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ORGANIC AND INORGANIC TOXICANTS IN SEDIMENT AND MARINE BIRDS FROM PUGET SOUND

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PREFACE

One of the objectives of the MESA (Marine EcoSystems Analysis) Puget Sound Project is to determine the concentration and distribution of toxic chemicals in Puget Sound. Major emphasis thus far has been placed upon chemical analyses of sediments and benthic fish and invertebrates to satisfy this objective. Relatively high concentrations of many chemicals have been detected in sediments from urban bays of the Sound. However, no sediment chemistry data were acquired in the initial surveys for some areas of the Sound, specifically Colvos Passage and parts of southern Puget Sound. Thus, our understanding of the distribution of selected chemicals in Puget Sound was incomplete. Also, no tissue chemistry data were collected for top predators, including marine birds, thus, there was little information to use to determine if toxic chemicals, observed in sediments and lower trophic level biota, were being transferred to upper trophic level animals. The study described in this report was initiated to provide information to fill some of these data gaps. The Contracting Officer's Technical Representative for this study was Edward R. Long of the MESA Puget Sound Project staff.

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ORGANIC AND INORGANIC TOXICANTS IN SEDIMENT AND MARINE BIRDS FROM PUGET SOUND

SUMMARY

Inorganic and organic pollutants have been discharged into harbors around the central basin of Puget Sound for many years. The objectives of this study were: (1) To determine the extent of impact of contaminants to sediments in selected areas not previously sampled and (2) to determine the concentrations of contaminants in marine birds. Sediments from 16 sampling sites were analyzed for selected inorganic and organic components. Nesting bird species and populations in the Puget Sound area were surveyed and counted. Literature was searched for indicators of the most likely bird species, organs or tissues to represent the accumulation of pollutants from Puget Sound. On that basis, the Great Blue Heron, the Pigeon Guillemot, and the Glaucous-Winged Gull were collected and tissue samples of those bird species were analyzed for selected inorganic and organic pollutants.

Emphasis was placed on sampling sediments from the areas of Colvos Passage and southern Puget Sound because data on their chemistry were minimal. Sediments were analyzed for 23 elements, 24 aromatic hydrocarbons, polychlorinated biphenyls, chlorinated butadienes and chlorinated benzenes.

The majority of the sediments analyzed contained higher concentrations of copper (Cu), zinc (Zn), arsenic (As), silver (Ag), antimony (Sb), mercury (Hg), and lead (Pb) than samples that had been collected from various other parts of Puget Sound. Known sources of these metals include river runoff, sewage, industrial waste water, motor vehicle exhaust, smelter stack dust and smelter slag.

Sediments collected south of the Narrows, near Fox Island, and north of Colvos Passage near Blake Island, had As to Sb ratios of between 2:1 and 5:1, which indicates that slag discharges are being deposited in those areas. Sediments collected from the Tacoma area or near Seattle or Case Inlet had ratios of approximately 10:1, indicating that particles released to the atmosphere from a smelter are being accumulated in those areas. Antimony is the only heavy metal that has a relatively distinct source in the Tacoma area and, therefore, can be used for tracing the transport and dispersion of Commencement Bay particles to other areas of Puget Sound as exemplified by the Sb in sediments of Carr Inlet and near Blake Island.

The distribution of aromatic hydrocarbons would suggest that substantial weathering of hydrocarbons in these same sediments had occurred. Lower molecular weight aromatic hydrocarbons (monoaromatics) characteristic of the composition of petroleum products were present only in very low concentrations indicating the absence of a recent spill, discharge or accumulation of oily particulate material.

The highest concentrations of aromatic hydrocarbons were detected in sediments from Gig Harbor and northeast of Blake Island. However, conclusions cannot be drawn from these data because of the limited sampling and high degree of variability that was observed in replicate samples from the same location. Normalizing sediment aromatic hydrocarbon concentrations against sediment organic carbon content and sediment grain size shows that the sediment sample collected from Gig Harbor appears to contain aromatic hydrocarbon concentrations considerably higher than what would be predicted from other sediments analyzed as a part of this study, strongly suggesting a localized input. The range in aromatic hydrocarbon concentrations was consistent with other reported studies which examined sediments from the same or adjacent regions of Puget Sound but were considerably lower than what has been detected in sediments collected from some areas containing major embayments and adjacent waterways.

Chlorinated butadienes were detected in all sediments sampled in this study from Colvos Passage and southern Puget Sound. This observation, coupled with our current understanding of the circulation patterns of Commencement Bay and central and southern Puget Sound, would have predicted that waterways adjacent to Commencement Bay are a likely source for these compounds. Correlation of chlorinated butadiene concentrations in sediments with sediment organic carbon content and sediment grain size showed considerable scatter, however, none of the chlorinated butadiene concentrations showed the level of disparity observed in the concentration of total aromatic hydrocarbons detected in the sediment from Gig Harbor.

No trichlorobenzenes (<0.6 µg/kg) or hexachlorobenzene (<0.1 µg/kg) were detected in the sediments that were sampled and only those from Gig Harbor and northeast of Blake Island contained detectable levels of PCB.

We conducted a survey of marine birds whose nesting and feeding habits appear to be associated with the major urban areas of the central basin. Extensive surveys showed that the southern Puget Sound area has little diversity in the kinds of nesting birds. Large concentrations of Glaucous-Winged Gulls nest along the Tacoma and Seattle waterways and on the north end of Marrowstone Island.

Based on the results of the bird survey, we collected and analyzed tissue of selected bird types (Great Blue Heron, Pigeon Guillemot and Glaucous-Winged Gull) from urban and nonurban areas for selected inorganic and organic contaminants. Seven of the metals detected (Co, Fe, Se, Cd, Hg, Pb, Zn) in tissues of the Glaucous-Winged Gull showed significant differences in concentrations between pairs from the same study sites. With the exception of high levels of Zn, the concentrations of metals in these birds are within the range of concentrations found in other wild marine birds around the world.

Copper concentrations were higher in the birds that we examined from Puget Sound than levels reported for several other marine bird species around the world.

The concentrations of mercury in tissues of herons from Commencement Bay exceeded those reported for the same tissues in most other marine birds collected around the world. The tolerance of these birds to higher concentrations of mercury may be related to the presence of increased metallothionein components or to an adaptation to the presence of a higher level of mercury contamination in the food or water where they forage.

With the exception of trace amounts of one DDE isomer, PCBs were the only class of organic contaminants detected in the tissues of the marine birds that were sampled. Aromatic hydrocarbons, a compound class not detected in the birds, are readily metabolized by fish. With the exception of hexachlorobutadiene, chlorinated butadienes were not detected in marine birds of this study and have not been detected in off-bottom fish of Puget Sound. These results support our hypothesis that transfer of these compounds to marine birds is influenced by their fate in fish. Chlorinated benzenes also were not detected in the tissue of marine birds of this study.

Birds collected from Elliott and Commencement Bays had higher tissue concentrations of PCBs (29-80,385 ng/g, wet wt) than birds collected from Protection Island (<0.8-75 ng/g, wet wt) and Sequim Bay (235-5,466 ng/g wet wt). The birds from the urban areas of Puget Sound, in some cases, have abnormally high concentrations relative to documented concentrations of PCBs in marine birds from other areas of the world. These concentration levels may contribute to the death of marine birds through direct poisoning or mobilization of adipose tissue or through sublethal effects on the birds at times of environmental stress.

The concentration of PCBs in a Pigeon Guillemot egg from this study was very high (~11 ppm) in the majority of cases in comparison with concentration in eggs of marine birds from other areas of North America. The concentration was also higher than that observed by others to eliminate hatchability in chicken eggs, but it was also at a level shown not to affect egg shell thickness.

Biomagnification of PCBs from off-bottom fish to marine birds ranged from approximately 100 to 1,000, which was roughly a factor of 10 lower than that observed for the biomagnification of PCBs from sea water to fish. Overall biomagnification from seawater to bird was 4,000 to 54 million and from seawater to bird egg was 220,000 to 7.5 million.

PCBs appear to be a relatively unique class of compounds in that neither fish nor birds have developed systems to permit effective elimination of those components through metabolism and excretion. Therefore, current abiotic and biotic concentrations of PCBs in Puget Sound could be producing body burdens of PCBs in marine birds sufficient to produce ecological stress. Increases in this body burden through increases in abiotic or biotic concentrations could enhance this stress leading to long-term impact to marine bird populations of Puget Sound.

1.0 INTRODUCTION

Over the past several years, the MESA Puget Sound Project, a part of the National Oceanic and Atmospheric Administration's Marine Ecosystems Analysis Program, and other agencies have sponsored or performed research which has resulted in the accumulation of data on the concentrations of organic and inorganic toxicants in the various abiotic and biotic compartments of Puget Sound and the Strait of Juan de Fuca (Riley, et al., 1981; Riley et al., 1980, Dexter et al., 1981; Konasewich et al., 1982; Malins, 1982; Gahler et al., 1982). Data on the chemistry of the sediments in Puget Sound and the Strait of Juan de Fuca are important to the better understanding of the historical impact of toxicants to the Puget Sound region and their distributions and fates. Scientists who study the tidal and circulation patterns of Puget Sound can use such information to aid in their interpretation of where these toxicants will be transported and accumulated in sediments over time. Such information is important in understanding the long-term accumulation of pollutants in a water body due to man's activities or to changes that may occur (reduction) due to the implementation of mitigative actions.

Other studies have reported on the relationship between the presence of these toxicants and effects on the marine biota of Puget Sound (Chapman et al., 1982; Malins et al., 1982; Konasewich et al., 1982; Swartz et al., 1982; Dexter et al., 1981; Malins et al., 1980). However, very little information is available on toxicant contamination in higher trophic level animals residing in this region. Such information is necessary to properly assess the extent of toxicant contamination to the biota and to determine how the levels of contamination are influenced by increases or decreases in toxicant input to Puget Sound.

The purpose of this study was three-fold: (1) To determine the concentrations of selected inorganic and organic toxicants in surface sediments from parts of central and southern Puget Sound suspected to have been contaminated by these pollutants during their discharge and advection out of Commencement Bay; (2) To conduct a survey of marine birds in Puget Sound; and (3) Based on the survey, to collect birds from urban and nonurban regions of Puget Sound and the Strait of Juan de Fuca and analyze selected tissues from these birds for selected organic and inorganic toxicants.

Results of this investigation have been used to increase our knowledge of the concentrations and distributions of toxicants in sediments from Puget Sound and the relationships between toxicants identified in the abiotic and biotic compartments of Puget Sound and marine birds of the same region. Such knowledge is necessary in order to better understand the impact of man's activities to this region.

2.0 METHODS AND MATERIALS

2.1 Sampling Sites

2.1.1 Sediments

The strategy for collecting sediments in Puget Sound was to sample areas suspected to be contaminated by organic chemicals and heavy metals discharged into and advected out of Commencement Bay. Past studies show that both organic chemicals and heavy metals accumulate at higher concentrations in fine grain muddy sediments than in coarser sandy sediments. Therefore, sediment sampling stations were chosen in areas either known or suspected to contain fine-grain sediments. Only the surface layer (0-5 cm) of sediment was sampled because this layer should reflect contaminants that have been deposited during the last decade (Crecelius et al., 1975; Curl, 1982 and Crecelius et al., 1983).

The water circulation pattern for the main basin and southern basin indicated that contaminants transported out of Commencement Bay will travel either northward into East Passage and Colvos Passage or southward through the Narrows and into the southern basin (McGary and Lincoln, 1977). Thus, station locations were selected in bays, harbors, inlets, and in several deep water locations north and south of the Narrows. Specific sites for the collection of sediments in August 1982 are shown in Figure 1. Sampling station locations and the water depths in which the sediment was collected are given in Table 1. East Passage was not sampled because METRO of Seattle was analyzing sediments from that area.

2.1.2. Birds

A survey of breeding marine birds in Puget Sound was conducted by subcontractors (T. R. Wahl and S. M. Speich) from June 21 through July 6, 1982. As part of this survey, both Elliott and Commencement Bays were searched for nest sites. These areas were of particular interest due to the known presence of elevated levels of organic and inorganic toxicants in water, suspended matter, sediments, and biota. These bays (Figure 2) served as two of our study sites and were considered as areas where elevated toxicant levels were expected. Protection Island, located in the eastern Strait of Juan de Fuca, served as a control area for Glaucous-Winged Gulls and Pigeon Guillemots and Sequim Bay served as a control site for the Great Blue Heron.

In Elliott Bay, the Pigeon Guillemot, Great Blue Heron, Mallard, Glaucous-Winged Gull and Belted Kingfisher were considered as sampling possibilities. In discussions with Edward Long of NOAA, we agreed to limit our collecting efforts to guillemots, herons, and gulls. Two nesting pairs of guillemots were located in Seattle's West Waterway. One nest contained four infertile eggs while the other contained two

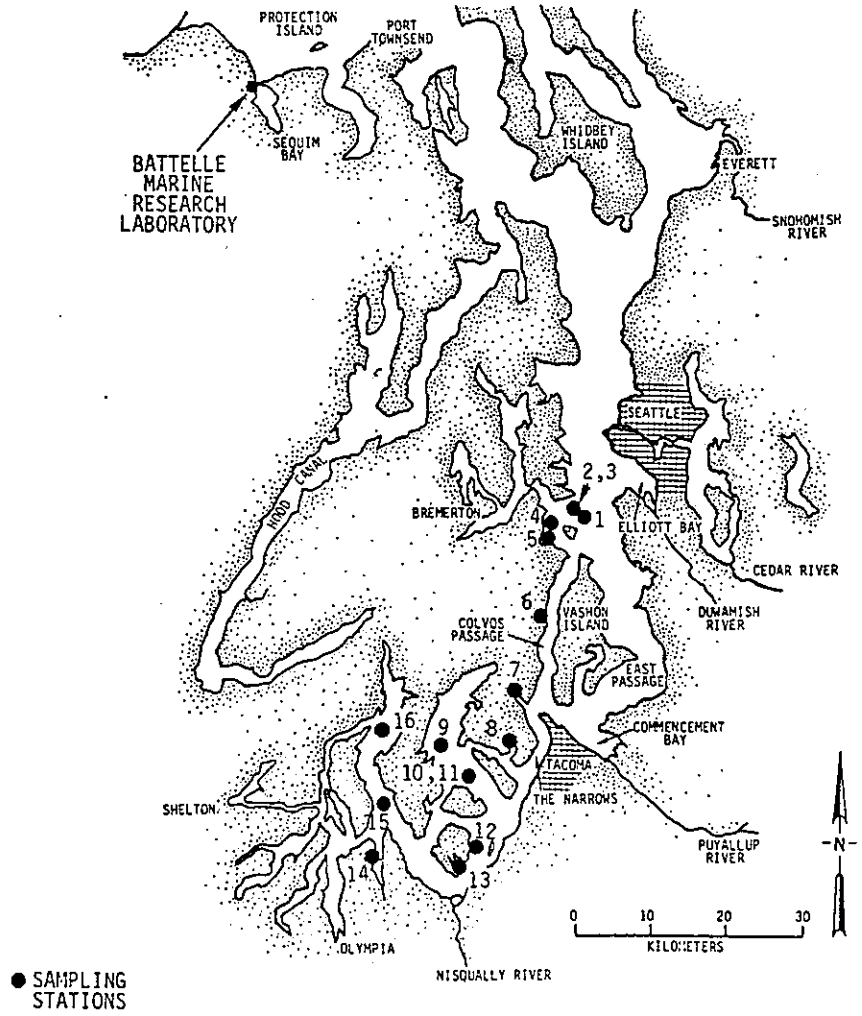

Figure 1

Sites and identification numbers of the sediment sampling stations in Puget Sound

young. One of the young was collected for tissue analysis and all eggs were saved for future analyses. These nests were the only nests we observed during the intensive July-August surveys. A colony of Glaucous-Winged Gulls located on Pier 30 of Seattle's East Waterway provided five young gulls. No nest sites were found for Great Blue Herons; therefore, adult birds were collected around Kellogg Island in the lower Duwamish River.

The preliminary surveys of the Tacoma waterways suggested that four nests of Pigeon Guillemots may be found in Blair and Milwaukee Waterways. Intensive nest searches in July and August indicated that no nests were present in either area. Thus, we were unable to collect any guillemots from Commencement Bay. A large colony of Glaucous-Winged Gulls was located on the St. Regis Paper Company dock

Table 1

Location and water depth of sediment sampling stations

Sample I.D.	Location			Depth
NG-1	Northeast of Blake Island	47° 33.5'N	122° 28.5'W	201 m
NG-2	North of Blake Island	47° 33.7'N	122° 29.6'W	88 m
NG-3	Replicate of NG-2	47° 33.7'N	122° 29.6'W	88 m
NG-4	West of Blake Island	47° 32.3'N	122° 30.7'W	110 m
NG-5	Yukon Harbor	47° 31.8'N	122° 31.8'W	10 m
NG-6	Olalla Bay	47° 25.2'N	122° 32.5'W	2 m
NG-7	Gig Harbor	47° 20.2'N	122° 35.0'W	7 m
NG-8	Wollochet Bay	47° 16.8'N	122° 35.6'W	18 m
NG-9	Carr Inlet North	47° 17.3'N	122° 42.4'W	91 m
NG-10	Carr Inlet South	47° 13.3'N	122° 37.9'W	143 m
NG-11	Replicate of NG-10	47° 13.3'N	122° 37.9'W	143 m
NG-12	East of Anderson Island	47° 10.5'N	122° 39.2'W	148 m
NG-13	Oro Bay	47° 8.5'N	122° 41.4'W	8 m
NG-14	Henderson Inlet	47° 9.4'N	122° 49.8'W	12 m
NG-15	South Case Inlet	47° 13.2'N	122° 49.2'W	82 m
NG-16	North Case Inlet	47° 17.8'N	122° 49.3'W	30 m

between the St. Paul and Middle Waterways where we collected five young gulls. No Great Blue Heron colonies occurred adjacent to the Tacoma Waterways. The closest colonies occurred at Peasley Canyon, Dumas Bay, and Maury Island (Shipe and Scott, 1981). The extent to which birds nesting at these sites utilize Commencement Bay is unknown, thus sampling tissues from young may not result in data representative of pollutants present in Commencement Bay. We therefore elected to collect adult birds which fed in Hylebos Waterway.

Several areas were examined as possible nonurban areas for collecting marine birds. Protection Island was chosen as the best site since it contained nesting guillemots and gulls. The guillemot collecting was facilitated because we were able to use samples collected by a Walla Walla College researcher, Dr. Joseph Galusha. Five young gulls were collected by Battelle researchers. A Great Blue Heron was found dead near the Battelle Marine Research facility in Sequim and served as a sample from a nonurban area.

2.2 Bird Survey

A survey of breeding marine birds in Puget Sound conducted by the subcontractors recorded observations of types of breeding birds, their abundance and nest site locations. The survey included the shorelines of Puget Sound in the area south of Point Marrowstone, excluding both Hood Canal and the waters east of Whidbey Island (Appendix A). This study was not intended as a comprehensive survey, but rather served as a basis for selecting birds for chemical analysis: We only looked for nesting birds.

Censuses covering 300 m widths were conducted from a small boat along open shorelines, bays, rocks and islands and adjacent open waters. Fixed-wing aircraft was used for a census along relatively straight, open shorelines and across open waters. These methods are the same as those used by Manuwal et al. (1979) in NOAA/MESA studies in northern Puget Sound waters in 1978-79 and thus provide for some continuity with data reported in this study. Several open water transects were conducted from ferries. Birds observed outside strip-transects were recorded for nonquantitative analyses. Approximately 50-60 hours, exclusive of travel time, were spent for a census of birds.

The study area (Figure 2) was divided into 41 geographic subregions, each essentially a roughly definable body of water, often corresponding to established designations used on navigation charts. Survey data within each of these subregions were tabulated and summed.

Intensive nest surveys were conducted in Elliott and Commencement Bays by R. E. Fitzner, Battelle, during July and August. These surveys provided precise locations of breeding birds and their nesting densities that were not included in the earlier work. Several additional breeding colonies of Glaucous-Winged Gulls were discovered during these surveys.

