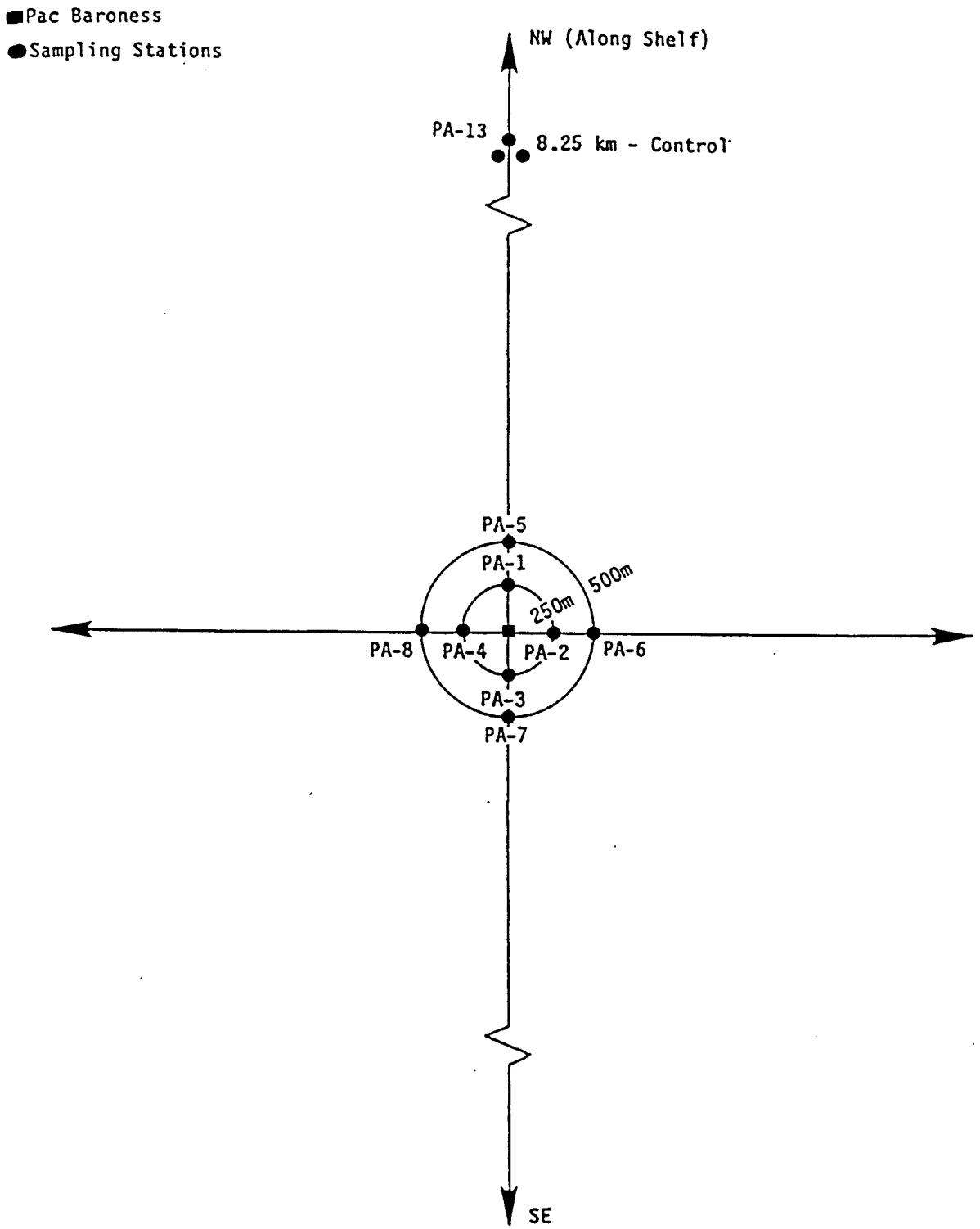


Figure 2. Nominal station design for sediment sampling. One sample was collected at each of the stations within a 500-m radius of the wreck. Three replicate samples were collected at the 8.25-km control site. The isobaths within the 500-m radius of the wreck are oriented in a NNE-SSW direction. Approximately 1 km from the wreck, the isobaths are oriented in the NW-SE direction.

Table 1. Reference Coordinates for Sediment Stations

Station	Latitude Longitude	Depth (M)
PA1	34°21.64'N 120°38.24'W	423
PA2	34°21.43'N 120°38.11'W	428
PA3	34°21.41'N 120°38.35'W	432
PA4	34°21.55'N 120°38.44'W	436
PA5	34°21.68'N 120°38.30'W	410
PA6	34°21.35'N 120°38.00'W	421
PA7	34°21.26'N 120°38.40'W	435
PA8	34°21.65'N 120°38.62'W	432
PA13-1	34°25.01'N 120°41.51'W	432
PA13-2	34°25.03'N 120°41.57'W	432
PA13-3	34°25.02'N 120°41.66'W	432

Latitude and longitude from Northstar 7000 algorithm.

Samples were collected with a Hessler-Sandia, 0.25-m^2 box corer partitioned into 25 individual, 0.01-m^2 subcores. From each sample, ten subcores were removed and prepared for macroinfaunal analysis. The upper 10 cm of each subcore were extruded from the box and live-sieved through a 0.3-mm mesh screen with filtered seawater. Material retained on the screen was placed in 16-oz jars and preserved with approximately 10% buffered formalin; all 10 subcores from the same box core were recombined during this sieving operation. Once samples were returned to the laboratory, they were resieved on a nest of 0.5-mm and 0.3-mm mesh screens, and transferred to 70% ethanol. The 0.5-mm size fraction was used for analysis of macroinfauna; the 0.3-mm fraction was archived.

From each box-core sample, the upper 2 cm of sediment were removed with a Teflon-coated scoop from an additional, solvent-rinsed subcore and used for hydrocarbon analysis. Following collection, hydrocarbon samples were placed in glass jars with Teflon-lined caps and maintained onboard the vessel in a freezer at -20°C. Samples were transferred frozen on dry ice to the laboratory, and stored in a freezer at -20°C until time of analysis.

A source-oil sample related to the Pac Baroness incident was supplied by the U.S. Coast Guard and identified as "Ship Oil." This sample was recovered from a surface slick adjacent to the sinking freighter. The oil was sampled in a glass jar with a Teflon-lined cap, stored on dry ice during shipping, and maintained at -20°C until analyzed.

2.3 ANALYSIS OF HYDROCARBONS

Saturated alkanes and polynuclear aromatic hydrocarbons (PAHs) were analyzed in each of the 11 sediment samples (eight wreck-site samples and three control samples) and the ship oil. Sample preparation consisted of a solvent-extracting phase followed by chromatographic column clean-up (Boehm et al., 1988). Briefly, sediment samples were prepared for analysis by thawing approximately 50 g of sediment, spiking with recovery-surrogate compounds (RISs) and extracting with 1:1 methylene chloride:acetone. The resulting methylene chloride was dried over sodium sulfate and concentrated to <4 mL by Kuderna-Danish techniques. The concentrated extract was then subjected to a combined silica gel and alumina chromatographic clean-up. A column, consisting of 10 g alumina and 20 g silica gel, was prepared and charged with the sample. The column was eluted first with 15 mL of pentane (F1) and then with 150 mL of 1:1 methylene chloride:pentane (F2). The two eluates (F1 and F2) were combined, and quantitation internal standards (QISs) were added. Saturated hydrocarbons were quantified relative to the QIS androstane, while aromatic compounds were quantified relative to the QIS orthoterphenyl. The samples were concentrated to approximately 500 µL and submitted for analysis.

Oil samples were prepared for analysis by diluting 50 mg of oil in two mL of hexane. The samples were spiked with the RIS and QIS, and submitted for analysis.

Samples were analyzed for 24 n-alkanes (C_{10}-C_{34}); five isoprenoids (pristane, phytane, isoprenoid 1380 and 1650, and farnesane 1470); and individual two to five-ring, polynuclear aromatic hydrocarbons (PAHs) by gas chromatography/mass-selection detection (GC/MSD) utilizing a Hewlett-Packard

Model 5970 gas chromatograph/mass spectrometer (GC/MS) coupled to a computerized data-acquisition system. The mass spectrometer was operated in the electron-impact (EI) mode, which scanned the mass range from 50 to 450 amu. The GC was fitted with a 30-m-long x 0.32-mm-diameter, DB-5 capillary column; helium (delivered at 30 cm/s) was used as the carrier gas. The oven temperature of the column during analysis was programmed from 60°C to 290°C at 4°C/min. Peak areas, response factors for each analyte, and subsequent quantification of analytes were calculated from the total-ion current profiles using the GC/MS data system.

Recovery of all analytes through this sample-preparation procedure was determined relative to the recovery of three surrogate compounds: naphthalene-d_8, acenaphthene-d_{10}, and perylene-d_{12}. Quality control of sample preparation and analysis was carried out by preparing and analyzing a control sample and a procedural blank with the batch of sediment and oil samples. Analysis of the samples was considered acceptable only if recovery of the surrogate compounds was in the 20 to 150% range, and the procedural blank was free from interferences.

As discussed above, three sediment replicates were collected at the control site. Upon analysis, one of the replicates (PA13-3) appeared to have been contaminated with non-petroleum hydrocarbons, either during collection or during sample processing in the laboratory. Consequently, this sample has not been used as a representative control sediment for chemistry purposes.

2.4 ANALYSIS OF MACROINFAUNA

Macroinfauna retained on the 0.5-mm sieve were analyzed in each of six samples, consisting of three control samples and three wreck-site samples. Each sample was comprised of 10 combined, 0.01-m^2 subcores, yielding a total surface area of 0.1m^2 per sample. The three wreck-site samples were selected based on the results of hydrocarbon analyses, and represent those stations with the highest alkane and PAH loadings. These three stations are PA1, PA4, and PA5.

Samples were sorted in the laboratory under dissecting microscopes. Samples were stained with a saturated solution of rose bengal to facilitate the sorting process. All individuals were enumerated and identified to the species level wherever possible. Animals that could not be identified to the species level or assigned a provisional species name (e.g., indeterminate juveniles, and damaged or fragmented specimens) usually were omitted from analysis. Such cases exist among polychaetes, molluscs, crustaceans, and nemerteans. One exception pertains to oligochaetes, which were included in analyses as a combined entity because of their numerical dominance. No ophiuroids, holothuroids, or sipunculids were found among Pac Baroness samples.

For quality control, a minimum of 10% of all samples sorted by any one technician was resorted by another trained technician. Additional measures were taken to ensure that the level of sorting error did not exceed 5% (i.e., the sample residue that was resorted by another technican, as part of a quality-control check, could not contain more than five percent of the total number of organisms contained in the original sample). Species identifications were confirmed by validation against voucher specimens or by consultation with other taxonomic experts.

Potential effects of the spill on macroinfauna were evaluated by examining changes in structure and composition of the whole fauna, and in individual species abundances, based on comparison between the three control and three wreck-site samples. Effects on the whole fauna were evaluated by examining differences in mean number of species; mean number of individuals (all species combined); Shannon-Wiener diversity, H' (Shannon and Weaver, 1963); evenness, J' (Pielou, 1966); species richness (S-1)/lnN (Margalef, 1967); ranking of dominants (five most abundant species in a sample); and relative species abundances, through application of numerical-classification procedures (Boesch, 1977).

