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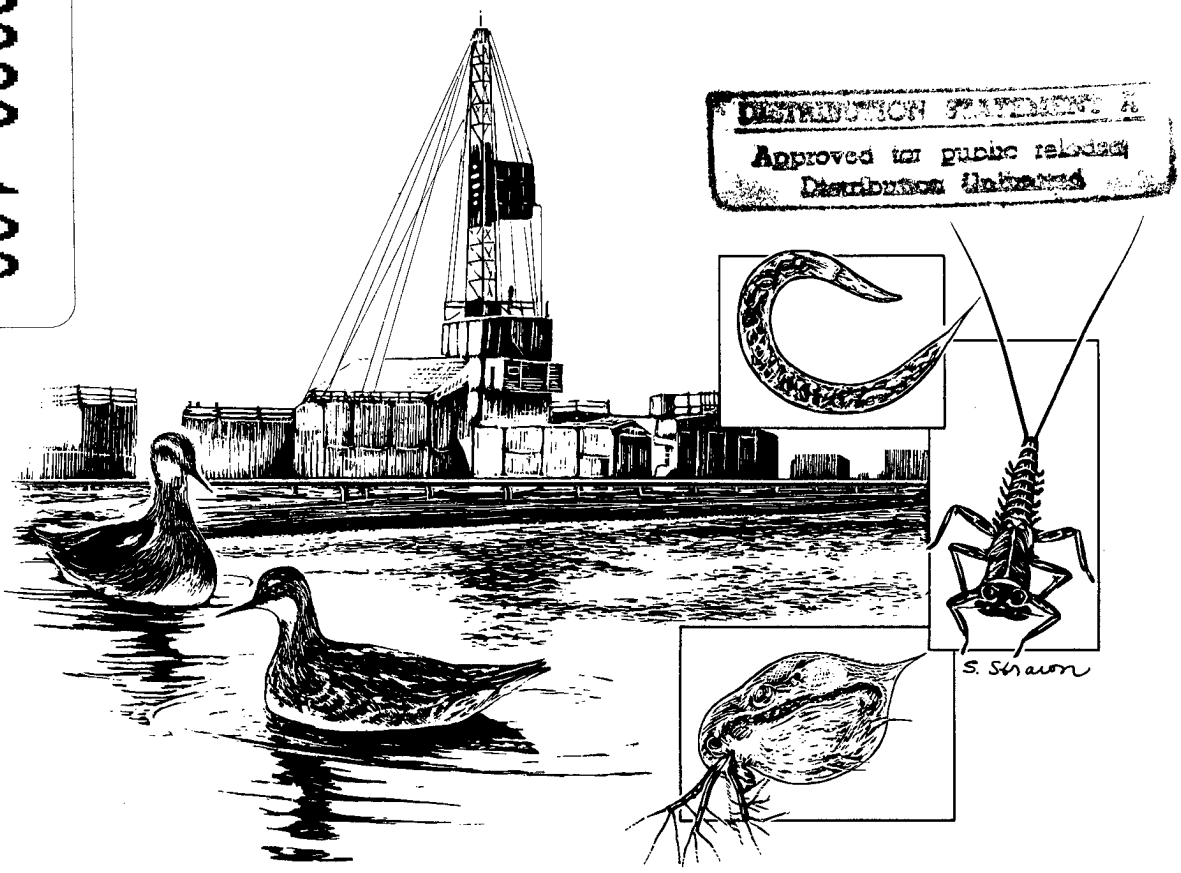
Effects of Prudhoe Bay Reserve Pit Fluids on Water Quality and Macroinvertebrates of Arctic Tundra Ponds in Alaska



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Effects of Prudhoe Bay Reserve Pit Fluids on Water Quality and Macroinvertebrates of Arctic Tundra Ponds in Alaska

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Preface

Drill mud wastes, together with other wastes from oil drilling operations, are typically stored in reserve pits, sometimes described simply as sumps. In locations where evaporation exceeds precipitation, these fluids usually remain contained in the reserve pit throughout the life of a production well and constitute only a small volume of liquid waste, depending on well depth. However, in areas such as Alaska's North Slope, with continuous permanently frozen ground (permafrost), evaporation rates are extremely low and snow drift fills the reserve pits annually. After snowmelt, little, if any, freeboard exists, making reserve pits especially prone to breaching, overtopping, and seepage.

As a result of the need for discharges, the State of Alaska has allowed, since 1983, the permitted discharge of reserve pit fluids to the tundra or to roads and pads, depending on the contents of the reserve pit fluids. This study was initiated to evaluate the impacts of intentionally and accidentally discharged reserve pit fluids on water quality and invertebrate populations in tundra ponds.

Our report is organized into five main sections: Introduction, Study Area, Methods and Materials, Results, and Discussion and Conclusions. Within the results section, subsections cover water quality, contaminant levels, and invertebrate richness and abundance. A final subsection concerns the relationship of water quality and contaminant variables to invertebrate richness and abundance patterns in the receiving environment.

The report summarizes results from our 1983 field study. Although the report should be useful in assessing impacts from reserve pit fluids under Arctic conditions and in evaluating possible management strategies, it was neither intended as an exhaustive study, nor can the results be wholly extrapolated to present-day oil field practices. Since 1983, state regulations concerning reserve pit fluid discharges have become increasingly stringent. Also, some industry practices have changed. For example, chrome lignosulfonate drill muds have been partly replaced by non-chrome lignosulfonates, and diesel oil has been largely replaced with less toxic mineral oil in drilling operations.

From 1985 to 1987, the Fish and Wildlife Service began additional studies on Prudhoe Bay reserve pit fluids to examine impacts to tundra pond water, sediment, and biota; to evaluate acute and chronic toxicity through bioassays; and to examine bio-uptake of metals and hydrocarbons by resident species—including invertebrates, sedges, fish, and birds. Reports on these investigations have not yet been prepared, but should also be consulted by the interested reader when they become available.

Summary

Macroinvertebrates from tundra ponds have been shown to be an important food of many waterfowl and shorebirds nesting in Arctic tundra wetlands. Birds in the Prudhoe Bay area of Alaska are among those that rely on such resources. We attempted to determine if water quality or the macroinvertebrate community of these ponds was being adversely effected by oil field operations. In particular, we examined the impacts of direct and indirect discharges of reserve pit fluids into tundra ponds. Reserve pit fluids, including drill muds and other wastes from well drilling operations diluted by snowmelt, constitute a large waste stream produced by the oil production industry.

In June 1983, preliminary inspections revealed visible oil sheens at 52% of all reserve pits inspected and discharges of reserve pit fluids from 61% of these pits. Many of these discharges were directly to tundra wetlands, and others were to gravel roads and pads. Heavy metal concentrations were high in fluids from all six of the pits sampled and hydrocarbon concentrations were high in fluids from three.

One month after preliminary observations, we took additional grab samples of water for water quality, metal, and hydrocarbon analyses and sweep net samples of invertebrates at the six drill sites, including samples from a reserve pit on the drill site, from a pond adjacent to the reserve pit, and from a more distant pond with connections to the adjacent pond. Similar samples were collected from three control ponds.

We used Friedman's method of randomized blocks to examine differences between drill site locations and reserve pit, adjacent pond and distant pond treatments. Differences between treatments were statistically significant ($P \leq 0.05$) for all water quality and biological measures, and far exceeded the differences between drill sites. Stepwise discriminant analyses of water quality, contaminant, and biological variables not significantly affected by location indicated that reserve pits, receiving ponds, distant ponds, and control ponds could be readily distinguished from each other on the basis of water quality and biological variables. However, location significantly affected most contaminant concentrations. Contaminants not affected by location (aluminum, arsenic, and aliphatic hydrocarbons) did not enable sufficient distinction between treatments. For the water quality characteristics, reserve pits and ponds were best separated by a primary discriminant function corresponding to a gradient in turbidity, and by a second discriminant function reflecting progressive increases in alkalinity from control ponds to distant ponds to receiving ponds. Among the biological variables, the total number of taxa was the biological measure first selected in the stepwise process; this variable alone was sufficient to distinguish among all treatments, accounting for about 89% of the variance between the treatment pits and ponds. Samples from all six reserve pits were devoid of invertebrates.

Comparisons of adjacent receiving ponds with control ponds by Kruskal-Wallis tests revealed the scope of effects of contaminants. Hardness, alkalinity, turbidity, chromium, barium, arsenic, and nickel were all elevated in receiving ponds ($P \leq 0.05$). Differences between distant ponds and control ponds were less pronounced, but alkalinity, chromium, and aliphatic hydrocarbons were higher, and the number of invertebrate taxa was lower in the distant ponds.

Results of simple linear regressions of chemical on biological data (pits excluded) were used to suggest water quality and contaminant variable indicative of adverse environmental impacts. Water quality characteristics that best predicted deteriorating biological conditions were alkalinity and hardness, and metals most indicative of biological change were arsenic and barium. In addition, chromium concentrations in reserve pits and ponds near drill sites may have exceeded chronic toxicity criteria for protection of aquatic life set by the U.S. Environmental Protection Agency (EPA), and high concentrations of chromium had obviously dispersed into distant ponds. Measurement of these variables should assist in more effectively screening reserve pit fluids before discharging to the tundra.

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Acknowledgments

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Effects of Prudhoe Bay Reserve Pit Fluids on Water Quality and Macroinvertebrates of Arctic Tundra Ponds in Alaska

Introduction

Prudhoe Bay, on the Beaufort Sea coast in Arctic Alaska, is the site of the largest oil field ever discovered in the United States or Canada (Fig. 1). The Prudhoe Bay area serves as the center for North Slope oil and gas exploration as well as a focal point for crude oil production. Associated with oil production activities is the possibility of environmental pollution. One source of contaminants is drilling fluids from reserve pits, also known as sumps.

Reserve pits associated with oil production on the North Slope are generally above-grade basins within gravel drilling pads. The pits are designed to hold drill muds, cuttings, and wastewaters from production drilling. They may also contain contaminated or uncontaminated snow, material from local oil spills, and other drilling wastes.

Reserve pit contents vary considerably, since more than 600 trade name materials, including thousands of components, are available for use (Dames and Moore 1978; Wright and Dudley 1982). Only a few components are typically used, however, in any particular oil field or individual well. The various components serve as weighting agents, viscosifiers, thinners, pH and ion controls, dispersants, corrosion inhibitors, lubricants, emulsifiers, foamers and defoamers, and flocculants. The geological formation being drilled also influences pit chemistry, as do the kinetics of the drill fluids, given the local pH, temperature, and other variables. Rapid chemical reactions that occur during drilling at high pressure and temperature are followed by slower changes in the pit, such as those resulting from decomposition by photochemical or other oxidation processes (National Research Council 1975; Karrick 1977), emulsification (Berridge et al. 1969), and microbial degradation (ZoBell 1973; Atlas 1975, 1981). In addition, the phase and location of different chemical species may vary depending on polymerization, sedimentation, freeze exclusion, flocculation, scavenging by and complexing with other compounds, resuspension by wind mixing, and entrainment in ice slurries or other substances.

National standards for permissible onshore discharges have not been developed, nor has a consensus on water quality for discharge of pit fluids been achieved by the states, due to the complexities of reserve pit chemistry, both within and between oil fields. Before 1983, pit fluids regularly entered nearby wetland habitats in the Prudhoe Bay area by seeping through reserve pit walls and bottoms, overtopping of pits, breaching (failure) of the berms, road dust control with the fluids, and deliberate discharge from the pits (dewatering) to adjacent ponds or wetlands. Beginning in 1983, the Alaska Department of Environmental Conservation (ADEC) began regulating discharges and granted a variance for disposal based on certain restrictions. Dewatering was prohibited if there was a visible oil sheen on the water surface in the pit or "if toxic substances or salt concentrations exceed those expected to cause damage to vegetation, fish and wildlife, or could affect public health." ADEC further stipulated that "in surface water receiving these discharges" State Water Quality Standards described in 18 ACC 70 not be violated. Subsequently, oil industry data on all discharges were requested. In June 1984, additional, more specific water quality standards for direct tundra discharge on the North Slope were promulgated in a General Permit, including a total settleable solids limit of 0.2 mL/L and a salinity limit of 3 ‰. In addition, ADEC required that pits not be discharged until one year after the last input of drilling effluent or other wastes.

