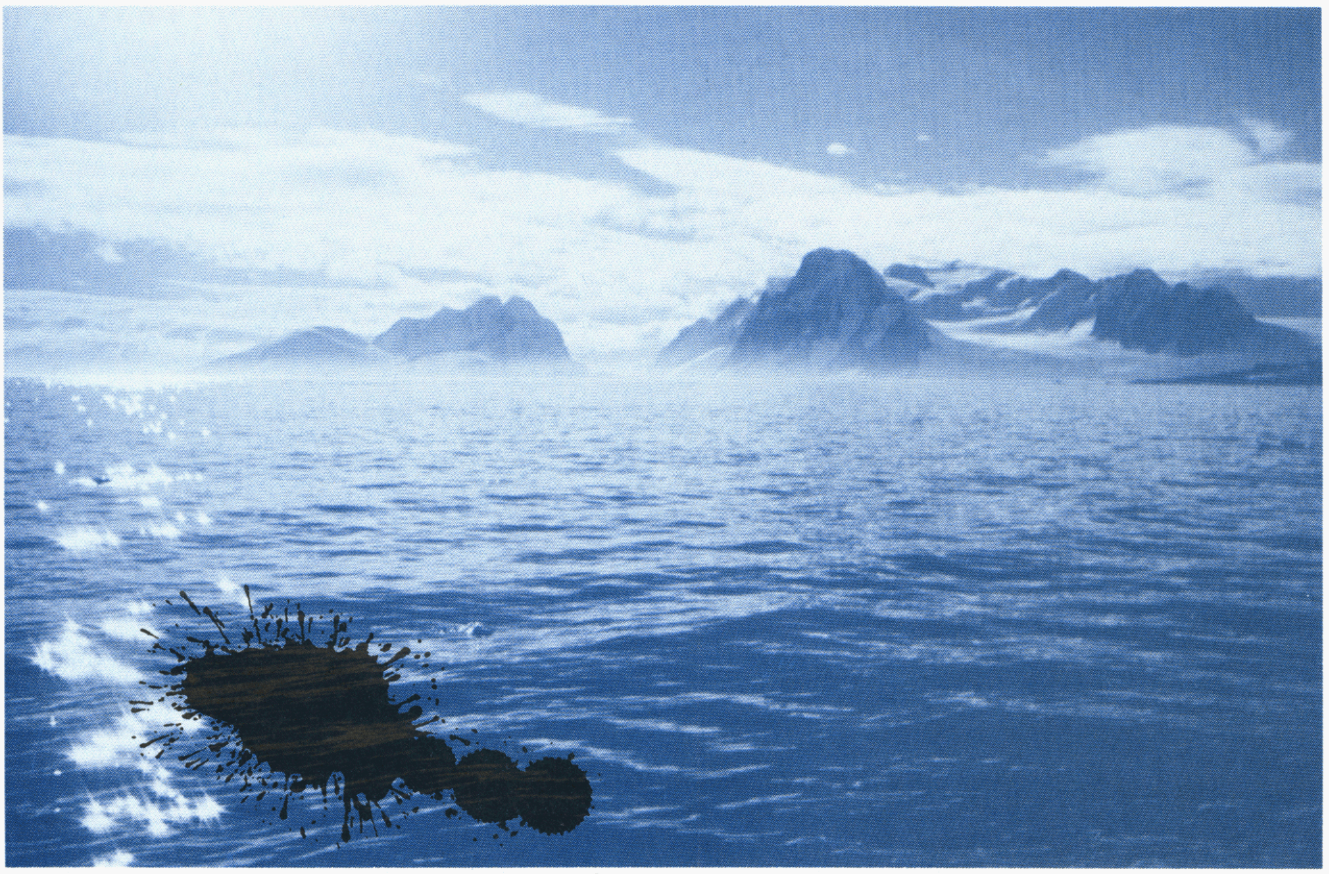
Oil spillage in Antarctica

Initial report of the National Science Foundation-sponsored Quick Response Team on the grounding of the Bahia Paraiso



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In retrospect, 1989 may be remembered as the year of the oil spill and the beginning of a heightened public awareness of the environmental consequences of uncontrolled discharges of petroleum to the marine environment. U.S. coastal waters received several accidental releases of petroleum on the East Coast, in the Gulf of Mexico, and along the Alaskan coast. The most publicized and largest release resulted from the grounding of the supertanker *Exxon Valdez* in Prince William Sound.