Unpaired Student t-tests were used to measure statistical differences in mean number of species, mean number of individuals for all species combined, and mean species abundances for individual species. The pooled t-statistic, which incorporates a combined variance term, was used in cases where sample variances were shown to be similar (based on Cochran's test for homogeneity of variances), and was evaluated at 2n-2 degrees of freedom. In cases where sample variances were not homogeneous, the unpooled t-statistic, which incorporates individual sample-variance terms, was used and was evaluated at the number of degrees of freedom calculated from an approximation formula. Tests were performed on untransformed data. An alpha value of 0.05 was selected as the significance level.

Concordance analysis (Kendall, 1975) was used to test for communality of the ranking of dominants between control and wreck-site samples. An alpha value of 0.05 was selected as the significance level. This test provided a measure of the degree of change in dominance structure between the two sampling areas.

Normal (Q-mode) numerical classification was performed with group-average sorting (also known as the unweighted pair-group method; Sneath and Sokal, 1973) as the clustering method and the Normalized Expected Species Shared (NESS; Grassle and Smith, 1976) as the similarity measure. Results were expressed in the form of dendrograms in which samples were ordered into groups of increasingly greater similarity based on resemblances of component-species abundances. The NESS similarity measure is based on the expected number of species shared between random subsamples of size m drawn from each of two sample populations that are under comparison. When a large number of species are shared between samples and their abundances are similar, a high estimate of similarity results (with values nearer to 1, on a scale of 0 to 1). An advantage of this similarity measure is that the contribution of dominant vs. rare species can be controlled by decreasing or increasing the subsample size (i.e., value of m). For small subsample sizes, dominant organisms have a greater influence on the measure, and for larger sizes the measure is sensitive to less common species. In the current study, analyses were run at m = 10 and m = 100.

3.0 RESULTS AND DISCUSSION

3.1 DISTRIBUTION AND LEVELS OF HYDROCARBONS

Data relating to the hydrocarbon content of surficial (0-2 cm) sediments throughout the study area are shown in Table 2. These data are provided for wreck-site samples (PA1 through PA8), control samples (PA13-1 and PA13-2), and

Table 2. Hydrocarbon Levels and Other Related Diagnostic Ratios for Pac Baroness Surficial-Sediment Samples, Ship Oil, and Background Comparison Stations Sampled During the California OCS Phase II Monitoring Program. Concentrations are Expressed in Terms of Sediment Dry Weight. (LALK = Lower Normal Alkanes; TALK = Total Normal Alkanes; 4,5 PAH = 4 and 5-ring Polynuclear Aromatic Hydrocarbons; N = Naphthalenes; P = Phenanthrenes; D = Dibenzothiophenes; F = Fluoranthenes)

Sample	LALK (µg/g)	TALK (µg/g)	LALK/TALK	ΣPAH[d] (µg/g)	ΣN (µg/g)	ΣP (µg/g)	ΣD (µg/g)	N/P	P/D
PA1	27.00	36.80	0.73	61.400	20.600	20.200	8.980	1.020	2.25
PA2	2.83	4.52	0.63	5.470	1.470	2.870	0.746	0.520	3.84
PA3	1.61	3.20	0.50	1.720	0.510	0.830	0.193	0.620	4.30
PA4	6.46	9.75	0.66	139.000	49.900	32.100	4.250	1.550	7.55
PA5	10.60	14.50	0.73	9.020	2.890	4.180	1.410	0.690	2.96
PA6	1.21	2.38	0.50	0.420	0.044	0.353	0.005	0.125	71.00
PA7	0.96	2.59	0.37	0.012	--	--	0.058	--	--
PA8	1.28	2.95	0.43	0.731	0.103	0.526	0.014	0.195	38.00
PA13-1	0.40	1.15	0.35	0.012	--	--	b	--	b
PA13-2	0.35	1.32	0.27	0.008	--	0.003	b	--	b
HIDALGO[a]	0.3±0.2	1.5±0.5	0.18±0.1	0.128±0.10	0.890	0.900	b	0.360	b
REGIONAL[c]	0.5±0.3	2.1±0.9	0.21±0.1	0.008±0.03	0.010	0.021	0.004	0.420	52.00
SHIP OIL	11,400	17,684	0.64	8,700	2,127	4,229	6,911	0.503	0.612

[a]Data from MMS California OCS Phase II Monitoring Program, Platform Hidalgo Study Area (Boehm, et al., 1988).

[b]Insufficient data. Most ΣD values below detection limits.

[c]Data from MMS California OCS Phase II Monitoring Program, Regional Stations (Boehm et al., 1988).

[d]ΣPAH = ΣN + ΣD + ΣP + ΣF + Σ4, 5PAH

ship oil. Also provided for comparison purposes are data from nearby stations (Regional and Platform Hidalgo sites) sampled on the MMS California OCS Phase II Monitoring Program (Boehm et al., 1988). Data for these samples focus on nine chemical parameters that reflect the loadings of hydrocarbons in the sediments and their relationships to the source oil.

The control samples collected 8.25 km from the wreck site are characterized by low hydrocarbon content. These samples are very similar in chemical composition to the Platform Hidalgo samples and Regional Station samples characterized during the MMS California OCS Phase II Monitoring Program (Boehm et al., 1988). Average TALK and ΣPAH values are similar among these various stations, ranging from approximately 1 to 2 μg/g and 0.01 to 0.1 μg/g, respectively. These low background alkane and PAH concentrations make these parameters sensitive monitors of petroleum hydrocarbon input throughout this study region.

Data compiled in Table 2 reveal that hydrocarbons deposited in sediments near the sunken freighter are not uniformly distributed. Based on TALK plus PAH data, samples from Stations PA1, PA4, PA5, and PA2 are a factor of six to 93 times higher in hydrocarbon content than the average background sample (i.e., 1.6 μg/g for TALK plus ΣPAH values for control and monitoring-program samples). Samples from stations PA6 and PA7 have TALK plus ΣPAH hydrocarbon concentrations approaching background values (i.e., only 1.8 and 1.6 times higher, respectively) while samples from Stations PA3 and PA8 have slightly elevated hydrocarbon concentrations relative to background (i.e., 3.1 and 2.3 times higher, respectively). Based on the limited array of data, it appears that a "plume" of oil spread (or is spreading) in a direction generally to the northwest of the wreck.

Profiles of hydrocarbons detected in samples with the highest loadings (PA1, PA4, and PA5) match the hydrocarbon GC/MS pattern of the ship oil. All major analyte peaks are present in these samples at the same relative ratios as those in the ship oil. Figure 3, which demonstrates this relationship, shows GC/MS traces of the ship oil and the sediment extract from Station PA1.

The LALK/TALK ratio of the sediments with the highest TALK amounts (PA1, PA2, PA3, PA4, PA5, and PA8) match the LALK/TALK ratio for the ship oil very well. These six samples have an average LALK/TALK ratio of 0.61. For reference, the LALK/TALK ratio for the ship oil is 0.64. Background samples (PA13-1, PA13-2, and the various monitoring-program samples) have LALK/TALK ratios that are a factor of two lower, ranging from 0.18 to 0.35. The predominance of lower normal alkanes in wreck-site sediments (reflected in the LALK values greater than about 1) and the resulting higher LALK/TALK ratios is indicative of the presence of petroleum hydrocarbons.

Total PAH levels in most wreck-site sediments (PA1 through PA6, and PA8) are elevated 10 to 3500 fold relative to the average background level of 0.04 μg/g (i.e., average of ΣPAH levels for Pac Baroness controls and various monitoring program samples). The upper end of this range is questionable, however, since the sample with the highest ΣPAH loading (PA4) contains unusually high proportions of four and five-ring PAH compounds, suggesting partial input from a combustion source. The sample with the next highest loading (PA1) still has a ΣPAH value approximately 1500 times greater than background; ΣPAH plus TALK for this sample is 61 times higher than the average background value of 1.6 μg/g reported above.

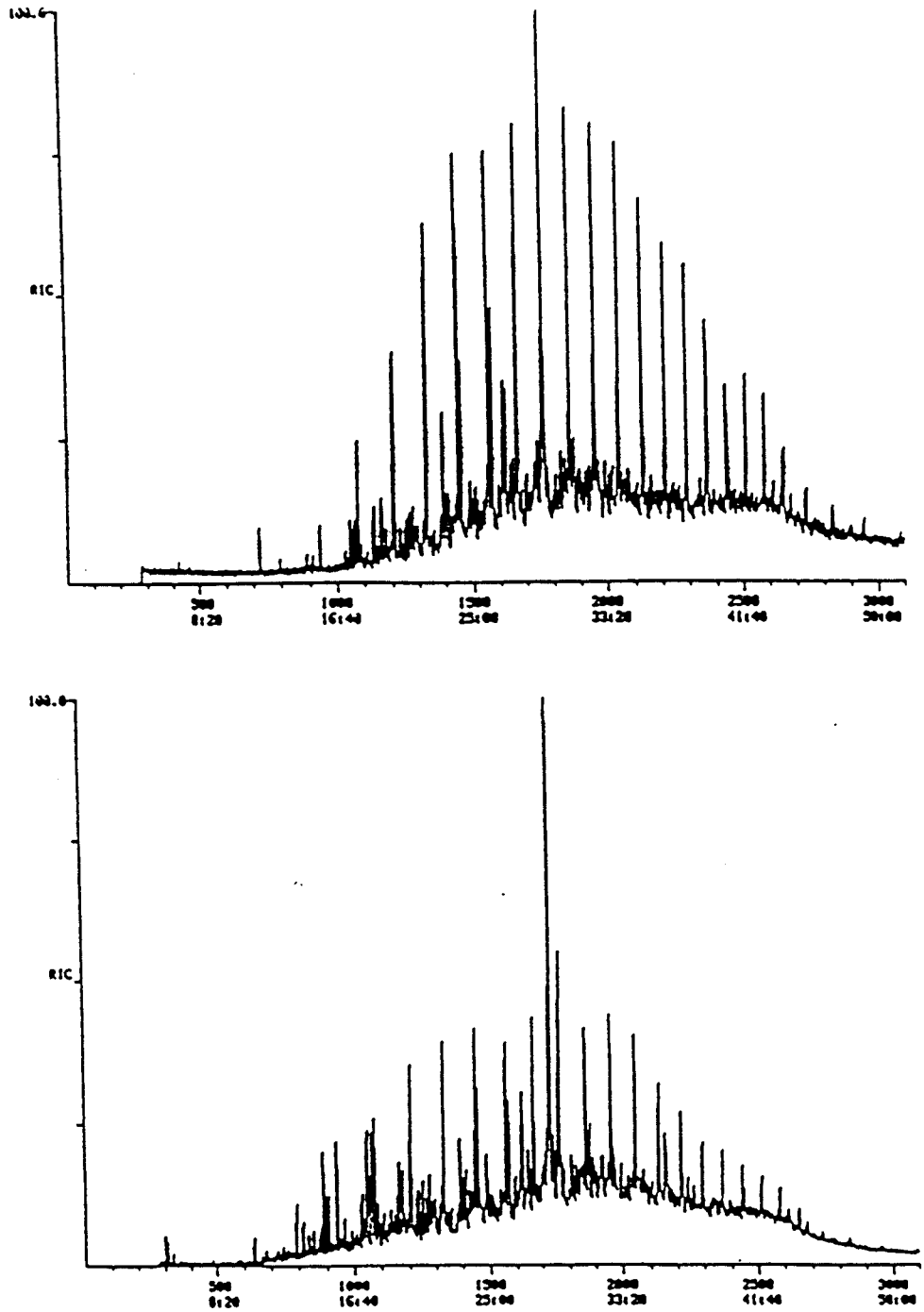


Figure 3. GC/MS total-ion chromatograms of sediment extract from the Pac Baroness wreck-site Station PA1 (bottom chromatogram) and "Ship Oil" (top chromatogram).