During summer 1983, the Fish and Wildlife Service began a study of the effects of pit fluid discharges on water quality and the macroinvertebrate community of tundra ponds. Water quality variables included pH, conductivity, dissolved oxygen, hardness,

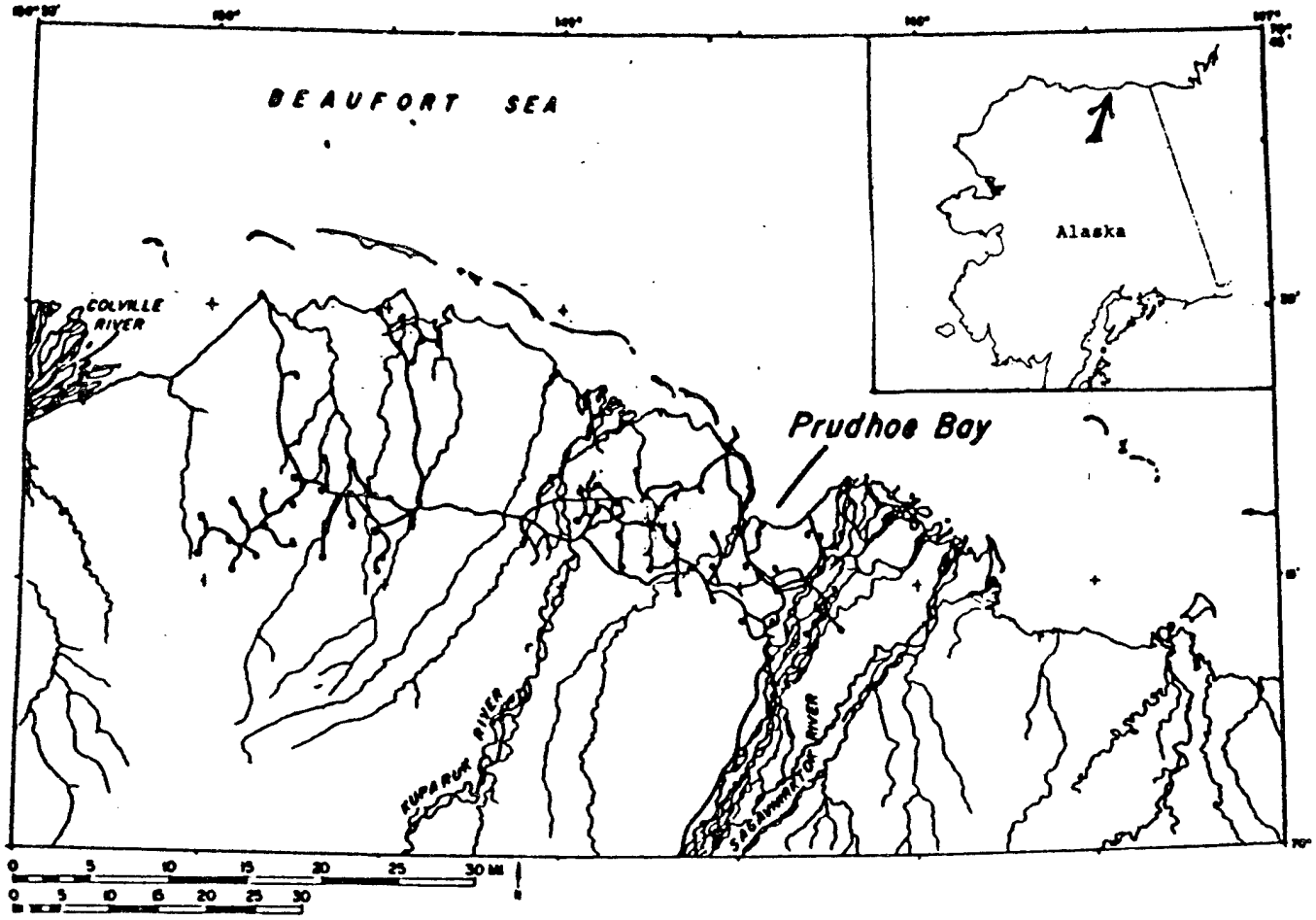


Fig. 1. *Prudhoe Bay, Alaska with general location denoted on insert.*

alkalinity, and turbidity. Water samples were also analyzed for arsenic and metal concentrations (aluminum, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, and zinc), as well as for hydrocarbon concentrations. Samples were collected from reserve pits, from ponds initially receiving reserve pit fluid discharges, and from more distant connected ponds. Three remote ponds (controls) were also examined. Aquatic macroinvertebrates were studied because they are resident species, sensitive to local environmental changes, and widely recognized as sensitive indicator organisms for a variety of environmental pollutants (Hilsenhoff 1977; Buikema and Cairns 1980; American Public Health Association [APHA] et al. 1981).

The North Slope serves as an important nesting, rearing, molting, and feeding ground for about 150 species of sea birds, shorebirds, waterfowl, raptors, and passerines (Norton et al. 1975). The study was undertaken because aquatic macroinvertebrates are an important food of many of the water birds in the Arctic (Pitelka 1959; Holmes 1966; Holmes and Pitelka 1968; Hilden and Vuolanto 1972; Bergman et al. 1977; Derksen et al. 1981; Connors 1983). The overall availability of invertebrates for food is an important consideration in rating suitability of wetland habitat for birds. Female ducks require a high protein diet during the nesting season (Moyle 1961; Bengston 1971) and their young have similar requirements for fast growth (Chura 1961; Collias and Collias 1963; Bartonek 1972). This high protein diet is generally supplied by aquatic macroinvertebrates in early summer before the emergence of adult insects.

We compared water quality and contaminant concentrations with aquatic invertebrate richness and abundance patterns to identify habitat changes. We assumed that any chronic detrimental effects on bird populations may not be observable for a number of years and that the degree of those effects will depend on decline of food organisms as well as on the bioaccumulation and biomagnification of contaminants, if these processes are occurring.

Study Area

The Prudhoe Bay area is characterized by flat open expanses of wet and moist tundra vegetation dominated by the sedge *Carex aquatilis* and the grass *Arctophila fulva* (Walker 1981). Shallow lakes and countless shallow ponds cover the area, which is entirely underlain with permafrost. Much of the area is flooded when the snow melts at breakup, usually in June. Surface sheet flow is supplemented by water transport through systems of interconnected polygon troughs that delineate the patterned ground. Drier areas are found mostly along shores of drained lake basins and on raised polygon rims, but even these areas may be flooded at breakup if the accumulation of snow is heavy or if melting is rapid.

The entire Prudhoe Bay area is traversed by a road system and pipelines and in the mid-1980s included more than 70 drill sites (= pads), as well as development centers and related facilities, all built on a layer of compacted gravel. Three north-south river systems are in the Prudhoe Bay area—the Sagavanirktok, Putuligayuk, and Kuparuk rivers.

We selected sample pond sites on the basis of (1) their proximity to a discharge site where direct or indirect discharges had occurred during June 1983, and (2) the availability of both an adjacent pond receiving the discharge and a more distant pond in the same drainage (with polygonal trough or surface connections to the adjacent pond).

Control and experimental ponds were selected on the basis of similarity in physical characteristics (including depth and temperature) and chemical characteristics (especially salinity).

We selected control ponds in areas with no previous development of drill pads within several miles. Figure 2 shows the location of sample and control sites. Three drill sites each were chosen in the Atlantic Richfield Company Alaska Inc. (ARCO; drill sites 6, 16, and 18) and in the Standard Alaska Production Company (SAPC; drill sites A, E, and N) portions of the Prudhoe oil field. All adjacent ponds were within 25 m of the gravel pad and were the direct receiving waters for the discharges from the reserve pits in June. Three of these ponds (at drill sites 16, 18, and A) were in contact with the gravel pad; two (at sites 18 and A) had additional gravel contact and were impounded on at least one additional side. A fourth receiving pond (site E) was not in contact with the pad, but had an extensive gravel bottom, as a result of gravel-contaminated snow being bulldozed into the pond. Discharges resulted from overtopping of a dike at drill site 6 and truck spraying of the pad at site 18, rather than from the direct pumping of effluent into the tundra, as at other sites.

The distant ponds were 35 to 115 m from the adjacent ponds (average distance, 93 m). They were connected to the adjacent ponds by polygonal troughs. At the time of discharge, surface sheet flow also probably occurred between adjacent and distant ponds. Two of the control ponds were within the designated area off Oliktok Road shown in Fig. 2. The remaining control site was north of drill site E.

Hereinafter we designate sample sites by the drill sites named above, and by treatment, where reserve pits are treatment 4; adjacent receiving ponds, treatment 3; distant ponds, treatment 2; and control ponds, treatment 1. Treatment is used strictly in a statistical sense to distinguish sample groups that are compared with each other, rather than in a biological sense to refer to a prescribed experimental treatment.

Materials and Methods

Preliminary sampling began on 6 June 1983. We visited accessible production pads in

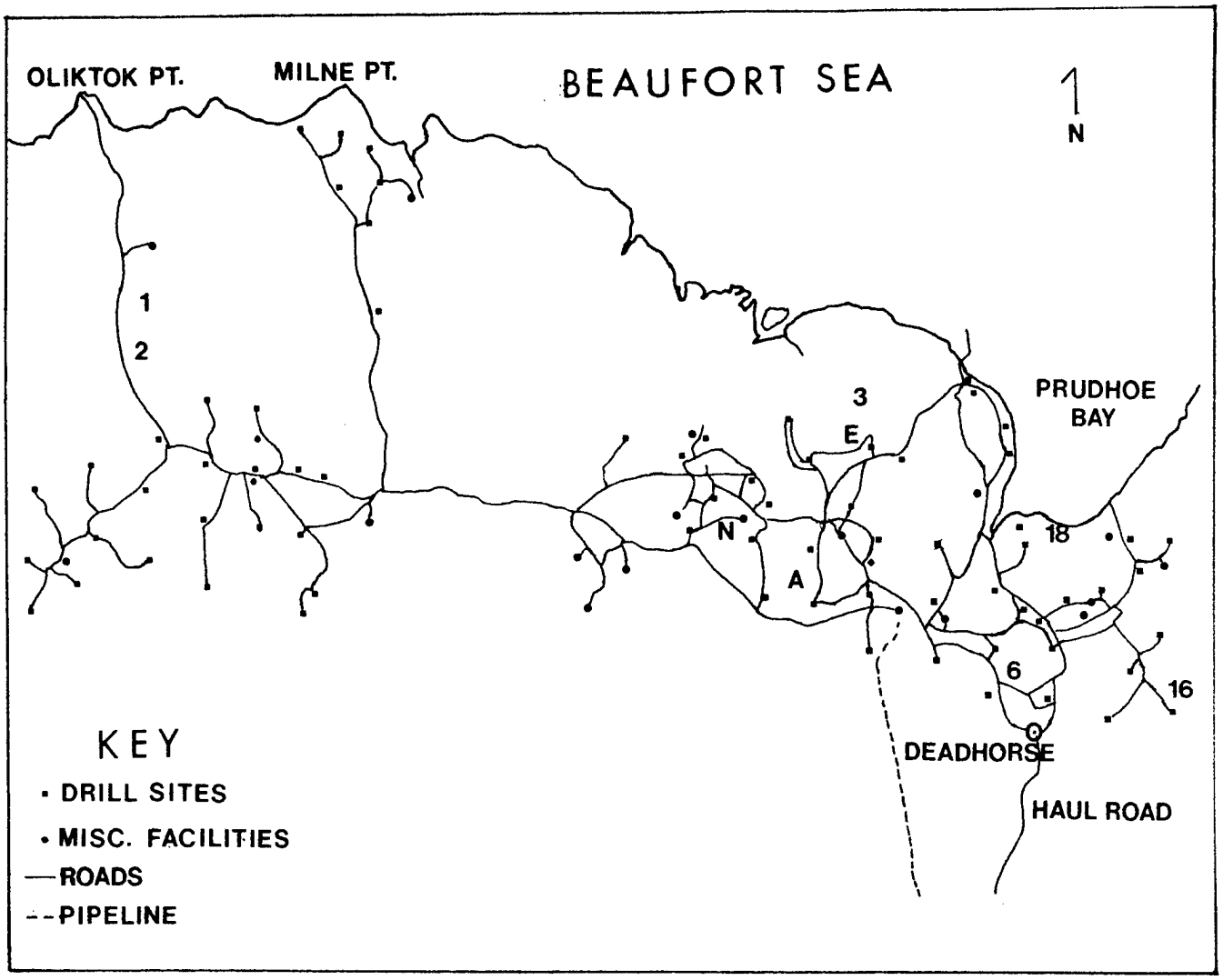


Fig. 2 *Map of Prudhoe Bay region showing drill pads, roads and sampling locations. ARCO drill sites 6, 16, and 18, SAPC drill sites (= pages) A, E, and N, and control ponds 1, 2, and 3 were sampled.*

the Prudhoe Bay oil field to determine which reserve pits were being dewatered and to quantify the number of pits with visible oil sheens and piles of drill cuttings. Grab samples were taken of discharge water for analysis of heavy metals and for hydrocarbon analysis. These samples, and samples taken later in the summer, are listed in Appendix Table A-1. Temperature, pH, and conductivity were also measured in the field during the June sampling. A HACH Mini-Digital pH Meter calibrated with buffer solutions was used to determine pH, and the remaining variables were measured with a YSI Model 33 SCT Meter and probe. The accuracy of conductivity measurements was checked with a conductivity standard.

We followed methods recommended by APHA et al. (1981) in collecting water samples: both the preliminary (June) samples and later samples for heavy metal analyses were collected in laboratory-cleaned, 1-L polyethylene bottles and preserved with analytical-grade concentrated nitric acid; hydrocarbon samples were collected in 1-L, laboratory-cleaned glass bottles and preserved with analytical-grade sulphuric acid. Samples were stored for several days at 0-4°C in coolers furnished with blue ice and then refrigerated. Samples were subsequently shipped in coolers with blue ice to the U.S. Fish and Wildlife Service, Patuxent National Wildlife Research Center (Laurel, Maryland) for analysis.

Six sample sites chosen in June were sampled again beginning 27 July 1983, about 1 month after the last discharges from the pits onto the tundra. Samples were taken to be analyzed for heavy metals and hydrocarbons from the previous point of discharge in each adjacent pond. Temperature, pH, and conductivity were measured as before, in addition to dissolved oxygen, hardness, alkalinity, turbidity, water depth, and sediment depth. A HACH AL-36B Titration Kit was used to determine dissolved oxygen, hardness, and alkalinity. To check the strength of the phenylarsine oxide titrant for the dissolved oxygen test, we used an iodide-iodate standard solution equivalent to 10 mg/L dissolved oxygen. An HF Instruments Model DRT-15 nephelometric turbidimeter was used to measure turbidity, after calibration with secondary standards. Water and sediment depths were measured by probing a wooden dowel first to the water/sediment interface and then to the bottom of the soft sediment layer. Characteristics measured at each site are reported in Appendix Table B-1.

Identical samples for chemical analysis were collected at the reserve pit, at adjacent ponds that had earlier received the pit discharges, at the distant ponds within the same drainage, and at the control ponds.

Invertebrate samples were collected with a sweep net (30.5 x 7.6 cm) having 7.9 meshes/cm, according to procedures used by Weller (1972), Howard (1974), and Abraham (1975). About 1 m^2 was sampled for macroinvertebrates (Fig. 3). Free-swimming planktonic and epibenthic invertebrates were all sampled by this method. Two complete sweeps were made from one location within the sample pond and captured organisms from each sweep were transferred to separate white enamel sorting trays for examination. If the samples appeared to be roughly similar, they were preserved together as one sample in 70% ethyl alcohol. If the samples did not appear to be similar, we discarded both to avoid bias as a result of making a sweep through an occasional swarm of *Daphnia* or copepods. Since this process was repeated at three locations, the three combined replicates from each pond represent six total sweeps for the site. This sampling was repeated at each of the six pits, six adjacent ponds, and six distant ponds, and at the three control ponds. Although the method was only semiquantitative, it enabled comparisons between treatments without introducing an even greater bias that can be incurred when the distribution of highly clustered populations is not specifically evaluated before quantitative sampling (Pielou 1978).