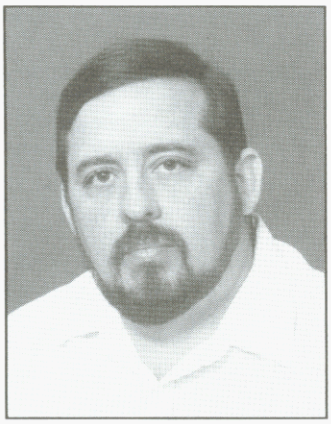
Early in 1989, before the *Valdez* accident, an incident had already focused international attention on human activities in polar climates—the wreck of a supply ship in Arthur Harbor, Antarctica. On January 28, 1989, the Argentine ship *Bahia Paraiso* ran aground near Anvers Island on the Antarctic Peninsula. More than 150,000 gallons of petroleum, primarily diesel fuel arctic (DFA), were released to the surrounding bays.

The *Bahia Paraiso* and the *Exxon Valdez* incidents provide contrasting oil spill scenarios including the amount and type of material released; the magnitude, methods, and rapidity of the clean-up response; the perceived immediate and long-term impact; and the fate of the spilled materials. There are also similarities between the two spills, including the remoteness of the location, the availability of clean-up equipment, and the polar climate. In this article the National Science Foundation (NSF)-sponsored Quick Response Team sent to investigate the *Bahia Paraiso* spill and invited contributors (Table 1) report the initial results of immediate and long-term monitoring programs initiated at the time of the spill.

The incident

Enroute to resupply an Argentine Antarctic base, the *Bahia Paraiso* ran aground on January 28, 1989, about 2 km from Palmer Station, a U.S. Antarctic research station. The *Bahia Paraiso* had just completed a sight-seeing visit to the station and was exiting Arthur Harbor when the accident occurred. The vessel contained a cargo of

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DFA, jet fuel, gasoline, and compressed gas cylinders totaling more than 250,000 gallons. A 30-foot tear in the ship's hull began to discharge petroleum into the waters of the surrounding bays almost immediately. Within four days of the accident 100 km^2 of sea surface was covered by an oil slick.

TABLE 1
The NSF-sponsored *Bahia Paraiso* spill Quick Response Team and invited contributors[a]

Participant	Study component	Institution
Mahlon C. Kennicutt II*	Hydrocarbon chemistry	Geochemical and Environmental Research Group, Texas A&M University
Stephen T. Sweet*		
William Fraser	Avian population biology	Point Reyes Bird Observatory
Mary E. Culver		
William L. Stockton*	Intertidal invertebrates and macroalgae	University of California–Santa Cruz
Kenneth Dunton*	Macroalgae physiology	University of Texas, Port Aransas
Larry Martin*		
David M. Karl*	Microbiology	University of Hawaii
Langdon Quetin*	Subtidal and intertidal Benthic ecologists	University of California–Santa Barbara
David Laur*		
Charles D. Amsler*		
Robin M. Ross		
Robert Rowley*		
Michael Neushul		
Jeffrey Hyland		
James Kennett		
James Campbell*		Battelle
Michael Fry	Bird physiology	University of California–Davis
Barrie Todd*		
Albert Bennett	Seabird behavior and population	University of California–Irvine
Zoe A. Eppley		
Margaret Rubega		
Timothy Targett	Fish studies	University of Delaware
Paul Grecay*		
Octavio Lecaros Palma*	Hydrocarbon and trace metal chemistry	University of Magallanes–Chile
Gustavo Ferrerya*	Benthic diatoms and microzooplankton	Antarctic Institute of Argentina
Vivianna Alder*		

[a]Ted DeLaca (NSF, Division of Polar Programs) coordinated the initial on-site spill response efforts; the Quick Response Team was led by Polly Penhale (NSF, Division of Polar Programs).
*Quick Response Team members.