The N/P ratios for the wreck-site sediments vary considerably because of weathering of ΣN, but generally are elevated relative to control and various monitoring-program samples, suggesting recent input from fresh petroleum sources. Comparison between N/P ratios of the wreck-site sediments with Platform Hidalgo sediments and Regional Station sediments are necessary because N/P ratios for the control site (PA13-1 and PA13-2) were below detection limits.

Dibenzothiophenes (ΣD) are found in all wreck-site sediments. The ΣD concentrations range from 0.005 μg/g (PA6) to 8.98 μg/g (PA1) and follow similar station trends as TALK and ΣPAH values. The relatively low P/D ratios for wreck-site sediments are caused by the elevated levels of ΣD, which in turn are indicative of recent inputs of petroleum hydrocarbons. Dibenzothiophenes are not detectable in control samples (PA13-1 and PA13-2) or at monitoring-program stations near Platform Hidalgo. P/D ratios at the Regional Stations from the monitoring program have an average value of 52. P/D ratios for the wreck-site sediments average about 5, showing an order-of-magnitude difference in the P/D ratio for these two areas.

3.2 EFFECTS ON MACROINFAUNA

3.2.1 Whole Fauna

Table 3 provides quantitative species lists and other community parameters for the three control and three wreck-site samples. Total numbers of species range from 40 to 43 among control samples, and from 20 to 33 among wreck-site samples. Total numbers of individuals range from 559 to 736 among control samples, and from 137 to 381 among wreck-site samples. These data reveal that there were large reductions in both numbers of species and individuals at the wreck-site in comparison to the control area. Table 4 shows the results of t-tests performed to examine the significance of these reductions. Both the average number of species and individuals are significantly lower (at alpha values $\leq$ 0.05) among wreck-site samples.

Data in Table 3 show that both sets of samples are comprised predominantly of polychaetes and crustaceans. However, among wreck-site samples, polychaetes represent 55% of the fauna and crustaceans represent only 27%, while at the control site crustaceans and polychaetes are more evenly proportioned, representing 45% and 42% of the fauna, respectively. This difference reflects a decline at the wreck site in numbers of crustaceans, the largest percentage of which is amphipods. Data in Table 5 show that the average density of amphipod species among wreck-site samples is significantly lower (at alpha $\leq$ 0.05).

Molluscs are the next most abundant taxonomic group at each site, representing 8% of the fauna among both samples sets. There are no obvious effects of the spill on molluscs as a group (with the exception of one of the component species, *Cadulus californicus*, as noted below).

Data in Table 3 also include values of Shannon-Wiener diversity (H'), evenness (J'), and species richness (S - 1/lnN). None of these functions reveal significant differences between wreck-site and control samples. Ranges of H' and J' overlap between the two sample sets, and are typical of the values obtained for samples collected at similar depths during the California OCS Phase II Monitoring Program (Blake *et al.*, 1988). Species richness values, however, are slightly lower among the wreck-site samples, reflecting an influence of the reduction in numbers of species on this measure.

Table 3. Species Abundances and Other Macrobenthic Community Parameters for Wreck-Site and Control Samples

Species	Wreck-Site			Control		
	PA1	PA4	PA5	PA13-1	PA13-2	PA13-3
POLYCHAETA						
Chloeia pinnata	7	1	6	67	141	165
Nephtys cornuta cornuta	48	70	71	71	101	106
Chaetozone nr. setosa	6	58	28	81	56	96
Levinsenia gracilis	7	23	21	47	46	54
Minuspio sp. A	12	30	26	47	19	33
Cossura candida	7	26	13	10	15	17
Cossura rostrata	1	16	5	13	3	11
Acmira lopezi lopezi	1	12	7	11	7	10
Prionospio lobulata	0	11	17	7	11	0
Glycinde armigera	0	0	1	5	3	4
Levinsenia oculata	0	0	0	9	3	0
Ophelina acuminata	0	0	0	0	1	5
Podarkeopsis sp. B	2	0	2	3	0	2
Subadyte mexicana	1	6	2	2	2	2
Onuphis iridescens	0	2	0	0	1	2
Heteromastus sp. A	0	0	1	0	0	0
Mediomastus sp. A	1	0	0	1	0	0
Phyllochaetopterus limicolus	0	0	0	0	1	1
Glycera branchiopoda	0	0	1	0	0	0
Euclymene delineata	0	0	0	1	1	0
Nephtys punctata	0	0	0	1	0	0
Ophelina pallida	0	0	1	0	0	1
Allia antennata	1	0	0	0	0	0
Cirrophorus branchiatus	0	0	2	0	1	0
Pectinaria californiensis	0	2	0	1	0	1
Harmothoe scriptoria	1	1	0	1	0	0
Laonice appellofi	0	1	0	0	0	0
Mugga sp. A	0	1	1	1	0	0

Table 3. Species Abundances and Other Macrobenthic Community Parameters for Wreck-Site and Control Samples (Continued)

Species	Wreck-Site			Control		
	PA1	PA4	PA5	PA13-1	PA13-2	PA13-3
CRUSTACEA						
Eudorella sp. 2	1	0	4	38	28	64
Paraphoxus oculatus	0	10	2	24	3	14
Munnopsurus sp. A	0	13	9	17	3	4
Araphura sp. B	1	3	2	0	7	11
Diastylis sp. 1	0	0	0	5	2	1
Harpiniopsis fulgens	0	0	0	3	2	9
Tritella tenuissima	0	0	0	3	5	4
Synchelidium shoemakeri	0	1	0	3	1	3
Leucon sp. H	0	3	4	1	1	2
Liljeborgia cota	0	0	0	0	2	2
Ampelisca careyi	0	0	0	0	1	2
Photis brevipes	0	0	0	0	1	3
Photis lacia	0	3	0	0	0	0
Photis sp. D	0	0	0	0	2	0
Bathymedon vulpeculus	0	1	0	2	0	1
Bathymedon sp. A	0	0	0	1	0	0
Monoculodes latissimanus	0	0	0	2	1	0
Nicippe tumida	0	0	0	1	1	0
Heterophoxus oculatus	0	0	0	0	0	1
Calastacus quinqueseriatus	0	0	0	0	0	2
Bathyleberis hancocki	0	0	0	1	0	0
Parasterope hulingsi	0	0	0	1	0	0
Parasterope barnesi	0	1	1	0	1	2
Philomedes dentata	0	1	0	0	0	0
Pseudomma sp. A	0	0	0	1	0	0
Pseudomma cf. roseum	0	0	0	0	0	1
Pseudomma truncatum	0	0	0	1	0	0
Leptognathia cf. breviremis	0	0	0	0	0	1
Hemileucon sp. 1	0	0	3	0	0	1
Leptosylis sp. 1	1	0	1	1	3	0
Campylaspis sp. 5	0	0	0	0	1	0
Campylaspis sp. 8	0	0	0	0	0	3
Campylaspis sp. 11	0	0	0	1	0	0
Eudorella sp. 3	0	0	1	0	0	0
Lampropidae sp. 1	0	1	0	0	0	0
Leucon sp. 2	0	0	1	0	0	0
Diastylis sp. 8	0	0	1	0	0	0

Table 3. Species Abundances and Other Macrobenthic Community Parameters for Wreck-Site and Control Samples (Continued)

Species	Wreck-Site			Control		
	PA1	PA4	PA5	PA13-1	PA13-2	PA13-3
MOLLUSCA						
Cadulus californicus	0	1	0	12	20	16
Chaetoderma sp. H	0	0	4	3	3	0
Amphissa bicolor	0	0	0	3	2	0
Chaetoderma sp. F	0	4	0	1	0	0
Chaetoderma hartmanae	1	0	0	0	2	0
Dentalium vallicolens	1	0	0	0	0	0
Dentalium rectius	0	0	0	0	1	0
Nuculana conceptionis	0	0	1	0	0	0
Galeommatidae Genus A, sp. A	0	0	1	0	0	0
ECHINODERMATA						
Brissopsis pacifica	0	2	0	0	0	2
Brisaster latifrons	2	3	1	2	0	0
OLIGOCHAETA						
Oligochaeta	35	72	61	53	55	75
OTHERS						
Listriolobus hexamyotus	0	1	0	0	0	0
Unident. invertebrate no. 1	0	0	0	0	0	2
Ceriantharia sp. R	0	1	0	0	0	0
Total No. Species	20	32	33	43	41	40
Total No. Individuals	137	381	302	559	560	736
Shannon-Wiener Diversity (H')	2.940	3.688	3.670	4.060	3.640	3.700
Evenness (J')	0.681	0.738	0.728	0.748	0.680	0.696
Species Richness (S-1/lnN)	3.860	5.216	5.600	6.640	6.320	5.910

Table 4. Average Number of Species and Individuals From Wreck-Site and Control Samples. Results of t-Tests Performed on Wreck-Site Vs. Control Comparisons of These Parameters Are Also Shown.

	Wreck Site (n = 3)	Control (n = 3)	t-Test Results
Ave. No. Species Per $0.1M^{-2}$	28.3	41.3	Significant (T = 3.05; DF = 4; alpha $\leq$ 0.05)
Ave. No. Individuals (All Species Combined) Per $0.1M^{-2}$	273	618	Significant (T = 3.73; DF = 4; alpha $\leq$ 0.05)

Table 5. Results of t-Tests Performed on a Wreck-Site Vs. Control Comparison of Amphipod Densities (all Amphipod Species Combined).

	Wreck Site (n = 3)	Control (n = 3)	t-Test Results
Ave. No. Individuals (All Amphipod Species Combined) Per $0.1M^{-2}$	5.7	32.3	Significant (T = 3.27; DF = 4; alpha $\leq$ 0.05)

Table 6 provides lists of the top-five dominants (i.e., five most abundant species) for wreck-site and control samples. Rank scores (score of 5 for the most abundant; score of 1 for the least abundant), densities, and cumulative percent abundance (relative to total faunal abundance) are also given. These top-five dominants represent 50% or greater of the total faunal abundance in each of the samples. Results of Kendall's concordance analysis (Kendall, 1975) reveal that the ranking of these dominants between the two sample sets (control samples vs. wreck-site samples) is significantly different at alpha $\leq$ 0.05. This difference provides an indication that the spill has caused a change in the dominance structure of the infaunal community in the vicinity of the wreck. A major factor contributing to this change is the decline in relative importance of the polychaete Chloeia pinnata among wreck-site samples. This polychaete, which is a consistently strong dominant among control samples, appears as a low-ranked dominant in only one of the wreck-site samples. Many of the individuals of this species from wreck-site samples contained heavily oiled setae, which probably reflects the animal's life style as a surface browser.