2.3 General Sampling and Analytical Strategy

Details of the sampling strategy for sediments and birds are given in Appendix B. The overall approach to the chemical analyses of bird tissue, bird egg and sediment is depicted in Figure 3. Brief descriptions of the approach are included in this section and details are given in Appendix C. Brief descriptions of the sampling and analytical strategies are described below.

2.3.1 Sediments

Samples of surface sediment (0-5 cm layer) were collected by a VanVeen grab sampler during August 1982. Approximately 200 g (wet wt) of surface sediment were removed from the sampler, homogenized, split and stored. The sediments designated for organic chemical analysis

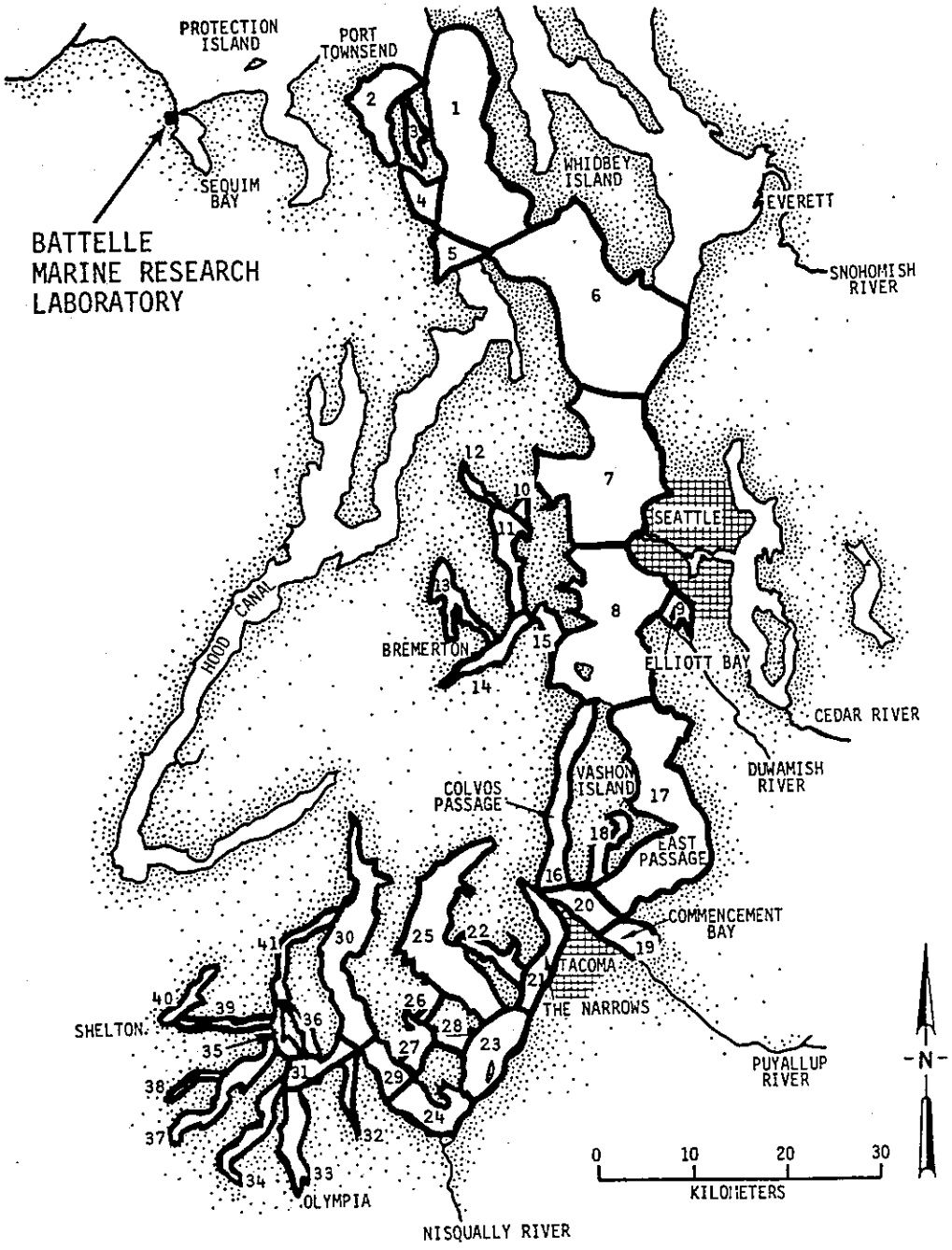

Figure 2

Study areas and subregions of marine bird surveys

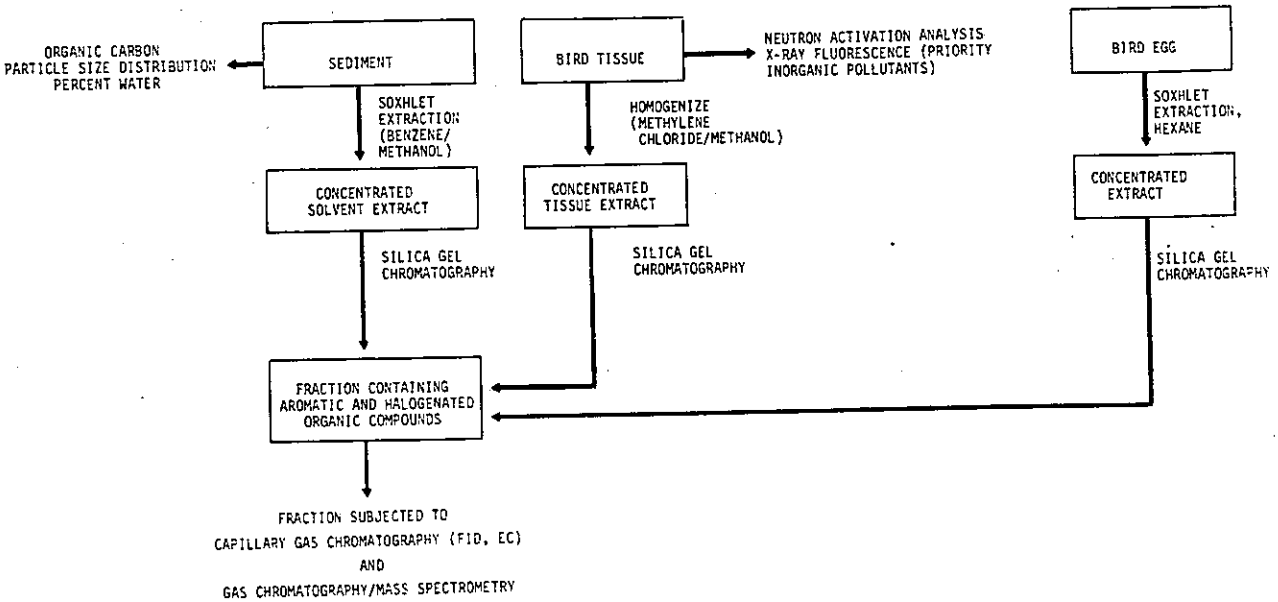

Figure 3

Overall approach to the preparation and fractionation for chemical analysis of extracts of sediment, bird tissue and bird egg

were frozen in precleaned glass jars and subsequently transported to the Battelle Richland facility. The sediments designated for metals, percent solids, organic carbon content, and grain size analysis were refrigerated, but not frozen. Details of the sampling approach are given in Appendix B.

Physical properties and organic carbon. The 16 sediment samples were analyzed for grain size, percent solids, and organic carbon. Grain size was determined by a combination of sieving and particle settling in water. The results are expressed as percent sand, silt, and clay. The total solid content of the sediment was determined by freeze-drying a known wet weight of sediment to constant weight. The organic carbon content of the sediments was determined by measuring the quantity of CO_2 generated when sediment was combusted. The carbonate carbon in the sediments was removed by dilute-acid treatment before the organic carbon determination. Details of the approaches are given in Appendix C.

Inorganic analysis of sediment. The inorganic constituents of sediments were quantified by neutron activation analysis (NAA), energy dispersive x-ray fluorescence (XRF) and atomic adsorption (AA). NBS environmental standards were used to calibrate the instruments. We used procedures for NAA as described by Ondov et al. (1975). The XRF

analytical procedure used in our laboratory and the results for 23 elements in standard reference materials are described by Nielson (1977). Details of the approach are described in Appendix C.

Organic analysis of sediment. We analyzed the sediment samples for a select group of aromatic hydrocarbons and halogenated organic compounds (e.g., chlorinated butadienes, chlorinated benzenes, and polychlorinated biphenyls). These compound types have been detected in sediments throughout the Puget Sound region and have been the focus of analysis schemes used by other agencies including NOAA, EPA, Seattle METRO and the Army Corps of Engineers. Thus, by focusing on these selected organic compound types, our data sets would be compatible with these other research organizations. These components were identified and quantified using capillary gas chromatography and capillary gas chromatography/mass spectrometry coupled with specific detectors. Details of the approaches are described in Appendix C.

Intercomparison study. Sediment from northeast of Blake Island (NG-1) and north of Blake Island (NG-3) were subsampled at the Battelle Marine Research Laboratory and frozen. One set of samples was sent along with other sediment subsamples to the Battelle Richland facility for the analysis of select aromatic hydrocarbons and halogenated organic compounds. The other set of subsamples of NG-1 and NG-3 were sent to Raleigh Farlow of Seattle METRO. Our methods for quantification of the above compounds in sediments are described in Appendix C. Briefly, Seattle Metro employs gas chromatographic/mass spectrometric stable isotope dilution/surrogate compound methods for quantification of aromatic hydrocarbon components. Halogenated organics (CBD and PCB) are quantified by gas chromatography employing an electron capture detector. Prior to gas chromatographic analysis, samples are subjected to cleanup, employing high pressure gel permeation chromatography to simplify the complex chemical matrix.

2.3.2 Birds

We examined the list of birds obtained from the breeding marine bird surveys, their abundance and nest site locations. These data were evaluated to determine which species would be most suitable for assessment of tissue distributions of organic and inorganic toxicants. We considered the abundance of species, ease of collection, and special importance in Puget Sound marine food chains. The list of potential study species was discussed with Edward R. Long, NOAA/OMPA, who suggested a tentative number of specimens to be collected. (Collecting methods are described in Appendix B.) Our specimens were collected from two urban areas (Elliott and Commencement Bays) and two sites (Protection Island and Sequim Bay) far removed from these urban areas. Those specimens are listed in Table 2. Of these specimens, two guillemots, twelve gulls and five herons were selected for chemical analysis. The gulls and guillemots collected were prefledglings while the herons were all adult birds. Tissues analyzed included liver and kidney in the gulls and guillemots; and liver, kidney and adipose in the herons. The tissue selection was based upon

Table 2

Bird specimens collected, and number of samples and sample types prepared for chemical analysis

Number Collected	Number Analyzed	Tissues Selected	Location	Date Collected
Great Blue Heron				
2 adults	2	L,K,A	Hylebos Waterway, Tacoma	Aug 1982
2 adults	2	L,K,A	Duwamish River, Kellogg Island, Seattle	3 Sep 1982
1 adult	1	L,K,A	Sequim Bay, Olympic Peninsula	Aug 1982
Pigeon Guillemot				
1 prefledgling	1	L,K	West Duwamish Waterway, Seattle	Aug 1982
4 infertile eggs	1		West Duwamish Waterway, Seattle	Aug 1982
2-3 prefledglings	1	L,K	Protection Island, Strait of Juan de Fuca	Aug 1982
2-3 infertile eggs			Protection Island, Strait of Juan de Fuca	Aug 1982
Glaucous-Winged Gull				
5 prefledglings	4	L,K	Puyallup River Delta, Tacoma Waterfront	Aug 1982
5 prefledglings	4	L,K	East Duwamish Waterway, Seattle	Aug 1982
5 prefledglings	4	L,K	Protection Island, Strait of Juan de Fuca	Aug 1982

1982 Totals:

Species	Samples Collected
Great Blue Heron	5 adults
Pigeon Guillemot	~4 prefledglings, ~8 eggs
Glaucous-Winged Gull	15 prefledglings

* L = Liver, K = Kidney, A = Adipose (fat)

published literature concerning target tissues and organs for organic and inorganic pollutants (Jenkins 1981, Olendorf et al. 1978, Hutton 1981). One guillemot egg was included for organic chemical analysis. The total number of bird samples analyzed was 44.

Inorganic analyses. Our selection of bird species, tissue types, and inorganic toxicants analyzed in this study was based largely on published findings related to the abundance, biological availability, and physiological actions of inorganics to marine birds summarized below. A variety of organic toxicants are present in the waters and sediments of Elliott and Commencement Bays. We chose birds that nest in Puget Sound and are abundant. The liver and kidney were chosen as target organs for tissue analysis of inorganic constituents.

The analyses of the kidney and liver tissues from Glaucous-Winged Gulls, Great Blue Herons and Pigeon Guillemots enables us to make comparisons between different feeding levels. We observed gulls as primarily intertidal invertebrate feeders while herons and guillemots were noted feeding primarily on fish. Jenkins (1981) provides a review of bird organs best selected to analyze for trace elements. The liver of birds was listed as the target organ for analysis of arsenic, cadmium, copper, mercury, and selenium. The kidney was the

selected organ for analysis of tin and nickel and was also used in analysis for mercury and cadmium. Olendorf et al. (1978) found that organic and inorganic mercury compounds were present in higher concentrations in the liver and kidney than in other organs.

Hutton (1981) studied accumulation of heavy metals in oystercatcher, skua, and herring gull. He found that the kidney was the critical organ for correlation of cadmium concentration and chronic effects. He also indicated that the age of the bird should be taken into account when assessing significance of renal cadmium levels. The binding of cadmium to the protein, metallothionein, appears to be responsible for its long biological half-life and its retention in the kidney. Thus, older birds would be expected to have higher cadmium levels than younger birds. Hutton (1981) also states that the kidney is a suitable organ for monitoring mercury accumulation because renal concentrations were similar to those in liver and concentrations in the kidney and liver were correlated.

Cheney et al. (1981) also indicate that age class and tissue type affect the patterns of accumulation of metals. Cadmium concentrations were found to be highest in kidney while lead concentrations were highest in the bone of adult birds. Stoneburner and Harrison (1981), Osborn et al. (1979), Hutton (1981) and Cheney et al. (1981) emphasized that seasonal, behavioral and physiological parameters affect the levels of inorganics in bird tissues. Tissue concentrations of toxicants differ among species because different feeding habits affect rates of exposure and physiological states are affected by age and breeding conditions.

Organic analyses. Polychlorinated biphenyls (PCBs), chlorinated butadienes (CBDs), and aromatic hydrocarbons (AHs) are a few of the more commonly known classes of toxicants identified in the abiotic and biotic compartments of Puget Sound. We selected adipose tissue from herons and liver and kidney from herons, gulls and guillemots for analysis of organic constituents. One Pigeon Guillemot egg from Elliott Bay was also analyzed for these same components.

Lawler et al. (1978) in a study of petroleum-exposed mallard ducks found that adipose tissue had accumulated far more aromatic hydrocarbons than other tissues. McEwan and Whitehead (1980) in studying petroleum hydrocarbon uptake in experimentally fed Glaucous-Winged Gulls and Mallard ducks found that gulls accumulated higher concentrations of hydrocarbons in liver and kidney than Mallards.

Greichus et al. (1973) state that both organochlorine insecticides and PCBs are stored in adipose tissue of birds and are difficult to eliminate from the body. Stendell (1976) states that PCBs are readily taken up in animal tissues and depuration rates are reasonably low. Like lipid soluble pesticides, PCBs accumulate in the adipose tissue and have been shown to move out of adipose tissue during lipid mobilization. In experimentally dosed birds, Dahlgren et al. (1972) and Lincer and Peakall (1973) found the highest PCB concentrations in adipose tissue followed by kidney, liver, brain, muscle and blood.

3.0 RESULTS

3.1 Sediments

3.1.1 Physical and Chemical Parameters

The results of sediment percent solids, organic carbon and grain size are summarized in Table 3 for each sediment. There is a relationship among these data due to the fact that coarser grain size sediments normally contain higher percent solids (that is, less water) and less organic carbon than finer grain size sediments. The grain size data are useful when interpreting the inorganic and organic compound data since these contaminants tend to accumulate on the surfaces of fine particles. The association of contaminants with fine-grain sediment is mainly due to the higher ratio of surface area to volume for muddy sediments than for sandy sediments. The coarsest

Table 3

Physical properties and organic carbon content of sediment

Sample Identification	Total Solids %	Total Organic Carbon % TOC	Sand (>0.063 mm) %	Silt (0.063 -0.004 mm) %	Clay (<0.004 mm) %
NG-1	32	1.50	22	54	24
NG-2	57	0.72	74	20	6
NG-3	33	0.67	69	23	8
NG-4	71	0.48	49	25	26
NG-5	73	0.25	89	5	6
NG-6	66	1.50	91	5	4
NG-7	52	1.10	66	34	0
NG-8	59	0.93	47	29	24
NG-9	45	1.40	54	29	17
NG-10	41	1.50	45	35	20
NG-11	31	1.40	37	61	2
NG-12	65	0.25	29	49	22
NG-13	66	0.57	88	12	0
NG-14	34	1.60	15	62	23
NG-15	36	1.30	31	45	24
NG-16	27	1.40	12	58	30

sediments were from stations 5, 6, and 13. The finest sediments were from stations 1, 11, and 16. Duplicate samples were collected at two locations to obtain an estimate of variability within a station. The duplicates came from stations 2 and 3 and stations 10 and 11. The agreement in physical properties between these two sets of duplicates indicates that the total solids vary 20% between duplicate grab samples, organic carbon varies 0.1%, and percent of silt or clay can vary at least 20%.

3.1.2. Inorganic Analysis

The elemental concentrations in two Canadian marine sediment reference materials (National Research Council of Canada, 1981) are summarized in Appendix D, Table D-1. These data indicate that our analytical techniques for elements in sediments were accurate. However, the accuracy of concentrations of Pb, Se, Ag, and Sc cannot be verified from these standards, because for Pb our detection level (0.5%) was not low enough and the other three elements were either not certified or reported for the standards. The concentrations of Se, Ag, and Sc were determined in U.S. National Bureau of Standard biological reference material (Appendix D, Table D-2) and are in agreement with certified values.

The concentrations of 23 elements in 16 sediments are shown in Appendix D, Tables D-3 and D-4. Samples 5 and 13 were analyzed in triplicate to demonstrate the analytical variability. The sample pairs, 2 and 3 and 10 and 11, are two different sediment samples from each of the two different stations and thus the differences in concentrations of elements between these pairs are an estimate of the combined field and analytical variability. Generally, the variability in element concentrations between different sediment samples collected from a station is equal to the analytical variability.

The concentrations of 18 elements in East Passage surface sediment and baseline sediment are also included in Appendix D, Tables D-3 and D-4, for comparative purposes. The East Passage surface sediment was collected from latitude 47° 28.9' N, longitude 122° 24.9' W, and a water depth of 190 m. The elemental concentrations in this sediment are typical for fine-grain surface sediments in the main basin. Sediments collected in industrial harbors or commercial waterways contain higher concentrations of several metals including Cu, Zn, As, Ag, Cd, Sb, Hg, and Pb (Crecelius et al., 1975; Dexter et al., 1981; Malins, 1982; Crecelius et al. 1983). A note of caution is given here because some of the Cd, Ag, As, and Se sediment data summarized by Dexter et al. (1981) and reported by Malins et al. (1980 and 1982) are enormously high and should be considered suspect.

The baseline sediment chemistry data in Tables D-3 and D-4 are from eight fine-grained sediment cores that were radiometrically age-dated to have been deposited approximately 100 years ago (Crecelius, unpublished data). These data are in agreement with those reported for similar age sediments from Commencement Bay sediment cores (Crecelius et al., 1983).

3.1.3 Organic Analysis

Screening for selected organic contaminants. Extracts of all samples of sediments from Colvos Passage and southern Puget Sound were subjected to a preliminary screening by capillary gas chromatography, equipped with electron capture and flame-ionization detectors to qualitatively determine the numbers and types of compound classes that were present. Based on this screening analysis, sediment extracts were selected that appeared to best represent the gross compositional characteristics of all of the sediments sampled. These extracts were then subjected to gas chromatographic/mass spectrometric (GC/MS) analysis to confirm the presence or absence of specific compounds and compound types in the sediments. This screening approach also was used in the preliminary analysis of all bird tissue samples.