Except for nematodes, preserved invertebrates were sorted and identified to order, suborder, or family. The various taxa used to determine taxonomic richness (i.e., total number of taxa) and taxonomic diversity (Shannon-Wiener H' diversity), together with code designations for taxa, are shown in Appendix Table C-1.

The following methods were used in the analysis of metals samples: hydride generation atomic absorption (arsenic and selenium); cold vapor atomic absorption (mercury); and flame atomic absorption (aluminum, lead, copper, zinc, nickel, cadmium, barium, and chromium). Instrumentation included a Coleman Model 50 Mercury Analyser and Perkin-Elmer Models 403, 460, and 703 Atomic Absorption Spectrophotometers. Determinations were made by comparison with aqueous standards.

Hydrocarbons were determined with a Hewlett-Packard Model 5711 Gas Chromatograph equipped with an FID Detector Model 18740 and a glass capillary inlet system. The Model 3352B Lab Data System, set up with chromatographic software, was used to integrate the peak areas. Metals and hydrocarbon data for the June sampling are presented in Appendix D in Tables D-1 and D-2, respectively. Appendixes E and F present corresponding July-August data.

Data were analyzed with an IBM PC computer linked to a DEC VAX 8800 mainframe computer at the University of Alaska, Fairbanks. SPSSX software was used for all analyses. Since all treatment data except those for controls were effectively taken in blocks (by drill site), a Friedman two-way analysis of variance for randomized blocks (Sokol and Rohlf 1981) was first used to examine the effect of treatment and location. Using this method, we ranked variates within each block for each treatment (reserve pit, receiving pond, and distant pond). Because block effects were few, we considered treatments at different drill sites as replicates for most remaining analyses.

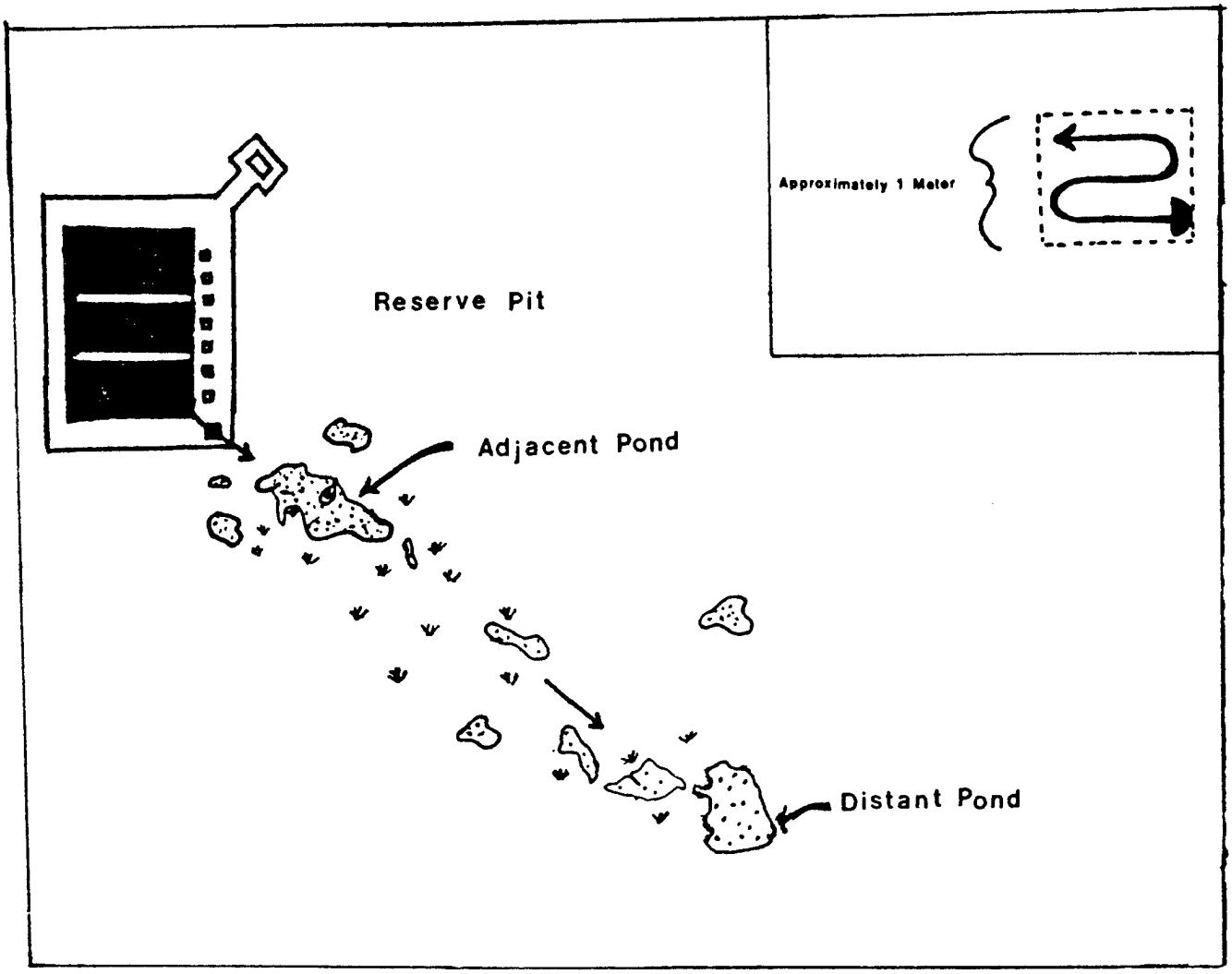


Fig. 3 *Schematic of generalized sampling area and sweep net sampling technique (insert).*

We used discriminant analysis to comprehensively evaluate measurable differences between all treatments, including control ponds. Distinguishing characteristics of water quality, contaminant levels, and biological variables were examined in three separate, stepwise discriminant analyses. This examination resulted in the discrimination of treatments by maximizing the among-treatment to within-treatment sums of squared deviations for multiple variables within each set (Cooley and Lohnes 1971). For these analyses, the F ratio-to-enter was set at 4 to exclude less important variables. Scatterplots and classification tables are presented depicting the success of the discriminant functions in separating and classifying each case in the results section. Additional discriminant analysis results are included in Appendix G.

We also made pairwise comparisons of receiving ponds, distant ponds, and control ponds, using the Kruskal-Wallis H test. Water quality and contaminant variables determined to be important in distinguishing between treatments by these analyses were regressed on selected biological variables to determine the variables correlated with adverse biological impacts.

Results

Water Quality

Water quality measurements made in late July and early August 1983, are shown in Appendix Table B-1. Comparison of the water

quality of the three control ponds with the six distant ponds, six adjacent ponds, and six reserve pits revealed noticeable trends in water quality change from the control ponds toward the reserve pits (Table 1). Turbidity and pH both tended to increase with treatment (control, far pond, adjacent pond, and reserve pit). Conductivity also tended to increase toward reserve pits; however, one of the three control ponds, located nearest to the coast, was naturally high in conductivity. Dissolved oxygen diminished from control to pit sites, but with the exception of one receiving pond, remained above 50% saturation (APHA et al. 1981). Hardness and alkalinity were higher in adjacent ponds than in reserve pits. High concentrations of metals, anionic detergents, or greater concentrations of suspended or colloidal organic matter may have interfered with hardness measurements in pits (APHA et al. 1981).

In Friedman tests, the variation between each of the above variables and treatment was significantly greater ($P \leq .05$) than the variation with location (Table 1). Consequently, we combined the different locations in the remaining analyses.

Discriminant analysis of water quality characteristics by treatment revealed a clear separation of reserve pits and pond types (Fig. 4). Although significant differences were found between treatments for all water quality variables, two discriminant functions accounted for 100% of the variance (64% and 36%). Reserve pit and pond treatments were best separated by Discriminant Function 1, corresponding to a gradient of increased turbidity and significant differences ($F_{3,17} = 15.18$, $P \leq .001$) between reserve pits and pond treatments. Receiving ponds, distant ponds, and control ponds were best separated by alkalinity ($F_{3,17} = 11.36$, $P \leq .001$). Alkalinity differences were generally sufficient to separate receiving ponds and distant ponds from control ponds after the variance explained by turbidity was removed. The highest degree of variation in discriminant function values occurred in reserve pits, while the lowest variation is seen in control ponds. Using Discriminant Functions 1 and 2 (turbidity and alkalinity), we misclassified only 3 of 21 waterbodies (two receiving ponds and one distant pond) as to treatment (Table 2).

Comparisons of receiving ponds and distant ponds with unmatched control ponds and with each other, by the Kruskal-Wallis H test, illustrate specific differences between pond treatments (Table 2). Alkalinity, hardness, and turbidity were all significantly higher ($P \leq .05$) in receiving ponds than in controls, whereas pH, conductivity, dissolved oxygen, water temperature, water depth, and sediment depth did not differ significantly between the two treatments. Alkalinity was the only water quality variable that was significantly different (higher) in distant ponds than in the controls.

Arsenic, Heavy Metals and Hydrocarbons

The analysis of preliminary samples of pit fluid from the June 1983 survey revealed high concentrations of arsenic and metals, including lead, copper, zinc, nickel, barium, chromium, and aluminum, in most of the pit water samples (Appendix Table D-1). The preliminary inspection of pads in June 1983 disclosed visible oil sheens at 17 of 33 pits (Appendix Table D-2). Likewise, high hydrocarbon concentrations were found in some of the pits sampled in June, particularly at drill sites A and 6 (sample sites 4 and 1, respectively, Appendix Table F-1). The composition of the hydrocarbon sample at drill site A resembled that of fresh Prudhoe Bay crude oil (Mackay et al. 1980).

Results of the laboratory analysis of arsenic and 10 heavy metals and selected aliphatic and aromatic hydrocarbons in July-August sampling of pits and ponds are given in Appendix Tables E-1 and F-2. In general, metal contaminant levels in pits tended to decrease from June to late July or early August. This was especially true when the metal concentration in June was high. However, decreases in concentrations of chromium and lead did not appear to be as great as those of copper, nickel, and zinc. Concentration levels of many metals may have reached an equilibrium point as a result of sorption onto the suspended material maintained in the water column after an initial post-breakup settling of heavier sediment fractions. However, the pattern of change was not entirely consistent, reflecting

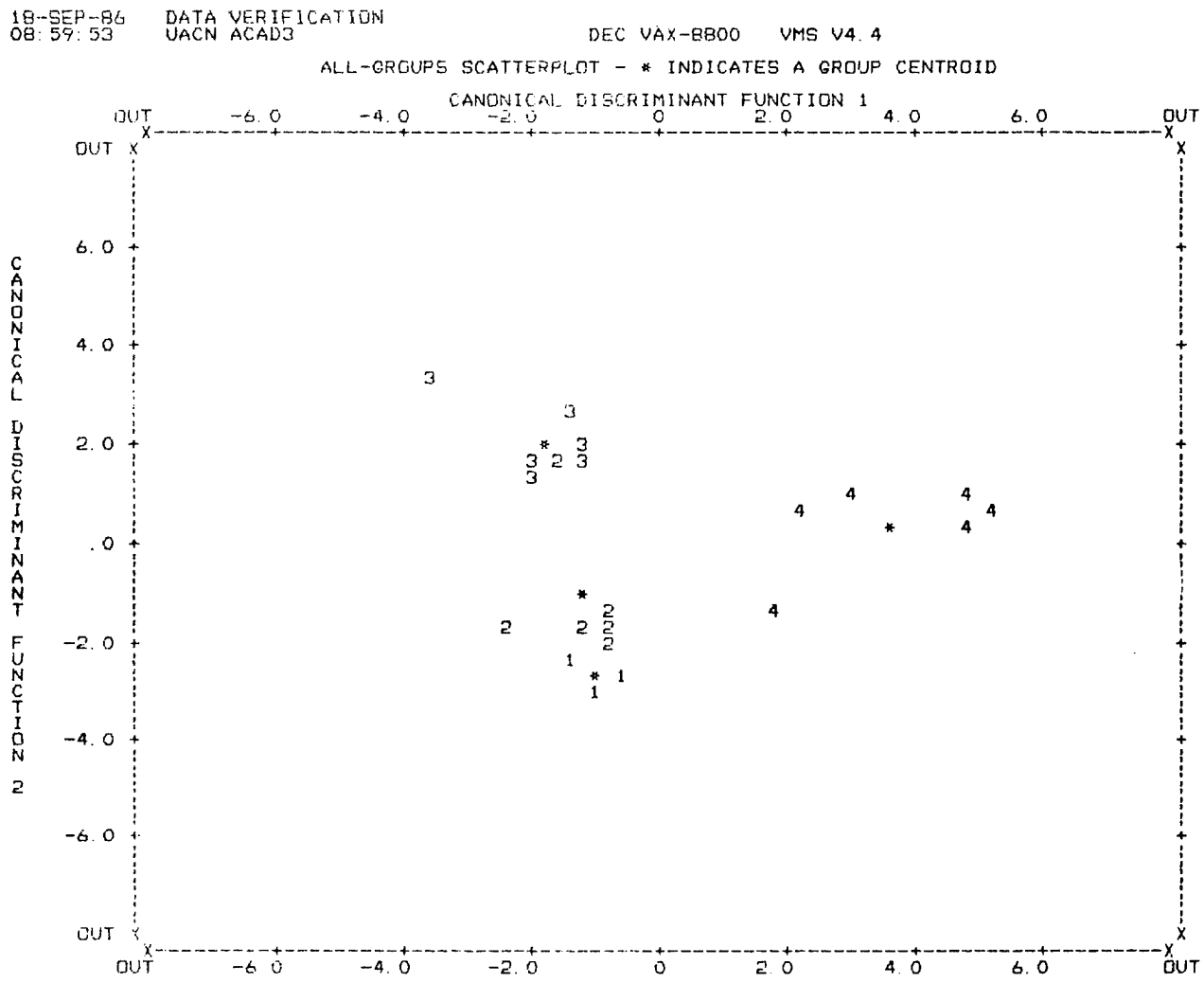


Fig. 4 *Scatterplot showing the maximal separation of reserve pits (4), receiving ponds (3), distant ponds (2), and control ponds (1) based on dicriminant analysis of water quality characteristics.*

possible heterogeneity in the concentration of metals within the pits for which our composite grab sampling was inadequate. Lead in one of the six pits and barium in four pits increased markedly in July-August.

