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Human Contamination of the Marine Environment—Arthur Harbor and McMurdo Sound, Antarctica

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Polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs), pesticides, and trace metal concentrations in McMurdo Sound and Arthur Harbor, Antarctica, sediments and marine biota are reported. Biomarkers of contaminant exposure, biliary metabolites and EROD assays, were also measured. Hydrocarbon and trace metal contamination are generally limited to within hundreds of meters of human settlements. Local releases of fossil fuels, disposal of waste materials, and aging of ship and station structures contribute to contamination. High concentrations of PCBs were detected in sediments (250–4200 ng g⁻¹) and organisms (up to 420 ng g⁻¹) from Winter Quarters Bay (WQB). Trace metal and PAH sediment concentrations rarely exceed levels known to cause toxic effects in marine organisms, whereas PCBs in WQB often do. Biological responses to exposure include the formation of PAH metabolites and the inducement of the P4501A detoxification system in fish. Induction of EROD activity in *in vitro* rat hepatoma H4IIE cell bioassays by tissue extracts correlated with known levels of PCB contamination in invertebrate tissues. Local sources of contaminants greatly exceed those attributable to long-distance atmospheric transport.

Introduction

Antarctica is considered to be one of the last pristine areas on earth. However, even this remotest of continents exhibits evidence of contamination by humans. These observations underscore concerns that human activities are impacting the earth on a global scale (*1*). Contaminants are introduced to Antarctica by scientific support activities, ship operations, atmospheric fallout, and disposal practices (*2*). Although there has been a human presence in Antarctica for decades, the number of visitors has dramatically risen in recent years, increasing the potential for contamination (*3*). Polycyclic aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs), and trace metal concentrations in sediments and marine organisms near two scientific stations in Antarctica are reported. Biochemical indices of contaminant exposure are also evaluated (*5–7*). Biliary metabolites of aromatic hydrocarbons and hepatic ethoxy resorufin-*O*-deethylase (EROD) activity in fish were measured. An *in vitro* assay, rat hepatoma H4IIE cells, was also used to estimate the toxicity of extracts of tissues from invertebrates (*8*). The results of these studies are integrated to assess the importance and origins of human-related contamination in Antarctica.

Study Locations. The following site descriptions highlight potential sources of contaminants at the two scientific stations studied (*9*). Palmer Station is located on Anvers Island on the Antarctic Peninsula (Figure 1A,B). Old Palmer Station was built next to the British Station Base N in 1965. The present Palmer Station was built in 1968 (Figure 1C). During austral summer, capacity is 43 people, but this is often exceeded (*9*). During the winter, the staff is generally reduced to fewer than 10 people. Abandoned dump sites where solid wastes were burned are located near Old Palmer Station and Palmer Station. Commonly used fuels are JP-1, diesel fuel arctic, diesel fuel marine, and leaded and unleaded gasoline. Lube oil, transmission fluid, and various greases are also common. Wastewater at Palmer Station includes sanitary sewage, seawater from aquariums, wastewater from laboratories, and brine from the desalinators. Fuel spills occur due to leakage from drains, leaks from full pipelines, overfilling of day tanks, and failure of fuel containers. Visiting ships are a source of contamination, and oil sheens are a common feature when ships are in port.

McMurdo Station consists of more than 100 structures located on Ross Island (Figure 1A,E; *9*). As an example, the average monthly population during the 1989–1990 austral summer and winter ranged from 882 to 1257 and from 100 to 250 people, respectively. Known sources of contamination at McMurdo include an abandoned disposal site located along the shore of Winter Quarters Bay (WQB) and a disposal

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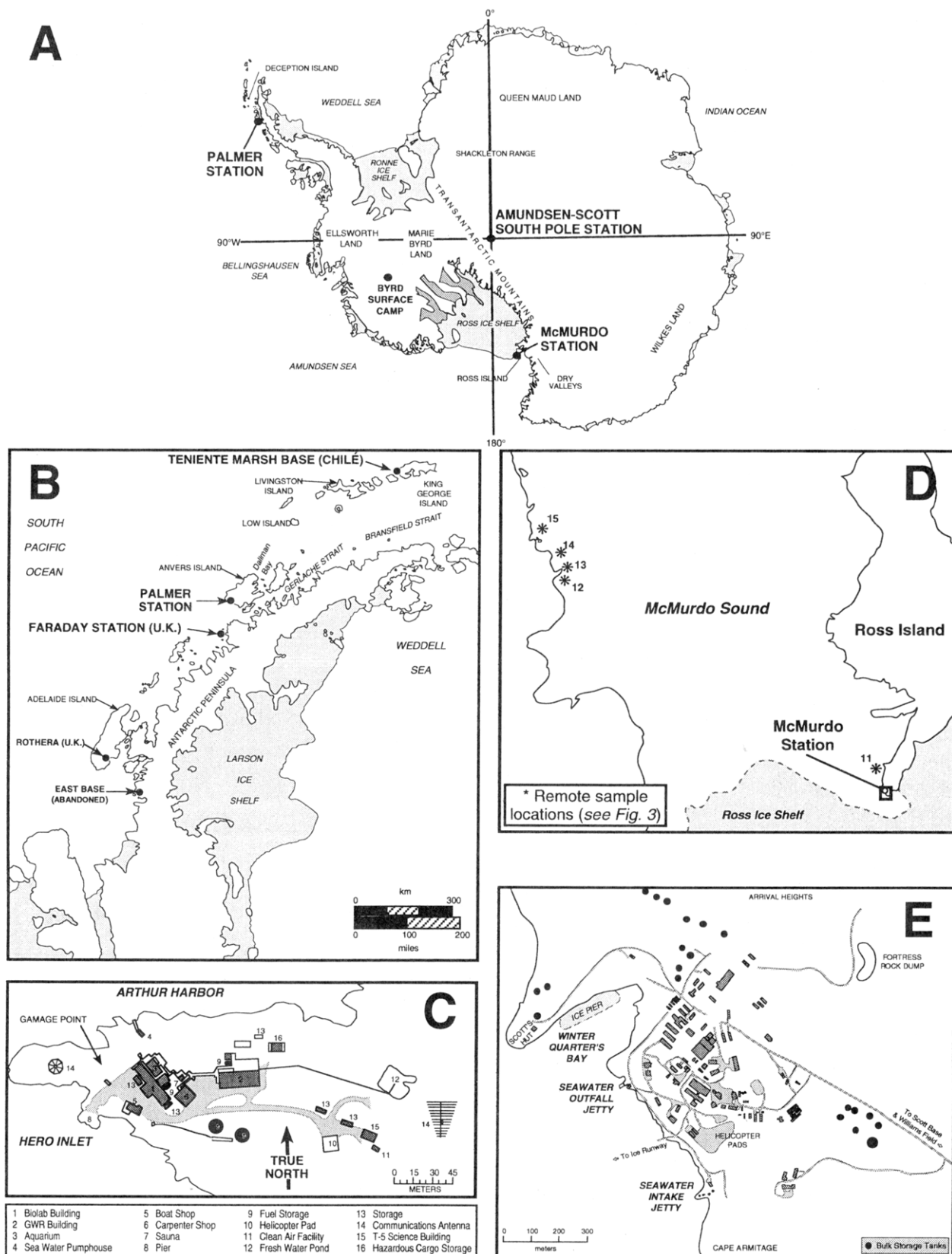† Geochemical and Environmental Research Group, Texas A&M University.
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FIGURE 1. Location of study sites: (A) Antarctic Continent; (B) Antarctic Peninsula; (C) Palmer Station; (D) McMurdo Sound; and (E) McMurdo Station.