Early observations of impacts

The first evidence of ecological damage was observed in the intertidal shore zone. Invertebrate mortality, mostly dead and dying limpets, was observed as early as February 1, with thousands of dead individuals being observed by February 4. Although it was difficult to quantitatively assess losses for many of the invertebrates, comparative evidence based on intertidal limpet censuses before and after the spill suggests as much as 50% of the littoral population may have perished in the immediate vicinity of the wreck (approximately a 2-km radius). Limpet mortality was heaviest in coves that retained oiled waters or were persistently replenished with oil due to the prevailing winds. Well-drained intertidal pools more distant from the spill were less affected.

The earliest evidence of lethal exposure of the area's sea birds to DFA was noted on February 1 when several dead, oiled Adelie penguins and blue-eyed shags were found in Biscoe Bay adjacent to Palmer Station. Documented mortality during the spill was estimated to be <300 individuals over a three-week period, with 89% being penguins and shags. The actual mortality may have been higher due to an underestimate of mortality caused by the severe weather conditions, the efficiency of scavengers and predators, and the abandonment of breeding colonies in response to the natural seasonal dispersal of chicks at this time of the year. On the other hand, a breeding failure among fish-eating birds (shags and South Polar skuas)—caused by natural factors—was underway coincident with the spill. Thus, only follow-up work can reliably gauge the spill-related mortality for these species.

Long-term monitoring

Palmer Station personnel and scientists instituted a comprehensive sampling program within one day of the spill. Samples included water, intertidal organisms, dead birds, sediment from beaches, and oil slicks. For more than four weeks samples were routinely collected at regular intervals to provide information on the dispersion, location, and effects of the spill. As a follow-up to these initial samplings, an environmental impact assessment team, representing disciplines not already present at the time of the spill, was established and dispatched to the area in early March by the NSF Division of Polar Programs (Table 1). The previously established stations were reoccupied and a comprehensive grid of sampling locations was established (Figure 1). The preliminary results of these efforts are presented here.

Hydrocarbon chemistry—The nature and fate of the spill. The majority of the fuel released from the *Bahia Paraiso* was DFA containing a jet fuel (JP-1) component. DFA contains high concentrations of semivolatile aromatic hydrocarbons such as naphthalenes and fluorenes as well as a range of aliphatic hydrocarbons (normal, branched, and cyclo) with eight to 30 carbons. The *n*-alkane molecular distribution maximizes at normal undecane, and toxic aromatics such as benzene, toluene, and xylenes are present at low concentrations.

The composition of the fresh slick remained relatively constant over the first six weeks of sampling. Higher molecular weight aromatics such as phenanthrenes, dibenzothiophenes, and chrysenes were present in the small amounts of lube oil released. Given the narrow, and low, boiling-point range of the DFA, little residue would be expected even after substantial weathering. Most resistant, high-molecular weight materials (i.e., asphaltenes) are removed during the (DFA) refining process.

Hydrocarbon analyses confirmed that macroalgae, limpets, and beaches were repeatedly stained with diesel fuel, and the highest levels were concentrated in intertidal areas downwind of the wreck. Macroalgae tended to act as a passive sampler and accurately reflect visual observations of the movement of the slick (summarized in Table 2). After being oiled the macroalgae were cleansed within a few days most likely by physical (evaporation) and mechanical (wave action, dissolution)

processes. The hydrocarbons adsorbed on the algae exhibited significant loss of the volatile components (through evaporation and dissolution) after only a few days' weathering. Reoiling of areas was apparent.

Intertidal limpets were heavily oiled over a six- to seven-week period. Total polycyclic aromatic hydrocarbon (PAH) concentrations in tissue samples were as high as 125,000 ppb immediately after the spill (Figure 2). The location of the most intense exposure varied with time. Within three weeks after the first spillage the highest PAH values were reduced by a factor of 3 to 5, and by six to seven weeks tissue levels were more than an order of magnitude lower than during the most intense oiling. In general, limpet hydrocarbon compositions were indicative of oil adsorbed or coated on exterior tissues and not biologically taken up.