There was also a general tendency for hydrocarbon concentrations to be lower at the second sampling than at the first. In pit A, concentrations were extremely high in June but almost negligible in late July (Appendix Table F-2, sample 16). On the other hand, some pits showed slight increases. Besides within-pit heterogeneity, weathering, and volatilization, several factors that may have confounded comparisons of metal and hydrocarbon concentrations in June and July included rope or skimming operations conducted by oil companies to clean up surface oil in pits, and possible additions to reserve pits between the sampling times. Specific wind-mixing events may also have influenced concentration levels by resuspending contaminants from sediments and by windrowing hydrocarbons at various pit edges.

In the midsummer (July-August) sampling, aluminum, barium, chromium, zinc and arsenic showed a pattern of increase from control ponds to the pits (Table 4). However, treatment differences at drill sites were only

significant ($P \leq .05$) for aluminum, arsenic, and aliphatic hydrocarbons (Table 4). Discriminant analysis of these variables failed to clearly differentiate between treatments. Aliphatic hydrocarbon concentrations did separate reserve pits from ponds at four of six sites but did not adequately separate receiving ponds from distant ponds and control ponds (Fig. 5).

Comparisons of specific pond treatments (reserve pits excluded) by Kruskal-Wallis tests (Table 5) were more informative. Concentrations of cadmium, chromium, barium, arsenic, and nickel were significantly higher in receiving ponds than in control ponds, whereas levels of chromium were significantly higher in distant ponds than in control ponds (Table 5). Thus, chromium was the most mobile metal in terms of dispersion into distant ponds.

Invertebrate Richness and Abundance

Lists of macroinvertebrate taxa and numbers found in each sample are presented in Appendix Tables C-1 and C-2. The six reserve pits were devoid of invertebrate taxa; receiving ponds each contained 2 to 5 taxa, distant ponds 4 to 10, and control ponds 10 to 13. Chironomids predominated in all ponds adjacent to reserve pits; other taxa were extremely rare. In contrast, the dominant taxa in various distant ponds included chironomids, calanoid copepods, daphnids, nemourids, and physids. In half the distant ponds, two of the above taxa codominated. Taxa in control ponds strongly resembled those in distant ponds. However, two to three taxa tended to be codominant and proportionally fewer taxa were rare. The most common taxa included chironomids, calanoid copepods, daphnids, nemourids, and (in one control) baetids. Two new taxa were found in control ponds, hydrids and pleids; however, these taxa were rare.

Treatments are compared in Table 6. The richness decreased sharply from treatments 1 to 4. Differences between treatments (versus between drill sites) were highly significant ($\chi^2 = 11.08$, $df = 2$, $P \leq .004$) (Table 6).

A similar trend in taxonomic richness was observed when H', the Shannon-Wiener Index for taxonomic diversity, was used instead of numerical comparisons of taxa. Likewise, the total abundance of organisms (log transformed) appeared to be strongly related to treatment. This pattern is largely attributable to the abundance pattern of crustaceans, primarily daphnids. Dipterans (especially chironomids) tended to increase in abundance in ponds adjacent to reserve pits, whereas nondipteran insects showed a corresponding decrease.

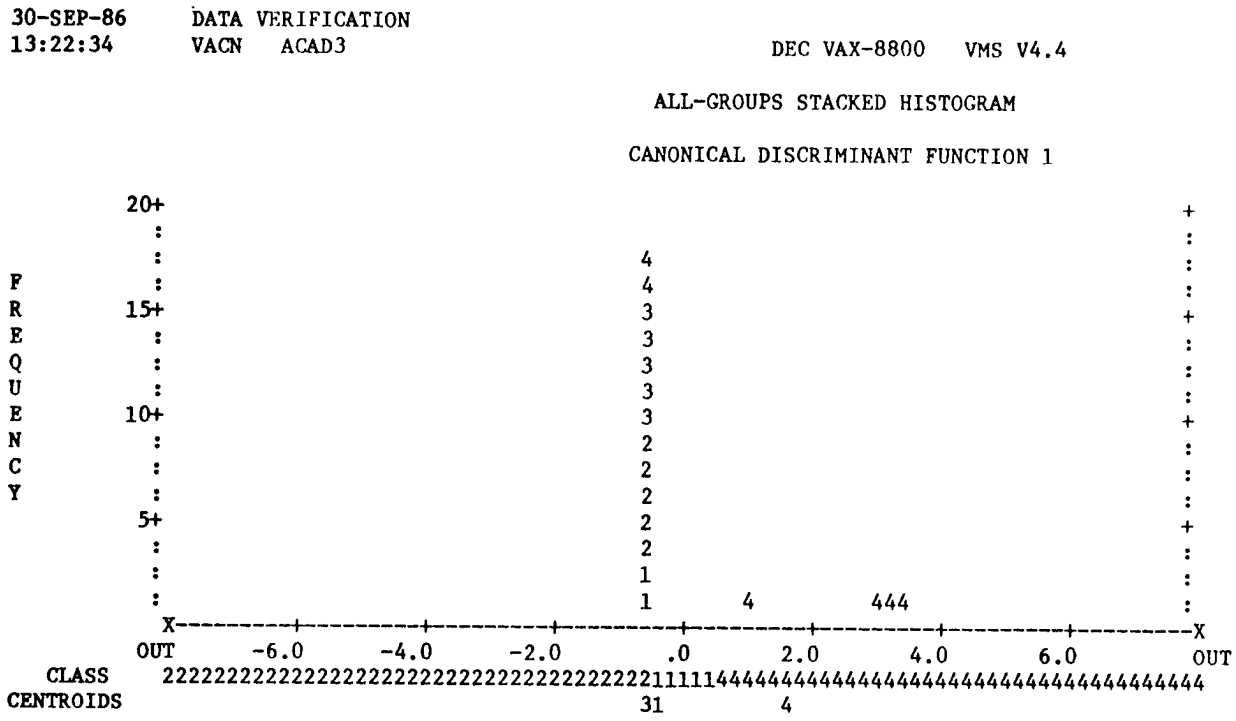
Since significant differences in all biological measures were reflections of treatment rather than drill site, as indicated by Friedman tests, locations were combined and a discriminant analysis was applied to all biological variables. Although all biological measures differed significantly between treatments, the first variable component of Discriminant Function 1, the total number of taxa ($F_{3,17} = 53.87$, $P \leq .001$), sufficiently discriminated between all treatments (see Appendix G), accounting for 89% of the variance; a minor contribution (11%) was also made by Discriminant Function 2, represented by the number of dipterans (Fig. 6). Three of 21 waterbodies (two distant ponds and one receiving pond) were misclassified by use of these functions (Table 7).

Pairwise statistical comparisons between receiving ponds, distant ponds, and control ponds through Kruskal-Wallis tests also showed that control ponds had a significantly greater number of invertebrate taxa, a higher diversity of these taxa, and more organisms, including more crustaceans and more insects, except dipterans (Table 8) than did adjacent ponds. Only one of these measures—total taxa—distinguished distant ponds from control ponds.

Correlations Between Invertebrate Populations and Water Quality and Contaminants

Water quality and contaminant variables selected as important in the discriminant and Kruskal-Wallis tests were regressed on biological variables to evaluate possible interrelations. Also, the data were plotted to evaluate possible curvilinear relationships that would be obscured by simple linear

Fig. 5 *Histogram showing the maximal separation of reserve pits (4), receiving ponds (3), distant ponds (2), and control ponds (1) based on discriminant analysis of biological variables.*



regressions. Reserve pit samples were excluded from this analysis, since they contained no invertebrates. None of the plots indicated an obvious bell-shaped response curve or other third-degree polynomial function. However, some of the relationships appeared to be best described by exponential functions. In these plots, the linear function was also indicative of the importance of the variable, hence no further analysis is presented. Table 9 shows the results of simple linear regression analysis.

The variable "total taxa" was negatively correlated with hardness, alkalinity, barium, and arsenic—as was Shannon-Wiener (H') taxon diversity. The total abundance of organisms (log-transformed) was not statistically correlated with any single variable. Nor were there linear correlations between the abundance of dipterans or crustaceans and any single water quality or contaminant variable. However, insects other than flies were positively associated ($P \leq .05$) with waters with high conductivity and high lead concentration.

Discussion and Conclusions

Our results indicated a clear difference in water quality and in biological measures between reserve pits, receiving ponds, distant ponds, and control ponds in the Prudhoe Bay area. These differences appeared to be related to fluid discharges from reserve pits into tundra ponds. Turbidity, alkalinity, pH, and conductivity tended to increase and dissolved oxygen to decline from remote (control) ponds to reserve pits. In discriminant analysis, turbidity most clearly separated reserve pits from all other treatments; other water quality variables distinguished the other three pond treatments.

Similar gradients of increase from control ponds to reserve pits were also demonstrated for arsenic and certain metals (barium, chromium, and zinc) and for hydrocarbons. However, none of these variables distinguished all the pond treatments from each other. Contamination of both receiving ponds and distant ponds sometimes caused sufficient overlap in concentrations (e.g., as in chromium) to preclude separation of these treatments. Certain metals were only detected sporadically in a given pond treatment (e.g., lead), or variance was exceedingly high within treatments (e.g., copper). Specific comparisons between receiving ponds and control ponds, however, revealed the scope of contamination more clearly. Receiving ponds had significantly greater concentrations of chromium, arsenic, cadmium, nickel, and barium than did control ponds, whereas chromium concentration was significantly higher in the distant ponds than in the controls.

Although the overall taxonomic richness, diversity, and abundance were low, reserve pits, receiving ponds, and distant ponds differed significantly in these biological measures. Except for dipteran abundance, values of all measures tended to decrease from control ponds to receiving ponds. In the discriminant analysis, the total number of taxa was sufficient to distinguish treatment groups: reserve pits supported no invertebrates, and progressively more taxa were sampled from receiving, distant, and control ponds. One of us (E. Snyder-Conn), in 1985 and 1986, found a few Prudhoe Bay reserve pits (2-3 in approximately 50) that supported copepods or daphnids. Thus, not all—but nearly all—reserve pits can be portrayed as devoid of invertebrates.

Unlike other invertebrate groups, dipterans—particularly chironomids—tended to increase in abundance in ponds that received direct discharges of reserve pit fluids. A shift in invertebrate community composition thus appeared to result in ponds receiving reserve pit discharges. However, crustaceans—the numerically most important zooplankton group—appeared to diminish in both abundance and diversity in ponds adjacent to reserve pits. Such shifts toward increasing numbers of dipterans and concomitantly diminished numbers of other macroinvertebrate taxa and lowered species diversity have also been documented in temperate streams affected by oily effluents (Wilhm and Dorris 1968; Wilhm 1970; Woodward and Riley 1983).

The contaminants of the greatest immediate concern in receiving ponds and ponds connected to them are chromium, arsenic, and barium. Evidence that chromium disperses

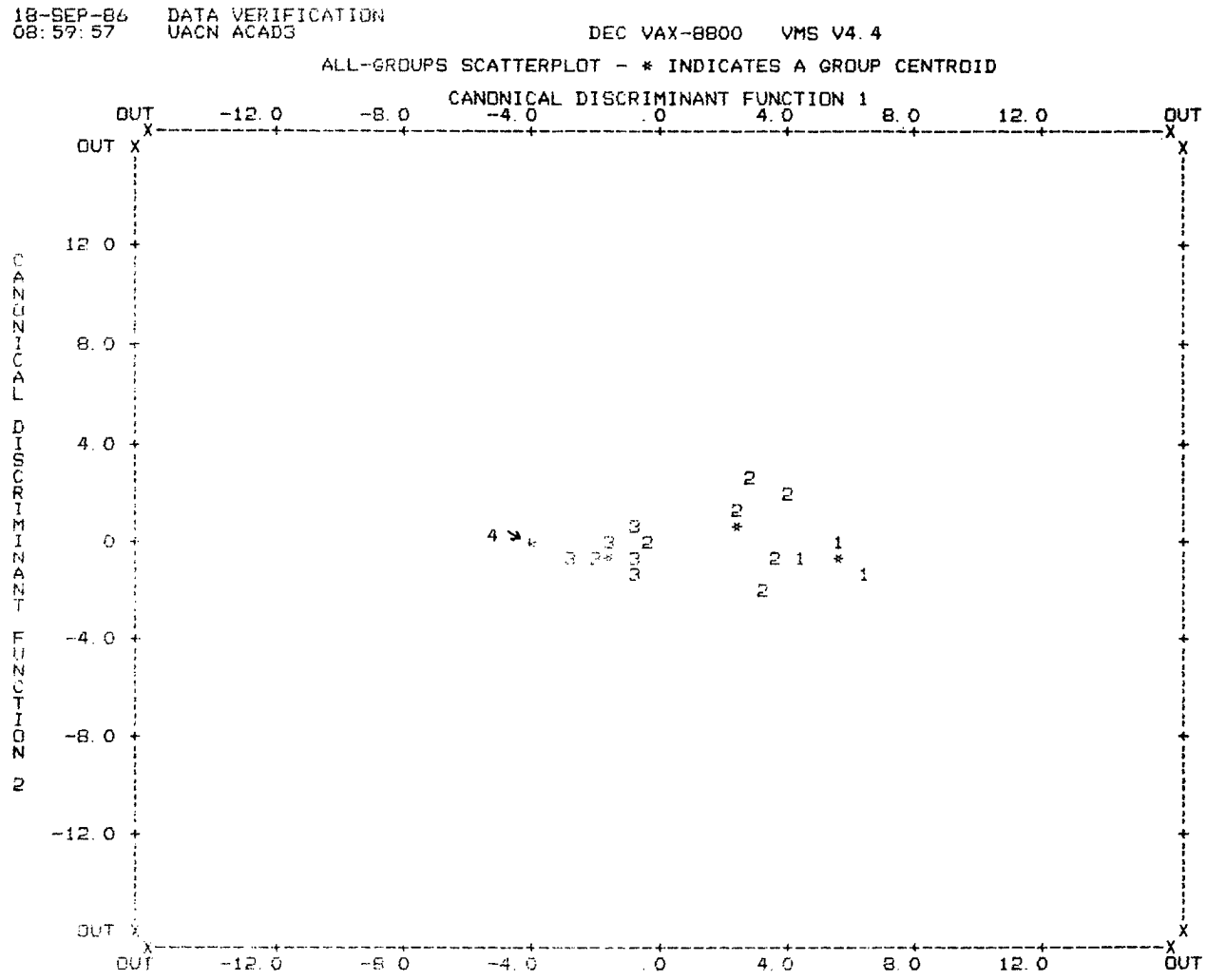


Fig. 6 *Scatterplot showing the maximal separation of reserve pits (4), receiving ponds (3), distant ponds (2), and control ponds (1) based on discriminant analysis of biological variables.*