area at Fortress Rock (closed in 1991). Extensive areas of submerged waste, equipment, 55-gal storage drums, and miscellaneous refuse exist along the entire eastern shoreline of WQB. Fuels commonly used at McMurdo are JP-5, JP-4, JP-8, unleaded gasoline, diesel fuel arctic, and diesel fuel marine. Bunker C fuels many of the ships that support

McMurdo Station. Wastewater discharge at McMurdo is estimated to be as high as 300 000 L day^{-1}. An additional 1 500 000 L of brine day^{-1} are also discharged. Wastewater has generally been discharged at the sea surface; however, sewage and gray water are now discharged from a submerged outfall (Figure 1E).
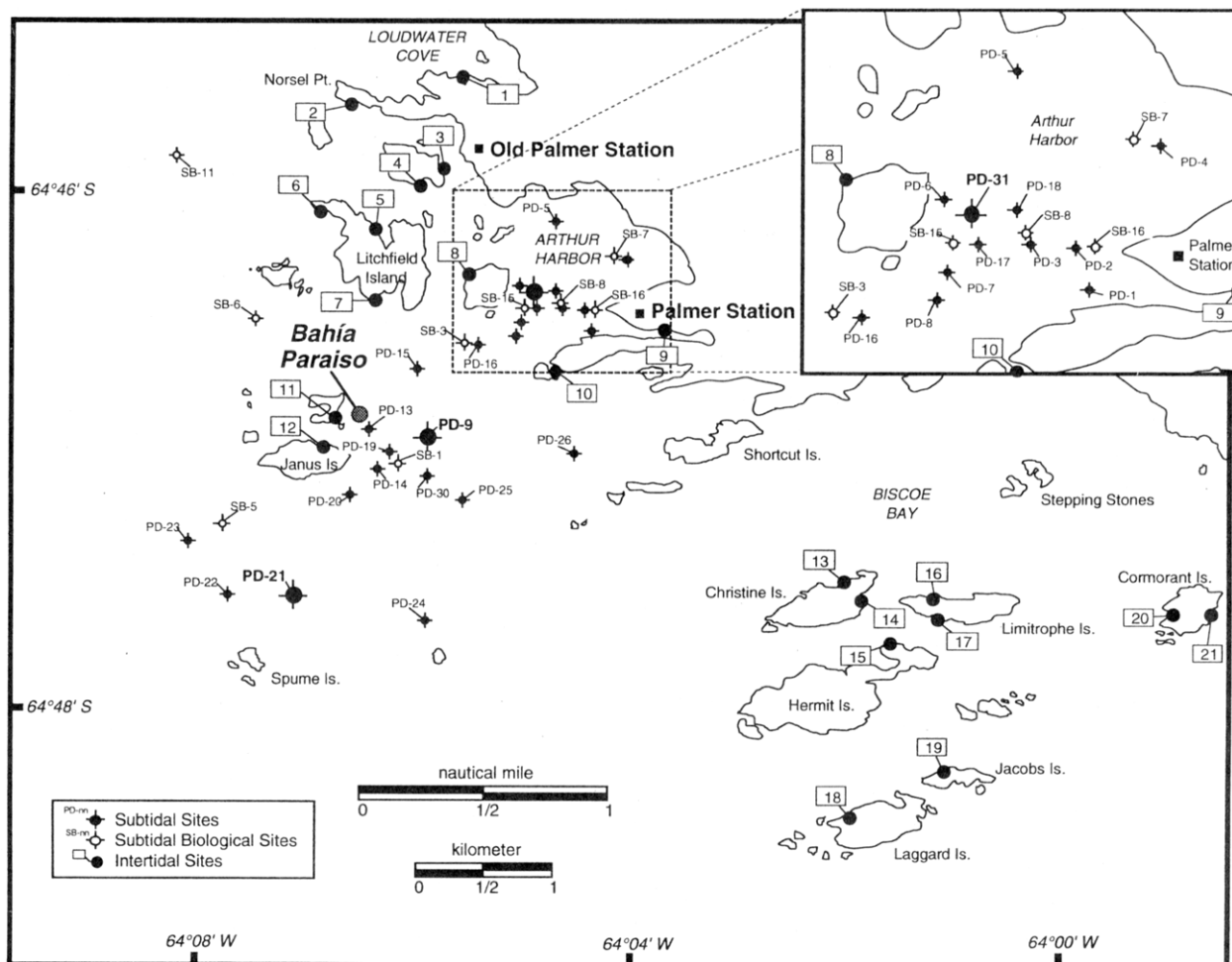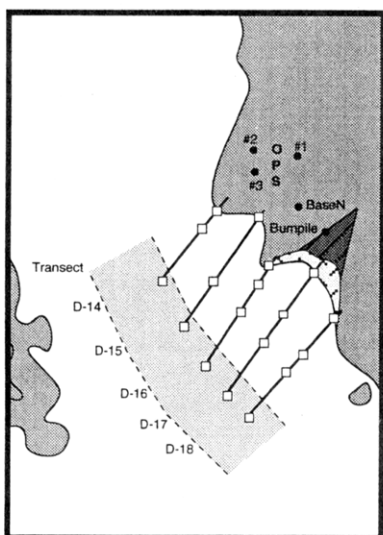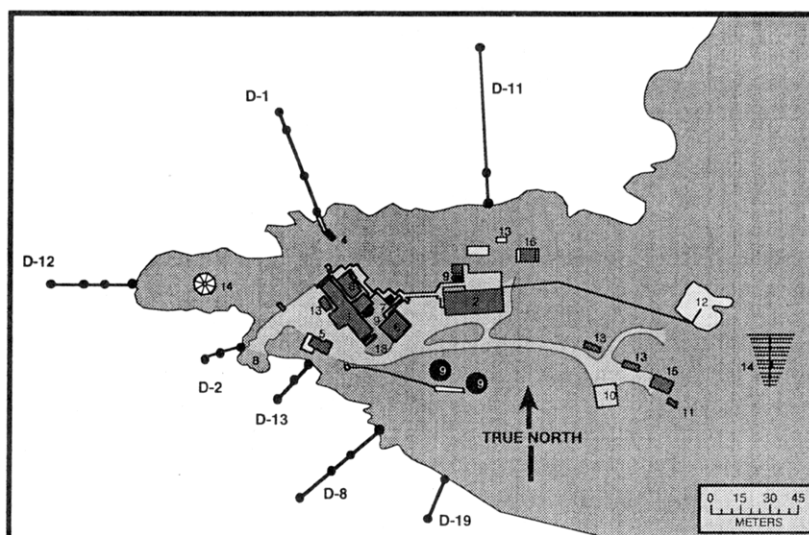
FIGURE 2. Sampling sites near Palmer Station.