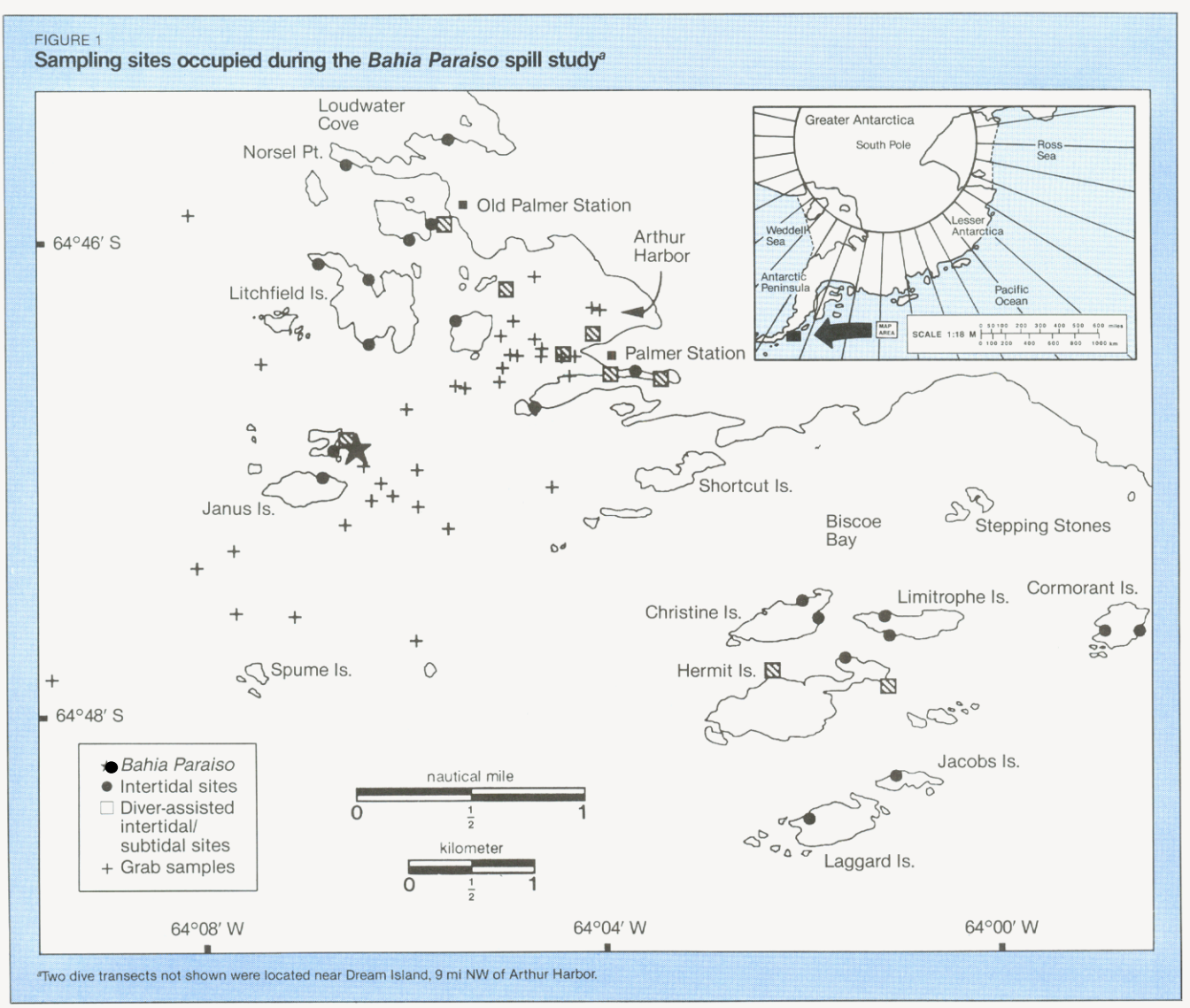
Although the presence of oil in water samples was generally restricted to areas directly under slicks, sediment in the intertidal zone remained oiled over a several-week period. Sediments below the intertidal zone and in the central portion of the bays were uncontaminated other than when in direct contact with the wreck. Intertidal beaches took days to weeks to be cleansed after oiling, and the fuel may persist for months in areas of relatively fine sediments and limited wave action. Few of these types of areas are present in the area of the spill. Concentrations of PAH in sediments immediately after the spill exceeded 1000 ppb in several cases.

Variations in oil composition and concentration with time suggest that a major portion of the diesel fuel rapidly evaporated, was diluted with seawater, and the residue was ultimately flushed from the immediate area of the spill by wave and current action.