Figure 4 provides dendrograms resulting from cluster analyses of control vs. wreck-site samples performed with NESS at m = 10 (Dendrogram A) and m = 100 (Dendrogram B) as the similarity measure and group-average sorting as the clustering method. In both dendrograms, wreck-site samples cluster separately from control samples, revealing differences in the structure and composition of these two basic sample sets. Dendrogram A, resulting from NESS run at m = 10, reveals the influence of dominant species on sample similarity, which leads to the formation of two distinct clusters (one containing control samples and the other containing the three wreck-site samples). When NESS is run at m = 100 (Dendrogram B) greater numbers of species, including less dominant ones, exert their influence on sample similarity; as a result, wreck-site sample PA1 clusters by itself, showing low similarity to the remaining two wreck-site samples as well as the controls. This result is consistent with the fact that sample PA1 experienced the greatest reductions in numbers of species and individuals (Table 3).

3.2.2 Individual Species Abundances

Among the species presented in Table 3, six show statistically significant reductions in abundance in wreck-site samples relative to controls, based on results of t-tests (at alpha $\leq$ 0.05). Histograms of the abundances of these species are provided in Figure 5. These species consist of the polychaetes Chloeia pinnata, Levinsenia gracilis, and Glycinde armigera; the crustaceans Eudorella sp. 2 (cumacean) and Tritella tenuissima (amphipod); and the mollusc Cadulus californicus. Three of these species (Chloeia pinnata, Levinsenia gracilis, and Eudorella sp. 2) are regarded as community dominants (Table 6).

4.0 CONCLUSIONS

Sediment samples collected in the vicinity of the Pac Baroness contain elevated levels of hydrocarbons that clearly originate from the fuel hold of the sunken freighter. This conclusion is supported by pattern comparison between GC/MS chromatograms of contaminated sediment and oil from the freighter, by comparison between relative amounts of major hydrocarbon components in the

Table 6. Lists of the Top-Five Dominants (i.e., Five Most Abundant Species) in Individual Samples From the Control and Wreck-Site Sampling Areas. Species Are Ranked From Highest (Score of 5) to Lowest (Score of 1). Abundance per Square Meter and Cumulative Percent Abundance (Relative to the Whole Fauna) are Also Listed for Each Species.

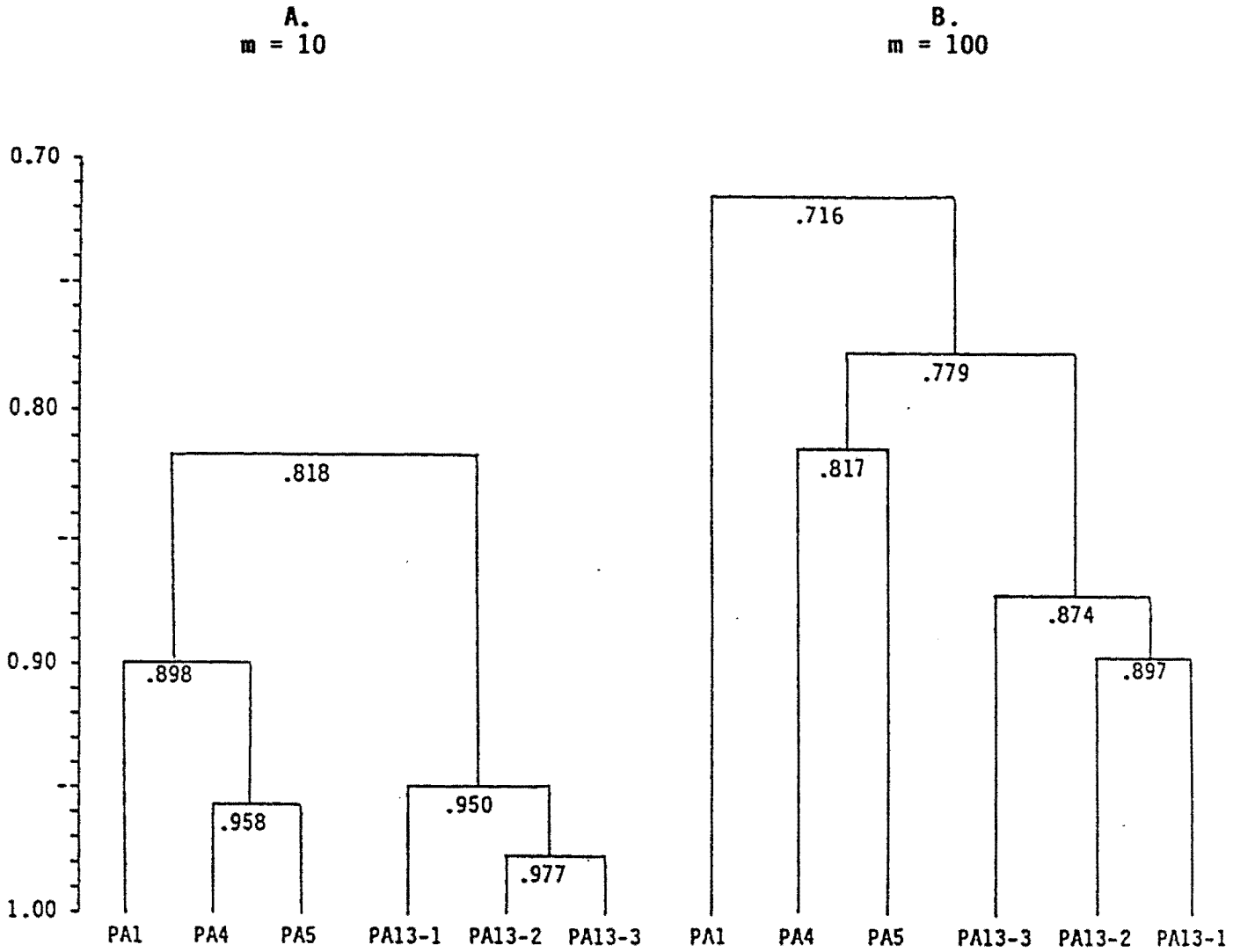
A. Control Samples

PA13-1				PA13-2				PA13-3			
Species	Rank Score	Density M^{-2}	CUM% Abundance	Species	Rank Score	Density M^{-2}	CUM% Abundance	Species	Rank Score	Density M^{-2}	CUM% Abundance
Chaetozone nr. *setosa*	5	810	14.5	*Chloeia pinnata*	5	1,410	25.2	*Chloeia pinnata*	5	1,650	22.4
Nephtys cornuta	4	710	27.2	*Nephtys cornuta*	4	1,010	43.2	*Nephtys cornuta*	4	1,060	36.8
Chloeia pinnata	3	670	39.2	*Chaetozone* nr. *setosa*	3	560	53.2	*Chaetozone* nr. *setosa*	3	960	49.8
Oligochaeta	2	530	48.7	Oligochaeta	2	550	63.0	Oligochaeta	2	750	60.0
Minuspio sp. A	1	470	57.1	*Levinsenia gracilis*	1	460	71.2	*Eudorella* sp. 2	1	640	68.7

B. Wreck-Site Samples

PA1				PA4				PA5			
Species	Rank Score	Density M^{-2}	CUM% Abundance	Species	Rank Score	Density M^{-2}	CUM% Abundance	Species	Rank Score	Density M^{-2}	CUM% Abundance
Nephtys cornuta	5	480	35.0	Oligochaeta	5	720	18.9	*Nephtys cornuta*	5	710	23.5
Oligochaeta	4	350	60.6	*Nephtys cornuta*	4	700	37.3	Oligochaeta	4	610	43.7
Minuspio sp. A	3	120	69.4	*Chaetozone* nr. *setosa*	3	580	52.5	*Chaetozone* nr. *setosa*	3	280	53.0
Chloeia pinnata	2	70	74.5	*Minuspio* sp. A	2	300	60.4	*Minuspio* sp. A	2	260	61.6
Cossura candida	1	70	79.6	*Cossura candida*	1	260	67.2	*Levinsenia gracilis*	1	210	68.6

Figure 4. Dendrograms resulting from cluster analyses of control vs. wreck-site samples, performed with NESS at m = 10(A) and m = 100(B) as the similarity measure and group-average sorting as the clustering method. PA1, PA4, and PA5 are wreck-site samples; PA13-1, PA13-2, and PA13-3 are control samples.



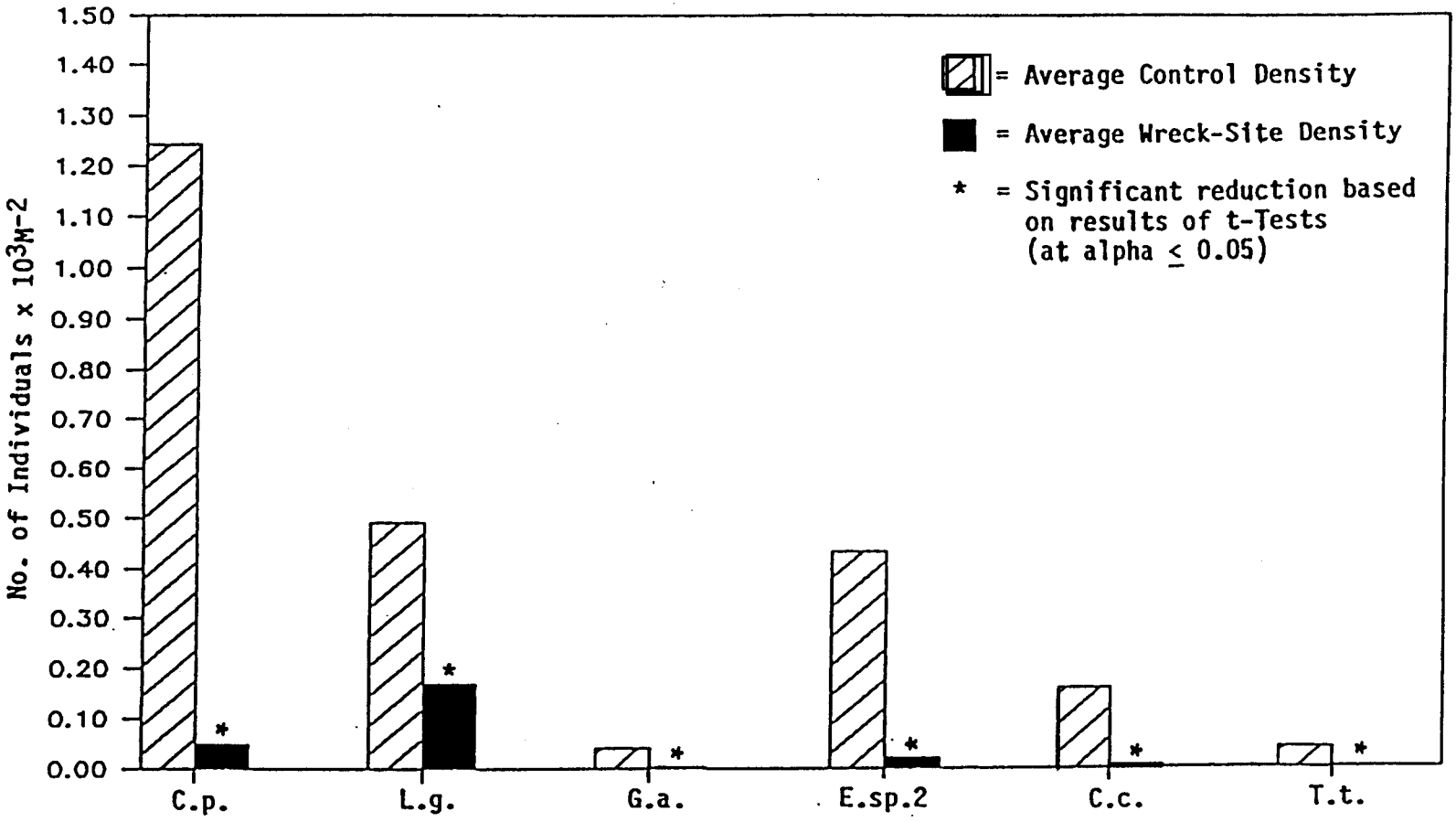


Figure 5. Density histograms for individual species with significantly lower abundances in wreck-site samples in comparison to controls. (C.p. = Chloeia pinnata; L.g. = Levinsenia gracilis; G.a. = Glycinde armigera; E.sp.2 = Eudorella sp. 2; C.c. = Cadulus californicus; T.t. = Tritella tenuissima).

sediments and the ship oil, and by the large degree of similarity between the sensitive LALK/TALK ratios for these various samples.