Sample Collection. Samples were first collected at Palmer Station in 1989 and then annually through 1993 (Figure 2). Sediments were collected by diver or Smith-McIntyre grab sampler and stored frozen (−20 °C). Syringes were used to sample the upper 0−5 cm of sediment from undisturbed areas of the Smith-McIntyre grab. Limpets (*Nacella concinna*) were collected by divers in inter- and subtidal areas. Tissues were stored frozen (−20 °C). *Notothenia coriiceps neglecta* were collected at Low Island and Dallman Bay using an otter trawl (5.5 m), near the *Bahía Paraiso* wreck, and around Palmer Station using traps and hook and line in 1991−1993 (Figure 1B). Samples were collected during the 1990−1991 and 1992−1993 austral summers from WQB (Figure 3). Sediment and benthic organisms, bivalves (*Laternula elliptica*), and fish (*Trematomus bernacchii*) were collected by divers. A series of samples remote from McMurdo Station were also sampled (Figure 1D).
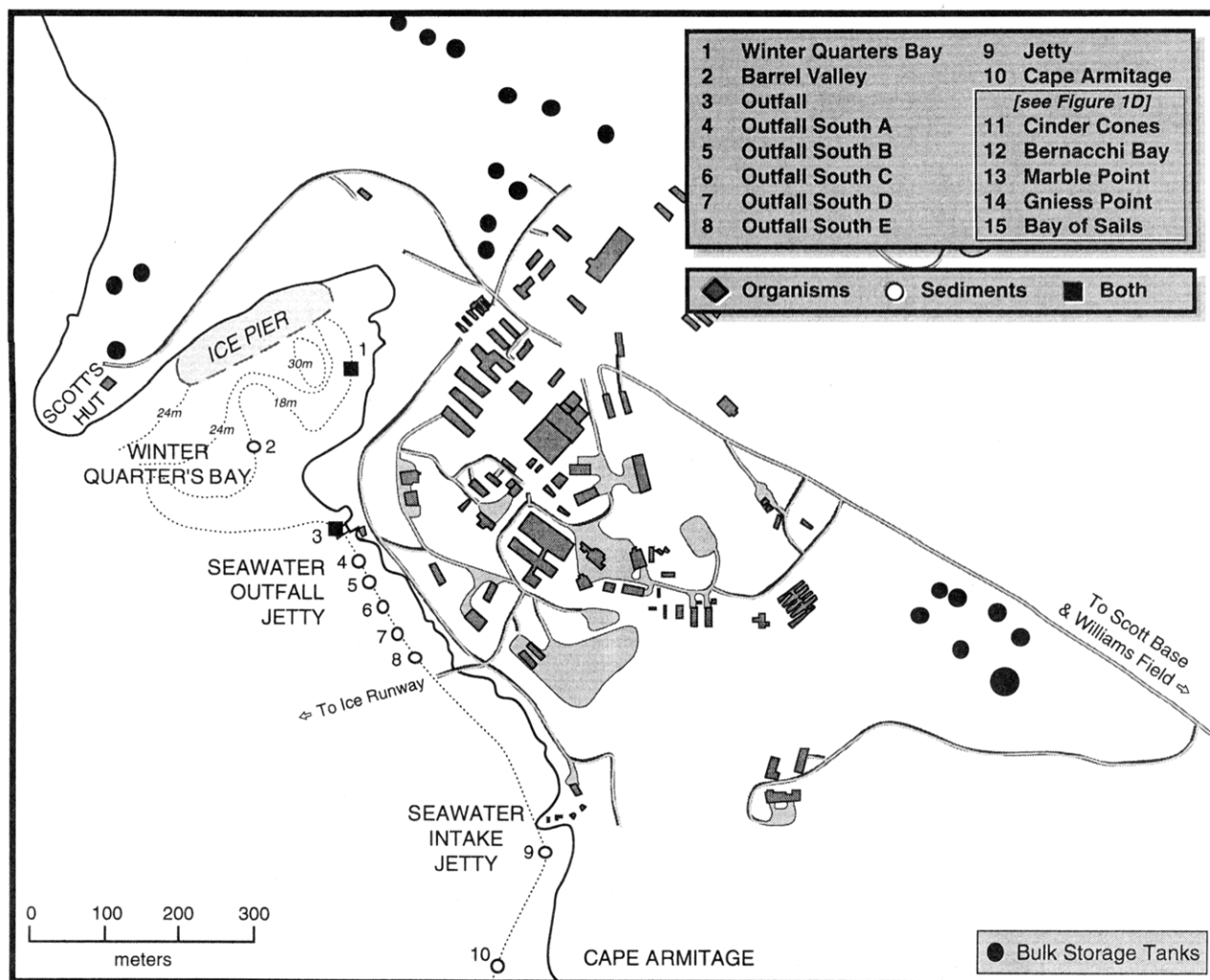
FIGURE 3. Sampling sites near McMurdo Station.