from receiving to distant ponds is particularly compelling (Fig. 5), since no chromium was detected in any of the control ponds. The mean concentration of chromium was 0.084 mg/L (range = 0.018 to 0.210 mg/L) in receiving ponds and 0.070 mg/L (range = 0 to 0.170 mg/L) in distant ponds. The U.S. Environmental Protection Agency (EPA) National Criteria for Protection of Aquatic Life are 0.011 mg/L for hexavalent chromium and 0.21-0.37 mg/L for trivalent chromium at hardnesses of 100-200 mg/L during chronic exposures (EPA 1986). The form of the chromium in our study is unknown, since only total chromium was measured. EPA (1984) found that a significant portion of the chromium present in two of six drill muds was in the hexavalent form and that about half of this form remained in the liquid versus solid test phase. Hexavalent chromium is soluble and stable in most well-oxygenated natural waters; its toxicity effects are little influenced by hardness (EPA 1980*a*). On the other hand, trivalent chromium is rapidly hydrolyzed,

precipitated, and sorbed in hard waters. Thus, some of the chromium sampled may have been hexavalent.

Arsenic, although apparently much less readily dispersed (Fig. 5), still appears to be increased in ponds adjacent to pits and in connected distant ponds. More important, arsenic showed a strong negative correlation with taxonomic richness and H' diversity in tundra ponds, even though it generally occurred at much lower levels in ponds than EPA's established chronic toxicity criterion for protection of freshwater life. The level for trivalent arsenic was established as 0.19 mg/L (EPA 1986). The results may reflect local sensitivity or a covariance relation. Arsenic concentrations were strongly correlated with levels of barium ($r = 0.81$), alkalinity ($r = 0.89$), turbidity ($r = 0.62$), and hardness ($r = 0.72$). Like chromium, arsenic poses a concern because its toxic effects—especially its chronic toxic effects such as slowed reproduction, reduced growth, and enzyme inhibition. Biomagnification in the food web is of lesser concern (EPA 1980*b*).

Barium is another metal of concern, since there is evidence for its dispersion from adjacent ponds to distant ponds (Fig. 5), and since barium levels were strongly correlated with turbidity, alkalinity, and hardness in our ponds. The probable effects of barium include interference with filter feeding and respiration and increased turbidity, producing a possible decrease in the primary productivity of affected waters. Another important detrimental physical change may occur in the sediment, since the grain size of barite is fine and may result in the physical smothering of benthic organisms. Indeed, most secondary production in tundra ponds is from chironomid larvae, which are primarily benthic (Hobbie 1973; Butler et al. 1980). Hence, indirect toxic effects may be expected, although direct toxicity from barium at the concentrations reported here is unlikely (National Research Council 1983). Indirect effects may explain why barium concentrations were negatively correlated with the total number of taxa and with H' diversity of the ponds.

By the very nature of regression analysis, the correlations demonstrated in this study cannot definitively establish cause and effect between chemical and biological variables. Water quality variables or contaminants not examined in this study may also play a role in determining decreases in diversity or abundance. Our analyses should not be used to establish the relative importance of specific contaminants or water quality variables, since they were measured at only one point in time, whereas the biological community obviously reflects long-term as well as short-term conditions. In particular, the relative importance of hydrocarbons could well have been underestimated, since some of these compounds could have volatilized or been biologically degraded during the period between discharge and sampling.

Another limitation of the analysis is that it cannot be used to identify the source of the contaminants. Although recent discharge of reserve pit fluids was the most likely source of deteriorating water quality of ponds in the vicinity of the reserve pits, other possible sources exist: earlier events of overtopping or breaching of reserve pit walls and subsequent surface flooding; persistent seepage from pits; unreported oil or wastewater spills during drilling operations; and contamination from fill material in gravel spilled and bulldozed from the drill site to receiving ponds. We reviewed field notes and photographs of the adjacent ponds to estimate the extent of gravel at each site. We found no significant positive or negative correlations between estimates of surface area covered by gravel and any water quality, contaminant, or biological variable.

Therefore, reserve pit fluid contamination is considered the most likely source of most contaminants and water quality changes. Numerous studies have established that barium and chromium are excellent tracers for the fate of drill fluids (Gettlesen and Laird 1980; Chow and Snyder 1980; Kalil 1980; Liss et al. 1980). Similarly, increased salinity, total dissolved solids, hardness, and alkalinity have been recorded at a stream site receiving oily field discharge water (Woodward and Riley 1983).

Despite the shortcomings of discriminant, regression, and other analyses in indicating cause and effect, these analyses are widely recognized as valuable in helping to forecast effects. Thus, waters with high turbidity, alkalinity, chromium, arsenic, or barium that are discharged or seep into tundra ponds will probably result in decreased taxonomic

diversity and abundance in the receiving pond and more limited detrimental effects in other ponds with connections to the receiving ponds. Therefore, reserve pit effluent should meet standards established for each of these variables to reduce the likelihood of biological impacts. Also, the possible cumulative effect of multiple discharges at the same location should be considered, since arsenic, salts, and metals could be expected to accumulate in lentic systems over time.

Although the variables described above would be highly useful in predischarge monitoring, we remain concerned that predischarge monitoring of metals and hydrocarbons will result in the reduction of direct tundra discharges, but cause an increase in disposal of reserve pit fluids by way of road treatment in the name of dust control. In 1983 and 1984, such road watering involved contaminated pit fluids that failed direct-discharge tests, and may have resulted in contaminants being spread over an even wider area of tundra wetlands.

As long as reserve pits fill in the spring, some type of draining will be necessary. Ideally, industry and agency efforts should concentrate on achieving reinjection of reserve pit fluids into the permafrost strata of wells. Alternatively, some measure of protection could be achieved by lessening the need for dewatering. Progress toward this goal could be made in several ways: by enacting conservation measures applicable to drilling fluids; by developing and implementing technologies that reduce mud fluid volumes; by designing pits to limit snow-drift accumulation; by building deeper pits that cover less total area; by manually disposing of snow contaminated with crude and other pollutants, before general snow removal from the pad; and by careful planning of the use of each pit. Coupled with predischarge monitoring for contaminants or the institution of pollution control technologies, such a program should greatly improve the protection afforded wildlife and wildlife habitat on the North Slope.

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Table 1. *Water quality variables versus treatment. Treatments include control ponds (1), distant ponds (2), receiving ponds (3), and reserve pits (4). Chi-square* (χ^2)and *probability (P) levels are from a Friedman two-way analysis of variance within and between drill sites. Control ponds were excluded from this analysis.*

Variable	*Treatment means*				χ^2	P
	1	2	3	4		
pH	7.61	7.93	7.89	8.36	7.00	.03*
Conductivity (μmhos/cm)	4000	2608	5358	5992	7.58	.02*
Dissolved oxygen (mg/L)	10.0	9.7	8.7	6.8	6.08	.05*
Hardness (mg/L)	185	297	673	240	6.33	.04*
Alkalinity (mg/L)	52	144	433	332	8.33	.02*
Turbidity (NTU)	0.6	1.2	9.4	40.8	12.00	.003**
Water depth (cm)	15.4	15.5	15.2	—	—	—
Sediment depth (cm)	33.2	35.9	40.5	—	—	—
Water temperature (°C)	7.3	8.7	8.8	7.0	9.08	.01*

*$P \leq .05$.

**$P \leq .01$.

Table 2. *Classification showing predicted versus actual group (treatment) membership based on discriminant analysis of water quality measurements.*

Actual group	Number of sites	*Predicted group membership* [a] 1	2	3	4
1	3	3	0	0	0
		100%	0%	0%	0%
2	6	1	5	0	0
		17%	83%	0%	0%
3	6	0	1	4	1
		10%	17%	67%	17%
4	6	0	0	0	6
		0	0	0	100%

[a] Sites correctly classified: 86%.

Table 3. *Kruskal-Wallis comparisons of water quality in pond treatments. Treatments include control ponds (1), distant ponds (2) and receiving ponds (3). Asterisk(s) show the probability ($P \leq .05$ or $.01$) of significantly lower values in the first treatment specified.*

	Treatment Comparison					
	1,3		1,2		2,3	
Characteristic	χ^2	P	χ^2	P	χ^2	P
pH	0.85	0.36	1.74	0.19	0.54	0.46
Conductivity	0.60	0.44	0.42	0.52	3.69	0.05*
Dissolved O_2	0.43	0.51	0.02	0.90	0.33	0.57
Hardness	4.89	0.03*	1.67	0.20	5.04	0.02*
Alkalinity	5.40	0.02*	4.94	0.03*	8.37	0.004**
Turbidity	5.40	0.02*	2.84	0.09	7.41	0.006**
Temperature	1.38	0.24	1.10	0.29	0.03	0.87
Water depth	0	1.00	0.07	0.80	0.03	0.87
Sediment depth	3.27	0.07	1.07	0.30	1.45	0.23

Table 4. *Metal and hydrocarbon concentrations versus treatment. Treatments include control ponds (1), distant ponds (2), receiving ponds (3), and reserve pits (4). Chi-square (χ^2) and probability (P) levels are from a Friedman two-way analysis of variance within and between drill sites. Control ponds were excluded from this analysis.*

Variable	*Treatment means (mg/L)* 1	2	3	4	χ^2	P
Metal						
Al	0.46	1.04	0.48	31.8	10.33	.006**
As	0.001	0.001	0.004	0.023	6.75	.03*
Ba	ND[a]	0.13	0.69	1.62	2.33	.31
Cd	0.0002	0.001	ND[a]	0.001	0.75	.69
Cr	ND[a]	0.070	0.084	0.118	2.33	.31
Cu	0.001	0.002	0.008	0.006	2.58	.27
Ni	0.003	0.036	0.044	0.043	1.58	.45
Pb	0.004	0.006	0.004	0.026	1.75	.42
Zn	0.001	0.039	0.026	0.124	5.58	.06
Hydrocarbons						
Aliphatic	0.006	0.001	0.003	0.401	9.33	.009*
Aromatic	0.0003	0.001	0.001	0.013	2.58	.27

* $P \leq .05$.
** $P \leq .01$.
[a]ND denotes none detected.

Table 5. *Kruskal-Wallis comparisons of contaminant levels in pond treatments. Treatments include control ponds (1), distant ponds (2), receiving ponds (3), and reserve pits (4). Asterisk(s) show the probability (P≤ .05 or .01) of significantly lower values in the first treatment specified.*

	Treatment Comparison					
	1,3		1,2		2,3	
Variable	χ^2	P	χ^2	P	χ^2	P
Lead	0.09	.76	0.08	.78	0.13	.72
Copper	2.03	.15	1.36	.24	1.64	.20
Zinc	0.32	.57	1.82	.18	0.69	.41
Cadmium	4.50	.04[a]	1.15	.28	1.00	.32
Chromium	5.59	.02*	4.09	.04*	0.23	.63
Barium	4.09	.04*	0.50	.48	3.22	.07
Arsenic	4.30	.04*	0.09	.76	5.61	.02*
Nickel	5.45	.02*	1.16	.28	1.65	.20
Aluminum	0.02	.90	0.82	.36	0.79	.37
Aromatics	0.28	.60	0.32	.57	1.43	.23
Aliphatics	1.07	.30	5.40	.02[b]	1.44	.23

[a] Treatment 1 values significantly higher than treatment 3.

[b] Treatment 1 values significantly higher than treatment 2.

Table 6. *Invertebrate population variables versus treatment. Treatments include control ponds (1), distant ponds (2), receiving ponds (3), and reserve pits (4). Chi-square (χ^2) and probability (P) levels are from a Friedman two-way analysis of variance within and between drill sites. Control ponds were excluded from this analysis.*

Community variables	*Treatment means*				χ^2	P
	1	2	3	4		
Total taxa	11.3	7.2	3.30	0	11.08	.004**
Total abundance of organisms	185	1617	510	0	9.00	.01**
Taxonomic diversity (H^1)	0.66	0.46	0.14	0	12.00	.003**
Total abundance of dipterans	30	13	49	0	9.25	.01**
Total abundance of other insects	43	3	0	0	6.25	.04*
Total abundance of crustaceans	100	1594	0.1	0	7.00	.03*

* $P \leq .05$.

** $P \leq .01$.

Table 7. *Classification showing predicted versus actual group (treatment) membership based on discriminant analysis of biological measurements.*

Actual group	Number of sites	*Predicted group membership*[a] 1	2	3	4
1	3	3	0	0	0
		100%	0%	0%	0%
2	6	2	4	0	0
		33%	67%	0%	0%
3	6	0	0	5	1
		0%	0%	83%	17%
4	6	0	0	0	6
		0	0	0	100%

[a]Percent of sites correctly classified: 86%.