Screening for aromatic hydrocarbons and halogenated organic compounds. Qualitative gas chromatographic analysis of the extracts of 16 sediment samples using flame ionization detection produced chromatograms containing very similar aromatic hydrocarbon profiles. Many components in the chromatographic profiles matched retention times with our standard mix used in the quantification of selected aromatic hydrocarbons (Figure 4). No profile revealed the presence of a hot spot containing low molecular weight aromatics (possibly representing a petroleum distillate) as observed in the analysis of a sediment core from Blair Waterway (Riley et al., 1981).

Analysis of the same set of samples using electron capture detection (Figure 5) showed, in 13 out of the 16 samples, the presence of a set of electron-capturing components whose profiles and retention times were similar to chlorinated butadienes detected previously in cores from Hylebos Waterway (Riley et al., 1981) and Commencement Bay (Crecelius et al., 1983). Only sediment samples from northeast of Blake Island and Gig Harbor showed components indicative of PCB. Based on these observations, we selected a sample of sediment from north of Blake Island for our GC/MS analyses.

GC/MS Analysis of Sediment Sample. GC/MS analysis of a sediment sample from north of Blake Island confirmed the presence of aromatic hydrocarbons. We also confirmed the presence of trichloro- and tetrachloro-butadienes. Further examination did not reveal the presence of detectable levels of hexachlorobutadiene, trichlorobenzenes or hexachlorobenzene.

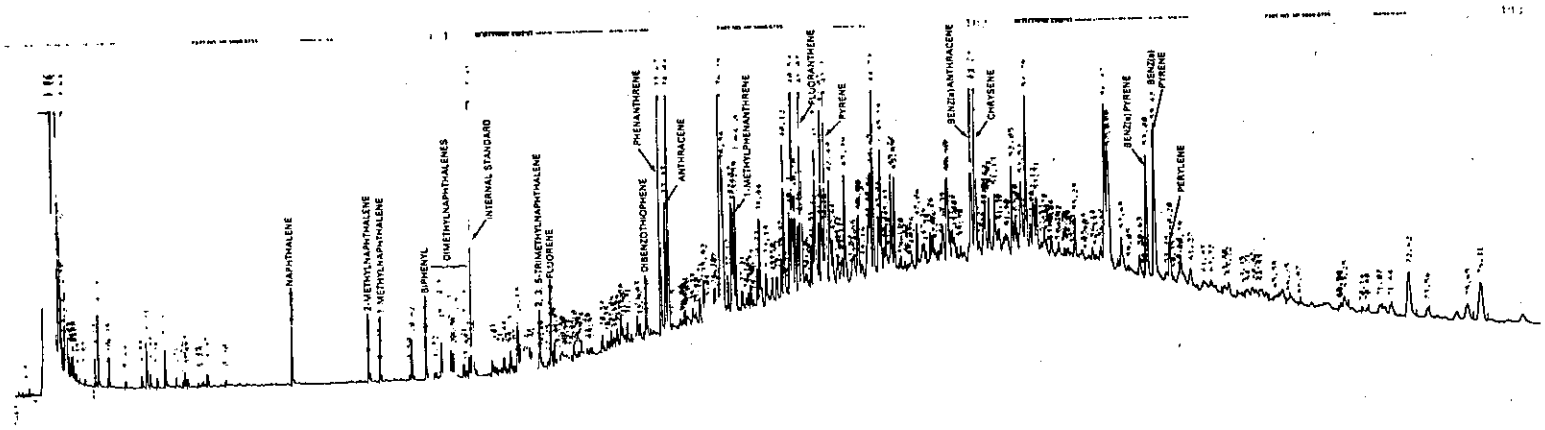

Figure 4

GC chromatogram (FID detection) depicting the aromatic hydrocarbon components isolated from Gig Harbor (NG-7) sediment sample. Components named are those present in our standard mix.

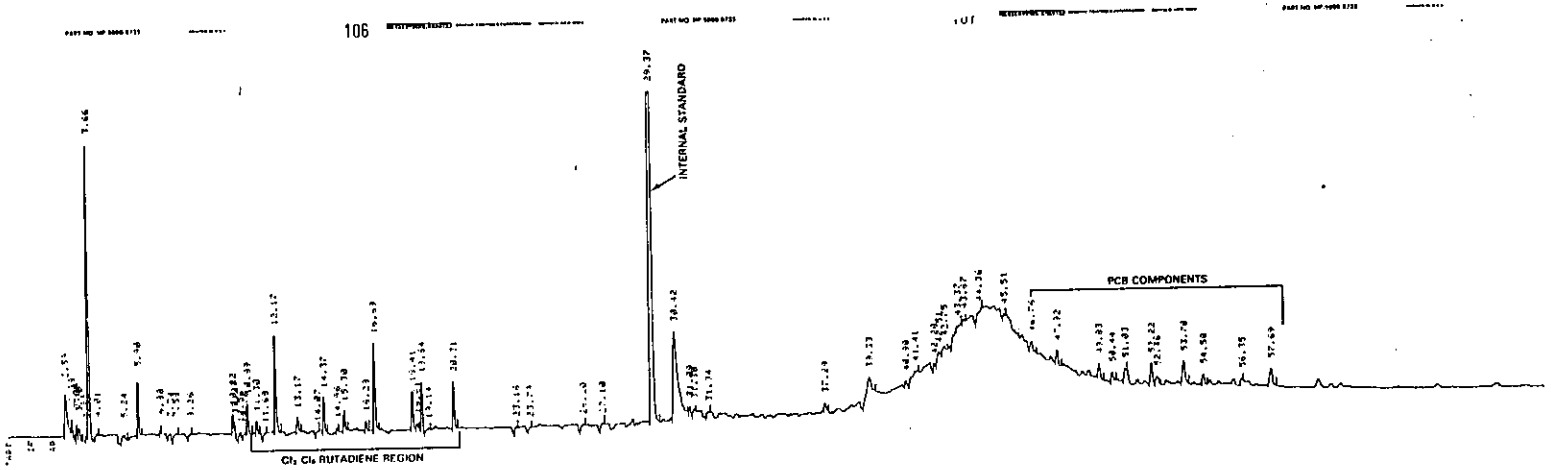

Figure 5

GC chromatogram (EC detector) depicting the halogenated components isolated from Gig Harbor (NG-7) sediment sample

Profile of total selected aromatic hydrocarbons in sediments. A summation of the concentrations of selected aromatic hydrocarbons in sediments as a function of station location are shown in Figure 6. Concentrations of aromatic hydrocarbons varied considerably from station to station and ranged from a low of 30 µg/kg at Yukon Harbor (NG-5) to a high of 2,154 µg/kg at Gig Harbor (NG-7). Due to the limited number of samples analyzed, our profile should not be taken as the absolute profile for the aromatic hydrocarbon distributions in Colvos Passage and southern Puget Sound. This point is supported by the results of duplicate analyses at two of the stations (Figure 6). In one case (stations NG-2, NG-3), total aromatic hydrocarbon concentrations were almost identical (331 vs 342 µg/kg). However, in the other case (stations NG-10, NG-11) variability was 56%. Detailed results of our sediment aromatic hydrocarbon analyses are listed in Appendix E in Tables E-1 through E-6. The distribution of individual aromatic hydrocarbons favored the higher molecular weight components containing three or more rings.

Relationships between aromatic hydrocarbon (AH) concentrations in sediments and sediment organic carbon and sediment grain size. Concentrations of the summation of selected aromatic hydrocarbons in sediment listed in Figure 6 were plotted against sediment organic carbon content and sediment grain size (Figure 7). This correlation was made with exclusion of sediment from Gig Harbor where aromatic hydrocarbon concentrations were quite high relative to organic carbon content and grain size. Neither relationship showed a strong correlation ($r = 0.61$ vs 0.39), however, of the two, aromatic hydrocarbon concentrations were more strongly correlated with sediment organic carbon content.

Profile of total selected halogenated organic compounds in sediments. A summation of the concentrations of PCB and CBD detected in sediments from central and southern Puget Sound are summarized in Figure 8. Trichlorobenzenes and hexachlorobenzene were not detected in these sediments. Detailed results of our analyses of sediments for halogenated organics are listed in Appendix E, Table E-7. Only the sediment samples collected from northeast of Blake Island and Gig Harbor contained detectable levels of PCB. Concentrations in these sediments were 36 µg/kg and 27 µg/kg, respectively. The highest concentration of CBD was detected in sediment from Carr Inlet South (89 µg/kg); the lowest was detected in sediments collected from Olalla Bay (1 µg/kg). Concentrations of CBD on replicate samples (NG-2, NG-3) from north of Blake Island and Carr Inlet South (NG-10, NG-11) were within a factor of two of each other.

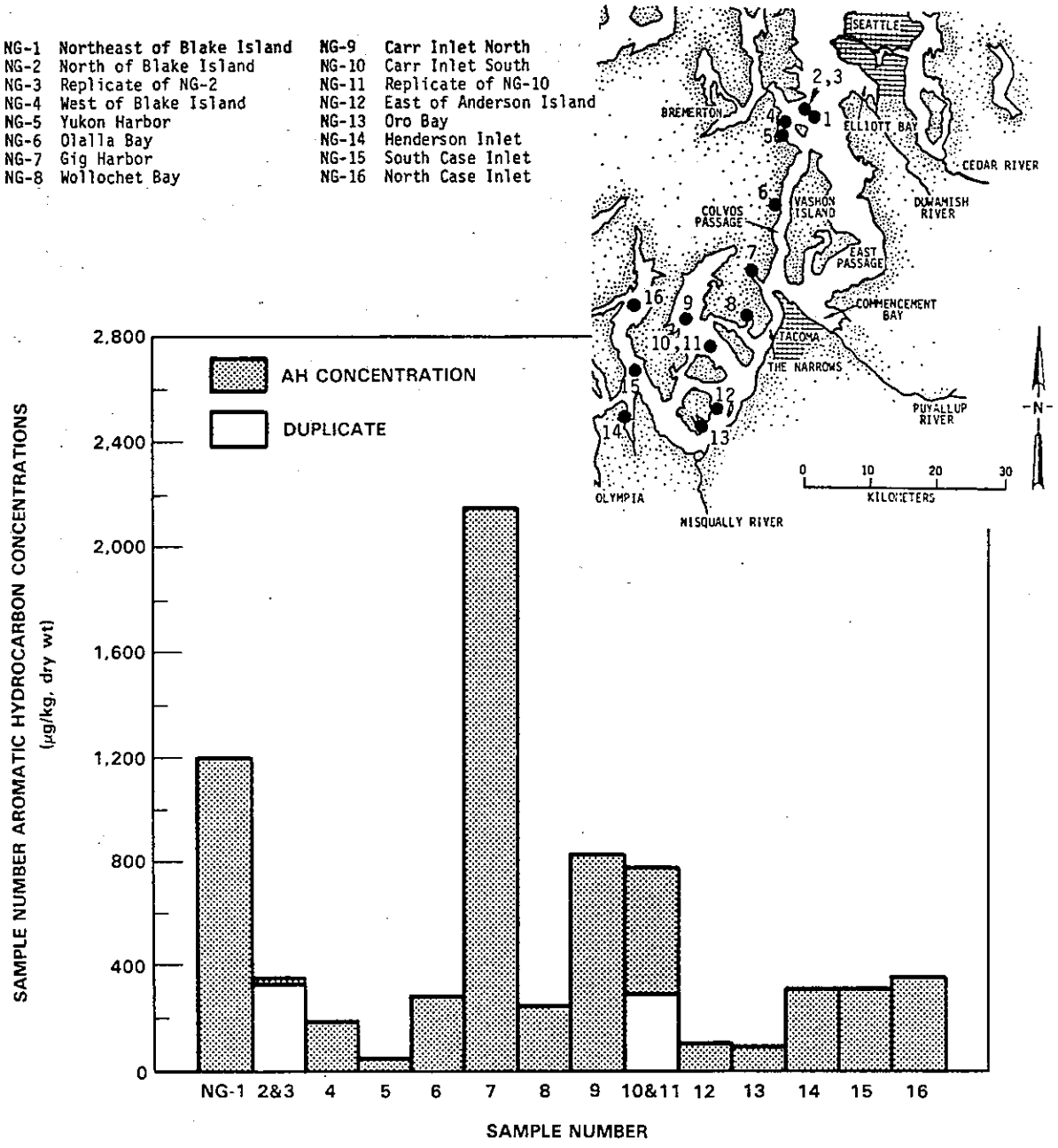

Figure 6

A summation of the concentrations of selected aromatic hydrocarbons in sediments from Colvos Passage and southern Puget Sound. Details of these results can be found in Appendix E, Tables E-1 through E-6.

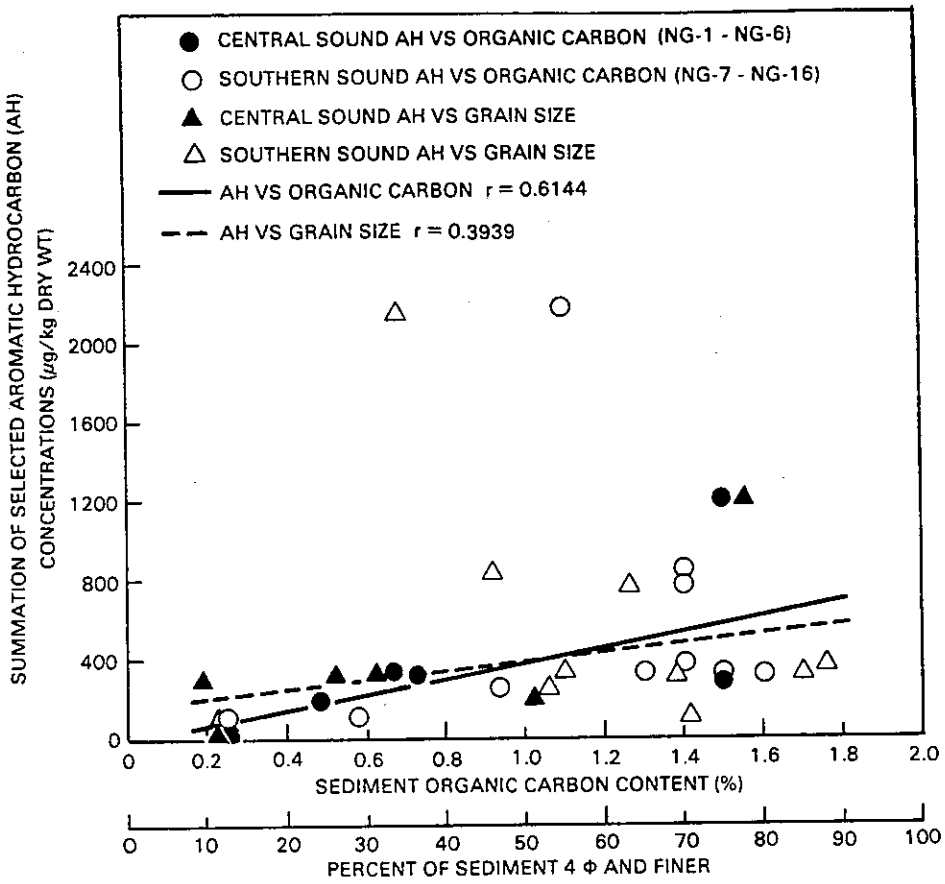

Figure 7

Plots of the concentrations of the summation of selected aromatic hydrocarbons versus (A) sediment organic carbon content and (B) sediment grain size.
Correlations exclude sample from Gig Harbor (NG-7).

Relationships between chlorinated butadiene (CBD) concentrations in sediments and sediment organic carbon content and sediment grain size. Concentrations of the summation of chlorinated butadienes (Figure 8) were plotted against sediment organic carbon content and sediment grain size (Figure 9). Neither relationship showed a strong correlation ($r = 0.72$ vs 0.40), however, as with the aromatic hydrocarbons, CBD concentrations were more strongly correlated with sediment organic carbon content. These correlations were made with the exclusion of sediment from Olalla Bay (NG-6) and Wollechet Bay (NG-8) where the CBD concentrations were quite low relative to what would be predicted on the basis of organic carbon content or grain size.

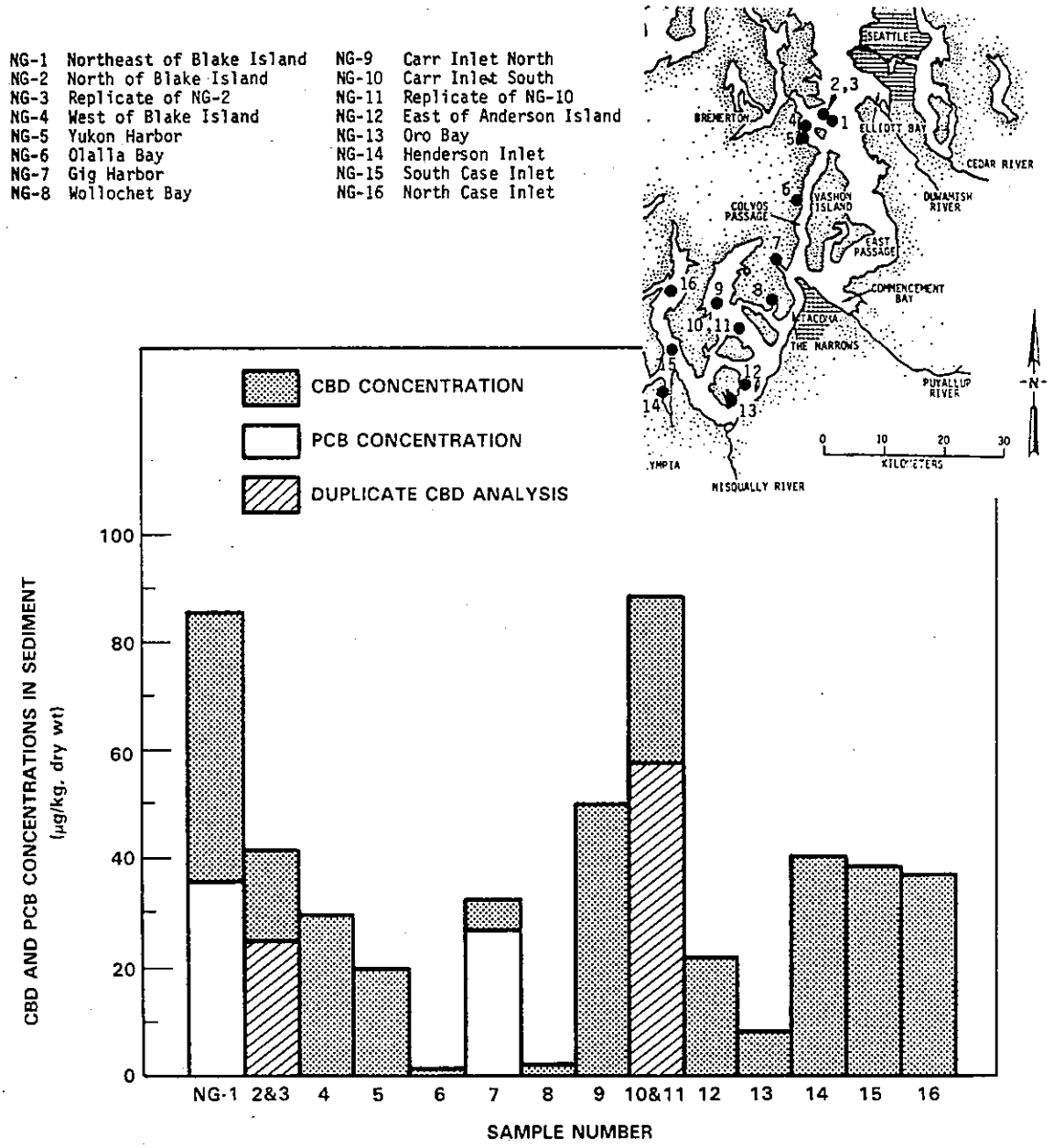

Figure 8

A summation of concentrations of total PCBs and total CBDs in sediments from Colvos Passage and southern Puget Sound. Details of these results can be found in Appendix E, Table E-7

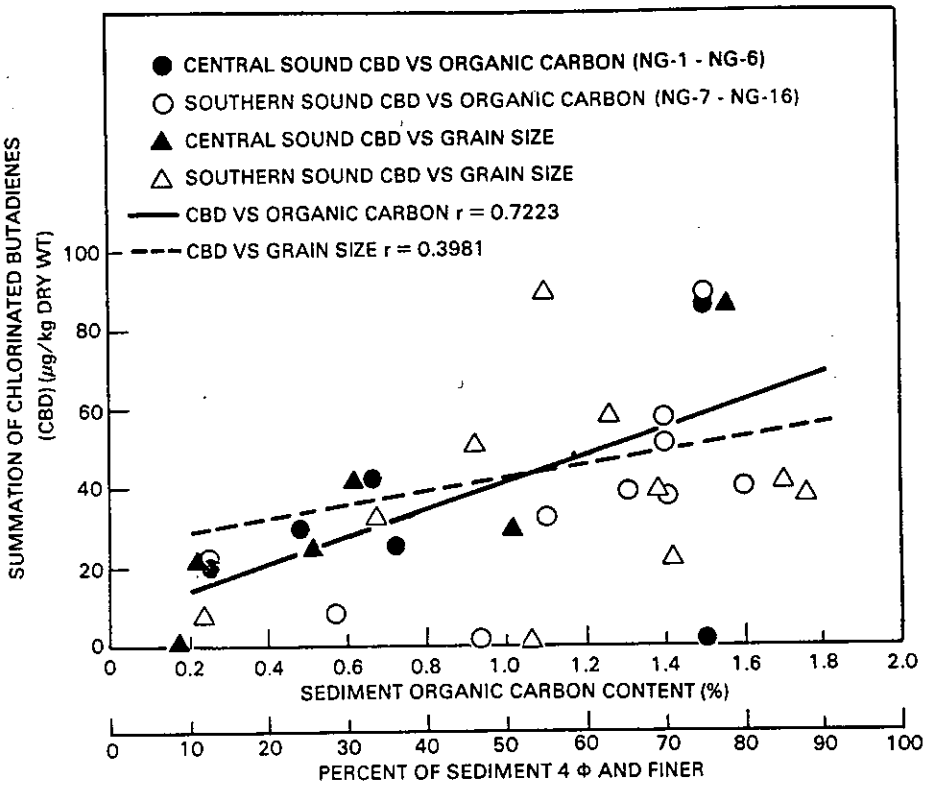

Figure 9

Plots of the concentrations of the summation of chlorinated butadienes vs (A) sediment organic carbon content and (B) sediment grain size. Correlations exclude samples from Olalla Bay (NG-6) and Wollochet Bay (NG-8).