Analytical Techniques. The methods employed for contaminant analyses are those utilized for the NOAA National Status and Trends Program (10, 11). The analytical scheme is described in detail elsewhere for organic contaminants (10). For sediments, a total of 10 g of freeze-dried sediment was Soxhlet-extracted with methylene chloride and concentrated in Kuderna–Danish tubes. Approximately 25 g of wet tissue was used for analysis. The tissue was extracted three times with 100 mL of methylene chloride using a Tekmar Tissumizer homogenizer. Sediment and tissue extracts were fractionated by alumina/silica (80–100 mesh) column chromatography. Activated copper was added to the top of the column for sediment samples to remove elemental sulfur. For tissue samples, the aromatic/organochlorine fraction was further purified by high-performance liquid chromatography gel permeation chromatography. Aromatic hydrocarbons were quantified by gas chromatography with mass spectrometric detection (HP-5890-GC/HP-5970-MSD; 30 m × 0.25 mm, 0.32 m film thickness DB-5 fused-silica capillary column, J&W Scientific Inc.), the initial temperature was 60 °C, temperature programmed at 12 °C/min to 300 °C, and held at the final temperature for 6 min. Pesticides and PCBs were quantified by gas chromatography in the splitless mode using an electron capture detector (ECD). A 30 m × 0.25 mm i.d. (0.25 μm film thickness) fused-silica column with DB-5 bonded phase (J&W Scientific Inc.) provided component separations. The chromatographic conditions were 100 °C for 1 min, then 5 °C/min until 140 °C, hold for 1 min, then 1.5 °C/min to 250 °C, hold for 1 min, and then 10 °C/min to a final temperature of 300 °C.

The major analytical techniques for trace metal determination were atomic absorption spectrophotometry (AAS) in the flame mode when possible and graphic furnace (GF/AAS) or cold vapor techniques when necessary to obtain better sensitivity (11). Sediment and tissue samples were freeze-dried and completely dissolved in acids by pressure digestion in Teflon bombs. Standard reference materials and blanks were digested and analyzed with every batch of samples. Concentrations of Fe, Mn, and Zn were determined by flame AAS using a Perkins-Elmer Model 306 instrument. Concentrations of Ag, As, Cd, Cr, Cu, Ni, Pb, and Se were determined with a Perkins-Elmer Zeeman 3030 instrument equipped with a HGA-600 furnace and a AS-60 autosampler. Mercury was determined by cold vapor AAS following a slightly modified EPA Method 245.5 aqua-regia/permanganate digestion.

Bile was analyzed by an HPLC/fluorescence detection method described in Krahn et al. (12). Aromatic compounds fluorescing at naphthalene (290/335), phenanthrene (260/380), and benzo[a]pyrene (380/430) excitation/emission wavelengths were analyzed. Metabolites eluting from the column within specific retention times were summed to yield total fluorescence based on equivalents of known amounts of naphthalene, phenanthrene, and benzo[a]-

pyrene standards. GC/MS identification and quantitation of metabolites in bile were conducted on hydrolyzed bile using a method modified after Varanasi et al. (13).

Microsomes for EROD activity were prepared by differential centrifugation from either fresh livers or livers stored in liquid nitrogen using modifications of a protocol described by Stegeman et al. (5). Livers were homogenized in a 0.1 M Tris, pH 7.5, buffer containing 0.25 M sucrose. EROD assays were conducted as described by Pohl and Fouts (31) with modifications. Fluorescent metabolites were determined with a spectrofluorometer at excitation and emission of 500 and 585 nm, respectively.

Extracts of L. eliptica collected from McMurdo Sound were used for in vitro rat hepatoma H4IIE cell bioassays. The rat hepatoma bioassays were conducted as described in McDonald et al. (14).