Table 8. *Kruskal-Wallis comparisons of biological measures in pond treatments. Treatments include control ponds (1), distant ponds (2) and receiving ponds (3). Asterisk(s) show the probability (P≤ .05 or .01) of significantly higher values in the first treatment specified.*

	Treatment Comparison					
	1,3		1,2		2,3	
Variable	χ^2	P	χ^2	P	χ^2	P
Total taxa	5.59	.02*	4.90	.03*	7.13	.008**
H^1 diversity	5.40	.02*	1.67	.20	5.03	.03*
Total abundance	5.45	.02*	0.60	.44	0.10	.75
Crustacea	5.63	.02*	0.60	.44	4.17	.04*
Diptera	1.07	.30	2.40	.12	5.77	.02[a]
Other insects	7.62	.006**	1.74	.19	7.24	.007**

[a] Treatment 2 abundance is significantly higher than treatment 3.

Table 9. *Correlation coefficients (r values) from simple linear regressions of water quality, metal levels, and hydrocarbon concentrations on invertebrate community measures. These regressions were performed using pond data only (pits excluded). For each analysis, the sample size (N) is 15.*

Variable	Total taxa	Total organisms[a]	Composite diversity H'	Dipteran abundance	Crustacean abundance[a]	Other insect abundance
Water Quality						
pH	-.2795	.3977	-.3993	.1450	.1103	-.5112
Salinity	.0430	.2899	-.3507	.4168	-.1180	.5502*
Dissolved oxygen	-.1699	-.0631	.2508	-.2462	-.1647	.2176
Hardness	-.5487*	.0356	-.6929**	.2659	-.1649	-.1469
Alkalinity	-.6887**	-.2436	-.6404*	.3226	-.2755	-.3155
Turbidity	-.3530	-.3686	-.1802	-.1931	-.0466	-.1308
Temperature	-.4583	.1030	-.3703	.3792	-.3721	-.4747
Metal						
Barium	-.5529*	-.1020	-.5569*	.0139	-.0755	-.2465
Chromium	-.3490	.1967	-.4714	.3639	-.0738	-.2991
Arsenic	-.6424**	-.3274	-.5238*	.2232	-.2656	-.3189
Lead	+.2263	-.2621	.3089	-.4404	-.0863	.5159*
Hydrocarbons						
Aliphatics (total)	.2790	-.1192	.2289	.1008	-.0477	.2865
Aromatics (total)	-.3987	.1186	-.4540	.3341	-.2742	.2670

*P ≤ .05.
**P ≤ .01.
[a] log-transformed abundance.

Table A-1. *Prudhoe Bay sample collection data and treatment designation 7 June - 8 August, 1983.*[a]

Sample number	Sample sites[b]	Treatment number[c]	Date
1	ARCO Drill Site 6 (pit)	-	7 June
2	ARCO Drill Site 16 (pit)	-	6 June
3	ARCO Drill Site 18 (pit)	-	6 June
4	SAPC Pad A (pit)	-	8 June
5	SAPC Pad E (pit)	-	7 June
6	SAPC Pad N (pit)	-	8 June
7	Pad N (pit)	4	27 July
8	Pad N (adjacent pond)	3	27 July
9	Pad N (distant pond)	2	27 July
10	Drill Site 6 (pit)	4	28 July
11	Drill Site 6 (adjacent pond)	3	28 July
12	Drill Site 6 (distant pond)	2	28 July
13	Drill Site 16 (pit)	4	28 July
14	Drill Site 16 (adjacent pond)	3	28 July
15	Drill Site 16 (distant pond)	2	28 July
16	Pad A (pit)	4	29 July
17	Pad A (adjacent pond)	3	29 July
18	Pad A (distant pond)	2	29 July
19	Pad E (pit)	4	29 July
20	Pad E (adjacent pond)	3	29 July
21	Pad E (distant pond)	2	29 July
22	Drill Site 18 (pit)	4	30 July
23	Drill Site 18 (adjacent pond)	3	30 July
24	Drill Site 18 (distant pond)	2	30 July
25	Oliktok (control 1)	1	31 July
26	Oliktok (control 2)	1	31 July
27	Pad E (control 3)	1	1 August

[a] See Fig. 2 for locations of sampling sites.

[b] Drill sites are termed drill sites by ARCO and pads by SAPC.

[c] For statistical analyses, the following numbers were used as treatments: reserve pits, 4; adjacent receiving ponds, 3; distant ponds linked to receiving ponds, 2; and remote control ponds, 1. Samples 1-6 were also reserve pits, but these June samples were not included in the statistical analyses.

Table B-1. *Site characteristics, Prudhoe Bay, Alaska, June-August 1983.*

Sample number	Treatment number	Water temp. (°C)	pH	Conductivity (umhos)/cm	Salinity (‰)	Dissolved Oxygen (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	Turbidity (NTU)	Water depth (mm)	Sediment depth (mm)
1	4	1	8.1	1,100	1	—	—	—	—	—	—
2	4	0	7.5	280	0	—	—	—	—	—	—
3	4	3	9.2	1,350	1	—	—	—	—	—	—
4	4	1	8.1	350	1	—	—	—	—	—	—
5	4	1	8.3	1,400	1.5	—	—	—	—	—	—
6	4	3	7.8	950	0.9	—	—	—	—	—	—
7	4	7	8.4	3,650	3	9	346	104	23	—	—
8	3	10	8.3	4,800	4	13	797	277	2	169	407
9	2	9	7.3	1,500	1	10	191	156	1.2	52	321
10	4	5	8.8	8,000	6.5	7	156	502	42	—	—
11	3	6	7.7	8,000	6.5	3	953	658	4	262	321
12	2	6	8.3	3,200	3	12	364	156	1	258	322
13	4	8	8.4	3,800	3.5	10	87	433	38	—	—
14	3	9	7.9	3,000	2	10	346	416	2.9	97	475
15	2	9	8.0	2,100	1.5	11	173	121	0.54	140	340
16	4	8	8.0	7,500	6	3	294	242	56	—	—
17	3	10	7.9	7,000	5	9	468	346	3.9	142	343
18	2	10	7.7	1,350	1	10	156	69	2.1	234	370
19	4	9	8.1	7,000	6	6	294	277	28	—	—
20	3	12	7.9	6,500	5	10	468	294	2.5	154	401
21	2	11	8.3	4,400	3.5	7	675	242	1.8	102	388
22	4	5	8.5	6,000	5	6	260	433	58	—	—
23	3	6	7.6	2,850	2.5	7	1,004	606	41	89	481
24	2	7	8.0	3,100	2.5	8	225	121	0.8	143	410
25	1	8	8.0	1,150	0.7	10	87	35	0.38	135	389
26	1	9	7.6	1,350	1	9	121	52	0.62	121	313
27	1	5	7.2	9,500	8	11	346	69	0.84	206	295

Table C-1. *Aquatic macroinvertebrates and code designations for taxa from Prudhoe Bay sample sites, July-August 1983.*[a]

Taxonomic Classification	Code
Phylum Cnidaria	
Class Hydrozoa	
Order Hydridae	O
Phylum Nematoda	
Phylum Annelida	
Class Oligochaeta	
Order Haplotaxida	
Family Tubificidae	R
Phylum Arthropoda	
Class Crustacea	
Subclass Branchiopoda	
Order Anostraca	G
Order Notostraca	K
Order Cladocera	
Family Daphnidae	C
Order Copepoda	
Suborder Calanoida	B
Suborder Cyclopoida	S
Order Ostracoda	F
Class Arachnida	
Order Acari (Hydracarina)	
Family Lebertiidae	I
Class Insecta	
Order Collembola	P
Order Ephemeroptera	
Family Baetidae	U
Family Siphlonuridae	D
Order Plecoptera	
Family Nemouridae	E
Order Trichoptera	
Family Limnephilidae	M
Order Hemiptera	
Family Pleidae	V
Order Coleoptera	
Family Dytiscidae	T
Order Diptera	
Family Chironomidae	A
Family Culicidae	H
Family Dixidae	J
Family Tipulidae	Q
Phylum Mollusca	
Class Gastropoda	
Order Pulmonata	
Family Physidae	N

[a] Nomenclature based on Pennak (1978).

Table C-2. *Numbers of different aquatic invertebrate taxa and numbers of specific taxa from each sample location, Prudhoe Bay, Alaska, July-August, 1983.*[a]

Sample number	Sweep sample no.	Number of taxa	Average number[b]	Number of individuals/ taxon (see Table C-1 code)
8	1	1		(64)A
	2	1	1	(42)A
	3	2		(39)A, (1)B
9	1	6		(14)A, (2)I, (2)L, (2)M 2)D, (1)F;
	2	3	5	2)A, (2)E, (1)L;
	3	5		(7)A, (2)D, (1)M, (1)L, (1)N
11	1	2		(23)A, (1)C
	2	5	3	(113)A, (2)H, (1)N (1)B, (1)C
	3	3		(47)A, (2)C, (1)N
12	1	10		(261)B, (250)C, (5)G, (3)E, (2)H,(1)I, (1)A, (1)J,
	2	5	7	1)F, (1)K; (123)B, (48)C,
	3	7		(4)G, (1)H, (1)D; (263)B, (198)C, (3)F, (2)A, (2)E, (2)G, (1)D
14	1	2		(39)A, (2)C
	2	3	2	(35)A, (2)S, (1)H
	3	2		43)A, (7)S
15	1	6		(7)N, (4)J, (4)E, (3)C, (1)A, (1)G;
	2	6	6	(7)N, (8)E, (1)P, (1)I, (1)U, (1)C;
	3	7		(7)E, (6)N, (6)C, (5)A, (4)U, (4)B, (1)M
17	1	3		(34)A, (2)N, (2)S
	2	3	3	(40)A, (4)N, (1)I
	3	4		(42)A, (1)N, (1)C, (1)T
18	1	4		(34)B, (4)G, (2)C, (1)M 1
	2	3	4	(32)B, (5)G, (2)C
	3	4		(26)B, (4)G, (3)C, (1)K
20	1	2		(107)A, (5)H
	2	3	2	(78)A, (4)H, (1)Q
	3	1		(97)A

21	1	7		(10,640)C, (354)S, (31)A (26)F, (17)B, (3)P, (2)H;
	2	5	6	(9,350)C, (183)S, (22)A, (15)B, (3)F;
	3	7		(6,675)C, (122)S, (28)A (10)B, (4)F, (3)T, (2)H
23	1	2		(14)A, (3)C
	2	3	2	(5)A, (2)C, (1)S
	3	2		(3)A, (1)C
24	1	9		(33)A, (26)N, (4)F, (3)Q, (3)M, (3)P, (2)R, (1)I, (1)L;
	2	4	6	(48)A, (29)N, (2)F, (1)M;
	3	6		(30)A, (20)N, (2)F, (2)M, (1)C, (1)R
25	1	10		(39)B, (35)C, (26)A, (19)E, (3)D,(2)G, (1)F, (1)O, (1)J, (1)P;
	2	6	9	(34)C, (30)A, (30)B, (14)E, (2)J, (1)P;
	3	11		(34)C, (23)A, (15)B, (7)E, (5)J, (2)N, (2)F, (1)P, (1)Q, (1)R, (1)G
26	1	7		(19)A, (10)G, (7)C, (3)N (3)E, (1)M, (1)F;
	2	6	8	(109)C, (86)A, (6)B, (4)G (2)N, (1)F;
	3	10		(24)A, (20)B, (19)C, (10)G, (4)N, (1)D, (1)E, (1)I, (1)M, (1)J
27	1	13		(159)U, (156)B, (19)E, (16)A, (13)F, (12)C, (4)G, (3)P, (3)D, (2)J, (2)M, (2)T, (1)V;
	2	13	12	(127)B, (30)U, (21)A, (20)F (12)C, (10)M, (8)E, (4)N, (3)G, (2)P, (1)I, (1)O, (1)H;
	3	11		(154)U, (139)B, (26)C, (20)E, (17)A, (5)M, (5)F, (3)T, (1)N, (1)G, (1)V

[a] No invertebrate sampling occurred for samples 1-6. Invertebrates were absent from reserve pits sample numbers 7, 10, 13, 16, 19 and 22 in the July-August sample period.

[b] Average number of taxa per sweep set. Statistical treatment used total number of taxa (see text).

Table D-1. *Results of preliminary analyses for heavy metals, Prudhoe Bay reserve pit samples, June 1983.*[a]

Sample site	Lead	Copper	Zinc	Nickel	Cadmium	Barium	Chromium	Mercury	Arsenic	Aluminum
1	0.094	0.25	0.20	ND	0.0008	2.8	0.65	ND	0.020	15.0
2	0.20	0.029	0.078	0.036	ND	1.2	0.37	ND	0.010	12.0
3	0.18	0.12	0.87	0.090	ND	10.0	0.75	ND	0.033	18.0
4	0.17	0.21	0.69	0.05	0.0087	5.0	0.12	0.0006	0.020	11.0
5	0.014	0.0084	0.053	0.019	ND	ND	0.13	ND	0.004	5.3
6	0.0037	ND	0.69	ND	ND	ND	0.048	ND	0.0017	5.6

[a] Results are in mg/L, or parts per million (ppm), wet weight. The lower detection limits (mg/L) were 0.005 for aluminum and nickel; 0.05 for barium; 0.0005 for lead, copper, and chromium; 0.0001 for zinc and cadmium; 0.0004 for mercury; and 0.001 for arsenic and selenium. No selenium was detected in any sample. ND = not detected.

Table D-2. *Preliminary observations of reserve pit dewatering and presence of oil and drill muds, Prudhoe Bay, Alaska, June 1983.*[a]

Location	Oil visible in pit	Drill muds visible in pit	Evidence of dewatering	Discharge location[b]
DS-1	Y	Y	Y	R
DS-2	N	N	Y	R
DS-3	N	N	N	-
DS-4	N	Y	N	-
DS-5	N	N	N	-
DS-6	Y	Y	Y	R
DS-7	Y	Y	Y	R
DS-9	N	N	N	-
DS-11	N	N	N	-
DS-12	Y	Y	N	-
DS-13	N	Y	Y	R
DS-14	Y	Y	Y	T&R
DS-15	N	Y	Y	R
DS-16	N	N	Y	T&R
DS-17	N	N	Y	T
DS-18	Y	Y	Y	R
Pad A	Y	N	Y	T&R
Pad B	Y	Y	Y	T
Pad C	Y	Y	N	-
Pad D	Y	Y	Y	T
Pad E	N	N	Y	T
Pad F	N	N	Y	R
Pad G	N	Y	Y	T
Pad H	Y	Y	Y	R
Pad J	N	Y	N	-
Pad M	Y	Y	N	-
Pad N	Y	Y	Y	T
Pad Q	Y	Y	N	-
Pad R	Y	Y	Y	T
Pad T	N	N	N	-
Pad U	N	N	N	-
Pad X	Y	Y	Y	T&R
Pad Y	Y	Y	N	-
	17 Y (52%) 16 N	21 Y (64%) 12 N	20 Y (61%) 13 N	9 R (27%) 7 T (21%) 4 T&R (12%)

[a] N = No; Y = Yes.