The distribution of oil in the vicinity of the wreck site apparently is not uniform. Although a more extensive survey would be required to determine the exact spatial extent of hydrocarbon contamination, it can be seen that samples from Stations PA1, PA4, and PA5, located within the northwestern sector of the sampling array, contain the highest levels of oil (TALK plus ΣPAH). These levels are within one to two orders of magnitude (15 to 93 times) higher than the average background level (1.6 μg/g for TALK plus ΣPAH values from control and monitoring-program samples). Samples from Stations PA6 and PA7, located within the southeastern sector of the sampling array, contain oil at concentrations that are within a factor of two relative to background.

Macroinfauna were analyzed from the three control samples and the three wreck-site samples with the highest hydrocarbon loadings (PA1, PA4, and PA5). Statistical and other mathematical comparisons between these two basic sample sets reveal distinct effects of the spill on the structure and composition of the infaunal community within the immediate wreck-site area, and on the abundances of several component species. Evidence of such effects is provided by differences in mean number of species; mean number of individuals (all species combined); dominance structure; relative species abundances (clustering of faunal similarity); and the abundances of several component species (six species of polychaetes, crustaceans, and molluscs, three of which are normal community dominants). The combined abundance of all amphipod species is also significantly lower in wreck-site samples in comparison to controls; amphipod crustaceans are known as being sensitive to oil toxicity (Cabioch et al., 1978); Sanders et al., 1980).

The cause of these biological effects could be related to physical disturbance of the sediments; oil toxicity or other related effects due to entanglement and smothering; copper toxicity; or a combination of these sources. Video tapes and still photographs of the sea floor surrounding the wreck reveal a zone of large surface cracks and upheaved slabs of sediment (Margolis, 1988) providing evidence that physical disturbance could be partly responsible for the effects. Direct evidence of an oil-related source of impact exists, since macrofauna were analyzed from the same samples that contained the highest hydrocarbon loadings in the sediment. Additional evidence for oil-related effects is provided by the fact that visible quantities of oil were observed in these samples as they were being processed on board the research vessel, and were found on the body surfaces and in the guts of animals living in the samples. Evidence of a copper-related source of impact also is provided by the fact that these same three sediment samples contain copper at concentrations ranging from 830 (PA5) to 24,000 (PA1) μg/g dry weight, which are 38 to 1,090 times higher, respectively, than the average control concentration of 22 μg/g (Stan Margolis, UCSB, personal communication). This latter control concentration is similar to the background concentrations of copper found in sediments at nearby stations sampled on the MMS California OCS Phase II Monitoring Program, which range from 8 to 31 μg/g dry weight and average 16 μg/g (Crecelius, 1988).

Regardless of the exact cause, these initial environmental effects are unique in consideration of the extreme water depth within which the spill incident occurred. Most previous oil-spill studies, for example, have reported

effects either in intertidal or relatively shallow, subtidal systems (e.g., within depths of about 10 to 40 m for the highly visible West Falmouth and Amoco Cadiz spills, respectively). In the current study, distinct adverse effects on the benthos are reported at water depths of 410 to 436 m. The authors also are not aware of prior studies of the effects of copper at these depths. The elevated levels of both oil and copper observed in surficial sediments surrounding the Pac Baroness reveal that these chemical contaminants were mixed directly into bottom sediments, probably as a result of the resuspension of sediments as the vessel made contact with the sea floor.

Results of this preliminary study document initial environmental effects of the Pac Baroness incident out to the limits of the current sampling array (i.e., within a 500-m radius of the wreck). The spatial extent and persistence of these effects with time should be the subjects of additional follow-up studies, particularly in view of the magnitude of initial chemical contamination and effects on the benthos, the possibility of subsequent food-chain effects, and the potential sources of sediment and pollutant transport throughout this region.

The authors are confident, however, that the above effects should not interfere with the ability to detect and monitor potential drilling-related changes in the environment as part of the ongoing California OCS Phase II Monitoring Program (Hyland and Neff, 1988). The closest stations that are being monitored are about 15 km to the NW of the Pac Baroness. Although these stations are in the same general direction as the initial path of contamination from the Pac Baroness, immediate effects of the spill apparently did not reach these monitoring sites, as evidenced by the lack of effects among Pac Baroness controls, located about halfway between the wreck site and these nearest monitoring sites. Furthermore, any subsequent spill-related effects that may occur at these sites should be traceable and distinguishable from potential drilling-related sources of impact. For example, with respect to hydrocarbons the ship oil is very distinguishable from typical production oil. Comparisons of the ship oil to Platform Holly production oil (analyzed previously by Boehm et al., 1988) show that there are large differences in the shapes of gas chromatograms (revealing the greater complexity of the production oil relative to the more refined nature of the ship oil) and in the relative values of sensitive diagnostic ratios (e.g., phenanthrene/dibenzothiophene, C_{17}/pristane, and C_{18}/phytane). With respect to copper, spill-related sources of contamination should be distinguishable from drilling-related sources by correlating the presence of copper with other metals, such as barium, which most likely would appear along with the copper if the true source was a drilling discharge.

5.0 ACKNOWLEDGMENTS

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OIL POLLUTION CONTROL. A COOPERATIVE EFFORT

ENVIRONMENTAL EFFECTS OF THE *PAC BARONESS* OIL AND COPPER SPILL

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ABSTRACT: *A study was conducted to investigate the initial environmental effects of an offshore oil and copper spill resulting from the sinking of the freighter* Pac Baroness *approximately 19 kilometers (km) southwest of Point Conception, California, at a water depth of 430 meters (m). Gas chromatography with mass spectrometry detection (GC/MS) was used to examine the distribution and levels of hydrocarbons in surficial sediments and to compare patterns of hydrocarbons in the sediments to those of a source-oil sample obtained from the vessel. Potential impacts of the spill on macroinfauna were also evaluated by examining changes in community structure and composition and in abundances of component species, based on comparison between control and wreck-site samples. Results of the chemical analyses show that sediment samples collected in the vicinity of the* Pac Baroness *contain elevated levels of hydrocarbons and other petroleum components that clearly originate from the oil on board the sunken vessel. Statistical comparisons of the macroinfaunal data reveal distinct biological effects of the spill within the immediate surrounding area of the vessel, at water depths of 410 to 436 m. Among these effects are significant reductions in mean number of species, mean number of individuals (all species combined), abundances of several component species (half of which are dominants within the community), and the combined abundance of sensitive amphipod species. These initial levels of contamination and associated environmental effects are unique in consideration of the extreme water depth in which the spill occurred.*

On September 21, 1987, the 564-foot (ft) freighter *Pac Baroness* collided in fog with another vessel, the *Atlantic Wing*, and later sank approximately 19 km southwest of Point Conception, California, at a depth of 430 m. This site (Figure 1) is located just south of stations that are being studied by a team of scientists from Battelle and other research organizations as part of an offshore environmental monitoring program sponsored by the Minerals Management Service (MMS). The MMS study, designed to assess potential long-term, cumulative impacts of oil and gas development and production along the California outer continental shelf (OCS), provides background data on a variety of environmental parameters and processes in the vicinity of the *Pac Baroness* wreck.[5]

The *Pac Baroness* was carrying a cargo of 21,000 metric tons of a finely powdered copper concentrate, of which approximately 71 percent was comprised of chalcopyrite ($CuFeS_2$); the remainder consisted primarily of chalcocite (Cu_2S), covellite (CuS_2), and trace amounts of native metallic copper.[6] The vessel was also carrying a combined volume of 378,943 gallons (gal) of fuel and lubricating oils, consisting of 339,360 gal of intermediate-grade fuel oil (similar to No. 4 fuel oil), 29,568 gal of marine diesel (between No. 2 and No. 3 fuel oil), and 10,015 gal of lubricating oil.[4]

The sinking of the vessel resulted in an initial spill of an estimated 20,000 gal of oil, which created a visible surface slick that was tracked by Coast Guard overflights for several days. Colored plumes of powder noted by observers present at the time of the sinking also indicated that some of the copper ore had escaped into the water column from ruptured bulkheads and hatches in the vessel's cargo holds. There was further belief that if the vessel broke apart as it made contact with the sea floor, then both the oil and copper ore could become mixed directly into bottom sediments.

The copper ore on board the *Pac Baroness* consisted principally of relatively insoluble copper sulfide; however, it is possible that contact of the material with dissolved oxygen present in the sea water would promote oxidation of the sulfide, eventually leading to increased concentrations of dissolved copper. Both copper (in the oxidized, soluble form) and petroleum hydrocarbons can be toxic to marine organisms, even at dilute concentrations. Also, coating of organisms with oil could result in death from the physical effects of entanglement and smothering.

Because of the possible transport of these contaminants through the marine ecosystem and resulting biological effects, Battelle and the University of California at Santa Barbara (UCSB) received funds to

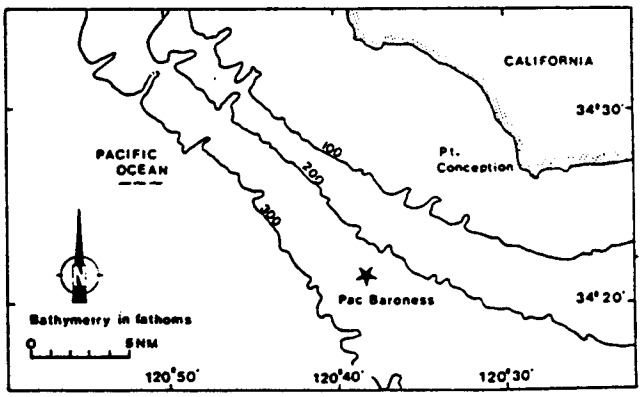

Figure 1. Map of study area and position of the sunken vessel *Pac Baroness* (34°21.43'N, 120°38.29'W)

conduct a preliminary environmental investigation of the *Pac Baroness* incident. The objectives of this joint study were to locate the sunken vessel, examine the extent of initial contamination (with a focus on copper and petroleum hydrocarbons), and determine the potential impact on benthic communities of the immediate area. The current report presents results of hydrocarbon and macrofaunal analyses performed by Battelle. Additional work relating to the analysis of copper in water, sediments, and biota is being performed by UCSB and will be reported elsewhere in the literature.

Methods

Location and description of the sunken vessel. An initial field survey consisting of two legs was conducted in the vicinity of the wreck from November 17 to 20, 1987 on the research vessel M/V *Aloha*, owned and operated by International Underwater Contractors Inc. (IUC). The first leg was devoted to locating and describing the condition of the sunken vessel; the second leg was devoted to obtaining environmental samples for biological and chemical analyses.