Sediment intercomparison study. Results of the sediment intercomparison study between Battelle-Northwest and the Municipality of Metropolitan Seattle (METRO) are summarized in Table 4. Concentrations of selected aromatic hydrocarbons reported by METRO were higher than those reported by Battelle-Northwest. Battelle-Northwest used capillary gas chromatography coupled with flame ionization detection and an internal standard method to quantify these components. Values reported were corrected for procedural losses. METRO used a GC/MS method coupled with deuterated recovery standards to quantify these components. For the halogenated organic compounds, both organizations used capillary gas chromatography coupled with an electron capture detector for quantification. For both total CBD and total PCB, METRO reported higher values than Battelle-Northwest. METRO's data were corrected for procedural losses using halogenated organic compounds (e.g., chlorobenzenes) with similar boiling points for CBDs, whereas Battelle-Northwest's PCB and CBD data were not corrected for procedural losses. Procedural losses are losses that occur during the

Table 4

Concentrations (µg/kg, dry wt) of AHs, PCBs and CBDs in selected sediments from Puget Sound. Battelle-Northwest/METRO Intercomparison.

Component	Sample NG-1		Sample NG-3	
	Battelle-Northwest	METRO	Battelle-Northwest	METRO
Naphthalene	22	53	10	37
Fluorene	9	48	2	<20
Phenanthrene	29	98	7	37
Anthracene	38	34	10	<12
Fluoranthene	128	195	33	100
Pyrene	132	285	40	115
Benz(a)anthracene	195	214	62	64
Chrysene	184	245	55	84
Benzo(a)pyrene	96	250	26	83
Total selected aromatics	833	1,340	245	520
Total CBDs	86*	478	42*	307
Total PCBs	36*	67	N**	27

* Not corrected for procedural losses.

** N indicates PCBs not detected at measurable concentrations. The detection limit is similar to 0.1 µg/kg for individual PCB components.

preparation of sample extracts for gas chromatographic analysis. Trends between the laboratories for all three classes of compounds were consistent. That is to say, both labs showed that the concentrations of all components in sample NG-3 were lower than in sample NG-1.

3.2 Bird Survey

The numbers of birds observed by species during the June-July, 1982, breeding bird surveys are given in Table 5. These birds were known to be, or were very likely, nesting within each subregion shown

Table 5

Subregion totals of marine birds in the study area, June-July 1982 (individuals observed) Subregions correspond to those noted in Figure 2.

Subspecies	Pelagic Cormorant	Great Blue Heron	Canada Goose	Goose sp.	Mallard	Bald Eagle	Osprey	Glaucous-Winged Gull	Pigeon Guillemot	Marbled Murrelet
1 Southern Admiralty Inlet		2				1			13	20
2 Port Townsend	80	2				1		100	71	159
3 Killisut Harbor		6							118	
4 Oak Bay		1							21	49
5 Hood Canal Entrance		2						44	19	27
6 Northern Puget Sound		28							10	1
7 North Central Puget Sound		9	2	2	10			1	32	4
8 Central Puget Sound		5			4				15	12
9 Elliott Bay		11	20		30			28*	2	
10 Agate Passage									27	
11 Port Orchard		14			4				46	4
12 Liberty Bay				4					20	
13 Dyes Inlet		8			36				18	
14 Sinclair Inlet		14			16				8	
15 Rich Passage					16				1	1
16 Colvos Passage		3			4				1	
17 East Passage		9			20					1
18 Quartermaster Harbor		1		1	2				3	1
19 Dalco Passage									2	
20 Commencement Bay		29	6		45			529	10	
21 The Narrows									3	2
22 Hal Passage				4	32				11	
23 Steilacoom	**								5	3
24 Nisqually Reach		32				1			28	12
25 Carr Inlet		34			41	2			105	4
26 Pitt Passage		1				1			18	
27 Drayton Passage		8				1			9	4
28 Balch Passage									8	
29 Treble Point - Johnson Point		1				1			35	2
30 Case Inlet		51					N	N	93	5
31 Dana Passage		1							9	2
32 Henderson Inlet		6				2			12	
33 Budd Inlet		4			9			30	36	
34 Eld Inlet		1			2				21	
35 Squazin Pass Area		10		4	2				19	
36 Peale Passage		2					N		11	
37 Totten Inlet		35			7				44	
38 Skookum Inlet		2							8	
39 Hammersley Inlet		10		3	13		1		49	
40 Oakland Bay		7			5	1		150	1	
41 Pickering Passage		14	1	4	8				8	
Total number of Individuals	80	363	29	22	306	11	1	882	970	313

* Reported number of 300 pairs nesting on buildings on or near Seattle Waterfront not included here.

** Totals include birds observed only along the outer edge of the delta viewed from well offshore in small boats.

N = possible nesting in the vicinity.

in Figure 2. These data reflect the numbers of individual birds observed, not pairs or nests, and include only those birds in breeding plumage.

We began the bird sample collection after we received the results of the subcontracted bird survey. While searching for collection sites, we also recorded numbers and locations of breeding and nonbreeding birds and nesting sites. Table 6 provides a list of species that we observed by location, by date, and provides estimates of the numbers of nests.

3.3 Analysis of Bird Tissue

3.3.1 Inorganic Analysis

Pollutant concentrations may vary seasonally (Gilbertson, 1974) and most likely will vary among bird species having different feeding and behavioral strategies (Bull et al., 1977). Table 7 lists the identification and physical properties of each tissue sample analyzed. Interspecific comparisons of the inorganic or organic residues detected in marine birds from the various study sites (Tacoma, Commencement Bay; Seattle, Elliott Bay; Protection Island, Sequim Bay), or among species, are probably of little value except to show that species of different feeding habits have different metal levels in their tissues. Table F-1 in Appendix F provides raw data on the inorganic analysis of tissues from each sample.

The mean concentrations of selected metals found in the livers and kidneys of four prefledglings from the three Glaucous-Winged Gull populations we sampled are presented in Table 8. Their values were compared statistically, using a nonparametric one-way Analysis of Variance (ANOVA). If a significant ANOVA was detected, the Mann-Whitney test (Ryan et al., 1981; Snedecor and Cochran, 1980) for determining significant differences between study site pairs was applied. This enabled us to evaluate where the differences occurred (i.e., Seattle vs Tacoma; Seattle vs Protection Island; or Tacoma vs Protection Island).

Seven of the metals analyzed showed differences in their concentrations in tissues between study site pairs (Table 9). Some of the tissue metal concentrations were different only between one pair of study sites (Fe, Zn) while others (Co, Se, Cd, Hg, Pb) had levels which were significantly different between two or all study site pairs. Concentrations of Co in liver were highest in Protection Island birds and lowest in Elliott Bay birds. A statistical comparison of these two study sites indicated concentrations of Co to be significantly different between means $\alpha = 0.05$. Concentrations of Co in kidney of the same birds also revealed a significant difference between Elliott Bay and Protection Island and between Commencement Bay and Protection Island. Again, Protection Island birds contained the highest concentrations of Co.

Table 6

Observations during July-September, 1982, bird surveys in Elliott and Commencement Bays

Location	Date	Birds Observed	Nests Observed
Seattle, West Waterway P/S dock	July 20	2 Pigeon Guillemots	2 1-2 young 1-4 infertile eggs
Seattle, Pier 30 East Waterway	July 20	60-75 Glaucous-Winged Gulls	30-40 nests over 2/3 with young rest with eggs
Seattle, East Waterway	July 20	4 Canada Geese 6 Mallards 8 Great Blue Herons 1 Kingfisher	
Tacoma, between St. Regis Mill and City Waterway	July 21	500-600 Glaucous-Winged Gulls	250 nests 60% with young 4-5 weeks old
Tacoma, St. Regis, Puyallup River Dock	July 21	400-500 Glaucous-Winged Gulls	200 nests
Tacoma, Blair Waterway		1 Pigeon Guillemot 2 Spotted Sandpipers 5 Great Blue Herons 2 Mallards	
Tacoma, Milwaukee Waterway	July 21	1 Pigeon Guillemot	
Tacoma, Hylebos Waterway	July 21	15 Canada Geese 20 Mallards 20 Great Blue Herons 2 Kingfishers 100 Glaucous-Winged Gulls	
Tacoma, Hylebos Waterway-below Highway 509 Bridge	July 29	1000 Glaucous-Winged Gulls 20 Mallards 10 Great Blue Herons 25 Western Sandpipers 4 Killdeer 1 Kingfisher	
Tacoma, Hylebos Waterway-below 4300 Street		580 Glaucous-Winged Gulls 4 Great Blue Herons 8 Western Sandpipers 15 Mallards	
Tacoma, Hylebos Waterway-above Highway 509 Bridge		2 Glaucous-Winged Gulls 2 Great Blue Herons 2 Killdeers 6 Mallards	
Tacoma, Hylebos Waterway-below Highway 509 Bridge on log boom and mud flats.	August 20	1000 Glaucous-Winged Gulls 20 New Gulls [redacted]10 Great Blue Herons 20 Mallards	
Seattle, Kellogg Island	September 2	30-40 Great Blue Herons 70-100 Mallards 2 Double Crested Cormorants 40 Glaucous-Winged Gulls 2 Kingfishers 10 Killdeers Numerous (over 300) Sandpipers	

Table 7

Bird tissue identification

Sample I.D.	Location	Species	Tissue	% dry matter*
HTL-1	Tacoma	Great Blue Heron	Liver	--
HTK-1	Tacoma	Great Blue Heron	Kidney	24.4
HTF-1	Tacoma	Great Blue Heron	Fat	88.5
HTL-2	Tacoma	Great Blue Heron	Liver	29.2
HTK-2	Tacoma	Great Blue Heron	Kidney	23-8
HTF-2	Tacoma	Great Blue Heron	Fat	89.5
GTL-1	Tacoma	Glaucous-Winged Gull	Liver	22.9
GTK-1	Tacoma	Glaucous-Winged Gull	Kidney	20.6
GTL-2	Tacoma	Glaucous-Winged Gull	Liver	24.1
GTK-2	Tacoma	Glaucous-Winged Gull	Kidney	21.3
GTL-3	Tacoma	Glaucous-Winged Gull	Liver	23.7
GTK-3	Tacoma	Glaucous-Winged Gull	Kidney	20.1
GTL-4	Tacoma	Glaucous-Winged Gull	Liver	--
GTK-4	Tacoma	Glaucous-Winged Gull	Kidney	24.3
HSL-1	Seattle	Great Blue Heron	Liver	24.6
HSK-1	Seattle	Great Blue Heron	Kidney	22.7
HSF-1	Seattle	Great Blue Heron	Fat	46.4
HSL-2	Seattle	Great Blue Heron	Liver	30.2
HSK-2	Seattle	Great Blue Heron	Kidney	24.3
HSF-2	Seattle	Great Blue Heron	Fat	81.7
GSL-1	Seattle	Glaucous-Winged Gull	Liver	23.9
GSK-1	Seattle	Glaucous-Winged Gull	Kidney	20.9
GSL-2	Seattle	Glaucous-Winged Gull	Liver	24.1
GSK-2	Seattle	Glaucous-Winged Gull	Kidney	20.8
GSL-3	Seattle	Glaucous-Winged Gull	Liver	24.0
GSK-3	Seattle	Glaucous-Winged Gull	Kidney	23.1
GSL-4	Seattle	Glaucous-Winged Gull	Liver	22.9
GSK-4	Seattle	Glaucous-Winged Gull	Kidney	20.6
PGSL-1	Seattle	Pigeon Guillemot	Liver	27.0
PGSK-1	Seattle	Pigeon Guillemot	Kidney	22.8
HSQL-1	Sequim	Great Blue Heron	Liver	34.8
HSQK-1	Sequim	Great Blue Heron	Kidney	21.2
HSQF-1	Sequim	Great Blue Heron	Fat**	10.6
PGPIL-1	Protection Island	Pigeon Guillemot	Liver	26.7
PGPIK-1	Protection Island	Pigeon Guillemot	Kidney	17.4
GPIL-1	Protection Island	Glaucous-Winged Gull	Liver	23.5
GPIK-1	Protection Island	Glaucous-Winged Gull	Kidney	20.3
GPIL-2	Protection Island	Glaucous-Winged Gull	Liver	24.5
GPIK-2	Protection Island	Glaucous-Winged Gull	Kidney	20.1
GPIL-3	Protection Island	Glaucous-Winged Gull	Liver	22.0
GPIK-3	Protection Island	Glaucous-Winged Gull	Kidney	21.9
GPIL-4	Protection Island	Glaucous-Winged Gull	Liver	24.6
GPIK-4	Protection Island	Glaucous-Winged Gull	Kidney	20.9

* % dry matter was determined by weight difference. Wet tissue from thawed dissected birds was weighed and then freeze-dried to constant weight.

** This bird died of starvation, leaving only connective tissue in the fat.

Table 8

Concentrations (µg/g, dry wt X±SE) of selected metals in liver and kidney of Glaucous-Winged Gulls collected from Puget Sound

	Commencement Bay Tacoma (N=4)		Elliott Bay Seattle (N=4)		Strait of Juan de Fuca Protection Island (N=4)	
	Liver	Kidney	Liver	Kidney	Liver	Kidney
Co	0.27±0.03	0.41±0.03	0.24±0	0.33±0.05	0.38±0.03	1.16±0.13
Fe	608±134	427±60	739±221	680±29	1172±81	628±36
Cr	0.40	0.53±0.05	0.37±0.19	0.58±0.04	0.53±0.05	0.43±0.03
Ni	0.04±0.02	0.07±0.01	0.01±0.01	0.02±0.02	0.02±0.1	0.08±0.03
Cu	29.1±6.7	11.8±0.4	32.7±1.7	11.7±1.0	62.7±16.1	13.1±1.9
Se	23.0±0.2	5.9±0.7	4.5±0.4	7.3±0.5	7.0±0.3	11.6±0.7
Ag	0.26±0.09	0.004±0.001	0.33±0.08	0.003	0.50±0.14	0.008±0.003
Cd	0.20±0.07	0.39±0.03	0.05±0.02	0.08±0.03	0.05±0.01	0.13±0.03
Sb	0.07±0.02	0.04±0.01	0.04±0.01	0.06±0.02	0.07±0.03	0.08±0.01
Hg	0.75±0.07	0.78±0.05	1.03±0.14	0.81±0.07	0.16±0.01	0.25±0.05
Pb	0.36±0.10	0.72±0.09	0.43±0.04	1.47±0.12	0.05	0.21±0.10
Zn	97.5±1.1	91.3±3.7	92.1±2.4	86.0±2.2	79.5±8.8	77.2±6.9
As	0.66±0.17	1.29±0.19	1.09±0.32	0.73±0.11	[redacted]±0.22	1.14±0.10

0.66

Concentrations of iron (Fe) were significantly different in livers of young gulls collected from Commencement Bay and Protection Island. As with Co, the concentration of Fe was highest in Protection Island birds. Concentrations of Fe in kidneys from birds from Elliott Bay were significantly higher than those from Commencement Bay.

Selenium concentrations in both liver and kidney tissues appear to follow a pattern among study sites. Commencement Bay gulls contained the lowest concentrations, Elliott Bay birds intermediate concentrations and Protection Island birds contained the highest concentrations of Se.

The mean concentrations of cadmium (Cd) in liver and kidney of Commencement Bay gulls were significantly different from the means for gulls from Elliott Bay and Protection Island.

Concentrations of mercury (Hg) were highest in gull livers and kidneys from Commencement and Elliott Bays and lowest in those gull tisues from Protection Island. The highest concentrations of Hg occurred in gull tissues from Elliott Bay, but these were not significantly different from those observed in gull tissues from Tacoma.

Table 9

Significant differences in trace element levels in liver and kidney tissues of Glaucous-Winged Gulls from Puget Sound (Mann-Whitney test, Conover, 1971)

	Liver	Kidney	Liver	Kidney
	Cobalt		Iron	
Commencement Bay	0.27±0.03	0.41±0.03	608±134	427±60
Elliott Bay	0.24±0.00	0.33±0.05	739±221	680±30
Strait of Juan de Fuca	0.38±0.03	1.16±0.13	1172±81	628±37
	Selenium		Cadmium	
Commencement Bay	2.96±0.24	5.89±0.65	0.20±0.07	0.39±0.03
Elliott Bay	4.48±0.42	7.28±0.52	0.05±0.02	0.08±0.03
Strait of Juan de Fuca	7.03±0.28	11.58±0.71	0.05±0.01	0.13±0.03
	Mercury		Lead	
Commencement Bay	0.75±0.07	0.78±0.05	0.36±0.10	0.72±0.09
Elliot Bay	1.03±0.14	0.81±0.07	0.43±0.04	1.47±0.12
Strait of Juan de Fuca	0.16±0.01	0.25±0.05	0.05	0.21±0.10
			Zinc	
Commencement Bay			97.5±1.1	
Elliot Bay			92.1±2.4	
Strait of Juan de Fuca			79.5±8.8	

Brackets connecting study sites indicate significant differences in means at the $\alpha = 0.05$ level.

Concentrations of lead (Pb) in livers of gulls from the three study sites followed the same pattern as Hg. Concentrations of Pb were different in kidneys from birds from Elliott Bay when compared to birds from Commencement Bay and Protection Island. Concentrations of Pb were higher in kidney tissue than in liver tissue for all three study sites.

In comparing the three study sites, only zinc (Zn) in tissue of birds from Commencement Bay differed significantly from the concentrations of Zn in the tissue of birds from Elliott Bay and Protection Island.

Tables 10 and 11 provide the inorganic data for the five herons and two guillemots respectively. These data are not statistically treated due to the small sample sizes from each study site.