[b] T = direct tundra discharge; R = discharge on roads and pads by spraying from a tanker or overtopping.

Table E-1. *Results of heavy metals analyses, Prudhoe Bay reserve pit samples, July-August 1983.*[a]

Sample site	Lead	Copper	Zinc	Cadmium	Chromium	Arsenic	Nickel	Alumimum	Barium
7	0.0052	0.0059	0.056	ND	0.088	0.0053	0.022	2.6	0.92
8	ND	0.029	ND	ND	0.11	0.0029	0.018	1.1	0.66
9	0.023	0.0035	0.012	ND	0.05	0.0028	0.014	1.4	ND
10	0.018	0.016	0.2	ND	0.12	0.050	0.13	97	4.4
11	ND	0.0043	0.080	ND	0.21	0.0054	0.088	ND	0.67
12	0.0033	0.0046	0.12	0.00056	0.049	ND	0.17	2.5	ND
13	0.0008	0.0052	0.33	0.0009	0.21	0.030	0.086	69	3.9
14	0.0064	0.004	0.069	ND	0.078	0.0053	0.016	1.3	0.59
15	ND	0.00062	0.082	ND	0.021	ND	0.007	0.46	ND
16	ND	ND	0.046	ND	0.12	0.016	0.015	2.7	ND
17	ND	ND	ND	ND	0.057	0.0023	0.011	ND	0.61
18	0.0042	0.0011	0.019	ND	ND	ND	ND	1.3	ND
19	0.093	0.003	0.098	ND	0.16	0.038	0.005	13	0.52
20	ND	0.0059	ND	ND	0.030	0.0015	0.026	1	ND
21	ND	0.0009	ND	ND	0.13	0.0028	0.024	ND	0.77
22	0.037	0.0025	ND	0.00013	0.0042	ND	ND	9	ND
23	0.014	0.0023	0.0039	ND	0.018	0.0064	0.101	0.53	1.6
24	ND	0.0015	ND	ND	0.17	ND	ND	0.6	ND
25	ND	0.00058	ND	ND	ND	ND	ND	0.036	ND
26	ND	0.0025	0.0039	0.00017	ND	0.0017	0.008	1.3	ND
27	0.020	ND	ND	0.00020	ND	ND	ND	0.03	ND

[a] Results are in mg/L, or parts per million (ppm), wet weight. The lower detection limits (mg/L) were 0.005 for aluminum and nickel; 0.05 for barium; 0.0005 for lead, copper, and chromium; 0.0001 for zinc and cadmium; 0.0004 for mercury; and 0.001 for arsenic and selenium. No mercury or selenium was detected in any of the samples. ND = not detected.

Table F-1. *Results of preliminary hydrocarbon analyses, Prudhoe Bay reserve pit samples, June 1983.*[a]

	Sample Site Numbers					
	1	2	3	4	5	6
Aliphatics						
Dodecane	0.11	ND	0.031	630	0.0050	0.0029
Tridecane	0.51	ND	0.067	1000	0.0092	0.014
Tetradecane	1.4	0.00068	0.14	1100	0.013	0.052
Octylcyclohexane	0.30	ND	0.012	110	0.0026	0.0032
Pentadecane	2.6	ND	0.31	1200	0.015	0.097
Nonylcyclohexane	0.51	ND	0.038	210	0.0028	0.0095
Hexadecane	2.8	ND	0.41	930	0.0080	0.077
Heptadecane	1.9	ND	0.33	570	0.0064	0.052
Pristane	1.5	ND	0.31	540	0.0052	0.043
Octadecane	1.2	ND	0.31	350	0.0052	0.029
Phytane	1.07	ND	0.17	210	0.0026	0.020
Nonadecane	0.61	ND	0.19	160	0.0023	0.0097
Eicosane	0.35	ND	0.15	59	0.0011	0.0037
Aromatics						
Naphthalene	0.0054	ND	0.0059	16	ND	ND
Fluorene	0.35	ND	0.11	57	ND	0.0025
Phenanthrene	0.37	ND	0.15	57	ND	0.0023
Anthracene	0.30	ND	0.12	59	ND	0.0027
Fluoranthene	0.37	ND	0.12	ND	ND	ND
Pyrene	0.23	ND	0.23	ND	ND	ND
1,2-Benzanthracene	ND	ND	ND	ND	ND	ND
Chrysene	ND	ND	ND	ND	ND	ND
Benzo(b)fluoranthene	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND
Benzo(e)pyrene	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene	ND	ND	ND	ND	ND	ND
Perylene	ND	ND	ND	ND	ND	ND
1,2,5,6-Dibenzanthracene	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND

[a] Results are in mg/L, or parts per million (ppm), wet weight. The lower limit of reportable residues =0.0003 mg/L. ND = not detected.

Table F-2. *Results of hydrocarbon analyses, Prudhoe Bay, July-August 1983.*[a]

	Sample site numbers					
	7	8	9	10	11	12
Aliphatics						
Dodecane	0.074	0.00036	0.0012	0.17	0.00010	0.00034
Tridecane	0.10	0.00034	ND	0.22	ND	ND
Tetradecane	0.091	0.00023	0.000890	0.077	0.00027	ND
Octylcyclohexane	0.017	ND	ND	0.027	ND	ND
Pentadecane	0.094	0.00068	ND	0.091	0.00039	ND
Nonylcyclohexane	0.018	ND	ND	0.025	ND	ND
Hexadecane	0.077	0.00090	ND	0.068	0.00090	ND
Heptadecane	0.055	0.00058	ND	0.0095	0.00054	ND
Pristane	0.036	0.00039	ND	0.014	0.00051	ND
Octadecane	0.034	0.00032	ND	0.012	0.00044	ND
Phytane	0.026	ND	ND	0.013	0.00023	ND
Nonadecane	0.016	0.00027	ND	0.015	0.00036	ND
Eicosane	0.006	ND	ND	0.015	0.00029	ND
Aromatics						
Naphthalene	0.0034	0.0010	ND	0.0018	ND	ND
1-Methylnaphthalene	0.0070	ND	ND	0.0059	ND	ND
2-Ethylnaphthalene	0.0023	ND	ND	0.00050	ND	ND
1,5-Dimethylnaphthalene	0.0021	ND	ND	0.0012	ND	ND
4-Phenyltoluene	0.0024	ND	ND	ND	ND	ND
1,3,5-Trimethylnaphthalene	0.0110	ND	ND	ND	ND	ND
Fluorene	0.0062	ND	ND	0.0026	ND	ND
Phenanthrene	0.0031	ND	ND	0.0086	ND	ND

	13	14	15	16	17	18
Aliphatics						
Dodecane	0.0012	ND	0.00080	0.00065	0.00022	0.00068
Tridecane	0.00040	ND	ND	0.00021	0.00015	ND
Tetradecane	0.0015	ND	0.00054	0.00090	0.00066	0.00022
Octylcyclohexane	ND	ND	ND	ND	ND	ND
Pentadecane	0.0012	0.00020	ND	0.0012	0.00057	ND
Nonylcyclohexane	ND	ND	ND	ND	ND	ND
Hexadecane	0.0013	0.00028	ND	0.0019	0.00082	ND
Heptadecane	0.00075	0.00019	ND	0.0018	0.00080	ND
Pristane	0.00068	0.00020	ND	0.0019	0.00082	ND
Octadecane	0.00026	ND	ND	0.0018	0.00048	ND
Phytane	ND	ND	ND	0.0012	0.00032	ND
Nonadecane	ND	ND	ND	0.0011	0.00037	ND
Eicosane	ND	ND	ND	0.00043	0.00034	ND
Aromatics						
Naphthalene	0.00013	ND	0.00049	0.00034	0.00021	ND
1-Methylnaphthalene	ND	ND	ND	0.00056	0.00075	ND
2-Ethylnaphthalene	ND	ND	ND	ND	ND	ND
1,5-Dimethylnaphthalene	ND	ND	ND	0.00059	0.00014	ND
4-Phenyltoluene	ND	ND	ND	ND	ND	ND
1,3,5-Trimethylnaphthalene	ND	ND	ND	ND	0.00027	ND
Fluorene	ND	ND	ND	0.0029	ND	ND
Phenanthrene	ND	ND	ND	ND	ND	ND

	19	20	21	22	23	24
Aliphatics						
Dodecane	0.036	ND	ND	0.11	ND	0.0014
Tridecane	0.074	ND	ND	0.13	ND	ND
Tetradecane	0.051	ND	ND	0.10	0.00040	0.00093
Octylcyclohexane	0.019	ND	ND	0.026	ND	ND
Pentadecane	0.034	ND	ND	0.096	0.00058	ND
Nonylcyclohexane	0.016	ND	ND	0.019	ND	ND
Hexadecane	0.044	ND	ND	0.073	0.00070	0.00023
Heptadecane	0.0078	ND	ND	0.026	0.00079	ND
Pristane	0.0065	ND	0.00052	0.041	0.0011	ND
Octadecane	0.0046	ND	0.00031	0.025	ND	ND
Phytane	0.0031	ND	ND	0.011	ND	ND
Nonadecane	0.0020	ND	ND	0.015	ND	ND
Eicosane	0.00083	ND	ND	0.013	ND	ND
Aromatics						
Naphthalene	0.00016	0.0016	0.0015	0.0015	0.0017	ND
1-Methylnaphthalene	ND	ND	ND	0.0046	ND	ND
2-Ethylnaphthalene	ND	ND	ND	0.00031	ND	ND
1,5-Dimethylnaphthalene	0.0012	ND	ND	0.0012	ND	ND
4-Phenyltoluene	ND	ND	ND	ND	ND	ND
1,3,5-Trimethylnaphthalene	ND	ND	ND	0.0022	ND	ND
Fluorene	ND	ND	ND	0.0010	ND	ND
Phenanthrene	ND	ND	ND	0.0068	ND	ND

	25	26	27	28
Aliphatics				
Dodecane	0.0017	0.0024	0.0015	0.00084
Tridecane	ND	0.0010	0.00063	0.00019
Tetradecane	0.0013	0.0033	0.0024	0.0011
Octylcyclohexane	ND	ND	ND	ND
Pentadecane	ND	0.00077	0.00022	0.00015
Nonylcyclohexane	ND	0.00015	0.00074	ND
Hexadecane	0.00031	0.0012	ND	0.00030
Heptadecane	ND	ND	ND	ND
Pristane	ND	ND	ND	ND
Octadecane	ND	ND	ND	ND
Phytane	ND	ND	ND	ND
Nonadecane	ND	ND	ND	ND
Eicosane	ND	ND	ND	ND
Aromatics				
Naphthalene	ND	0.00050	ND	0.00039
1-Methylnaphthalene	0.00027	0.00019	ND	0.00027
2-Ethylnaphthalene	ND	ND	ND	ND
1,5-Dimethylnaphthalene	ND	ND	ND	ND
4-Phenyltoluene	ND	ND	ND	ND
1,3,5-Trimethylnaphthalene	ND	ND	ND	ND
Fluorene	ND	ND	ND	ND
Phenanthrene	ND	ND	ND	ND

[a] All results are in mg/L, or parts per million (ppm), wet weight. The lower limit of reportable residues = 0.0003 ppm. ND = not detected.

Table G-1. *Computer printout of stepwise discriminant analysis of water quality variables by treatment.*

30-SEP-86 DATA VERIFICATION
13:22:34 VACN ACAD3 DEC VAX-8800 VMS V4.4

* *

AT STEP 1, TURB WAS INCLUDED IN THE ANALYSIS.

		DEGREES OF FREEDOM		SIGNIF.	BETWEEN GROUPS
WILKS' LAMBDA	0.27179	1	3 17.0		
EQUIVALENT F	15.1827		3 17.0	0.0000	

----------VARIABLES IN THE ANALYSIS AFTER STEP 1 ----------

VARIABLE	TOLERANCE	F TO REMOVE	WILKS'LAMBDA
TURB	1.0000000	15.183	

----------VARIABLES NOT IN THE ANALYSIS AFTER STEP 1 ----------

VARIABLE	TOLERANCE	MINIMUM TOLERANCE	F TO ENTER	WILKS' LAMBDA
PH	0.9649363	0.9649353	2.5970	0.18278
COND	0.9959498	0.9959498	1.4495	0.21371
DO	0.8569348	0.8569348	0.80566E-01	0.26775
HARD	0.9069145	0.9069145	7.3180	0.11458
ALK	0.7510666	0.7510666	8.8660	0.10209
TEMP	0.8341398	0.8341398	0.82962	0.23520

F STATISTICS AND SIGNIFICANCES BETWEEN PAIRS OF GROUPS AFTER STEP 1
EACH F STATISTIC HAS 1 AND 17.0 DEGREES OF FREEDOM.

GROUP	1	2	3
2	0.61394E-02 0.9385		
3	1.1808 0.2924	1.5250 0.2337	
4	24.776 0.0001	36.003 0.0000	22.709 0.0002

* *

AT STEP 2, ALK WAS INCLUDED IN THE ANALYSIS.