Location of the *Pac Baroness* was accomplished through the use of side-scan sonar (operated by the U.S. Geological Survey) and the research vessel's fathometer. Coordinates of the sunken vessel, obtained with a Loran Northstar 7000 navigation system, are 34°21.43'N and 120°38.29'W; Loran C time delays are TDX = 27826.1 and TDY = 41785.7. UTM Zone-10 coordinates, obtained with a Motorola Miniranger system, are N3804100.9 and E717220.2; Miniranger navigation was provided by Land and Sea Surveys Inc.

The side-scan images indicate that the *Pac Baroness* is resting on its keel in about 430 m of water and is oriented in a north-south direction with the bow pointed to the south-southwest. The ship appears to be twisted and fractured into three pieces. These same images also show a zone of scattered debris within a radius of approximately 200 m. Based on these images, it seemed likely at the time of sampling that cargo and fuel compartments had been breached, providing a source of escape for the oil and copper ore.

This scenario was later confirmed by the appearance of visible quantities of oil in sediments collected on the second leg of the November cruise and by the results of a photographic inspection of the vessel and surrounding area, performed with a remotely operated vehicle (ROV) during a follow-up cruise conducted by UCSB and IUC from January 12 to 15, 1988. Video footage and still photographs obtained on this follow-up cruise provided direct evidence of the presence of the fractured vessel, of ruptured cargo holds, and of a disturbed sediment zone surrounding the vessel.

Sampling locations and methods. Bottom sediments for chemical and macrofaunal analyses were collected on the November 1987 cruise at an array of eight stations (represented by one sample per each station) within a 500-m radius of the wreck and at a control station (represented by three replicate samples) located at the same depth 8.25 km to the northwest. Figure 2 illustrates the sampling design and position of each station relative to the wreck site.

Samples were collected with a Hessler-Sandia 0.25-m^2 box corer partitioned into 25, individual 0.01-m^2 subcores. From each sample, ten subcores were removed and prepared for macroinfaunal analysis. The upper 10 centimeters (cm) of each subcore were live-sieved through a 0.3-millimeter (mm) screen with filtered seawater; all 10 subcores from the same box core were recombined during this sieving operation. Material retained on the screen was placed in 16-ounce (oz) jars and preserved with approximately 10-percent buffered formalin. Once samples were returned to the laboratory, they were resieved on a nest of 0.5-mm and 0.3-mm screens and transferred to 70-percent ethanol. The 0.5-mm fraction was used for analysis of macroinfauna; the 0.3-mm fraction was archived.

From each box core, the upper 2 cm of sediment were removed with a Teflon-coated scoop from an additional, solvent-rinsed subcore and used for hydrocarbon analysis. Following collection, hydrocarbon samples were placed in glass jars with Teflon-lined caps and maintained on board the vessel in a freezer at −20° Celsius (C). Samples were transferred frozen on dry ice to the laboratory, and stored in a freezer at −20° C until time of analysis.

A source-oil sample related to the *Pac Baroness* incident was supplied by the U.S. Coast Guard and was identified as "Ship Oil." This sample was recovered from a surface slick immediately adjacent to the sinking freighter. The oil was sampled in a glass jar with a Teflon-lined cap, stored on dry ice during shipping, and maintained at −20° C until analyzed.

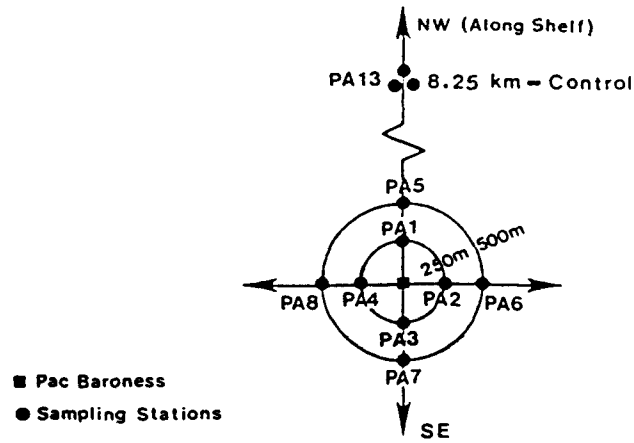

Figure 2. Nominal station design for sediment sampling—One sample was collected at each of the stations within a 500-m radius of the wreck. Three replicate samples were collected at the 8.25-km control site. The isobaths within the 500-m radius of the wreck are oriented in a NNE-SSW direction. Approximately 1 km from the wreck the isobaths are oriented in the NW-SE direction.

Analysis of hydrocarbons. Saturated alkanes and polynuclear aromatic hydrocarbons (PAHs) were analyzed in each of 10 sediment samples (eight wreck-site samples and two control samples) and the ship oil. Sample preparation consisted of a solvent-extracting phase followed by chromatographic column cleanup.[1] Sediment samples were prepared for analysis by first thawing approximately 50 grams (g) of sediment, spiking with recovery internal surrogates (RISs) for quality-control purposes, and extracting with a 1-to-1 solution of methylene chloride and acetone. This initial extract was dried over sodium sulfate and concentrated to less than 4 milliliters (mL) by Kuderna-Danish techniques.

The concentrated extract was then subjected to a combined silica-gel and alumina-chromatographic cleanup process. A column, consisting of 10 g alumina and 20 g silica gel, was prepared and charged with the sample. The column was eluted first with 15 mL of pentane (F1 fraction) and then with 150 mL of a 1-to-1 solution of methylene chloride and pentane (F2 fraction). The two eluates (F1 and F2 fractions) were combined, and quantitation internal standards (QISs) were added. Saturated hydrocarbons were quantified relative to the QIS androstane, while aromatic compounds were quantified relative to the QIS orthoterphenyl. The samples were concentrated to approximately 500 microliters (μL) and submitted for analysis.

The source-oil sample was prepared for analysis by diluting 50 milligrams (mg) of oil in two mL of hexane. The samples were spiked with RIS and QIS compounds, and submitted for analysis.

Samples were analyzed for 24 *n*-alkanes (C_{10}–C_{34}), five isoprenoids (pristane, phytane, isoprenoid 1380 and 1650, and farnesane 1470) and individual two to five-ring polynuclear aromatic hydrocarbons (PAHs) by gas chromatography/mass-selection detection (GC/MSD) on a Hewlett-Packard Model 5970 gas chromatograph/mass spectrometer (GC/MS) coupled to a computerized data-acquisition system. The mass spectrometer was operated in the electron-impact (EI) mode, which scanned the mass range from 50 to 450 atomic mass units (amu). The GC was fitted with a 30-m-long × 0.32-mm-diameter DB-5 capillary column; helium delivered at 30 cm/second (s) was used as the carrier gas. The oven temperature of the column during analysis was programmed from 60° C to 290° C at 4° C/minute (min). Peak areas, response factors for each analyte, and subsequent quantification of analytes were calculated from the total-ion profiles using the GC/MS data system.

Analysis of macroinfauna. Macroinfauna retained on the 0.5-mm sieve were analyzed in each of six samples: three control and three wreck-site samples. Each sample consisted of 10 combined 0.01-m^2 subcores, yielding a total surface area of 0.1 m^2 per sample. The three

wreck-site samples were selected based on results of hydrocarbon analyses, and represent those stations with the highest alkane and PAH loadings. These three stations are PA1, PA4, and PA5.

Samples were sorted in the laboratory under dissecting microscopes and were stained with a saturated solution of rose bengal to facilitate the sorting process. All individuals were enumerated and identified to the species level wherever possible.

Potential effects of the spill on macroinfauna were evaluated by examining changes in structure and composition of the whole fauna and in individual species abundances, based on comparison between the three control and three wreck-site samples. Effects on the whole fauna were evaluated by examining differences in mean number of species, mean number of individuals (all species combined), and relative species abundances through application of numerical-classification procedures.[2]

Unpaired Student t-tests were used to measure statistical differences in mean number of species, mean number of individuals for all species combined, and mean species abundances for individual species. The pooled t-statistic, which incorporates a combined variance term, was used when sample variances were shown to be similar (based on Cochran's test for homogeneity of variances) and was evaluated at 2n-2 degrees of freedom. When sample variances were not homogeneous, the unpooled t-statistic, which incorporates individual sample-variance terms, was used and was evaluated at an approximated number of degrees of freedom. Tests were performed on untransformed data. An alpha value of 0.05 was selected as the significance level.

Normal (Q-mode) numerical classification was performed with group-average sorting (also known as the unweighted pair-group method)[12] as the clustering method and the normalized expected species shared (NESS)[7] as the similarity measure. Results were expressed in the form of dendrograms in which samples were ordered into groups of increasingly greater similarity based on resemblances of component-species abundances. The NESS similarity measure is based on the expected number of species shared between random subsamples of size m drawn from each of two sample populations that are under comparison. When a large number of species are shared between samples and their abundances are similar, a high estimate of similarity results (with values nearer to 1, on a scale of 0 to 1). An advantage of this similarity measure is that the contribution of dominant vs. rare species can be controlled by decreasing or increasing the subsample size (that is, value of m). For small subsample sizes, dominant organisms have a greater influence on the measure, and for larger sizes the measure is sensitive to less common species. In the current study, analyses were run at $m = 10$ and $m = 100$.

Results and discussion

Distribution and levels of hydrocarbons. Data relating to the hydrocarbon content of surficial (0–2 cm) sediments throughout the study area are shown in Table 1. These data are provided for wreck-site samples (PA1 through PA8), control samples (PA13-1 and PA13-2), and ship oil. Also provided for comparison purposes are data from nearby stations (Regional and Platform Hidalgo sites) sampled on the MMS California OCS Monitoring Program.[1] Data for these samples focus on nine chemical parameters that reflect the loadings of hydrocarbons in the sediments and their relationships to the source oil.

The control samples collected 8.25 km from the wreck site are characterized by low hydrocarbon content. Average total normal alkanes (TALK) and ΣPAH values for the two controls are 1.23 μg/g and 0.01 μg/g, respectively, which are very similar to the background levels characterized for samples collected on the MMS monitoring program.[1]

Table 1 also reveals that hydrocarbons deposited in sediments near the sunken freighter are not uniformly distributed and are extremely high at some stations. Based on TALK plus PAH data, samples from stations PA1, PA4, PA5, and PA2 are a factor of six to 93 times higher in hydrocarbon content than the average background sample (that is, 1.6 μg/g for TALK plus ΣPAH values for control and MMS monitoring program samples). Samples from stations PA6 and PA7 have TALK plus ΣPAH hydrocarbon concentrations approaching background values (that is, only 1.8 and 1.6 times higher, respectively) while samples from stations PA3 and PA8 have slightly elevated hydrocarbon concentrations relative to background (that is, 3.1 and 2.3 times higher, respectively). These data suggest that a "plume" of oil spread in a direction to the northwest of the wreck.

Profiles of hydrocarbons detected in samples with the highest loadings (PA1, PA4, and PA5) match the hydrocarbon GC/MS pattern of the ship oil. All major analyte peaks are present in these samples at the same relative ratios as those in the ship oil. Figure 3, which demonstrates this relationship, shows GC/MS traces of the ship oil and the sediment extract from station PA1.