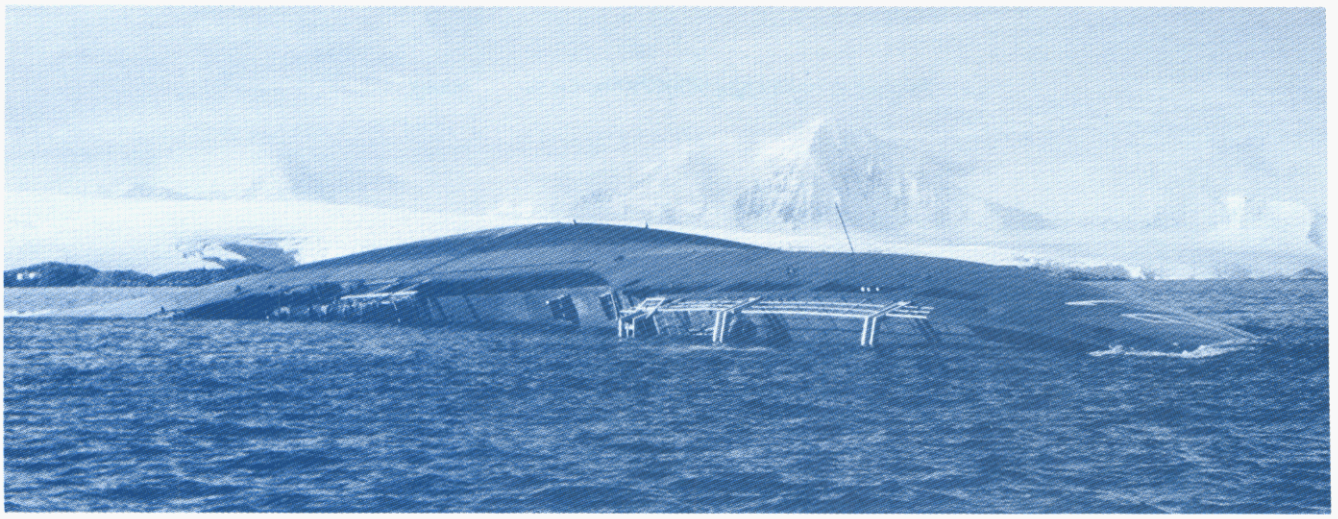
Avian biology and population dynamics. The *Paraiso* spill occurred at the middle to end of the breeding season for seven bird species and potentially affected 40,000 individuals. In the main phase of DFA spillage, adult diving bird (penguins and shags) mortality from fouling and toxicity occurred, but was minimal. Direct effects of oil were not apparent in adult surface-feeding birds, although many species fed on organisms killed by oil (krill and limpets).

Six to eight weeks after the spill, there was little or no residue of oil remaining on birds' feathers. Effects of oil on reproduction were observed in two species of birds. Blue-eyed shag nestlings died of toxicity and abandonment. This mortality was exacerbated by a disappearance of prey due to natural factors. South Polar skuas suffered a complete reproductive failure while oil was present, but the causal agent may be natural (lack of food) or spill-related. It has been speculated that this failure may be due to the oil disrupting normal parental behavior when parents neglected their territories while cleaning themselves after feeding in slicks. Longer term studies will be needed to more fully resolve natural population variability from spill-induced effects. Young gulls and penguins left the area during the spill; the effect of the oil on their populations remains to be determined.

FIGURE 1
Sampling sites occupied during the *Bahia Paraiso* spill study[a]



[a]Two dive transects not shown were located near Dream Island, 9 mi NW of Arthur Harbor.

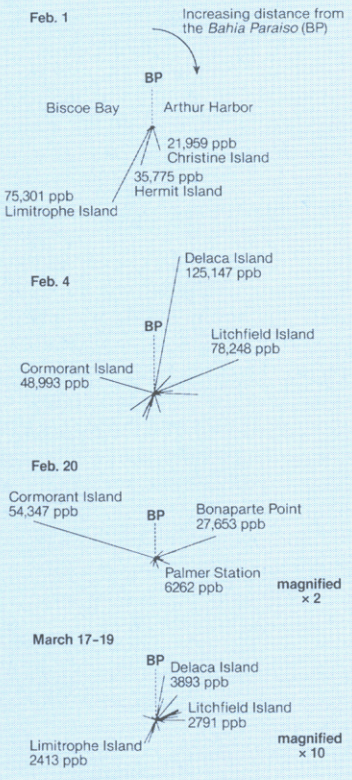


Intertidal communities. Limpet populations appeared to have substantially recovered in the intertidal zone, probably repopulated by subtidal individuals, within four to six weeks after the spill. During March, inter- and midtidal algae appeared to be as numerous as before the spill. In both cases (limpets and algae) these observations are speculative because little if any prespill quantitative baseline information on the distribution and abundance of intertidal flora and fauna is available.