3.3.2 Organic Analysis

Screening of bird tissue and egg sample for aromatic hydrocarbons and halogenated organic compounds. All bird tissue samples were subjected to preliminary screening by GC as previously described for sediments. Analysis employing flame ionization detectors revealed the absence, in the majority of cases, of components at retention times that were congruent with the aromatic hydrocarbon components of our standard. No conspicuous component patterns were observed in any of these chromatograms. GC analysis employing electron capture detection indicated that the majority of tissue samples contained PCBs in the molecular weight range of Arochlor 1260. In addition to PCBs, many of the samples of tissue of birds collected from the urban areas (Seattle, Tacoma) contained other electron capturing components in the retention time region for chlorinated butadienes (Figure 10). Some samples of adipose tissue contained higher concentrations of these same components. Based on these observations, a Glaucous-Winged Gull liver sample from Tacoma and a sample of adipose tissue from a heron from Seattle were selected for GC/MS analysis. Also, since we only had one egg sample (pigeon guillemot, Seattle), we also subjected it to GC/MS analysis.

GC and GC/MS analysis of Pigeon Guillemot egg. GC/MS analysis of the egg sample confirmed the presence of PCB in the Cl_4 to Cl_7 molecular weight range (Figure 11). No DDT or DDD isomers were detected, however, an isomer of DDE was detected. GC analysis using electron capture detection did not reveal the presence of any other class of halogenated organic components (e.g., chlorinated butadienes, chlorinated benzenes).

GC/MS analysis of Glaucous-Winged Gull liver sample. GC/MS analysis of the liver tissue sample from a gull collected from Seattle confirmed the absence of specific aromatic hydrocarbons that were a part of our quantification scheme. Peaks corresponding in retention time to some of these aromatic components are assumed to be natural components of the bird tissue. Chlorinated biphenyls were confirmed in the tissue as well as the same DDE isomer detected in the egg sample. No DDT or DDD isomers were detected. In addition, we were not able to detect the presence of chlorinated butadienes, trichlorobenzenes or hexachlorobenzene. These latter results were consistent with the absence of GC retention time matches between the chlorinated butadiene components detected in sediments with the electron capturing components detected in the bird tissue samples. Detection levels for individual aromatic hydrocarbons in bird tissue are listed in Appendix G, Tables G-1 through G-10.

GC/MS analysis of heron adipose tissue sample. In order to further support the results obtained from the GC/MS analysis of the gull liver sample, we analyzed a sample of adipose tissue obtained

Table 10

Concentrations (µg/g, dry wt) of selected metals in liver, kidney, and adipose tissues of Great Blue Heron collected from Puget Sound

	Co	Fe	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Hg	Pb
Commencement Bay													
Bird #1													
Liver	0.055	1362	0.5	0.01	35.6	112.4	0.08	4.02	0.114	0.040	0.02	11.7	0.17
Kidney	0.211	1115	0.4	0.01	7.99	60.3	0.60	4.69	0.003	0.103	0.08	6.45	0.24
Adipose (Fat)	[redacted] < 0.016	16	0.4	0.01	0.52	1.6	0.04	0.02	0.003	0.084	0.02	0.136	0.05
Bird #2													
Liver	0.118	2686	0.4	0.02	48.0	119.1	0.61	6.15	0.581	0.149	0.05	16.4	1.55
Kidney	0.179	1244	0.4	0.10	9.26	49.9	1.07	18.36	0.011	0.522	0.05	2.38	[redacted] 0.29
Adipose (Fat)	0.016	20	0.4	0.01	0.19	0.9	0.16	0.16	0.003	0.006	0.02	0.081	0.30
Elliott Bay													
Bird #3			< 0.04										
Liver	0.119	1420	[redacted]	< 0.4	47	135.1	0.24	4.44	0.933	0.045	0.07	3.26	0.27
Kidney	(0.337, 0.311, 0.317)	(1141, 1235 1196)	(0.4, 0.4, 0.4)	(0.07, 0.06, 0.02)	(7.35, 7.48, 7.43)	(48.8, 51.2, 46.9)	(0.79, 1.00, 0.97)	(5.58, 4.89, 5.09)	(0.014, 0.003, 0.003)	(0.098, 0.120, 0.076)	(0.05, [redacted] 0.06, 0.05)	(1.91, 1.83, [redacted] 2.13)	(0.29, [redacted] 0.22, [redacted] 0.21)
Adipose (Fat)	0.016	114	0.4	0.06	1.10	7.6	0.23	0.25	0.003	0.006	0.02	0.192	0.05
Bird #4													
Liver	0.186	871	0.7	0.01	33.5	174	0.60	7.5	0.265	0.130	0.38	8.98	0.27
Kidney	0.382	919	0.4	0.04	9.13	52.1	0.60	6.0	0.003	0.159	0.16	4.19	0.58
Adipose (Fat)	0.016	33	0.4	0.01	0.45	3.7	0.23	0.14	0.003	0.006	0.04	0.27	0.25
Sequim Bay													
Bird #5													
Liver	0.131	2842	0.4	0.01	65	280.4	0.28	7.31	0.645	0.035	0.05	2.75	0.10
Kidney	0.516	312	0.7	0.8	11.5	71.0	0.41	10.03	0.003	0.116	0.02	1.41	0.11
Adipose (Fat)	0.053	213	1.5	0.79	7.12	112.4	0.26	2.94	0.003	0.046	0.42	0.465	0.68

Table 11

Concentrations (µg/g, dry wt) of selected metals in liver and kidney tissues from Pigeon Guillemots collected from Puget Sound

Metal	Elliot Bay		Strait of Juan de Fuca	
	Kidney	Liver	Kidney	Liver
Co	0.065	0.016	0.185	0.073
Fe	856	1257	633	664
Cr	0.70	0.80	[redacted] 0.90	[redacted] <0.4
Ni	0.50	0.05	0.13	0.02
Cu	8.34	21.3	10.74	15.5
Se	60.1	76.9	59.6	54.5
Ag	3.02	1.82	1.00	0.69
Cd	5.24	3.11	5.01	2.27
Sb	0.003	0.034	0.003	0.084
Hg	0.111	0.039	0.588	0.065
Pb	0.07	0.04	0.08	0.02
Zn	0.686	0.94	0.490	0.699
As	0.82	0.20	0.12	0.12

from a Seattle Great Blue Heron. The electron capturing compounds present in the chromatogram from this heron sample were the same in terms of retention time to those observed in the chromatogram associated with the gull liver sample; however, the concentrations of the compounds in the sample of adipose tissue were much higher. As with the liver sample, none of the compounds in this sample could be identified as containing halogen with the exception of PCB. Further examination of the spectra of components in the earlier retention time region of the chromatogram indicates that some of the classes of compounds that are present appear to be aldehydes, ketones, and alcohols. Examples of several of these spectra are shown in Appendix H, Figures H-1 through H-9.

Polychlorinated biphenyls (PCB) in marine birds. The results of the quantification of the concentrations of PCB in tissue of selected marine birds and egg from Puget Sound are summarized in Table 12. Appendix I, Tables I-1 through I-3, provide additional details on our analysis of bird tissue for halogenated organic compounds. PCBs were the only class of halogenated organic compounds detected in marine bird tissues. Adipose tissue contained the highest concentrations of PCB, followed by liver and kidney. Glaucous-Winged Gulls collected from Tacoma (Commencement Bay) had the highest PCB concentrations in liver, $\bar{x}$=575 ppb (wet wt), followed by birds from Seattle, $\bar{x}$=190 ppb,

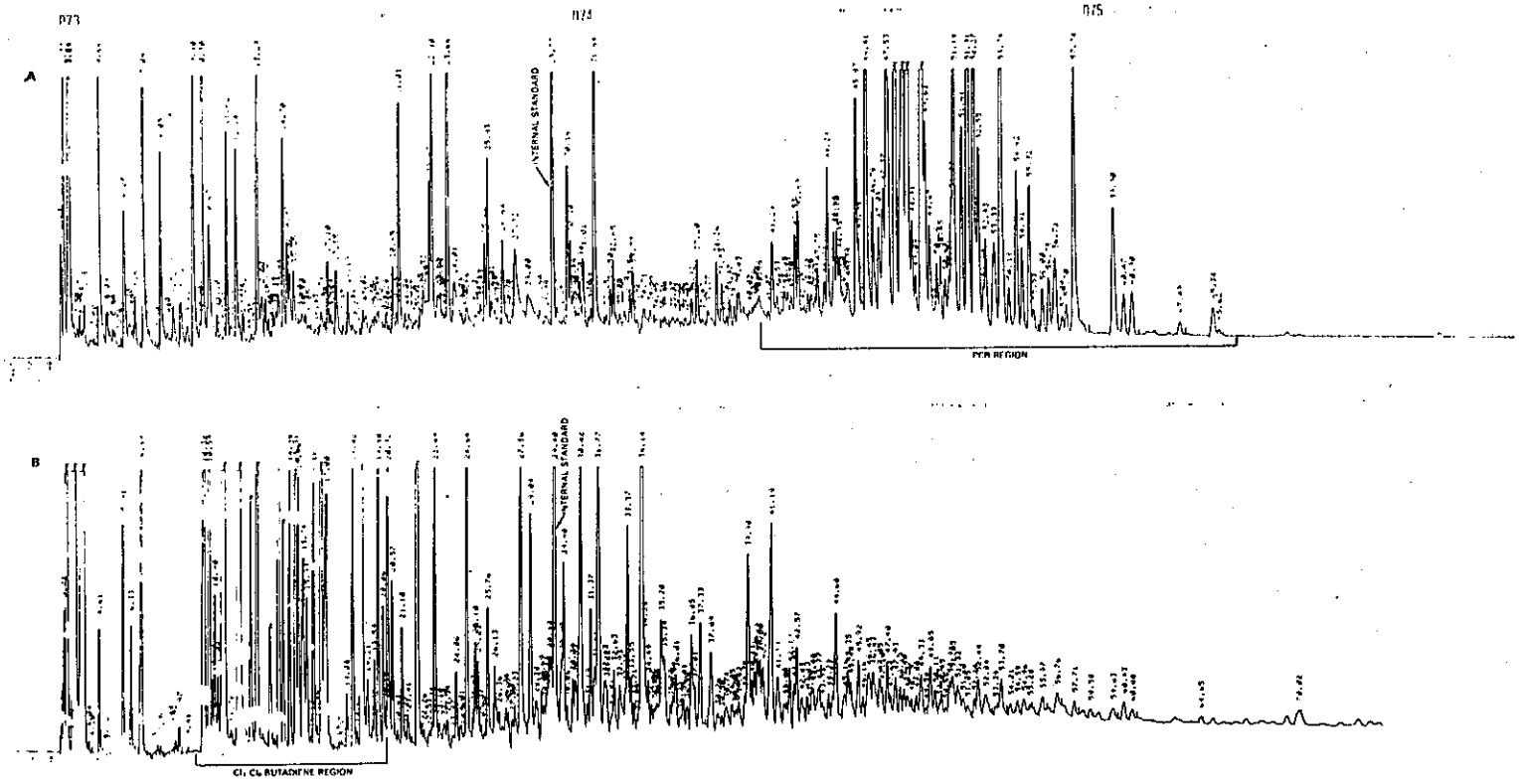

Figure 10

Capillary gas chromatogram, employing electron capture detector, depicting (A) electron capturing components isolated from Great Blue Heron liver collected from Tacoma, and (B) electron capturing components from extract isolated from sediment collected from Hylebos Waterway, Tacoma (Riley et al., 1981)

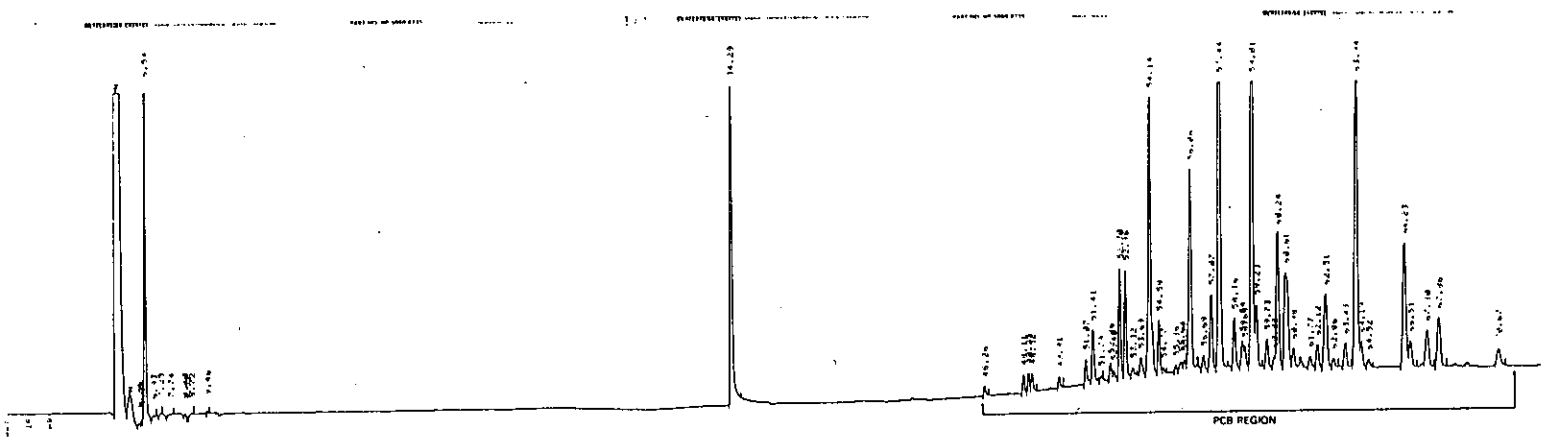

Figure 11

Capillary gas chromatogram, employing electron capture detection, depicting halogenated components isolated from Pigeon Guillemot egg.
Egg collected from West Duwamish Waterway, Seattle

Table 12

Concentration of total PCBs in tissue of selected marine birds and egg from Puget Sound. H = Great Blue Heron, PG = Pigeon Guillmot, G = Glaucous-Winged Gull.

Sample Type	Location	Bird	Total PCB (ng/g, wet wt)		Sample Type	Location	Bird	Total PCB (ng/g, wet wt)	
									$\bar{x}$±SE
Liver	Seattle	1 H	1,304	x=3,196	Liver	Seattle	1 G	142	
		2 H	5,087				2 G	125	190±36
	Tacoma	1 H	1,030	x=1,466			3 G	212	
		2 H	1,902				4 G	281	
	Sequim Bay	1 H	747			Tacoma	1 G	1,095	
							2 G	474	575±191
Kidney	Seattle	1 H	536	x=1.308			3 G	551	
		2 H	2,080				4 G	181	
	Tacoma	1 H	384	x=442		Protection Island	1 G	75	
		2 H	500				2 G	19	41±15
	Sequim Bay	1 H	235				3 G	29	
							4 G	182*	
Adipose	Seattle	1 H	14,600	x=33,148	Kidney	Seattle	1 G	29	
		2 H	51,696				2 G	42	52±10
	Tacoma	1 H	80,385	x=53,296			3 G	67	
		2 H	26,206				4 G	68	
	Sequim Bay	1 H	5,466			Tacoma	1 G	141	
							2 G	97	107±28
Liver	Seattle	1 PG	387				3 G	158	
	Protection Island	1 PG	28				4 G	32	
						Protection Island	1 G	7	
							2 G	<0.8	6±0
Kidney	Seattle	1 PG	<2.4				3 G	6	
	Protection Island	1 PG	<6.4				4 G	6	
Egg	Seattle	1 PG	11,262						

* Gas chromatographic interference precludes this from being a valid number.

and Protection Island, $\bar{x}$ = 41 ppb. The Protection Island mean value is based on three birds; gas chromatographic peak interference led to rejection of data from one bird in our calculations. In comparing the three study sites using the Mann-Whitney nonparametric statistical test, we found significant differences (α = 0.05) between the PCB concentrations in birds from Elliott Bay and Protection Island, Commencement Bay and Protection Island, but no significant difference between PCB concentrations in birds from Elliott and Commencement Bay. Gulls from the urban areas are more contaminated with PCBs than birds inhabiting the nonurban Protection Island.

Concentrations of PCBs in the Great Blue Herons were higher than those of young Glaucous-Winged Gulls or the young Pigeon Guillemots. Concentrations of PCBs were high in all tissues, but concentrations in adipose tissue were higher than detected in kidney and liver. Our sample size of herons is low, therefore, among-site statistical comparisons were not made. Elliott and Commencement Bay herons appear to contain similar concentrations of PCB, ranging from 1.03 to 5.09 ppm (wet wt) in livers and 14.6 to 80.4 ppm in adipose tissue. The highest concentrations of PCBs in liver came from an Elliott Bay heron, while the highest concentration of PCBs in adipose tissue came from a Commencement Bay heron.

Concentrations of PCBs in the two Pigeon Guillemots were highest in liver tissue. No guillemot adipose samples were taken for analysis. The guillemot from Elliott Bay had a PCB concentration of 0.387 ppm wet wt in its liver while the Protection Island bird contained only 0.028 ppm. An egg taken from a clutch of four infertile eggs on the Seattle waterfront was also analyzed for PCBs. It contained 11.3 ppm (wet wt). The other three eggs were saved for future analysis.

4.0 DISCUSSION

4.1 Sediment Inorganic Chemistry

Sediment samples were collected north and south of Tacoma for the purpose of examining the transport of contaminants from Commencement Bay to other regions of Puget Sound. The sediments of Commencement Bay and adjacent industrial waterways are contaminated with a variety of heavy metals, aromatic hydrocarbons and chlorinated organic compounds. Several of these contaminants, including As, Sb, and CBD, are at much higher concentrations than in sediments from other industrial areas of Puget Sound. Thus, the concentrations of As, Sb, and CBD may be used as indication of transport from Commencement Bay to other regions of Puget Sound.

The water circulation of Puget Sound indicates that particles leaving Commencement Bay would be transported either northward through Colvos Passage or southward through the Narrows to the southern part of Puget Sound (Cannon and Grigsby, 1982). There is also the possibility of some transport into East Passage. We have assumed that particle-bound contaminants would be deposited in fine-grain sediments downstream of Commencement Bay; consequently, sediments were collected in regions of Colvos Passage, north of Colvos Passage, and south of the Narrows where fine-grain sediments were either known or suspected to be present. Published grain-size data indicate that no fine-grain sediments are present in Colvos Passage, or in the Narrows (Roberts, 1974). The presence of strong tidal currents in these areas, shown on current charts, is supporting evidence that fine-grain sediments accumulate where current speed decreases north of Blake Island and south of the Narrows, in Carr Inlet and Case Inlet. Other sediment accumulation sites that were not examined include Quartermaster Harbor (northwest of Commencement Bay) and East Passage (northeast of Commencement Bay).

Previous trace element analyses of Puget Sound sediments by Crecelius et al. (1975) have shown that As and Sb are elevated in sediments both north and south of Tacoma. The major source of the elevated concentrations of As and Sb is the ASARCO copper smelter located on the west end of Commencement Bay. The smelter releases particles to the atmosphere through a tall stack and to the seawater through disposal of slag. The As to Sb ratio in smelter stack dust is approximately 10:1. The atmospheric deposition of stack dust has elevated the concentration of As and Sb in Quartermaster Harbor and East Passage. The ratios of As to Sb in these sediments are approximately 10:1. The slag particles that are transported by seawater have an As to Sb ratio of approximately 1:1. Sediments south of the Narrows, near Fox Island, and north of Colvos Passage near Blake Island have ratios of between 2:1 and 5:1 which indicates that slag is the major source of As and Sb at these sites. Uncontaminated or baseline sediments have ratios of approximately 10:1 and the concentrations of As and Sb are approximately 7 ppm As and 0.7 ppm Sb.

The majority of the sediments are contaminated with Cu, Zn, As, Ag, Sb, Hg, and Pb when compared to baseline sediment. Our "baseline" sediment is muddy sediment deposited approximately 100 years ago in Puget Sound's main basin (area north of Tacoma Narrows to south end of Whidbey Island). The concentrations of metals in Commencement Bay sediments deposited over 100 years ago are similar to baseline concentrations listed in Appendix D, Tables D-3 and D-4 (Crecelius et al., 1975; Curl, 1982 and Crecelius et al., 1983).