Contaminant Inventories and Sources. Chemicals introduced to Antarctica in the largest quantities are fossil fuels and refined products. Petroleum is widely used at scientific bases for transportation and heat. In addition, trace metals and synthetic organic compounds are also commonly released to the environment by human activities. Palmer Station has been shown to emanate low concentrations of hydrocarbons (15, 16). The hydrocarbons are derived from spills and boat, ship, and fueling activities. Runoff due to snowmelt and rain transports traces of fuel, leachate from dump sites, and dust and particulates from station activities into the harbor. Most potential hydrocarbon contaminants in Arthur Harbor are volatile and would occur primarily as slicks if spilled. Transport to subtidal sediments is by absorption onto particles and deposition through the water column. In most areas fine-grain sediments only occur at water depths greater than 10 m with shallower areas consisting of exposed bedrock or large gravel or boulder beaches. The sediments in Arthur Harbor are quite mobile. Winds, currents, and ice scouring effectively transport sediments out of the bay on a regular basis. From one year to the next, fine-grained sediments can disappear from sampling sites. Little of the Bahía Paraíso spill of 600 000 L of diesel fuel arctic (DFA) was detectable in subtidal sediments (17, 4). Localized, one-time events related to human activities release PAH to the harbor resulting in contamination of subtidal sediment. For example, hydrocarbons in subtidal sediments directly adjacent to Old Palmer Station were elevated after cleanup activities at the site. It is suspected that soil tainted with hydrocarbons washed into the channel and was rapidly deposited along the central axis of the channel (15).

Total PAH concentrations in sediments collected during the 1990–1991 austral summer from McMurdo Sound varied from below the method detection limit (MDL) to 6267 ng g^{-1}. Sediments collected in the 1992–1993 austral summer varied from <MDL to 6339 ng g^{-1} (MDL for the sum of all PAH is estimated to be ~150–200 ng g^{-1}). Nine sediments collected in WQB in late 1993 had PAH concentrations ranging from 360 to 13 000 ng g^{-1} with the highest levels at the head of WQB. WQB sediments contained high concentrations of petroleum from several sources (i.e., diesel fuel, lube oil, biodegraded residues, pyrogenic residues) either spilled at the site or transported to the bay by runoff from adjacent land areas. Surface runoff is predominantly due to snowmelt. Runoff carries traces of fuel due to spillage, leachate from former dump sites, and dust and particulates created by station activities (9). The highest PAH were associated with contamination

by spilled fuel as evidenced by the predominance of naphthalenes and phenanthrenes. While lower in concentration, pyrogenic PAH (high temperature, combustion) paralleled the increase in fuel PAH, suggesting a common origin in runoff. Pyrogenic PAH were almost exclusively in WQB sediments and rapidly decreased with distance from the bay. The abandoned dump site along the eastern shoreline of WQB is the presumed source of pyrogenic PAH. In 1992–1993, divers collected samples of unusual "rivers" of black, viscous fluids that originated from discrete seeps along the subtidal adjacent to the former dump site in WQB. These fluids contained 1–6 ppm PAH. The remaining fluid is of an unknown composition and origin. Remote stations within McMurdo Sound contained sediment PAH concentrations near or below the method detection limit (Figure 1D). Traces of naphthalenes and phenanthrenes were present, indicating low levels of fuel contamination (possibly occurring during sampling). Pyrogenic PAH were not detected above the method detection limit at stations in remote areas of McMurdo Sound.

Three sediment samples from Arthur Harbor were analyzed for PCBs. Total PCB concentrations were low but detectable (4.2, 3.6, and 2.8 ng g^{-1}). PCBs were detected in all samples collected near McMurdo Station. The highest concentrations encountered were in sediments from WQB (680–1280 ng g^{-1}) and the sewage outfall (350–690 ng g^{-1}). Another set of 38 sediment samples collected on a grid pattern from WQB in December 1993 were screened for PCBs. Concentrations exceeded 1000 ng g^{-1} at five locations and ranged from 250 to 4300 ng g^{-1} (dry weight basis). PCB concentrations in sediment collected by the drinking water intake were 64 ng g^{-1}. All sediments analyzed within WQB exceeded this level. PCB concentrations rapidly decrease away from the outfall at the mouth of WQB and are 1–2 orders of magnitude lower near Cape Armitage (18–28 ng g^{-1}), a distance of less than 1 km. This pattern was previously reported in a study by Risebrough et al. (18). Concentrations of PCBs measured in the sediments collected at remote sites were below 1 ng g^{-1}.

Sediments in WQB are known to be enriched in certain trace metals. Lenihan et al. (19) found greater concentrations of most metals (silver, cadmium, copper, lead, mercury, and zinc) in sediments from WQB compared to those outside the bay. Because of the proximity of the metal-enriched areas to an old dump site and a present-day sewage outfall, the enrichments were attributed to human activity. However, the metal distribution pattern is complex. The findings of Lenihan et al. (19) were confirmed and extended by the present study. Sediments sampled in WQB are apparently rich in "basaltic" volcanic debris. High Ni and Cr values found at WQB and control sites correlate with high Fe to Al ratios and the geology of the McMurdo area. Basaltic materials enriched in Fe and Cr are also depleted in Pb and Cd, and that pattern was noted in McMurdo Sound sediments. However, the high Fe concentrations may also be due to discarded metal scrap and aging of structures rather than mineralogy. If, as seems likely, McMurdo Sound sediments contain variable amounts of basaltic debris, attributing high metal concentrations to human activity must be done with caution. This is not to say that human influence is not evident, it clearly is. Some samples from Winter Quarters Bay and the sewage outfall area are significantly enriched in Ag, As, Pb, Sb, Sn, and Zn. Tin at the outfall is especially high (up to 25 μg g^{-1}). However, copper, nickel and chromium are near normal

values for basaltic debris with maximum values of 92, 85, and 25.2 μg g^{-1}, respectively. The high Cd values reported by Lenihan et al. (19) were not confirmed in this study, and only low levels of Se and Hg were observed (maximum concentration of 0.4 and 0.17 μg g^{-1}, respectively).