Subtidal communities. Benthic ecologists established permanent intertidal–subtidal dive transects from the supralittoral zone to subtidal depths of 20 m at three oiled and two nonimpacted sites on hard-bottom substrates. Transects were photographically documented and samples quantitatively collected. Deeper subtidal sites (between 20 and 180 m) were sampled with a grab sampler. The analyses will assess the effect of the oil spill on community structure and compare historical data to assess long-term temporal variations within infaunal assemblages. Preliminary assessments of control and impacted areas suggest little, if any, effect on subtidal communities.

Microbiological processes. Microbiological studies suggest that indigenous densities of hydrocarbon-oxidizing bacteria and degradation rates are extremely low compared with temperate climates. Microbial hydrocarbon oxidation was measured by monitoring the rate of $^{14}C\text{-}CO_2$ evolution from incubations of seawater, plankton concentrates, and sediments enhanced with radiolabeled ^{14}C-hexadecane ($n\text{-}C_{16}$).

FIGURE 2
Summary of PAH concentrations in intertidal limpet tissues at various post-spill sampling times

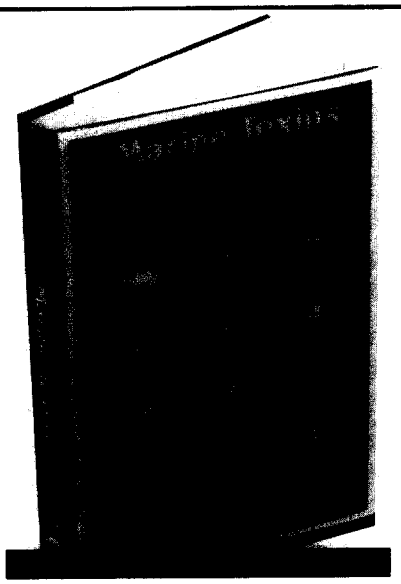


Distance from the spill increases in a clockwise direction with each "spoke" representing a discrete sampling location. The length of the spoke is scaled as indicated to PAH concentration (ppb).

TABLE 2
Summary of the progression of events following the *Bahia Paraiso* spill[a]

Date (1989)	Event
Jan. 28	*Bahia Paraiso* runs aground and begins to leak. Fraser and Culver, on site due to other studies, begin preliminary monitoring work.
Jan. 29–30	Visual observations suggest that the spill remained fairly concentrated in the Arthur Harbor area near the wreck and Torgensen Island.
Jan. 31	Winds, currents, and tides free the *Bahia Paraiso* and it drifts to a new location near DeLaca Island. The slick oils nearby islands and flows into Biscoe Bay and on the seaward side of Laggard and Jacobs Island.
Feb. 1	Intertidal contamination of macroalgae in the immediate vicinity of the wreck and the seaward edges of the outer islands: Norsel Pt., Laggard, Jacobs, Limitroph, and Cormorant Islands.
Feb. 4	The slick, moved by winds, is concentrated in Arthur Harbor and the central portion of Biscoe Bay where macroalgae are oiled.
Feb. 4–7	Chilean and Argentine navies survey the wreck and lay the first containment booms.
Feb. 7–9	U.S. team arrives, surveys the wreck, and begins skimming operations.
Feb. 20	Biscoe Bay had been extensively flushed and the main contamination was centered in Arthur Harbor as evidenced by macroalgae contamination.
Mid-March	Pumping of fuel from the ship, skimming operations, and plugging of leaks ceases and the clean-up and salvage teams depart.
March 15–17 (arrival of the Quick Response Team)	Oil release from the wreck is greatly mitigated and oil staining of macroalgae is only apparent in close proximity to the wreck—Delaca and Janis Islands, Bonaparte Point.