Some sources of these seven enriched metals include sewage, rivers, industrial waste water, motor vehicle exhaust, smelter stack dust, and smelter slag. The relative importance of these sources for each metal has not been adequately determined. A preliminary Pb budget for the main basin of Puget Sound indicates atmospheric input and waste water are roughly equal (Curl, 1982). This should result in Pb derived from these two anthropogenic sources being distributed over the main basin. An As and Sb budget for Puget Sound indicates the Tacoma ASARCO smelter has been the major anthropogenic source of these elements (Crecelius, 1974). Our preliminary Ag budget for the main basin indicates sewage outfalls are the major anthropogenic input of this heavy metal. Dexter et al. (1981) estimated input of As, Cu, Pb, and Zn to Puget Sound. Their results indicate that for As and Pb atmospheric input would be the major anthropogenic source, and for Cu and Zn waste water would dominate.

Antimony (Sb) is the only heavy metal that has a relatively distinct source in the Tacoma area and, therefore, can be used for tracing the transport and dispersion of Commencement Bay particles to other areas of Puget Sound. The enrichment of Sb in sediments of Carr Inlet and near Blake Island may be evidence to this process. The source of other metals such as Ag, Hg, and Pb that are enriched in sediments of Carr and Case Inlets of southern Puget Sound is not as obvious. However, since the southern basin has relatively few anthropogenic sources of these metals, the major sources are probably a combination of atmospheric dust and seawater transport of metal-rich suspended matter from the main basin. The greater metal enrichment in Carr than Case Inlet may be due to proximity to the main basin or differences in sedimentation rates which could dilute contaminants.

4.2 Aromatic Hydrocarbons in Sediments

This study has provided information on the chemistry of Puget Sound sediments in regions of the Sound (Colvos Passage and southern) where limited sediment analyses have been performed and reported in the literature.

The distribution of aromatic hydrocarbons detected in sediment from Colvos Passage and southern Puget Sound suggests that substantial weathering of hydrocarbon components of this material had occurred. The absence of high concentrations of low molecular weight aromatic hydrocarbons characteristic of the composition of petroleum products

indicates the absence of impact to these sediments due to a recent oil spill, oil discharge or accumulation of oily particulate material. The range in concentrations of aromatic hydrocarbons was consistent with those reported by others who have examined sediments from the same or adjacent regions of Puget Sound (Malins et al., 1982). However, concentrations were considerably lower than some detected in sediments collected from major embayments and adjacent waterways (Malins et al., 1982; Riley et al., 1981). The highest concentrations of aromatic hydrocarbons were detected in sediments collected from Gig Harbor and northeast of Blake Island. However, these data need to be interpreted with caution due to the absence of statistical validation based on a large sample data set. Sediment aromatic hydrocarbon concentrations were normalized against sediment organic carbon content and grain size. On these bases, the sediment sample from Gig Harbor appears to contain aromatic hydrocarbon concentrations considerably higher than what would be predicted on the basis of sediment organic carbon content or sediment grain size, strongly suggesting a localized input. However, additional sampling would be required in this area to attempt to verify this result. In general, our data (AH vs organic carbon, AH vs grain size) is in agreement with literature data summarized by Dexter et al. (1981) indicating that spatial heterogeneity obscures these relationships due to localized inputs.

4.3 Halogenated Organic Compounds in Sediments

A majority of sediments (12 of 14) sampled from locations in Colvos Passage and southern Puget Sound did not contain detectable levels of PCB. The two sediments that contained PCB had concentration levels (<100 ppb) similar to concentrations of PCB detected in sediments from other nonurban areas of Puget Sound (Malins et al., 1982; Dexter et al., 1981; Konasewich et al., 1982) and the Gulf of Mexico (Dennis, 1976). Concentrations of PCB in sediments from our study were considerably less than were observed for sediments impacted by point discharges (Riley et al., 1981) or spills in Puget Sound (Blazevich et al., 1977) or other estuarine systems such as the Hudson River/New York Bight region (Bopp et al., 1981; MacLeod et al., 1981).

Low concentrations of chlorinated butadienes (CBD) were detected in all of the sediments collected from Colvos Passage and southern Puget Sound suggesting that transport of these components has occurred from an urban area (in this case, most likely Commencement Bay) and accumulation has occurred in areas remote from their origin. This is consistent with other studies that have reported the presence of trace levels (<10 ppb) of CBD in sediments collected from Budd Inlet and Case Inlet (Malins et al., 1980, 1982). Data on the concentrations of CBD in East Passage, for comparative purposes, are scant. Researchers at METRO have detected hexachlorobutadiene in the range of 1.6 to 5.7 ppb in several sediments in East Passage. We did not detect this component in our sediment samples. This is not surprising based on the observations of Malins et al. (1982) that concentrations of CBDs

and other organics are quite variable. They also found tetrachlorobutadienes to be in sediments at higher concentrations than hexachlorobutadiene. As with the aromatic hydrocarbon correlations, the CBD correlations show considerable scatter. However, unlike the Gig Harbor sediment sample for aromatic hydrocarbons, none of the data points in the CBD correlation deviated substantially from each other.

Current understanding of circulation patterns associated with the Commencement Bay region of Puget Sound may provide us with a better understanding as to the reason for the presence of CBDs in sediments from central and southern Puget Sound. Although limited studies of the circulation patterns surrounding Commencement Bay have been conducted, the general concensus at this time (Dexter et al., 1981) is that surface waters tend to move out of Commencement Bay through Dalco Passage and then either southward through the Narrows into southern Puget Sound or northward through Colvos Passage. These patterns coupled with the physical and chemical properties of the sediments would influence the location of the deposition and chemistry of the sediments in these areas. Our detection of chlorinated butadienes in central and southern Puget Sound sediments would be consistent with these circulation patterns. Also, because the time of original deposition of chlorinated butadienes may go back as far as 15 years, higher concentrations of these components may be present at greater depths in these areas. Sampling of sediments with depth from these areas could provide additional information in support of current circulation/deposition theories.

4.4 Intercomparison Study

Intercomparison of analytical data from two laboratories using different sample workup procedures and instrumental approaches, even though they are using sediment from the same batch, can produce similar or dissimilar results. These variations in results are exemplified by the number of efforts by different research organizations to demonstrate that laboratories can, in fact, produce comparable data sets given the opportunity to analyze the same sediment sample. Over the last several years, NOAA, National Analytical Facility in Seattle, has conducted several intercomparison studies involving analytical laboratories from around the country. Each successive study has attempted to eliminate those factors that would lead to the greatest variability associated with the procedures used by the different laboratories. The published results of the most recent studies (MacLeod et al., 1982), in which 38 selected alkanes and aromatics were extracted from carefully homogenized sediment using one of two published methods and quantified by capillary gas chromatography, showed six (a total of 13 laboratories participated) of the participating laboratories (of which we were one) to produce results that generally agreed within a factor of 2 with the reference data. We consider this to be excellent results. The sum of the selected aromatic hydrocarbons quantified by Battelle-Northwest and

METRO are within a factor of 2 for both sediment samples (Table 4). On an individual compound basis, no single compound differs by more than a factor of 5. These results are quite acceptable, considering the differences in sample workup and analytical procedures used and the possible nonhomogeniety of the sample analyzed as compared to what can be achieved under more tightly controlled conditions ascribed to by MacLeod in his intercomparison studies.

Although the differences in the concentrations of total CBDs and PCBs reported by the laboratories (Battelle-Northwest/METRO) were somewhat larger than observed for the differences between aromatic concentrations, much of the concentration difference between CBDs and PCBs could be explained on the basis of differences of accounting for losses of these compounds during workup procedures and differences due to sample heterogeneity.

4.5 Breeding Bird Surveys - Southern Puget Sound

4.5.1 Locations of Nesting Activity

The study area (Figure 2) has little diversity in the way of nesting marine birds as compared to Northern Puget Sound and the Strait of Juan de Fuca (Manuwal, 1977). Surveys did reveal large concentrations of Glaucous-Winged Gulls occurred along the Tacoma and Seattle waterways and on the north end of Marrowstone Island.

Killisut Harbor (Area 3, Figure 2). The cliffs around this harbor, especially at Fort Flagler State Park on Marrowstone Island, provide nesting sites for Pigeon Guillemots. A small Glaucous-Winged Gull colony is present on a spit at the north end of Marrowstone Island. Large numbers of Black Oystercatchers (probably non-nesting) and Harlequin ducks were also observed at this location. People using the spit for recreation created a disturbance among the nesting birds. A navigation marker tower offshore to the north was used by pelagic cormorants for nesting. This was the only cormorant nest site observed in the study area and consisted of about 40 pairs.

Colvos Rock (Area 16, Figure 2). A small Glaucous-Winged Gull colony occurred on the largest Colvos Rock. This was the only gull nesting site in the study area, other than the Indian Island spit, which was not man-made.

Elliott Bay and Duwamish Waterway (Area 9, Figure 2). We observed between 25 and 30 Glaucous-Winged Gull nests on pier 30 in the East Waterway. Eddy (1982) reported that nearly 300 pair nested in downtown Seattle and along the Seattle waterfront. We did not conduct complete surveys of the area, however, numerous young birds were sighted on several warehouse roofs at Pier 91 and on office buildings. Gulls have adapted well to a variety of man-made structures for nesting. A single gull nest was observed on a piling at the boat ramp on Duwamish Head.

Two pairs of Pigeon Guillemots were found nesting on East Waterway under the P/S freight dock.

Commencement Bay (Area 20, Figure 2). We estimate that there were approximately 450 nests of Glaucous-Winged Gulls in Commencement Bay in 1982. Two separate colonies were found on derelict piers near the St. Regis paper mill. No Pigeon Guillemots were found nesting in the Bay.

Cutts Island Area (Area 25, Figure 2). Pigeon Guillemots were widespread in Carr Inlet, with a noticeable concentration (14 pairs) at Cutts Island, where people also went for recreation.

Budd Inlet (Area 33, Figure 2). About fifteen nesting pairs of Glaucous-Winged Gulls were observed in scattered locations along the western Olympic Peninsula shoreline.

Hammersley Inlet (Area 39, Figure 2). The eastern, unpopulated portion of this inlet had a high number of Pigeon Guillemots foraging in it (~49). Nesting locations were not found.

Oakland Bay (Area 40, Figure 2). About 150 Glaucous-Winged Gulls were observed from a distance at a known nesting colony near the mill at Shelton. The nesting colony is probably less than 75 pair. Small numbers of Glaucous-Winged Gulls also nest singly at many locations on old docks and boathouses. In addition to gulls, Great Blue Herons, Pigeon Guillemots and Marbled Murrelets were observed foraging in concentrations in Oakland Bay. The nesting of these species may or may not occur in close proximity to their foraging areas.

4.5.2 Account of the Species Observed

Here is an overview of the relationship that the southern Puget Sound marine bird nesting areas have to other Puget Sound nesting areas. Species closely associated with the marine environment, which breed or almost certainly breed, within the study area are incorporated.

Pelagic Cormorant. A single nesting colony was found on a navigation marker tower northwest of Marrowstone Island. This colony was the only one observed in the study area. A Pelagic Cormorant colony was observed here in 1971 (Fitzner, personal observation) indicating that these birds have used this nesting site for over a decade . The colony in 1982 was estimated to be about 40 pairs. Non-breeding cormorants were localized and were relatively few. In surveys of northern Puget Sound and the Strait of Juan de Fuca, Manuwal et al. (1979) estimated the presence of 950 Pelagic Cormorants. The distribution of breeding colonies in Washington is strongly influenced by the availability of steep cliffs inaccessible to predators.

Great Blue Heron. During the June-July, 1982, subcontracted surveys, the Great Blue Heron was observed often along shorelines and in the waterways of Tacoma and Seattle (Table 13). No nesting colonies were found. This was anticipated since this species nest in upland areas. During August and September, our surveys provided locations and breeding densities for four colonies associated with southern Puget Sound. The results of these surveys and data for other colonies covered by a census in 1981 by Shipe and Scott are provided in Table 13.

Canada Goose. Large numbers of Canada Geese (~150), probably of the subspecies, Branta canadensis moffitti, were observed in Elliott and Commencement Bays which was unexpected. Family groups were common in the Duwamish Waterway, Seattle, and in Hylebos Waterway, Tacoma. These birds were observed feeding on aquatic plants, mostly algae, found clinging to pilings and logs. Domestic geese were also observed in Elliott and Commencement Bays.

Mallard. Mallards, both domestic and wild types, were observed on Elliott and Commencement Bays. The populations may be as high as 200 birds in Commencement Bay and 300 in Elliott Bay. Many of the birds observed were in family units and were often associated with

Table 13

Heron colony locations and nesting densities
in southern Puget Sound

Colony Location	Number Nest	Date of Survey
Dumas Bay County Park	24	2 August 1982
Peasley Canyon (near Auburn)	14	3 June 1982
Fort Lewis (near DuPont)	35	27 April, 3 June 1982
McNeil Island	70	3 June 1982
Maury Island	Unknown	1981 (Shipe and Scott 1981)
Grass Lake	6-8	1981 (Shipe and Scott 1981)
Seahurst	4	1981 (Shipe and Scott 1981)
Weowna	4	1981 (Shipe and Scott 1981)
Woodinville/Crystal Lake	40	1981 (Shipe and Scott 1981)

tidal flats where they fed on algae. Some birds no doubt receive food handouts from people, however, at Hylebos Waterway in Tacoma we observed the birds foraging regularly in tidal ponds during low tide on pieces of algae and other plant matter.

Bald Eagle. Eleven Bald Eagles representing perhaps six pairs of birds were observed in the study area (Table 5). No nests were observed. Grubb et al. (1975) found 20 active nests in Puget Sound (from Port Townsend south) in 1975. Bald Eagles are an important top consumer in Puget Sound and could be used for monitoring purposes through analysis of food scraps, egg shells, and feathers.

Osprey. One bird and two probable nests were observed (Table 5). The nests were seen at Case Inlet and Peale Passage.

Glaucous-Winged Gull. The Glaucous-Winged Gull is perhaps the most abundant nesting marine bird in southern Puget Sound. Known colonies and numbers of nests are:

Location	Number of Nests
Indian Island, near Port Townsend	50
Colvos Rock, Hood Canal Entrance	22
Elliott Bay	300 (Eddy 1982)
Commencement Bay	450
Shelton Waterfront	20
Olympia Waterfront	15
Total	857 pairs

Manuwal et al. (1979) reported on the occurrence of 7,242 Glaucous-Winged Gull nests in an area encompassing the Strait of Juan de Fuca and northern Puget Sound. The 857 pairs that we observed would bring the total nesting population in Puget Sound and the Strait of Juan de Fuca to over 8000. In considering the distribution and abundance of this species in Washington, it would be a useful resource for large scale biomonitoring purposes.

Pigeon Guillemot. The June and July surveys of marine birds in Puget Sound estimated that between 600-700 pairs nest in the area wherever suitable cliffs are found. The surveyors also believed that the birds nested under piers although no nests were found. During our July and August intensive nest searching in Elliott and Commencement Bays, two nests were found in Elliott Bay under the P/S Dock in the West Waterway. The birds nested in 6 in. diameter holes in concrete pilings supporting the P/S dock. The pilings were approximately 24 in. thick and the holes passing through them created short burrows for

nesting. These holes could be modified to enhance nesting, by closing off one end and placing a ramp at their entrances. The holes are intended for passage of metal ducts and wiring, however, they are currently not being used.

Marbled Murrelet. Murrelets were concentrated in the northern part of the study area. Their presence is attributed to their breeding nearby and using the Puget Sound for foraging; however, no nests were observed. The population of breeding birds in the study area may be considerably higher than the total in Table 5 because the species is difficult to see during transect counts. There may have been a maximum of about 300 pairs present in the study area.

4.5.3 Fate and Effects of Selected Metals in Marine Birds

The concentrations of Co detected in Glaucous-Winged Gulls (0.33 to 1.16 ppm in kidney) are equivalent to or lower than those found in prefledgling Black Crowned Night Herons on the Atlantic coast. The concentrations are higher than those reported for seawater (0.00027 ppm by Jenkins, 1981) but less than soil (8.0 ppm dry wt). Cobalt is one of the elements which we know little about concerning concentration or effects on wildlife. We found few studies dealing with cobalt and even fewer discussing effects. More baseline data on concentrations in Puget Sound birds, their prey, aquatic plants, seawater and sediments are needed. We found no literature on the concentration of Fe in marine birds. Since Protection Island served as our control site for gulls, we have assumed that concentrations of Fe in birds from there represent background levels. No significantly higher concentrations of Fe were detected in birds although higher concentrations would be of concern.

Hutton (1981) indicated an interesting correlation between selenium (Se) and mercury (Hg). He noted a parallel accumulation of Se and Hg in the livers and kidneys of seabirds. Selenium is known to exert a protective influence on Hg toxicity in experimental animals (Parizek and Ostadalova, 1967; Potter and Matrone, 1974) and the co-accumulation of these two elements may thus signify the presence of an antagonistic interaction of Se and Hg. In marine mammals, the increment of liver Hg and Se occurs on a 1:1 molar basis (Koeman et al., 1973, Martin et al., 1976). Hutton (1981) found that the molar increment between liver and kidney Se between two seabird species was less than one; however, the concentrations of Se on a molar basis always exceeded those of Hg. We observed the same situation with the concentration of Se always exceeding the concentration of Hg in the gulls collected from Puget Sound.

We did not observe the parallel accumulation of Se and Hg reported by Hutton (1981). There appeared, however, to be an inverse relationship between Hg and concentrations of Se -- at least between the highest and lowest Hg values. For instance, the concentration of Hg in livers from Commencement Bay gulls averaged 0.75 ppm with Se

being 2.96 ppm for the same group. At Protection Island, the concentration of Hg was 0.16 ppm, but Se was 7.03 ppm. Perhaps there is some sort of antagonistic interaction between selenium and mercury. The higher concentrations of selenium at Protection Island may actually be operating to detoxify mercury. Perhaps once a threshold concentration of selenium is reached, mercury concentration may be reduced.

The concentrations of selenium that we detected in marine birds agree with those reported for sooty terns in the Gulf of Mexico and Hawaii, as well as with those reported for oystercatchers, herring gulls, and great skua from the United Kingdom. The distribution of selenium is poorly documented in seabirds from Puget Sound and coastal waters of the Northwest. More baseline data are needed to determine the potential role of selenium in the environment.

Cadmium (Cd) is absorbed in tissues and is deposited primarily in liver and kidney (Cheney et al., 1981). Birds collected from Tacoma appear to be exposed to a cadmium source that is not present at the other sites. The Cd concentrations that we report for these birds, however, are not considered high. All of the Cd concentrations found in Glaucous-Winged Gulls were comparable and within the range reported for other wild birds (Table 14).

The concentrations of mercury detected in the liver and kidney of gulls in this study are similar to concentrations found in wild birds from other areas of the world. However, there are differences in the concentrations of mercury in the tissues of birds collected from Elliott and Commencement Bays and the birds captured from Protection Island. Gulls living in the urban areas are accumulating more mercury inferring that mercury is more available. Whether the added burden of mercury to this system is of consequence is presently unclear. Osborn et al. (1979) indicated that mercury concentrations which they observed in three seabird species may be producing subtle sublethal effects. Because the mercury concentrations found in young gulls from Commencement and Elliott Bays were close to those reported by Osborn et al. (1979), the same could be said of the gulls of this study. Low concentrations of methylmercury and mercury (equivalent perhaps to 1 mg/kg Hg) can interfere with the physiology of neuromuscular functions (Manalis and Cooper, 1975; Juang and Yonemura, 1975) and thus Osborn et al. (1979) reasoned that it is conceivable that the seabirds they studied were suffering from some sublethal adverse effect when the mercury was present at the neuromuscular junction.