The LALK/TALK ratio (LALK, lower normal alkanes) of the sediments with the highest TALK amounts (PA1, PA2, PA3, PA4, PA5, and PA8) match the LALK/TALK ratio for the ship oil very well. These six samples have an average LALK/TALK ratio of 0.61. For reference, the LALK/TALK ratio for the ship oil is 0.64. Background samples (PA13-1, PA13-2, and the various MMS monitoring program samples) have LALK/TALK ratios that are a factor of two lower, ranging from 0.18 to 0.35. The predominance of lower normal alkanes in wreck-site sediments (reflected in the LALK values greater than

Table 1. Hydrocarbon levels and other related diagnostic ratios for *Pac Baroness* surficial-sediment samples, ship oil, and background comparison stations sampled during the MMS California OCS Monitoring Program. Concentrations are expressed in terms of sediment dry weight. (LALK=lower normal alkanes; TALK=total normal alkanes; 4,5 PAH=4 and 5-ring polynuclear aromatic hydrocarbons; N=naphthalenes; P=phenanthrenes; D=dibenzothiophenes; F=fluoranthenes)

Sample	LALK (μg/g)	TALK (μg/g)	LALK/ TALK	ΣPAH[4] (μg/g)	ΣN (μg/g)	ΣP (μg/g)	ΣD (μg/g)	N/P	P/D
PA1	27.00	36.80	0.73	61.400	20.600	20.200	8.980	1.020	2.25
PA2	2.83	4.52	0.63	5.470	1.470	2.870	0.746	0.512	3.84
PA3	1.61	3.20	0.50	1.720	0.510	0.830	0.193	0.614	4.30
PA4	6.46	9.75	0.66	139.000	49.900	32.100	4.250	1.550	7.55
PA5	10.60	14.50	0.73	9.020	2.890	4.180	1.410	0.690	2.96
PA6	1.21	2.38	0.50	0.420	0.044	0.353	0.005	0.125	71.00
PA7	0.96	2.59	0.37	0.012	—	—	0.058	—	—
PA8	1.28	2.95	0.43	0.731	0.103	0.526	0.014	0.196	38.00
PA13-1	0.40	1.15	0.35	0.012	—	—	[2]	—	[2]
PA13-2	0.35	1.32	0.27	0.008	—	0.003	[2]	—	[2]
Hidalgo[1]	0.3 ± 0.2	1.5 ± 0.5	0.18 ± 0.1	0.128 ± 0.10	0.094	0.0548	[2]	0.172	[2]
Regional[3]	0.5 ± 0.3	2.1 ± 0.9	0.21 ± 0.1	0.083 ± 0.03	0.010	0.021	0.0004	0.476	52.00
Ship oil	11,400	17,684	0.64	8,700	2,127	4,229	6,911	0.503	0.612

1. Data from MMS California OCS Monitoring Program, Platform Hidalgo study area[1]
2. Insufficient data; most ΣD values below detection limits
3. Data from MMS California OCS Monitoring Program, regional stations[1]
4. ΣPAH = ΣN + ΣD + ΣF + Σ4, 5PAH

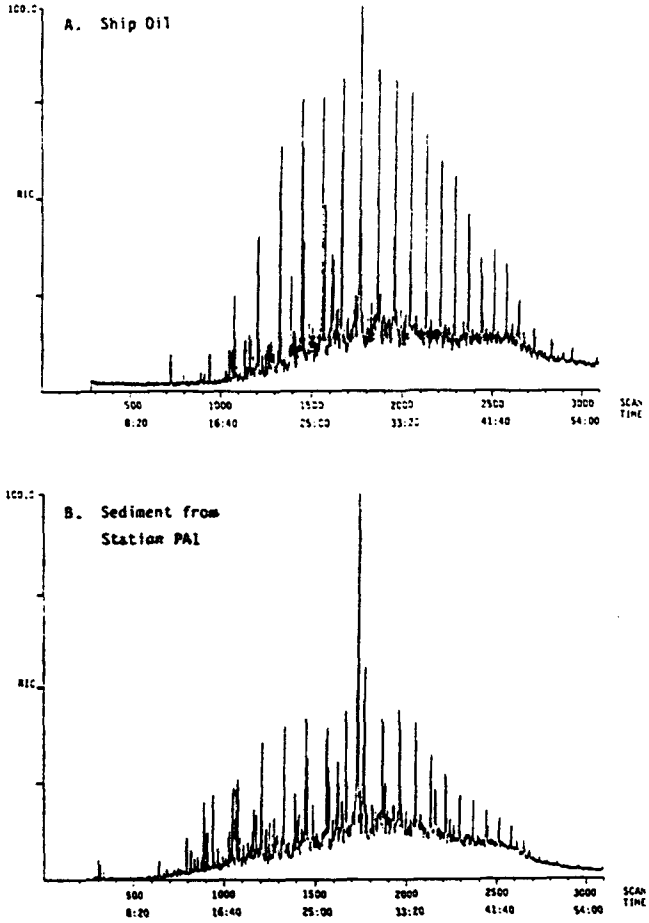

Figure 3. GC/MS total-ion chromatograms of "Ship Oil" (A) and sediment extract from the *Pac Baroness* wreck-site Station PA1 (B)

about 1) and the resulting higher LALK/TALK ratios are indicative of the presence of petroleum hydrocarbons.

Total PAH levels in most wreck-site sediments (PA1 through PA6, and PA8) are elevated 7 to 2,317 fold relative to the average background level of 0.06 μg/g (i.e., average of ΣPAH levels for *Pac Baroness* controls and various MMS monitoring program samples). The upper end of this range is questionable, however, since the sample with the highest ΣPAH loading (PA4) contains unusually high proportions of four and five-ring PAH compounds, suggesting partial input from a combustion source. The sample with the next highest loading (PA1) still has a ΣPAH value approximately 1,000 times greater than background; ΣPAH plus TALK for this sample is 61 times higher than the average background value of 1.6 μg/g reported above.

N/P ratios for wreck-site sediments vary considerably because of weathering of ΣN, but generally are elevated relative to control and various MMS monitoring program samples, suggesting recent inputs of petroleum hydrocarbons. ΣN and ΣP values are below or near detection limits for controls.

Dibenzothiophenes (ΣD) are found in all wreck-site sediments. The ΣD concentrations range from 0.005 μg/g (PA6) to 8.98 μg/g (PA1) and follow similar station trends as TALK and ΣPAH values. The relatively low P/D ratios for wreck-site sediments are caused by the elevated levels of ΣD, which in turn are indicative of recent inputs of petroleum hydrocarbons. Dibenzothiophenes are not detectable in control samples (PA13-1 and PA13-2) or at MMS monitoring program stations near Platform Hidalgo. P/D ratios at the regional stations from the MMS monitoring program have an average value of 52. P/D ratios for the wreck-site sediments average about 5, showing an order-of-magnitude difference in the P/D ratio for these two areas.

Effects on macroinfauna. ***Whole fauna.*** Table 2 provides a comparison of various macrobenthic community parameters for the three control versus three wreck-site samples. Total numbers of species range from 40 to 43 among control samples, and from 20 to 33 among wreck-site samples. Total numbers of individuals range from 559 to 736 among control samples, and from 137 to 381 among wreck-site samples. These data reveal that there were large reductions in both numbers of species and individuals at the wreck-site in comparison to the control area. Table 3 shows the results of t-tests performed to examine the significance of these reductions. Both the average number of species and individuals are significantly lower (at alpha values ≤ 0.05) among wreck-site samples.

Table 2 also shows that both sets of samples are comprised predominantly of polychaetes and crustaceans. However, among wreck-site samples, polychaetes represent an average of 55 percent of the fauna and crustaceans represent an average of only 27 percent, while at the control site crustaceans and polychaetes are more evenly proportioned, representing averages of 45 percent and 42 percent of the fauna, respectively. This difference reflects a decline at the wreck site in numbers of crustaceans, the largest percentage of which is comprised of amphipods. Table 4 shows that the average density of amphipod species among wreck-site samples is significantly lower (at alpha ≤ 0.05).

Molluscs are the next most abundant taxonomic group at each site, representing an average of 8 percent of the fauna among both sample sets. There are no obvious effects of the spill on molluscs as a group (with the exception of one species, *Cadulus californicus*, as noted below).

Figure 4 provides dendrograms resulting from cluster analyses of control vs. wreck-site samples performed with NESS at $m = 10$ (Dendrogram A) and $m = 100$ (Dendrogram B) as the similarity measure and group-average sorting as the clustering method. In both dendrograms, wreck-site samples cluster separately from control samples, revealing differences in the structure and composition of these two basic sample sets. Dendrogram A, resulting from NESS run at $m = 10$, reveals the influence of dominant species on sample similarity, which leads to the formation of two distinct clusters (one containing control samples and the other containing the three wreck-site samples). When NESS is run at $m = 100$ (Dendrogram B) greater numbers of species, including less dominant ones, exert their influence on sample similarity; as a result, wreck-site sample PA1 clusters by itself, showing low similarity to the remaining two wreck-site samples as well as the controls. This result is consistent with the fact that sample PA1 experienced the greatest reductions in numbers of species and individuals.

Table 2. Macrobenthic community parameters for wreck-site and control samples

	Wreck-site			Control		
Parameter	PA1	PA4	PA5	PA13-1	PA13-2	PA13-3
Total number of species	20	32	33	43	41	40
Total number of individuals	137	381	302	559	560	736
Relative faunal composition (percent)						
• Polychaetes	65.0	47.0	52.0	44.0	41.5	40.0
• Crustaceans	15.0	31.0	33.0	42.0	44.0	50.0
• Molluscs	10.0	6.0	9.0	9.0	12.0	2.5
• Others	10.0	16.0	6.0	5.0	2.5	7.5

Table 3. Average number of species and individuals from wreck-site and control samples. Results of t-tests performed on wreck-site vs control comparisons of these parameters are also shown.

	Wreck site (n = 3)	Control (n = 3)	t-Test results
Average number of species per $0.1M^{-2}$	28.3	41.3	Significant (T = 3.05; DF = 4; alpha ≤ 0.05)
Average number of individuals (all species combined) per $0.1M^{-2}$	273	618	Significant (T = 3.73; DF = 4; alpha ≤ 0.05)

Individual species abundances. Among the various species identified in this study, six show statistically significant reductions in abundance in wreck-site samples relative to controls, based on results of t-tests (at alpha ≤ 0.05). Histograms of the abundances of these species are provided in Figure 5. These species consist of the polychaetes *Chloeia pinnata, Levinsenia gracilis,* and *Glycinde armigera*; the crustaceans *Eudorella* sp. 2 (cumacean) and *Tritella tenuissima* (amphipod); and the mollusc *Cadulus californicus*. Three of these species (*Chloeia pinnata, Levinsenia gracilis,* and *Eudorella* sp. 2) are regarded as community dominants (that is, they are among the five most abundant species for a particular sample).

Chloeia pinnata is a consistently strong dominant among control samples. The decline in the abundance of this species in wreck-site samples is largely responsible for an observed shift in the dominance structure of the infaunal community at the wreck site. Although the data are now shown here, this latter change can be revealed by results of concordance analysis[9] performed on the ranking of dominants between the two sample sets. The decline in *Chloeia* is consistent with the fact that many of the individuals of this species from wreck-site samples contained heavily oiled setae.