[a]Based on visual observations and diesel-fuel-arctic staining of macroalgae as determined by fluorescence spectroscopy and gas chromatography.



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Microbiological hydrocarbon oxidation occurred in sediments at very low rates (<100 g n-C_{16}/cm^3/year). No differences were apparent in rates measured from oiled and control areas. The microbiological turnover time of hexadecane was greater than two years.

Mammals and fishes. The effects of the spill on benthic fishes appeared to be negligible. Hydrocarbon analysis of stomach contents of *Horpaginfer anarcticus* collected near the wreck showed that DFA was present. Fish collected at the wreck site fed normally and appeared healthy in all respects when monitored in aquaria at Palmer Station.

The effects of the spill on the area's seals and other marine mammals was negligible. Although some oiled animals were encountered, no mortalities or stress were recorded. Unlike the situation with sea birds, which were at the peak of reproductive activities when the spill occurred, marine mammals were for the most part absent from the area in early February and did not begin moving into the area until early March, by which time the heaviest concentrations of oil had dispersed. It is very doubtful, therefore, that the spill had any impacts on their populations.

Exposure experiments

Laboratory experiments to determine the effect of DFA exposure on various portions of the ecological system were undertaken at Palmer Station and continued after the field effort. Exposure of three species of marine macroalgae to the water soluble (4 °C) fraction of DFA (WSF DFA, up to 20% v/v) produced no statistically significant reduction in photosynthesis (measured by oxygen evolution at photosaturation over a 96-h period). In *Porphyra endiviifolia*, phycocyanin was significantly reduced when exposed to a 10% solution of the WSF DFA. For *Palmaria decipiens*, concentrations of chlorophyll *a* and phycoerythrin were significantly lower at a 20% solution of the WSF DFA in seawater. Phycocyanin enables *Porphyra* to maintain high rates of photosynthesis throughout the green and into the orange region of the action spectrum. The lack of significant change in photosynthetic rate after exposure to the WSF DFA in these two species is not understood, but may be related to the high variability in O_2 measurements and short-term compensatory response by photosynthetic pigments that were not significantly affected.

Exposure of microbial communities to DFA produced no acute toxic effects (based on the rate of respiration of ^{14}C-labeled acetate). This lack of effect may be due to the short exposure periods (hours to days) or the microbiologically benign characteristics of the petroleum.

Summary, future directions

The immediate effects of the spill were restricted to within a few kilometers of the wreck over a several-week period due to reduction in leakage, cleanup, weathering of the spill, and flushing of the area. The intertidal zone was most directly affected with oil-fouled macroalgae, limpets, birds, sediments, and rocks. Little sediment is present in the study area, and most beaches are composed of pebble-sized or larger rocks, which provide few places for the slick to concentrate away from wave and wind action. This setting prevents the oil from permanently depositing on the islands, except on beaches and above the surf zone, and ultimately results in evaporation, transport from the area, and dilution of the slick.

The simultaneity of several factors contributed to limiting the impact of the spill both areally and over time. These factors include the volatility of the released product, the volume of material released, the variable and severe weather conditions, the common occurrence of off-shore winds and currents, and the lack of low-energy intertidal areas for the fuel to accumulate. The primary removal mechanisms were evaporation, dilution, and transport from the area, with only minor affects from microbial oxidation, photooxidation, and biological uptake. Longer term sublethal effects have yet to be documented but appear to be limited to limpet and bird population dynamics if any can be recognized at all.

The *Bahia Paraiso* has continued to slowly leak oil during the winter period, with visible slicks being reported by station personnel. The continued oiling of islands in the immediate vicinity of the wreck (including the extensive Adelie penguin rookery) raises the specter of long-term, low-level chronic hydrocarbon exposure of these ecosystems. As of this writing, follow-up assessment of bird and limpet populations is being completed, and a reoccupation of the hydrocarbon sampling sites is planned for March–April 1990 to provide an opportunity to assess the longer term impact on the environment.

***Mahlon C. Kennicutt II** is an associate research scientist in the Geochemical and Environmental Research Group within the Department of Oceanography at Texas A&M University. He received a Ph.D. in oceanography from Texas A&M University in 1980. His professional interests include environmental chemistry, organic geochemistry, and marine organic chemistry.*