The few subtidal samples from Palmer Station that were analyzed had Al and Fe concentrations and ratios similar to average upper continental crustal material. Trace elements in the sediments were not significantly enriched above normal background values. A couple of abandoned dump sites that still exist at Palmer Station and Old Palmer Station were sampled in 1991. Metal levels in soil/waste samples were high with mean levels ($n = 18$) of the following: 13 μg g^{-1} silver, 62 μg g^{-1} arsenic, 22 μg g^{-1} cadmium, 140 μg g^{-1} chromium, 2100 μg g^{-1} copper, 1600 μg g^{-1} lead, and 3600 μg g^{-1} zinc. Because of the concern for possible transport to the marine environment, samples from Arthur Harbor, offshore of Old Palmer Station, and near Palmer Station were also analyzed for metals (see Figure 1). Metals were determined in soil samples from oil spill areas around Palmer Station, Old Palmer Station, and Base N. Metal levels of all soil samples were quite high compared to control sediments. However, there was little evidence of elevated levels of metals in subtidal sediments collected near Palmer Station or Old Palmer Station compared to remote areas. This could be due to a lack of significant transport of contaminated soil/leachate from contaminated sites to the marine environment or extensive sediment transport of sediment out of the bay by currents, wind, and ice scouring.

Accumulation of Contaminants in Biota. As a first-order indication of exposure, contaminant levels in biota tissues are often measured. Accumulation of contaminants indicates that the contaminants are present in the surrounding environment and are biologically available. Limpets in the intertidal zone are chronically exposed to hydrocarbons near Palmer Station and Old Palmer Station. PAH in limpet tissues near the station are primarily low molecular weight, lipid-soluble compounds. The mode of exposure is most likely slicks and/or runoff as evidenced by the rapid decrease in PAH contamination in limpet tissues with water depth (Figure 4). PAH concentrations in bivalve tissues (L. elliptica) from McMurdo Sound were highest in WQB and decreased with distance from WQB. However, PAH concentrations were only occasionally above the MDL even in WQB and were in all cases predominantly naphthalenes. PAH at distant locations were below the MDL except for one tissue. Trematomus bernacchii viscera from WQB and Cinder Cones were analyzed for PAH. The fish tissues from WQB were higher than the controls, 656 ± 319 and 200 ± 72 ng g^{-1} ($n = 6$), respectively. The PAH were predominantly naphthalenes with occasional phenanthrenes present. Traces of pyrogenic PAH were detected, suggesting that some of the PAH could be due to sediments entrained in the fish viscera.

In general, limpets from Arthur Harbor exhibited low total PCB concentrations with no clear spatial or temporal distribution. However, intertidal limpets collected adjacent to Old Palmer and Palmer Stations were elevated in total PCB concentrations (56.9, 29.3, 28.5, and 75.7 ng g^{-1}, respectively). In limpets collected in the vicinity of Palmer Station, PCBs contained nearly equal amounts of hexa-, hepta-, and pentachlorobiphenyls. The predominant congeners were 153/132, 180, 187, 138/160, 174, 101, 110, 118, and 149/123. This profile is similar to that of a mixture of Aroclors 1254 and 1260. In contrast, limpets collected near Old Palmer Station contained a predominance of PCB congeners with six and seven chlorines, characteristic of Aroclor 1260. Predominant congeners were 138/160, 187, 180, 128, 153, 132, 177, 149/123, and 118. The predominance of high molecular weight congeners strongly suggests a local source of PCBs rather than atmospheric transport. No significant differences were observed in the total PCB concentrations between organisms collected in the vicinity of Arthur Harbor during 1989 (mean = 18.3 ±xb18.5 ng g^{-1}, range = 8.7–28.5 ng g^{-1}, $n = 4$) and 1991 (mean = 14.0 ± 4.2 ng g^{-1}, range = 10.4–19.6 ng g^{-1}, $n = 5$). In most cases, subtidal limpet PCB concentrations were lower than in the intertidal, suggesting a runoff source. Except for locations directly adjacent to the station, the PCB levels in limpets in Arthur Harbor were comparable to those in bivalve tissues (L. elliptica) collected at remote locations in McMurdo Sound. PCB concentrations in bivalve tissues from Winter Quarters Bay (400 and 430 ng g^{-1}) and the sewage outfall (380 and 410 ng g^{-1}) were 20–80 times higher than the PCB levels in bivalves from more remote areas of McMurdo Sound (range = 5.1–22 ng g^{-1}; mean = 9.8 ng g^{-1}). DDT and its derivatives, DDD and DDE, were also detected in sediments and organisms from McMurdo Sound and Arthur Harbor. Other toxic organic compounds occasionally detected at very low concentrations in sediments and organisms included α- and γ-hexachlorohexane, hexachlorobenzenes, α-chlordane, and trans- and cis-nonachlor.

Limpets near Palmer Station and at distant reference sites showed considerable variation in metal concentrations. All limpets collected near Palmer Station were enriched in Fe by factors of 2–10, about half were enriched in Cu by factors of 2–3, but only a few were enriched in other metals. Many of the high Fe samples were also high in Cr and Ni, which could be due to entrained sediment. The normal aging of station structures and vessels contribute metals to runoff.

Biological Responses. Measuring contaminant levels in tissues is often used to demonstrate exposure. However, these data may not accurately reflect exposure or effect. Biological markers of exposure indicate the presence of biologically available contaminants and can serve as sensitive indicators of specific classes of contaminants.

Concentrations of naphthalene (33 000 ± 14 000 ng g^{-1}) and phenanthrene (5100 ± 2000 ng g^{-1}) metabolites were consistently low in fish captured at remote sites along the Antarctic Peninsula. The concentrations of biliary PAH metabolites in N. coriiceps neglecta captured near Palmer Station (naphthalene = 77 000 ± 46 000 ng g^{-1}; phenanthrene = 11 000 ± 8300 ng g^{-1}) and adjacent to the Bahía Paraíso wreckage (naphthalene = 69 000 ± 56 000 ng g^{-1}) were significantly higher; however, there was considerable overlap. The presence of biliary PAH metabolites was confirmed by GC/MS analysis (20). Metabolites of phenanthrenes and dibenzothiophenes were detected in the bile of fish captured in Arthur Harbor. Individual metabolites were identified in four of seven fish captured near the wreckage of the Bahía Paraíso and in three fish caught near Palmer Station. Bile from fish collected at remote sites contained no metabolites detectable by GC/MS.