Table 4. Results of t-tests performed on a wreck-site vs control comparison of amphipod densities (all amphipod species combined)

	Wreck site (n = 3)	Control (n = 3)	t-Test results
Average number of individuals (All amphipod species combined) per $0.1M^{-2}$	5.7	32.3	Significant (T = 3.27; DF = 4; alpha ≤ 0.05)

Conclusions

Sediment samples collected in the vicinity of the *Pac Baroness* contain elevated levels of hydrocarbons that clearly originate from the fuel hold of the sunken freighter. This conclusion is supported by pattern comparison between GC/MS chromatograms of contaminated sediment and oil from the freighter, by comparison between relative amounts of major hydrocarbon components in the sediments and the ship oil, and by the large degree of similarity between the sensitive LALK/TALK ratios for these various samples.

The spatial distribution of oil in the vicinity of the wreck site apparently is not uniform. Stations PA1, PA4, and PA5, located within the northwestern sector of the sampling array, contain the highest levels of oil (TALK plus ΣPAH). These levels are within one to two orders of magnitude (15 to 93 times) higher than the average background level (1.6 μg/g for TALK plus ΣPAH values from control and MMS

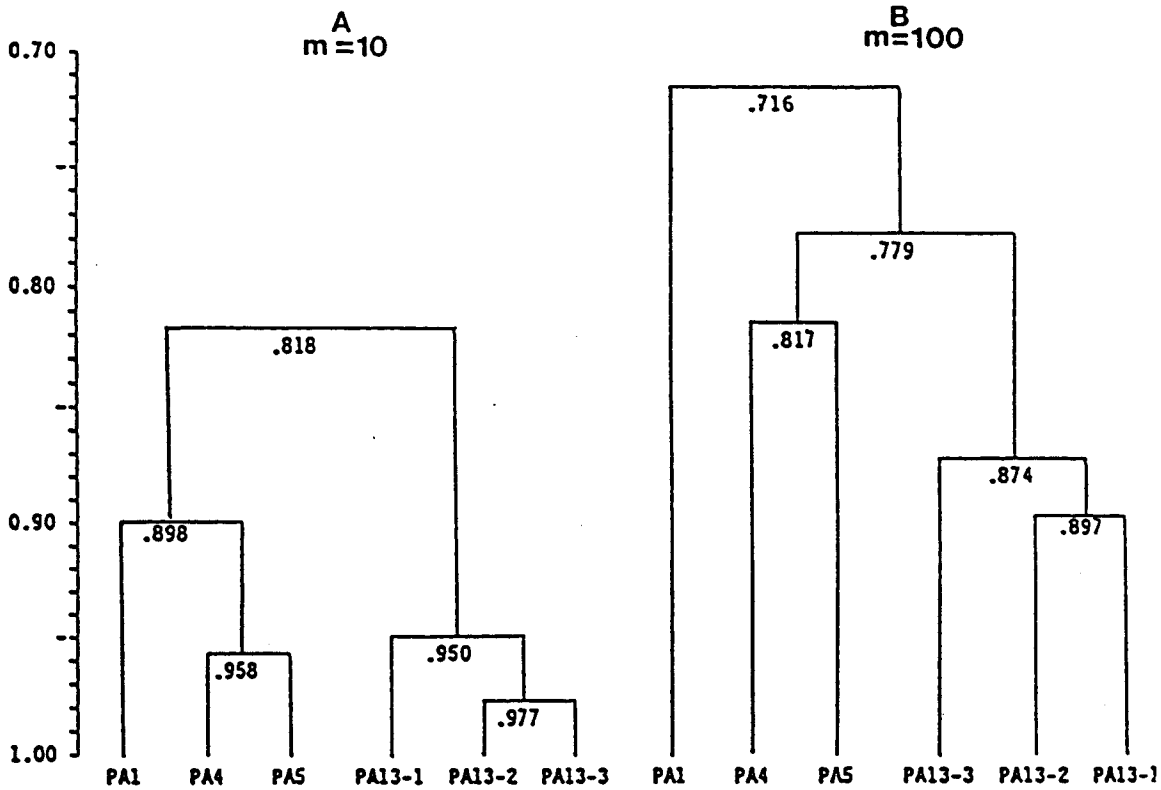

Figure 4. Dendrograms resulting from cluster analyses of control vs. wreck-site samples, performed with NESS at m = 10(A) and m = 100(B) as the similarity measure and group-average sorting as the clustering method. PA1, PA4, and PA5 are wreck-site samples; PA13-1, PA13-2, and PA13-3 are control samples

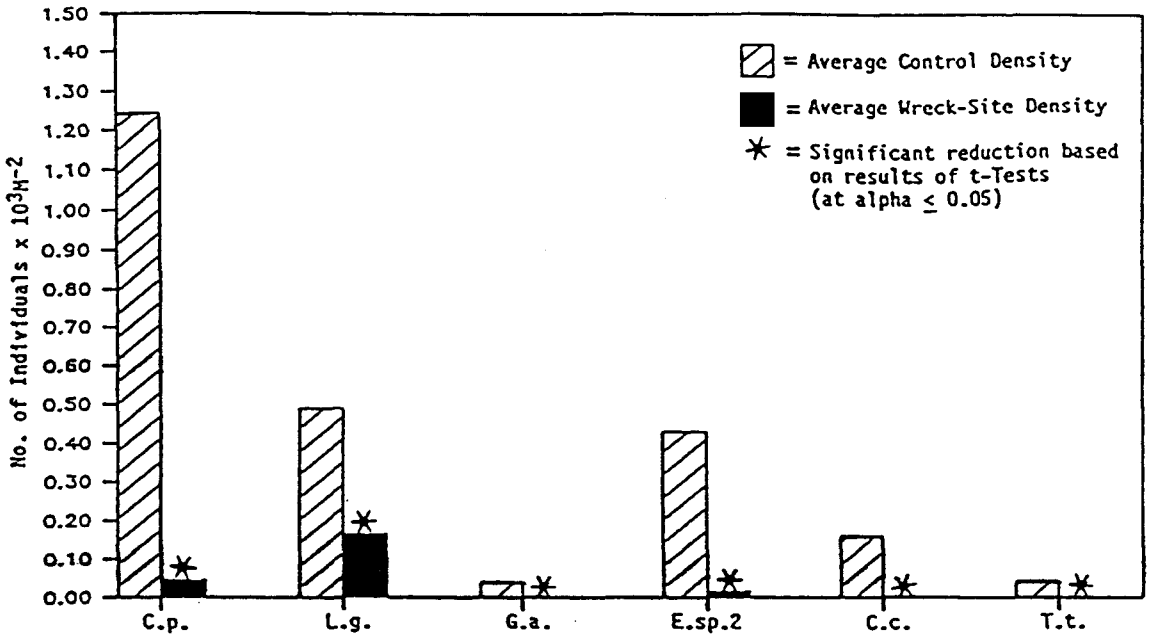

Figure 5. Density histograms for individual species that revealed significantly lower abundances in wreck-site samples in comparison to controls. (C.p. = *Chloeia pinnata*; L.g. = *Levinsenia gracilis*; G.a. = *Glycinde armigera*; E.sp.2 = *Eudorella* sp.2; C.c. = *Cadulus californicus*; T.t. = *Tritella tenuissima*)

monitoring program samples). Concentrations of oil at Stations PA6 and PA7, located within the southeastern sector of the sampling array, are within a factor of two of background levels.

Macroinfauna were analyzed from the three control samples and the three wreck-site samples with the highest hydrocarbon loadings (PA1, PA4, and PA5). Statistical and other mathematical comparisons between these two basic sample sets reveal distinct effects of the spill on the structure and composition of the infaunal community within the immediate wreck-site area and on the abundances of several component species. Evidence of such effects is provided by differences in mean number of species, mean number of individuals (all species combined), relative species abundances (clustering of faunal similarity), and the abundances of several component species (six species of polychaetes, crustaceans, and molluscs, three of which are normal community dominants). The combined abundance of all amphipod species is also significantly lower in wreck-site samples in comparison to controls; amphipod crustaceans are known as being sensitive to oil toxicity.[3,11]

The cause of these biological effects could be related to physical disturbance of the sediments; oil toxicity or other related effects due to entanglement and smothering; copper toxicity; or a combination of these sources. Videotapes and still photographs of the sea floor surrounding the wreck reveal a zone of large surface cracks and upheaved sediment slabs, providing evidence that physical disturbance could be partly responsible for the effects. Direct evidence of an oil-related source of impact exists, since macrofauna were analyzed from the same samples that contained the highest hydrocarbon loadings in the sediment. Additional evidence for oil-related effects is provided by the fact that visible quantities of oil were observed in these samples as they were being processed on board the research vessel, and were found on the body surfaces and in the guts of animals living in the samples. Evidence of a copper-related source of impact also is provided by the fact that these same three sediment samples contain copper at concentrations ranging from 830 (PA5) to 24,000 (PA1) μg/g dry weight, which are 38 to 1,090 times higher, respectively, than the average control concentration of 22 μg/g.[10] This latter control concentration is similar to the background concentrations of copper found in sediments at nearby stations sampled on the MMS monitoring program, which range from 8 to 31 μg/g dry weight and average 16 μg/g.[5]

Regardless of the exact cause, these initial environmental effects are unique in consideration of the extreme water depth in which the spill occurred. Most previous oil spill studies, for example, have reported effects either in intertidal or relatively shallow, subtidal systems (for example, within depths of about 10 to 40 m for the highly visible West Falmouth and *Amoco Cadiz* spills, respectively). In the current study, distinct adverse effects on the benthos are reported at water depths of 410 to 436 m. The authors also are not aware of prior studies of the effects of copper at these depths. Elevated levels of oil and copper observed in surficial sediments surrounding the *Pac Baroness* reveal that these chemical contaminants were mixed directly into bottom sediments, probably as a result of the resuspension of sediments as the vessel made contact with the sea floor.

Results of this preliminary study document the initial environmental effects of the *Pac Baroness* incident out to the limits of the current sampling array (that is, within a 500-m radius of the wreck). The spatial extent and persistence of these effects with time should be the subjects of additional follow-up studies, particularly in view of the magnitude of initial chemical contamination and effects on the benthos, the possibility of subsequent food-chain effects, and the potential sources of sediment and pollutant transport throughout this region.

Acknowledgments

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December 18, 1987

Dr. Gary Brewer
Minerals Management Service
Pacific OCS Office
1340 West Sixth Street
Los Angeles, CA 90017

Re: **MMS Contract No. 14-12-0001-30262**

Dear Gary:

Enclosed please find a copy of the Cruise Report for the Pac Baroness Survey, Leg 1 and Leg 2. I have sent copies of the this document to all individuals on the copy list in this letter.

Sincerely,

Jeffrey L. Hyland

Jeffrey L. Hyland, Ph.D.
Program Manager

JLH/hms

Enclosure

cc: Ms. Frances Sullivan, MMS Contracting Officer
Dr. Donald Aurand, Chief of Environmental Studies Program
Mr. Bud Danenberger, MMS
Dr. James Kennett, UCSB
Dr. Stanley Margolis, UCSB
Dr. Paul Stout, UCSB
Dr. Richard Zimmer-Faust, UCSB
Dr. Rachel Haymon, UCSB
Dr. Brian Melzian, EPA
Mr. Tom Christian, U. S. Coast Guard
Mr. David Drake, U.S.G.S., Menlo Park
Dr. Paul Boehm, Battelle, Duxbury
Dr. Bill Steinhauer, Battelle, Duxbury
Dr. Margarete Steinhauer, Battelle, Duxbury