For the prefledgling Glaucous-Winged Gulls, kidney contained higher lead (Pb) concentrations than liver. Lead in the Commencement and Elliott Bay gulls is in the upper range of the concentrations found in other wild marine birds (Table 14). Higher concentrations of lead in kidney were also reported by Maedgen et al. (1982) for Royal and Sandwich terns and by Stoneburner and Harrison (1981) for sooty terns. Cheney et al. (1981), in a study of Louisiana herons and

Table 14

Concentrations (ppm) of selected metals in tissues of marine birds from sites along coastal regions of the world

Species	Location	Hg		Pb		Cd		Zn		Reference
		Liver	Kidney	Liver	Kidney	Liver	Kidney	Liver	Kidney	
Oyster Catcher (Haematopus ostralegus)	United Kingdom	0.18 (N=9)	0.15 (N=23)			2.63 (N=16)	6.75 (N=21)	34.48 (N=10)	32.85 (N=21)	Hutton 1981[†]
Herring Gull (Larus argentatus)	United Kingdom	1.02 (N=23)	0.97 (N=17)			0.50 (N=16)	3.25 (N=23)	22.9 (N=23)	24.4 (N=16)	Hutton 1981[†]
Great Skua (Catharacta skua)	United Kingdom	2.60 (N=12)	2.17 (N=11)			1.88 (N=12)	20.35 (N=12)	34.85 (N=12)	40.98 (N=11)	Hutton 1981[†]
Louisiana Heron* (Hydranassa tricolor)	Galveston Bay Texas			0.46±0.06 (N=9)	0.46±0.10 (N=9)	0.78±0.010 (N=9)	0.823±0.164 (N=9)			Cheney et al. 1981
Cattle Egret (Bubulcus ibis)	Galveston Bay Texas			0.41±0.05 (N=4)	0.35±0.15 (N=4)	0.111±0.024 (N=4)	1.271±0.260 (N=4)			Cheney et al. 1981
Royal Tern** (Thalasseus maximus)	Galveston Bay Texas			0.18±0.04 (N=5)	0.37±0.24 (N=5)	0.011±0.004 (N=5)	0.014±0.003 (N=5)			Maedgen et al. 1982
Sandwich Tern (Thalasseus sandvicensis)	Galveston Bay Texas			0.24±0.05 (N=5)	0.14±0.01 (N=5)	0.026±0.007 (N=5)	0.040±0.016 (N=5)			Maedgen et al. 1982
Sooty Tern (Sterna fuscata)	Dry Tortugas Gulf of Mexico	1.52±0.09 (N=10)	1.64±0.17 (N=10)			3.79±0.36 (N=10)	23.50±1.09 (N=10)			Stoneburner & Harrison 1981
Sooty Tern	Hawaii	1.59±0.79 (N=10)	1.36±0.19 (N=10)	0.03±0.01 (N=10)	1.73±0.20 (N=10)	2.03±0.19 (N=10)	16.65±1.79 (N=10)			Stoneburner & Harrison 1981
Common Tern (Young)	Long Island New York	1.36±0.91 (N=16)	1.13±0.92 (N=16)							Gochfeld 1980
Puffin (Fractercula arctica)	St. Kilda Outer Hebrides					5.2 (N=3)	25.8 (N=3)			Bull et al.[†] 1977
Fulmar (Fulmarus glacialis)	St. Kilda Outer Hebrides					8.08 (N=4)	31.47 (N=4)			Bull et al.[†] 1977
Manx Shearwater (Puffinus puffinus)	St. Kilda Outer Hebrides					6.01 (N=4)	34.0 (N=4)			Bull et al.[†] 1977
Leach's Petrel (Oceanodroma leucorhoa)	St. Kilda Outer Hebrides					8.26 (N=3)	23.04 (N=3)			Bull et al.[†] 1977
Storm Petrel (Hydrobates pelagicus)	St. Kilda Outer Hebrides					4.43 (N=4)	15.60 (N=4)			Bull et al.[†] 1977
Razorbill (Alca torda)	St. Kilda Outer Hebrides					0.47 (N=3)	4.07 (N=3)			Bull et al.[†] 1977
Black-crowned Night Heron (Nycticorax nycticorax)	Annex, North Carolina	1.07		0.27 (N=7)		-	-	162.0 (N=7)		Custer & Mulhern[†] 1983
Black-crowned Night Heron	Clarks Island Massachusetts	0.83		0.21 (N=3)		-	-	150.53 (N=3)		Custer & Mulhern[†] 1983
Black-crowned Night Heron	Hope Island Rhode Island	1.24		0.31		-	-	125.75		Custer & Mulhern[†] 1983
Puffin		1.14 (N=10)	1.26 (N=10)			4.98 (N=10)	28.5 (N=10)	29.5 (N=10)	41.0 (N=10)	Osborn et al.[†] 1979
Manx Shearwater		2.55 (N=10)	1.17 (N=10)			4.05 (N=10)	23.63 (N=10)	35.25 (N=10)	44 (N=10)	Osborn et al.[†] 1979
Fulmar		7.35 (N=5)	3.35 (N=5)			12.25 (N=5)	57.0 (N=5)	91.0 (N=5)	77.5 (N=5)	Osborn et al.[†] 1979
Glaucous-winged Gull (Larus glaucens)	Elliott Bay Commencement Bay Strait of Juan de Fuca	1.03 (N=2) 0.75 (N=2) 0.16 (N=1)	0.81 (N=2) 0.78 (N=2) 0.25 (N=1)	0.43 0.36 0.05	1.47 0.72 0.21	0.20 0.05 0.05	0.39 0.08 0.13	92.0 97.5 79.5	85.9 91.3 77.2	This study This study This study
Great Blue Heron (Ardea herodias)	Elliott Bay Commencement Bay Sequim Bay	3.3 11.7 2.80	0.2 6.4 1.4	0.27 0.17 0.10	0.56 0.24 0.11	0.13 0.14 0.04	0.16 0.52 0.15	174 122 280	52 60 71	This study This study This study
Pigeon Guillemot (Cepphus columba)	Elliott Bay Strait of Juan de Fuca	0.04 0.07	0.11 0.59	0.04 0.02	0.07 0.08	3.1 2.3	5.2 5.0	0.94 0.70	0.69 0.50	This study This study

* Adults

** Prefledglings

† Corresponding wet weight conversions calculated from dry weight values. Wet weight values are approximately 0.25% of dry weight.

cattle egrets, found that concentrations of Pb in liver of cattle egrets (downing young, prefledglings, and adult age classes) were higher than in kidney. Concentrations of lead in liver and kidney in Louisiana herons (downing young, prefledglings, adults) were nearly the same.

The zinc (Zn) concentrations that we observed in liver and kidney of young gulls in all three study sites are, in general, somewhat higher than reported in other marine birds (Table 14). Custer and Mulhern (1983) did report higher Zn concentrations in young Black-Crowned Night Herons from the Atlantic Coast. In comparing the three areas in this study, concentrations of zinc in birds from Commencement Bay differed significantly from birds from Elliott Bay or Protection Island. Zinc is known to be toxic to birds. Gasaway and Buss (1972) found that mallards fed a 3000 ppm zinc supplemented diet had high mortality and that all but 2 of 24 ducks died in 60 days. Mean Zn concentrations in liver and kidney of mallards, which died during the 3000 ppm feeding, were 401 and 413 ppm (wet wt) respectively; control birds had mean liver and kidney Zn concentrations of 54 and 27 ppm (wet wt) respectively. The concentrations we detected are nearer to those in the control birds and may be insignificant as a health hazard. Wild birds are subjected to a variety of natural stresses which laboratory birds are not. These natural stresses may promote sublethal effects which would not occur under laboratory conditions.

4.5.4 Relationship of Metal Concentrations to Feeding Strategies or Age

The Great Blue Herons and Pigeon Guillemots add several other dimensions to our study of metals in marine birds. First, these birds are primarily fish eaters. Second, the herons we collected were adult birds, not prefledglings. The Pigeon Guillemots and gulls were prefledglings. Several researchers (Hutton, 1981; Maedgen et al. 1982; Cheney et al. 1981) have found that trophic level position is related to metal concentrations in tissues; while still others report on age affecting level of accumulation (Maedgen et al. 1982). We compared the three species and two age groups to determine if there were differences that may be related to trophic position or age. We also examined the concentrations of selected metals in birds from the three study sites for differences between sites.

In the three bird species, kidney tissues contained the highest concentrations of cobalt. The Pigeon Guillemots had concentrations of cobalt an order of magnitude lower than the gulls or herons. The highest concentrations of cobalt for all three species occurred in birds from the nonurban areas. The differences observed may reflect some ontogenic differences in birds, trophic position, or age. Because the guillemots and gulls were nearly the same age, we expected them to be similar; however, this was not the case. No apparent relationship existed between cobalt tissue concentrations and bird

type (e.g., fish feeders, herons and guillemots). Thus, there may be some physiological process whereby cobalt is not bound to liver or kidney tissue or is bound to metal binding proteins and excreted.

The concentrations of iron in liver and kidney of heron at all three sites were consistently higher than concentrations detected in either the gulls or guillemots. This difference appears to be age-related. Concentrations of iron in gulls and herons from the nonurban areas were higher than from the urban areas while the guillemot from Elliott Bay had a liver concentration of iron nearly twice that of the bird from Protection Island.

Chromium concentrations were similar among bird species and among study sites, indicating that concentrations of this element may be similar in birds throughout Puget Sound and is either not a significant pollutant or is not getting into the food chain of marine birds.

Nickel concentrations were consistently low in all bird tissue sampled with the exception of kidney tissues from Pigeon Guillemots and kidney and adipose tissue from a dead heron collected at Sequim Bay. The concentration of nickel in heron kidney of 11.49 ppm (wet wt) is quite high and may have contributed to the starvation death of this bird. Custer and Mulhern (1983) believed that a Black-Crowned Night Heron which they found dead with a liver nickel concentration of 2.5 ppm (wet wt) probably died as a result of nickel poisoning. The kidney nickel concentrations of 0.13 and 0.50 ppm in Pigeon Guillemots from Protection Island and Elliott Bay, respectively, are an order of magnitude above most other concentrations that we detected in other tissues and may represent a potential problem.

Copper (Cu) concentrations were highest in liver tissue of Great Blue Herons (Sequim sample; 65 ppm liver, 72 ppm kidney). Gulls collected from Protection Island had liver concentrations of 62.7 ppm (wet wt). The concentration of Cu found in the liver of a Pigeon Guillemot collected from Elliott Bay was 21.3 ppm (wet wt). Custer and Mulhern (1983) consider the 24-381 ppm (dry wt) Cu in Black-Crowned Night Heron livers as high. This range, when extrapolated to a wet wt basis, equals a range of 5-100 ppm. The concentration of copper in livers of immature osprey collected in July in a Maryland study averaged 141 ppm (wet wt), while adults from the same area averaged 30 ppm (wet wt). Copper concentrations in immature ospreys collected from other areas in September averaged 4 ppm (wet wt), while adults from the same area averaged 30 ppm (wet wt). Immature ospreys collected from other areas in September had concentrations of copper which averaged 4 ppm (wet wt) (Wiemeyer et al., 1975). Copper concentrations in lesser Black-Backed Gulls averaged 17 ppm dry wt (4.5 ppm wet) (Lande, 1977) while Common Puffins ranged from 19-53 ppm dry wt (5-17 ppm wet wt) (Parslow and Jeffries, 1973). These elevated concentrations of copper are higher than reported for several marine bird species and indicate a potential problem.

Selenium, silver and cadmium concentrations were relatively low in all bird tissue samples except for the two Pigeon Guillemots. This species may be somewhat physiologically different from the Glaucous-Winged Gull or the Great Blue Heron in its capacity to metabolize or to bind these trace elements. There may be some mechanism that allows parallel accumulation of selenium, silver and cadmium in such a way that one or all of these elements interact to exert a protective influence on the toxicity of each other or on the toxicity of other elements.

Antimony (Sb) concentrations were low in most of the birds that we sampled (Tables 8, 10, 11). Two Great Blue Herons, one from Elliott Bay and one from Sequim Bay, had either kidney or liver concentrations an order of magnitude higher than the other birds.

Of the bird species studied, mercury (Hg) concentrations were highest in the liver of the Great Blue Heron. The concentrations of mercury in the livers of heron from this study exceed concentrations detected in most other marine birds collected from around the world (Table 14). The concentrations we observed in young gulls is similar to other findings, but concentrations detected in guillemot livers were generally lower. The higher concentrations we observed in herons may be related to the presence of intracellular binding sites. Perhaps herons contain more metallothionein-like materials which bind mercury. Mercury has also been shown to concentrate at or near the time of molt (Osborn et al., 1979). The herons we collected may have been undergoing molt at the time of capture. The herons may also have been foraging in an area of high mercury contamination. Of the three study sites, the Commencement Bay herons had the highest concentrations of mercury.

The concentrations of lead (Pb) were highest in the kidneys of prefledgling birds of this study. A heron collected in Commencement Bay was the exception, having a higher concentration of Pb in its liver. This bird also contained the highest concentration of Pb found in any of our samples (1.55 ppm wet wt). Most Pb concentrations ranged from 0.1 to 1.0 ppm (wet wt) and are in the general range of concentrations found in other marine birds from around the world (Table 14).

Zinc (Zn) was detected in all of the herons we collected. The liver was the principle tissue for accumulation. Concentration of Zn in the guillemots was significantly lower (by 3 orders of magnitude) relative to concentrations detected in gulls or herons. If Zn concentrations were simply correlated with age, the guillemots and gulls would have similar concentrations, and herons would have higher concentrations. This was not the case, however.

Tissue concentrations of arsenic (As) were consistently low with the exception of a heron liver from the Sequim area. Arsenic apparently is relatively immobile in food chains leading to marine

birds or perhaps is easily excreted and not stored. The presence of As has been documented in relatively high concentrations in sediment samples from Commencement Bay (Crecelius, 1974).

In examining the different levels of inorganics in the liver and kidney tissues of the three birds species, we noted some patterns that appear to be related to tissue accumulation, while others appear to be related to species physiology and still others show correlation with study site (urban vs nonurban). The intent of this study was to attempt to determine the concentrations and distributions of inorganics in marine birds but not to identify the precise mechanisms involved in inorganic uptake. In comparing our findings with those of other researchers, we tried to assess potential problems that may be present in relation to toxicity of inorganics. The above discussion points out only a few potential problems related to inorganics. Most of the levels we report agree with concentrations reported in birds monitored from other areas of the world that appeared to be healthy and to be reproducing at a normal rate.

4.5.5 Biological Processes

The differing concentrations of selected metals in marine bird species from urban and nonurban sites signifies that a variety of processes must be operating in uptake and retention.

The three bird species we studied represent different feeding strategies. Gulls are primarily omnivorous, at times feeding on fish and marine invertebrates, and often feeding on upland garbage. Great Blue Herons are carnivorous, feeding on fish and other marine animals in shallow water areas and sometimes on small terrestrial mammals. Pigeon Guillemots feed mostly on fish in both shallow and deep water.

The species also represented different age groups. The gulls and guillemots were young (5-6 weeks old) while the herons were adult birds. Adult birds are known to accumulate cadmium and mercury with age (Hulse et al., 1980). Our findings for mercury tend to confirm this, but cadmium data do not; young guillemots had the highest cadmium levels.

Besides different feeding strategies and age, physiology and intracellular differences between species, sexes and age classes may have an effect on inorganic uptake and retention (Osborn et al., 1979). Metallothionein has been reported to function in the binding of several metals and may be an important factor to consider in interpreting levels of metals in different bird species.

Several possible reasons could explain the fact that we did not detect either aromatic hydrocarbons, chlorinated butadienes or chlorinated benzenes in any of the bird species from Puget Sound. Since aromatic hydrocarbons are ubiquitous, they would tend to be available for uptake from the water column by fish. Both laboratory

and field investigations have shown that fish exposed to hydrocarbon-contaminated water accumulate aromatic hydrocarbons in various tissues, however, metabolism and excretion progressively reduce the body burden so that these hydrocarbons are not always detected (Malins and Hodgins, 1981). This is primarily due to the presence in the fish of active enzyme systems (aryl hydrocarbon monooxygenases). The results of Malins and Hodgins (1981) are supported by the very low or undetectable concentrations of aromatic hydrocarbons found in rockfish and English sole and undetectable concentrations in salmon and cod collected from various regions of Puget Sound (Malins et al., 1981). Since a primary source of food to marine birds of this study (herons and gulls) is fish, these results would support our results of not detecting these compounds in the various tissue types of marine birds that we analyzed. In addition, these bird species may also contain these enzyme systems, further reducing the likelihood of accumulation of these compound types.

With the exception of hexachlorobutadiene, chlorinated butadienes have not been detected in the skeletal muscle of salmon or cod although the same tissue contained detectable concentrations of PCBs (Malins et al., 1981). Again, if fish are assumed to be a main food source to marine birds of this study, these results would tend to support our findings of high concentrations of PCB in bird tissue with the absence of chlorinated butadienes.

The conclusion that one can draw from the results of our study and studies on the organic chemistry of fish of Puget Sound is that chemical structure plays an extremely important role in determining whether a specific compound type is transferable through the food web. PCB appears to be a unique class of compounds. Neither fish nor birds appear to have been able to develop systems to permit effective elimination of these components through metabolism and excretion. Therefore, if the concentrations of these compounds in the water column of Puget Sound were to increase, there could potentially be a significant increase in the concentrations of these components in marine birds leading to potential stress with subsequent potential long-term ecological impact. Conversely, decreases in the concentration of PCB in water could result in decreased concentrations of PCBs observed over time in fish and marine birds.

The effects of PCBs on marine birds are poorly understood. Toxicity studies have been conducted for pheasants (Dahlgren et al., 1972), Japanese Quail, Bob White Quail and Mallards (Hill et al., 1975). These studies provide a basis for predicting effects of PCBs on marine birds and provide some insight into the mechanisms of PCB uptake and retention. The work by Hill et al. (1975) presents subacute toxicities by measuring a median lethal dietary concentration (LC50) of PCBs fed to young birds during an 8-day test. The types of data generated in these kinds of tests indicate the relative toxicity of PCBs but do not provide any indication of a concentration of PCBs in tissue at time of death. There are studies which relate tissue concentration to effects on birds. Most of these studies provide only

concentrations in brain tissue without relating these concentrations to liver, kidney or adipose tissue (Dahlgren et al., 1972); Cromartie et al., 1975; Stendell, 1976). According to Dahlgren et al. (1972), concentrations in brain of 300-400 ppm (wet wt), indicated death due to PCB toxicosis. Stendell (1976) reports that brain concentrations of 349-763 ppm (wet wt) of PCBs were diagnostic of death in blackbirds. There was no analysis of any other tissues for comparison. Parslow and Jefferies (1973) analyzed livers and whole bodies of Pigeon Guillemots found dead in the Irish Sea; PCBs were implicated. The body load of PCBs in the birds that died was 4.66 µg/g (wet wt) which was about twice that detected in healthy birds collected from the same region. The physiological actions of PCBs and concentrations credited with inducing death or behavioral abnormalities are discussed by Olendorf et al. (1978).

Table 15 provides a list the concentrations of PCBs reported in marine birds from around the world. Concentrations of PCB in tissue of normal healthy birds appears to range from 0.1-10 ppm (wet wt) in liver and 10-50 ppm (wet wt) in adipose tissue. A Glaucous-Winged Gull from Bean Island on the North Atlantic (Bourne and Bogan, 1972) contained 311 ppm PCBs in its liver and another gull contained 535 ppm in adipose tissue. These concentrations represent some of the highest PCBs reported in marine birds. The concentrations reported by Bourne and Bogan (1972) appear to be given on a ppm wet wt basis; however, this is not stated in their paper. If the concentrations are on a lipid basis, they would be considerably lower. Another way to examine PCB contamination in Puget Sound marine birds is to relate the concentrations of PCBs in the tissue of birds of urban and nonurban areas of the Puget Sound region. In doing this, one can see that the birds of Elliott and Commencement Bay (urban areas) have higher body burdens of PCBs than birds from Protection Island and Sequim Bay (nonurban areas). It is apparent from Table 15 that the concentration of PCBs found in marine birds elsewhere in the world are lower than those of marine birds in Puget Sound.

The birds of Puget Sound, in some cases, contain abnormally high concentrations of PCBs. These high concentrations may contribute to the death of marine birds through direct poisoning or mobilization of adipose tissue or through other sublethal effects resulting from environmental stress.