Naphthalene and phenanthrene biliary metabolite concentrations were significantly different in Trematomus bernacchii captured at various locations in McMurdo Sound. The highest levels (140 000 ± 51 000 and 25 000 ± 13 000 ng g^{-1} for naphthalene and phenanthrene, respectively)
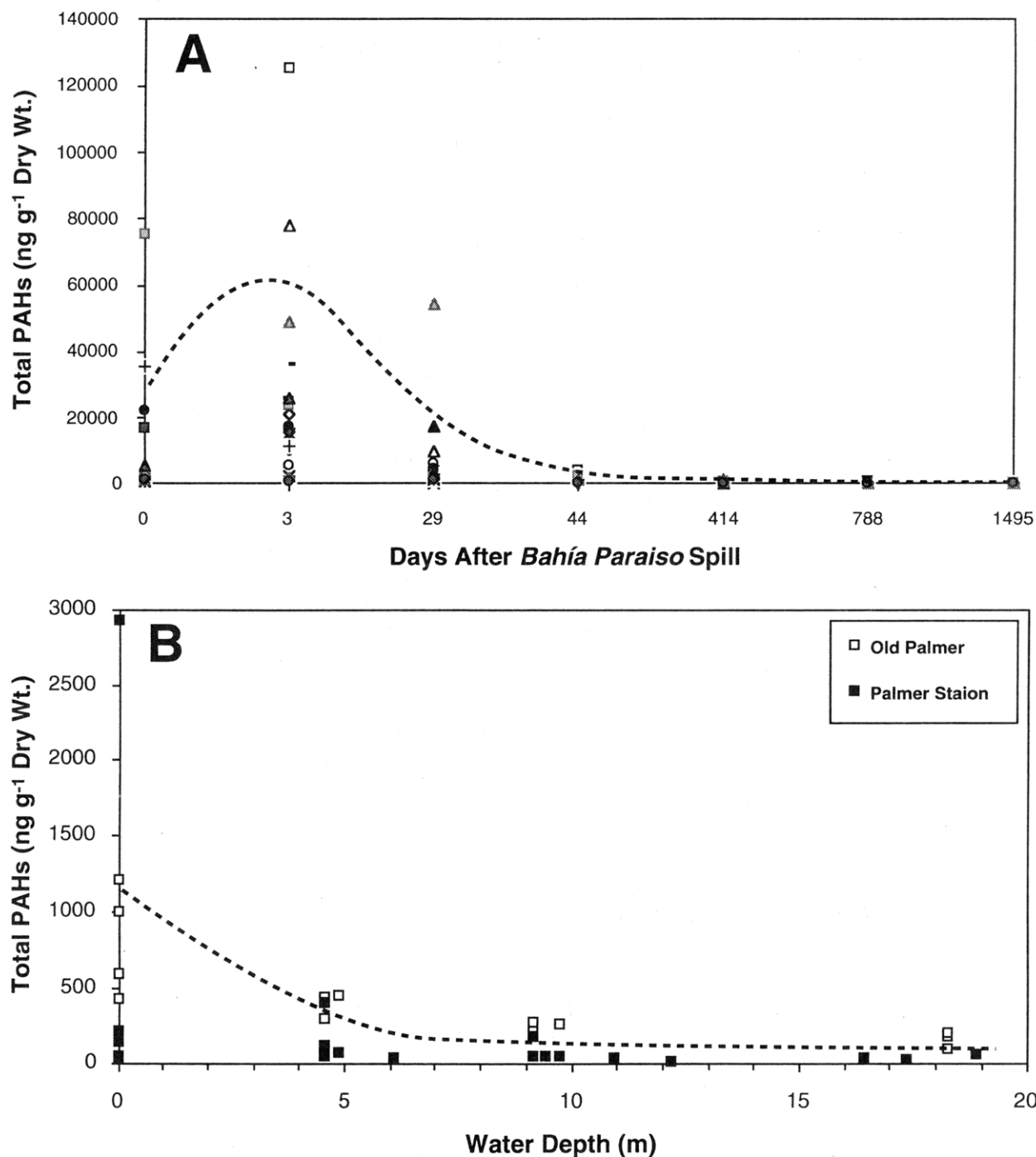
FIGURE 4. Distribution of PAH concentrations in limpets (A) in the intertidal with time since the *Bahía Paraiso* spill and (B) with depth in Arthur Harbor (see Figure 2 for locations).

were measured in fish collected in WQB. The lowest PAH metabolite concentrations (51 000 ± 27 000 and 7200 ± 3700 ng g^{-1} for naphthalene and phenanthrene, respectively) were measured in fish from Cinder Cones, a remote site. These data indicate that hydrocarbon contaminants associated with human activities have produced a biological response in resident organisms. Highly variable metabolite concentrations are due to several factors including the geographic range of the fish, fidelity to site, physiological state, and the exposure history (i.e., duration, intensity, etc.).

Hepatic EROD activities were low to nondetectable in *N. coriiceps neglecta* from remote sites along the Peninsula. The highest EROD activity was observed in fish captured near the pier at Palmer Station (121 ± 54 pmol min^{-1} mg^{-1}).

EROD activity was significantly lower in fish caught near the seawater intake (30 ± 20 pmol min^{-1} mg^{-1}) at Palmer Station and the *Bahía Paraiso* wreck (30 ● 29 pmol min^{-1} mg^{-1}). Biliary PAH metabolite levels and hepatic EROD activities were variable in fish captured near the *Bahía Paraiso* wreckage.