		DEGREES OF FREEDOM			SIGNIF.	BETWEEN GROUPS
WILKS' LAMBDA	0.10209	2	3	17.0		
EQUIVALENT F	11.3590		6	32.0	0.0000	

------------------VARIABLES IN THE ANALYSIS AFTER STEP 2 ------------------------------

VARIABLE	TOLERANCE	F TO REMOVE	WILKS'LAMBDA
ALK	0.7510666	8.8660	0.27179
TURB	0.7510666	14.736	0.38415

------------------VARIABLES NOT IN THE ANALYSIS AFTER STEP 2 ---------------------------

VARIABLE	TOLERANCE	MINIMUM TOLERANCE	F TO ENTER	WILKS' LAMBDA
PH	0.9514791	0.7146603	2.5369	0.06772
COND	0.9398731	0.7087779	1.0758	0.08401
DO	0.7440313	0.6521115	0.27959	0.09668
HARD	0.8530345	0.7064455	1.8313	0.07472
TEMP	0.6559375	0.5906117	2.3107	0.06982

F STATISTICS AND SIGNIFICANCES BETWEEN PAIRS OF GROUPS AFTER STEP 2
EACH F STATISTIC HAS 2 AND 16.0 DEGREES OF FREEDOM.

GROUP	1	2	3
2	0.64404 0.5383		
3	9.5995 0.0018	8.0211 0.0039	
4	11.972 0.0007	17.030 0.0001	19.676 0.0000

F LEVEL OR TOLERANCE OR VIN INSUFFICIENT FOR FURTHER COMPUTATION.

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS' LAMBDA	SIG.	LABEL
1	TURB		1	.27179	.0000	
2	ALK		2	.10209	.0000	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER'S LINEAR DISCRIMINANT FUNCTIONS)

TRT =	1	2	3	4
ALK	0.4217583E-02	0.1189447E-01	0.3304993E-01	0.9579615E-02
TURB	-0.1824537E-01	-0.5496690E-01	-0.1071466	0.2606257
(CONSTANT)	-1.490478	-2.209791	-8.036153	-8.296821

CANONICAL DISCRIMINANT FUNCTIONS

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	AFTER FUNCTION	WILKS' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					0	0.1020856	38.793	6	0.0000
1*	2.82179	64.35	64.35	0.8592685	1	0.3901495	16.001	2	0.0003
2*	1.56312	35.65	100.00	0.7809292					

* MARKS THE 2 CANONICAL DISCRIMINANT FUNCTIONS REMAINING IN THE ANALYSIS.

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2
ALK	-0.38823	1.08661
TURB	1.13540	-0.20569

STRUCTURE MATRIX:

POOLED WITHIN-GROUPS CORRELATIONS BETWEEN DISCRIMINATING VARIABLES AND CANONICAL DISCRIMINANT FUNCTIONS
(VARIABLES ORDERED BY SIZE OF CORRELATION WITHIN FUNCTION)

	FUNCTION 1	FUNCTION 2
TURB	0.94170*	0.33645
PH	-0.21537*	0.04624
ALK	0.17826	0.98398*
TEMP	-0.24149	-0.53455*
DO	-0.24314	-0.44368*
HARD	0.20921	0.32124*
COND	-0.13960	0.20159*

UNSTANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2
ALK	-0.3129421E-02	0.8758950E-02
TURB	0.9932624E-01	-0.1799416E-01
(CONSTANT)	-0.6327560	-2.073417

CANONICAL DISCRIMINANT FUNCTIONS EVALUATED AT GROUP MEANS (GROUP CINTROIDS)

GROUP	FUNCTION 1	FUNCTION 2
1	-0.73589	-1.62875
2	-0.96141	-0.83286
3	-1.05526	1.54890
4	2.38462	0.09833

Table G-2. *Computer printout of stepwise discriminant analysis of contaminant variables by treatment.*

```
30-SEP-86     DATA VERIFICATION
13:22:34      VACN   ACAD3
                                                  DEC VAX-8800    VMS V4.4

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

AT STEP  1,  ALI     WAS INCLUDED IN THE ANALYSIS.

                              DEGREES OF FREEDOM         SIGNIF.       BETWEEN GROUPS

WILKS' LAMBDA         0.46198   1    3       17.0
EQUIVALENT F          6.59949        3       17.0        0.0037

-----------------VARIABLES IN THE ANALYSIS AFTER STEP 1 ------------------------------

VARIABLE      TOLERANCE       F TO REMOVE      WILKS'LAMBDA

ALI           1.0000000          6.5995

-----------------VARIABLES NOT IN THE ANALYSIS AFTER STEP 1 --------------------------

                            MINIMUM
VARIABLE      TOLERANCE     TOLERANCE          F TO ENTER          WILKS' LAMBDA

PB            0.9833782     0.9833782          0.35897             0.43284
CU            0.9298435     0.9298435          1.0719              0.38467
ZN            0.9144201     0.9144201          2.6798              0.30748
CD            0.8163661     0.8163661          1.7491              0.34798
CR            0.8441411     0.8441411          3.4779              0.27963
AS            0.9929868     0.9929868          3.0579              0.29356
NI            0.9946464     0.9946464          0.42218             0.42809
AL            0.9860236     0.9860236          0.87296             0.39700
BA            0.9967322     0.9967322          0.98682             0.38984
ARO           0.4085402     0.4085402          0.15897E-01         0.46060

F STATISTICS AND SIGNIFICANCES BETWEEN PAIRS OF GROUPS AFTER STEP 1
EACH F STATISTIC HAS 1 AND 17.0 DEGREES OF FREEDOM.

              GROUP        1                    2                      3
  GROUP
    2               0.98196E-03
                    0.9754

    3               0.46895E-03          0.14059E-03
                    0.9830               0.9907

    4               9.1104              13.951                 13.862
                    0.0077               0.0016                 0.0017

F LEVEL OR TOLERANCE OR VIN INSUFFICIENT FOR FURTHER COMPUTATION.
```

50-SEP-86 DATA VERIFICATION
13:22:34 VACN ACAD3 DEC VAX-8800 VMS V4.4

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS' LAMBDA	SIG.	LABEL
1	ALI		1	.46198	.0037	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER'S LINEAR DISCRIMINANT FUNCTIONS)

TRT =	1	2	3	4
ALI	0.1713519E-03	0.5160028E-04	0.8859671E-04	0.1170596E-01
(CONSTANT)	-1.386797	-1.386340	-1.386429	-3.732072

CANONICAL DISCRIMINANT FUNCTIONS

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	: AFTER FUNCTION	WILKS' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					: 0	0.4619757	13.514	3	0.0036
1*	1.16462	100.00	100.00	0.7335014	:				

* MARKS THE 1 CANONICAL DISCRIMINANT FUNCTIONS REMAINING IN THE ANALYSIS.

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1
ALI	1.00000

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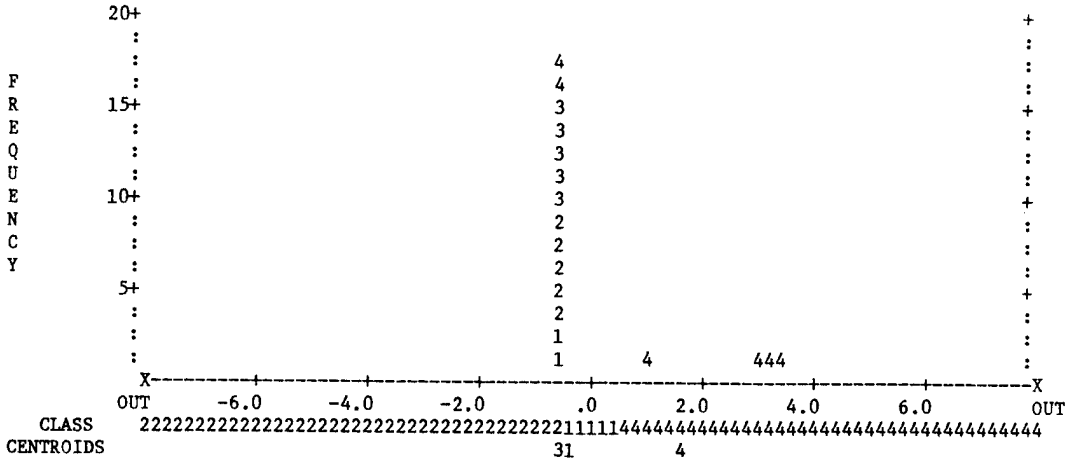
ALL-GROUPS STACKED HISTOGRAM

CANONICAL DISCRIMINANT FUNCTION 1



CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3	4
GROUP	1	3	2	0	1	0
			66.7%	0.0%	33.3%	0.0%
GROUP	2	6	0	4	2	0
			0.0%	66.7%	33.3%	0.0%
GROUP	3	6	1	2	3	0
			16.7%	33.3%	50.0%	0.0%
GROUP	4	6	2	0	0	4
			33.3%	0.0%	0.0%	66.7%

PERCENT OF "GROUPED" CASES CORRECTLY CLASSIFIED: 61.90%

Table G-3. *Computer printout of stepwise discriminant analysis of biological variables by treatment.*

30-SEP-86 DATA VERIFICATION
13:22:34 VACN ACAD3 DEC VAX-8800 VMS V4.4

* *

AT STEP 1, TOTAX WAS INCLUDED IN THE ANALYSIS.

		DEGREES OF FREEDOM		SIGNIF.	BETWEEN GROUPS
WILKS' LAMBDA	0.09518	1	3 17.0		
EQUIVALENT F	53.8683		3 17.0	0.0000	

----------VARIABLES IN THE ANALYSIS AFTER STEP 1 ----------

VARIABLE	TOLERANCE	F TO REMOVE	WILKS'LAMBDA
TOTAX	1.0000000	53.868	

----------VARIABLES NOT IN THE ANALYSIS AFTER STEP 1 ----------

VARIABLE	TOLERANCE	MINIMUM TOLERANCE	F TO ENTER	WILKS' LAMBDA
DIV	0.9880858	0.9880858	1.2449	0.07717
TOTORG	0.9999995	0.9999995	0.63965	0.08499
TOTCRUS	0.9999427	0.9999427	0.67765	0.08445
DIP	0.9913941	0.9913941	6.5438	0.04274
INS	0.8569322	0.8569322	1.7978	0.07119

F STATISTICS AND SIGNIFICANCES BETWEEN PAIRS OF GROUPS AFTER STEP 1
EACH F STATISTIC HAS 1 AND 17.0 DEGREES OF FREEDOM.

GROUP	1	2	3
2	17.978 0.0006		
3	66.274 0.0000	22.825 0.0002	
4	133.01 0.0000	79.779 0.0000	17.259 0.0007

* *

AT STEP 2, DIP WAS INCLUDED IN THE ANALYSIS.

		DEGREES OF FREEDOM			SIGNIF.	BETWEEN GROUPS
WILKS' LAMBDA	0.04274	2	3	17.0		
EQUIVALENT F	20.4641		6	32.0	0.0000	

------------------VARIABLES IN THE ANALYSIS AFTER STEP 2 --------------------------------

VARIABLE	TOLERANCE	F TO REMOVE	WILKS'LAMBDA
TOTAX	0.9913941	48.579	0.43205
DIP	0.9913941	6.5438	0.09518

------------------VARIABLES NOT IN THE ANALYSIS AFTER STEP 2 ----------------------------

VARIABLE	TOLERANCE	MINIMUM TOLERANCE	F TO ENTER	WILKS' LAMBDA
DIV	0.8763738	0.8763738	1.1289	0.03487
TOTORG	0.9558248	0.9558248	0.85545	0.03650
TOTCRUS	0.9585286	0.9585286	0.87795	0.03636
INS	0.7984782	0.7984782	1.9169	0.03090

F STATISTICS AND SIGNIFICANCES BETWEEN PAIRS OF GROUPS AFTER STEP 2
EACH F STATISTIC HAS 2 AND 16.0 DEGREES OF FREEDOM.

GROUP	1	2	3
2	8.8229 0.0026		
3	33.430 0.0000	17.353 0.0001	
4	63.263 0.0000	37.614 0.0000	16.170 0.0001

F LEVEL OR TOLERANCE OR VIN INSUFFICIENT FOR FURTHER COMPUTATION.

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS' LAMBDA	SIG.	LABEL
1	TOTAX		1	.09518	.0000	
2	DIP		2	.04274	.0000	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER'S LINEAR DISCRIMINANT FUNCTIONS)

TRT =	1	2	3	4
TOTAX	5.811417	3.695672	1.565818	0.0000000E+00
DIP	0.4514478E-01	0.1195379E-01	0.1276675	0.0000000E+00
(CONSTANT)	-34.99483	-14.70782	-7.113206	-1.386294

CANONICAL DISCRIMINANT FUNCTIONS

FUNCTION	EIGENVALUE	PERCENT OF VARIANCE	CUMULATIVE PERCENT	CANONICAL CORRELATION	AFTER FUNCTION	WILKS' LAMBDA	CHI-SQUARED	D.F.	SIGNIFICANCE
					0	0.0427409	53.594	6	0.0000
1*	9.50703	88.57	88.57	0.9512232	1	0.4490797	13.609	2	0.0011
2*	1.22678	11.43	100.00	0.7422400					

* MARKS THE 2 CANONICAL DISCRIMINANT FUNCTIONS REMAINING IN THE ANALYSIS.

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNCTION 1	FUNCTION 2
TOTAX	0.99899	-0.10341
DIP	0.01029	1.00428

50272-101

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7. Author(s)
Robin L. West and Elaine Snyder-Conn

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

June 1983 inspections at Prudhoe Bay, Alaska, revealed oil sheens at 52% of the reserve pits, and discharges of 61% to tundra and roads. Pits, adjacent, distant, and control ponds differed significantly ($P \leq .05$) in water quality and biological characteristics. Of the water quality characteristics, the primary discriminant function corresponded to a gradient in turbidity, and a second function reflected increases in alkalinity from control to receiving ponds. Among biological variables, total taxa accounted for 89% of the variance. Kruskal-Wallis tests showed that hardness, alkalinity, turbidity, chromium, barium, arsenic, and nickel were elevated in receiving versus control ponds ($P \leq .05$). Alkalinity, chromium, and aliphatic hydrocarbons were higher in distant ponds than in controls.

Regressions showed that alkalinity, hardness, arsenic, and barium were the water quality and contaminant variables that best predicted deteriorating biological conditions. Chromium concentrations were also high, and considerable mobility occurred for this metal. Measurement of these variables could assist in screening proposed discharges to tundra wetlands.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms
Arctic tundra ponds, aquatic invertebrates, Prudhoe Bay, reserve pits, pollution, metals, hydrocarbons, water quality

c. COSATI Field/Group

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