In vitro rat hepatoma H4IIE cell bioassays are used to determine the biological potency of extracts from samples known to contain "2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD)-like" (various halogenated and aromatic hydrocarbons) compounds. TCDD-like compounds elicit similar toxic and biochemical responses via the aryl hydrocarbon (Ah) receptor signal transduction pathway (*21*), and various responses including lethality and P4501A1 induction have been utilized to determine bioassay-derived TCDD toxic

equivalent (TEQ) values (8). Induction of EROD activity in rat hepatoma H4IIE cells by aliquots of tissue extracts of clams (L. elliptica) collected near McMurdo was measured. Lower induction activity (<320 pmol min^{-1} mg^{-1} g^{-1}) was observed in samples collected from remote sites than those collected in WQB (>2000 pmol min^{-1} mg^{-1} g^{-1}). TEQs were determined for the clam extracts using a dose–response curve for the induction of EROD activity in H4IIE cells by TCDD that was nearly linear from 0 to a 100% maximal response concentration of 1 nM TCDD. The TEQs calculated for L. elliptica extracts from control sites and contaminated sites ranged from nondetected to 0.25 and from 1.16 to 1.66 ng g^{-1}, respectively.

Discussion. In spite of its remote location, perturbation of the Antarctic environment by humans has been observed. Ship traffic to and from scientific facilities and visits from tourists create the potential for local contamination. The two scientific stations studied exhibit a "halo" of contaminants related to local releases of contaminants (i.e., spills and runoff). The most widespread contaminants are fossil fuels. In most locations, this contamination appears to be concentrated within a few hundred meters of the loci of the activity; however, areal extent is dependent on a number of variables including the intensity of the contamination, the composition of the contaminants, and the local oceanographic setting.

This study confirms previous reports of intense localized pollution in the sediments of WQB and the surrounding environs (e.g., refs 18 and 19). PAH widely occur in WQB sediments, and an unusually intense PCB contamination is present. As initially reported by Risebrough et al. (18), the PCB composition in sediments collected near McMurdo Station, are similar to that of Aroclor 1260 with little degradation evident. The distribution profile of PCB congeners, however, changes with distance from McMurdo Station suggesting some differential transport.

Comparing the PCB profile in sediments from WQB and near the outfall with PCB congeners in bivalves from these sites shows a slight depletion in high molecular weight congeners in tissues. Several reports have suggested that bioaccumulation of PCBs by different organisms is influenced by physicochemical factors (e.g. refs 22–24). Competitive partitioning between aqueous and nonpolar phases, e.g., lipids, as well as stereochemistry appear to be significant factors influencing the uptake of individual PCB congeners with four to six chlorine atoms (e.g., ref 25). The analysis of indigenous WQB organisms demonstrates that PCBs have accumulated in the Antarctica food web at these locations.

The presence of low levels of halogenated hydrocarbons throughout the Antarctic ecosystem has been used to indicate the importance of aerosol transport (2, 26, 27). However, the levels detected are exceedingly low, often challenging even the most sensitive analytical techniques. The evidence from this study suggests that long-distance atmospheric transport is a minor source of contaminants near scientific stations. Sediment and tissue from most control or remote sites show little or no evidence of persistent chemicals such as halogenated hydrocarbons, pyrogenic hydrocarbons, or trace metals. Although at significantly lower concentration, approximately the same suite of PCB congeners encountered in organisms collected in WQB were measured in clams collected from more remote areas of McMurdo Sound, suggesting a common source. Most occurrences can be attributed to localized

events including previously unrecognized sources of contaminants (i.e., PCBs). The most likely sources of high levels of contamination in Antarctica are local human activities.

Whereas the presence of contaminants in the Antarctic environment has been documented, little data exist on the impact that these contaminants have had on Antarctic fauna (28). Biological effects were implied from limpet and bird mortalities in Arthur Harbor after the grounding of the Bahía Paraíso (29, 30). In McMurdo Sound, changes in the benthic community structure were linked to the contaminants in WQB (19). PAH levels, even in the contaminated areas of WQB, are not at levels expected to cause toxic effects. However, these levels were exceeded for a period of time (days to weeks) in Arthur Harbor during a catastrophic release of DFA. In general though, normal activities have not led to persistent PAH contamination in sediments in excess of probable effects levels. In contrast, PCBs in WQB sediments exceed possible effects levels and in many cases exceed probable effects levels. In Arthur Harbor, PCBs were detectable but far below possible effects thresholds. A number of trace metals in WQB sediments exceed possible effects thresholds, but only soils/sediments taken directly from disposal areas exceed probable threshold levels. The detection of PAH metabolites in fish captured in Arthur Harbor was the first indication that the resident biota were responding to contaminant exposure. The induction of EROD activity in rat hepatoma H4IIE cells by aliquots of clam tissue extracts collected at McMurdo Sound confirms that toxic materials are accumulating in the resident biota.

Summary. The results of this study allow for a preliminary assessment of the environmental impact of humans at two scientific stations in the Antarctic. Hydrocarbon contamination near stations is a common feature. While most hydrocarbon contaminants are related to fuels, pyrogenic hydrocarbons have been introduced to the environment by open pit burning and disposal of spent oil. The extent of the halo of contaminants around stations is generally limited to hundreds of meters. While detectable, hydrocarbon contamination is low level and below biological effects thresholds except in acute cases such as WQB. Catastrophic events such as spills, improper disposal of chemicals, and disposal practices have led to contaminant concentrations that are as high as those in temperate climates near urbanized and populated areas and exceed thresholds known to induce biological effects and even mortality.

The intertidal is particularly vulnerable to exposure due to the nature of the contaminant releases (i.e., slicks) and is the most probable site of long-term chronic exposure. High-energy environments tend to dissipate the contaminants (i.e., Palmer Station). However, depositional environments retain contaminants for long periods of time (i.e., WQB). The cold temperatures tend to immobilize contaminants; however, physical transport processes (currents, waves) are an important mode of redistribution of contaminants due to the high-energy setting. Contaminants are detectable in Antarctic organisms. Biological responses to exposure have occurred at the biochemical level (i.e., inducible enzymes) and coincide with the presence of human activities. Contaminants have accumulated in fish, bivalves, and limpets, and thus the expectation is that these contaminants are being transmitted along the food chain. In some cases, biomagnification has led to bioaccumulation levels comparable to those observed in industrialized areas.

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