Concentration of PCBs in the guillemot egg from the Duwamish Waterway is high (11.3 ppm, wet wt) in the great majority of cases in comparison with eggs of marine birds from other areas of North America (Table 16). Our sample size (1) is inadequate to make any meaningful comparisons but does indicate that a potential problem may exist with PCB contamination in some marine birds inhabiting Puget Sound waters. Stendell (1976) reports that in studies with chickens, when the concentration of PCB in whole eggs reached 4.5 ppm, hatchability was almost completely eliminated. However, a study conducted in Puget Sound (Steve Herman, Evergreen State College, Olympia, Washington,

Table 15

Polychlorinated biphenyls in tissues of marine birds

Species	Location	PCB (ppm wet wt) Liver	Kidney	Adipose	Reference
Black Skimmer (Rynchops niger)	South Carolina	2.7 (N=23)	-	-	Blus & Stafford 1975
Double Crested Cormorant (Phalacrocorax auritus)	South Dakota	2.0 (N=10)	-	22.4 (N=8)	Greichus et al. 1973
White Pelican (Pelecanus crythrorynchros)	South Dakota	4.5 (N=3)	-	31.4 (N=3)	Greichus et al. 1973
Puffin (Fratercula arctica)	Scotland	5.9 (N=4)	-	31.0 (N=19)	Harris & Osborn 1981
Thick Billed Murre (Uria lomvia)	Greenland	-	-	3.65 [14.6]*	Braestrup et al. 1974
Cormorant (Phalacrocorax carbo)	Greenland	-	-	6.56 [26.23]	Braestrup et al. 1974
Sooty Tern (Sterna fuscata)	Ascension Island	-	-	0.057 (N=3)	Johnston 1973
Common Tern (Sterna hirundo)	Massachusetts	3.8 (N=1)	-		Bourne et al. 1977
Glaucous Gull (Larus hyperboreus)	Bear Island North Atlantic	72.0 (N=6)	-	535 (N=1)	Bourne & Bogan 1972
Lesser Black-Backed Gull (Larus fuscus)	Faroes	11.0 (N=3)	-	-	Bourne & Bogan 1972
Herring Gull (Larus argentatus)	Isle of May, Fife	0.31 (N=3)	-	17.17 (N=3)	Bourne & Bogan 1972
Black Guillemot (Cephus grylle)	Stornoway North Atlantic	0.2 (N=1)	-	-	Bourne & Bogan 1972
Common Murre (Uria aalge)	Faroes	0.74 (N=5)	-	-	Bourne & Bogan
Thick Billed Murre (Uria lomvia)	Bear Island North Atlantic	0.20 (N=2)	-	3.1 (N=2)	Bourne & Bogan 1972
Great Blue Heron (Ardea herodias)	Seattle (Elliott Bay)	3.2 (N=2)	1.6 (N=2)	33.1 (N=2)	This study
	Tacoma (Commencement Bay)	1.5 (N=2)	0.44 (N=2)	53.3 (N=2)	
	Sequim Bay	0.75 (N=1)	0.24 (N=1)	5.5 (N=1)	
Glaucous-Winged Gull (Larus glaucescens)	Seattle (Elliott Bay)	0.19 (N=4)	0.05 (N=4)		This study
	Tacoma (Commencement Bay)	0.58 (N=4)	0.11 (N=4)		
	Protection Island	0.041 (N=4)	0.005 (N=4)		
Pigeon Guillemot (Cepphus columba)	Seattle (Elliott Bay)	0.002 (N=1)			This study
	Protection Island	0.006 (N=1)			

* [ppm dry wt]

Table 16

Concentrations of polychlorinated biphenyls in eggs of fish-eating birds from North America

Species	Location	PCB (ppm - wet wt)		Reference
Common Murre (Uria aalge)	Gulf of Alaska	0.625	(N=5)	Olendorf et al. 1982
Tufted Puffin (Lunda airhata)	Gulf of Alaska	0.518	(N=5)	Olendorf et al. 1982
Thick-billed Murre (Uria lomvia)	Gulf of Alaska	0.259	(N=5)	Olendorf et al. 1982
Ancient Murrelet (Synthliboramphus antiquum)	Aleutian Islands	0.829	(N=5)	Olendorf et al. 1982
Common Murre	Aleutian Islands	0.136	(N=5)	Olendorf et al. 1982
Thick-Billed Murre	Aleutian Islands	0.090	(N=5)	Olendorf et al. 1982
Black Oyster catcher (Haematopus bachnasi)	Oregon Coast	0.32	(N=5)	Henny et al. 1981
Pigeon Guillemot (Cepphus columba)	Oregon Coast	0.33	(N=5)	Henny et al. 1981
Pelagic Cormorant (Phalacrocorax pelagicus)	Oregon Coast	0.68	(N=4)	Henny et al. 1981
Tufted Puffin	Oregon Coast	0.51	(N=3)	Henny et al. 1981
Brandt's Cormorant (phalacrocorax penicillatus)	Oregon Coast	0.61	(N=7)	Henny et al. 1981
Common Murre	Oregon Coast	0.52	(N=8)	Henny et al. 1981
Western Gull (Larus occidentalis)	Oregon Coast	0.47	(N=8)	Henny et al. 1981
Double Crested Cormorant (Phalacrocorax auritus)	Oregon Coast	1.3	(N=10)	Henny et al. 1981
Leach's Storm Petrel (Oceanodroma leucorhoa)	Oregon Coast	1.1	(N=11)	Henny et al. 1981
Fork-Tailed Storm Petrel	Oregon Coast	5.1	(N=1)	Henny et al. 1981
Brown Pelican (Pelecanus occidentalis)	South Carolina	7.63 (0.40-27.5)	(N=115)	Blus et al. 1979
Brown Pelican	Florida-Atlantic Coast	6.12 (0.25-13.0)	(N=51)	Blus et al. 1979
Least Tern (Sterna albifrons)	South Carolina	0.62	(N=15)	Blus & Prouty 1979
Double Crested Cormorant	South Dakota	5.7	(N=5)	Greichus et al. 1973
White Pelican (Pelecanus Crythorhynchos)	South Dakota	1.7	(N=3)	Greichus et al. 1973
Pigeon Guillemot	Washington (Puget Sound)	11.26	(N=1)	This study

unpublished data) showed no differences in the thicknesses of Pigeon Guillemot egg shells of eggs which had contained PCB concentrations in the range of 2.7 to 23.4 ppm (wet wt).

4.5.6 Biomagnification of PCBs from Water to Marine Birds

To gain a better understanding of the relationships between the concentrations of PCBs in the abiotic and biotic communities of the Puget Sound region, we estimated the biomagnification of PCBs from water to fish and from fish to various tissue types of marine birds. In doing so, the total biomagnification from water to marine bird tissues was also estimated. Table 17 summarizes the results of this exercise. In making the estimations listed in this table, several assumptions were made. First, it was assumed that the range of values used for concentrations of PCBs in the various compartments were equilibrium values. Second, biomagnification factors for the birds were based on fish as the primary food source and on the water column as the primary pathway for accumulation in the fish (Southworth et al., 1979) though the issue of the major route of uptake (gills or stomach) is far from resolved. Third, we used values of the concentrations of PCBs in muscle of off-bottom fish (although the fish species for which we have data may not be those the birds eat) for our calculations, although in some cases (Malins et al., 1982) the liver accumulated more (greater than 100x) PCBs than muscle. However, we felt that this was justified by the fact that the basic assumption is that birds eat the whole fish. Although the biomagnification from fish to marine birds was a factor of 10 lower than the accumulation from seawater to fish, the overall biomagnification from seawater to selected marine bird tissue ranged from 4,000 to 54 million. These biomagnification factors are fairly consistent with data summarized by Nisbet and Sarofim (1972). Transfer of PCBs to bird eggs is also quite interesting. For the one egg that we analyzed, biomagnification from seawater would be 220,000 to 7.5 million, but this also includes the transfer of the contamination to the next bird generation if the egg successfully hatches.

Table 17

Estimates of biomagnification of PCB from abiotic and biotic compartments of Puget Sound to selected tissue types and egg of marine birds

Compartment	Concentration of PCB	Biomagnification Range		
		Sea Water to Fish	Fish to Bird	Sea Water to Bird
Seawater	3 to 22 ng/l*			
Fish (muscle)	50 to 100 ng**	$(0.2\times10^4 - 3.4\times10^4)$		$(0.4\times10^4 - 3.4\times10^6)$
Marine birds			$(2 - 1\times10^2)$	
kidney/liver	200 to 5,000 ng/g†		$(1.5\times10^2 - 1.6\times10^3)$	$(7.5\times10^6 - 5.4\times10^7)$
adipose (fat)	15,000 to 80,000 ng/g†		$(1.1\times10^2 - 2.2\times10^2)$	$(2.2\times10^5 - 7.5\times10^6)$
egg	11,000 ng/g⊥			

* Pavlou and Dexter (1979)

** Gahler et al. (1982), Malins et al. (1982)

† This study

5.0 RECOMMENDATIONS

Sampling and analysis of sediment core profiles from Colvos Passage and southern Puget Sound would provide additional information on the historical input of CBD to this region. Such information would be useful to researchers working to understand circulation and tidal movements as they would apply to the transport and deposition of these compounds from a point source. In addition, one conclusion that can be made from the sediment chemistry is that the major source of Sb in the southern basin (waters south of The Narrows) is Tacoma. Tacoma and the Main Basin (waters between The Narrows and Point No Point) are probably significant sources of other metals since metal-rich suspended matter is always present in the main basin water that would be averted into the southern basin on each flood tide. To verify this conclusion would require estimating the relative inputs of metals to the southern basin. Verification may require sampling and analyzing rivers, wastewater outfalls, and seawater entering the main basin. We also recommend that the concentrations of metals in several age-dated cores be determined so the accumulation rate of metals in the southern basin can be compared with the rate for the main basin.

We have also learned from this study that while there is a wealth of information on the concentrations of a variety of inorganic and organic contaminants in marine birds from around the world and their corresponding habitats, there is little information available to permit extrapolation of this information to assess long-term risks to marine bird populations and the impact of mitigative actions in the field. Thus, there is a need to conduct additional studies to bridge these data gaps. Major missing components include good estimates of food chain transfer coefficients and experiments to better understand the impact of bioaccumulation including acute and chronic toxicity, hatching success and behavior. In addition, more experimental work needs to be performed to define the relationships between pollutant (organic and inorganic) tissue concentrations and such factors as feeding habits, age and breeding conditions. Results of these types of studies will lead to a better understanding of the influence of toxicant body burden and effects. Laboratory experimentation has provided LD50 information on a variety of organic contaminants and their toxicity in the white rat. However, insufficient work has been done to couple experimental work on wildlife populations with existing mammalian data sets to design experiments which might provide data useful in estimating potential transfer of pollutants from fish to birds. We note that fish are a common food source for man and birds and that these transfers might be similar. Such similarities, if identified, would be useful in assessing risk to man.

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APPENDIX A

Bird Survey

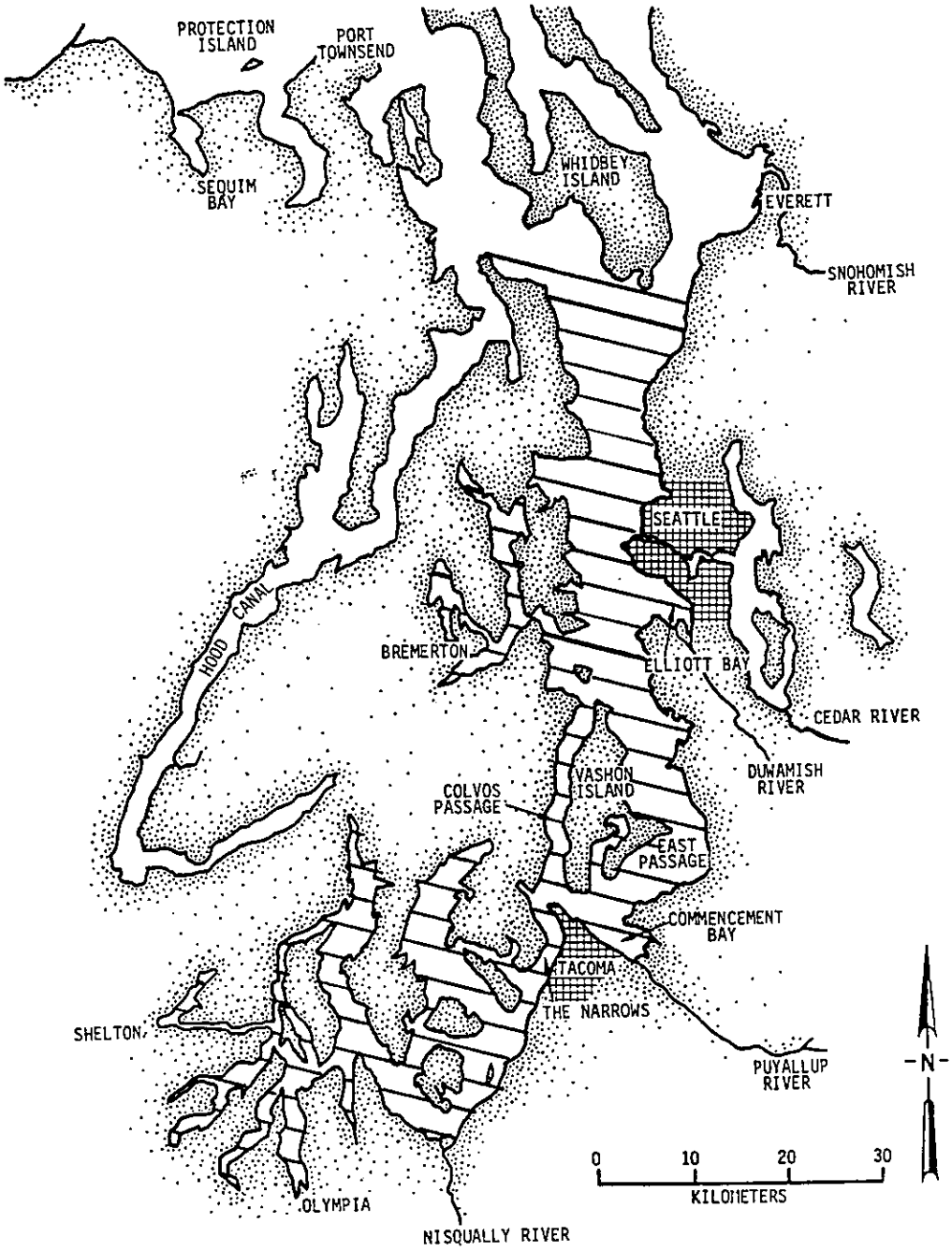

Figure A-1

Area surveyed by Wahl and Speich from June 21 to July 6, 1982

APPENDIX B

Sampling Methods

APPENDIX B

Sampling Methods

Sediments. Grab samples (0-5 cm layer, ~200 g wet wt) of central and southern Puget Sound sediments were collected from a Battelle-Northwest research vessel anchored at each sampling site. Sampling of this region of Puget Sound occurred in August 1982. The grab sample design (Van Veen) was of a type that avoided contamination of the sediments by either metals or organic compounds. Samples of the sediment were brought back to the Battelle Marine Research Laboratory, homogenized, split, and stored for analysis in precleaned wide-mouth glass jars. One half of the sediment samples were frozen (-70°C) and shipped to the Battelle Richland facility for organic chemical analysis. The sediment samples designated for metals, water content, and grain size analysis were refrigerated but not frozen. Replicate sediment samples were analyzed for metals to determine variability in sampling areas and variability within a sample. For organic analyses, only variability between replicate sediment samples was determined.

The sediment stations were selected on the basis of sediment grain size data, water circulation patterns and published data on contaminants in surface sediments of central and southern Puget Sound (Crecelius et al., 1975; Malins et al., 1980). The sampling design was planned for compatibility with sample analyses performed by METRO in Central Puget Sound.

Birds

Three species of birds were collected: Glaucous-Winged Gull, Great Blue Heron, and Pigeon Guillemot. The areas of collection and the techniques that we employed varied with the species which we had chosen for sampling.

Glaucous-Winged Gull. The gulls were prefledglings and were taken from previously observed nesting colonies. The colonies in Elliott and Commencement Bays were on old abandoned docks which we reached by boat at high tide. The Protection Island Colony nested on the ground and was reached by boat from Battelle's Sequim facility. Five specimens were hand-picked from each colony.

Great Blue Heron. Adults of this species were collected; two from the Seattle area, two from the Tacoma area, and one from Sequim Bay. Herons frequently perched on pilings. They fed at low tide and on the incoming tide in the mud flats which were penetrated by small fresh water streams.

Padded No. 2 metal jaw traps were submerged in the small streams in groups of three and were baited with herring. The herring were held with nylon monofilament line and the traps were anchored with braided cord. The herons, in their search for food on the mud flats,

waded through the small streams and eventually walked into the traps. Similar traps were previously placed on the tops of pilings. This technique was abandoned because of the small number of herons in proportion to the large number of pilings. The heron collected from Sequim Bay had been found dead.

Pigeon Guillemot. Two Pigeon Guillemots, aged 5 to 6 weeks, were sacrificed for analysis. In Elliott Bay, from a nest of two under the P/S freight dock in the West waterway, one bird was sacrificed for tissue chemistry. Four addled eggs from another nest were collected for analysis. On Protection Island, a specimen was removed from a nest under driftwood. Dr. Joseph Galusha, Walla Walla College, provided the kidney and liver tissues under his collection permit for pigeon guillemots.

APPENDIX C

Analytical Methods

APPENDIX C

Analytical Methods

Percent Total Solids of Sediment. Samples of sediment of known weight were freeze-dried to constant weight. Percent total solids was determined by weight difference.

Grain Size Analysis. Grain size was determined by a combination of sieving and particle settling rates in water.

Sediment Organic Carbon Content. The sediment organic carbon content was determined by wet oxidation of carbon to CO_2 in sealed ampoules after inorganic carbon was removed. The CO_2 produced was quantified by infrared light adsorption using an Oceanography International carbon analyzer.

Inorganic Analysis of Sediments. Several analytical techniques were used to determine the total concentration of 23 elements in the 16 sediment samples and two standard reference sediments. The techniques included neutron activation analysis (NAA) for Co, Cr, Se, Sb, and Sc; energy dispersive x-ray fluorescence (XRF) for Al, K, Ca, Ti, Mn, Fe, P, Si, Sr, V, Ni, Cu, Zn, As and Pb; and atomic absorption (AA) for Ag, Cd, and Hg.

The sediment samples were freeze-dried to constant weight and then homogenized. For neutron activation analysis, 0.5 g of sediment was activated in a nuclear reactor and the gamma rays of radionuclides of interest were counted using a Ge(Li) diode detector. The x-ray fluorescence technique required pressing a 0.5 g pellet of sediment. The x-ray excitation, detection, and data reduction are described by Nielson (1977). Before analysis by atom absorption -- 1.0 g of sediment was digested with 12 ml of a mixture containing 6.5 M HNO_3 and 3.0 M H_2SO_4 at 90°C in Pyrex® volumetric flasks with lids. After heating 2 hours, the indigestate was diluted to a volume of 100 ml with deionized water. Mercury was determined by cold vapor atomic adsorption. Silver and Cd were quantified by graphite furnace atomic absorption using a Perkin-Elmer 5000 Zeeman effect furnace.

The analytical uncertainty for the INAA and XRF techniques as determined by replicate analysis of a single sample, is usually not more than ±5% for one standard deviation. The uncertainty in the data due to variability among duplicate samples from a single station is approximately ±20% for one standard deviation.

Preparation of Sediment Samples for the Analysis of Aromatic Hydrocarbons and Halogenated Organic Compounds. Samples of sediment (100 g, wet wt) were thawed and placed in 150 ml Corex centrifuge tubes. Each sample was shaken twice with two 50 ml portions of methanol to remove the water. The methanol extracted sediments were slurried with methanol and transferred to Soxhlet thimbles and Soxhlet extracted with benzene/methanol according to the procedure of Clark

and Finley (1973). The Soxhlet extracts were combined with the two methanol extracts dried by passing through a glass column containing sodium sulfate and rotary evaporated to near dryness. The concentrated extracts were transferred to Solu-vials® and concentrated to one ml. Each sample was chromatographed over 15 g of silica gel (Davidson, 100-200 mesh). The columns were first eluted with 40 ml of hexane to remove non-polar hydrocarbons and then eluted with 86 ml of hexane/methylene chloride 80/20 to elute a fraction containing aromatic hydrocarbons and the halogenated organic compounds. The fraction containing the aromatic hydrocarbons and halogenated organic compounds was concentrated under a stream of nitrogen to a volume of 1 ml. Following addition of a mixture of hexamethylbenzene and 2-bromonaphthalene internal standards, individual components in the extracts were separated, characterized, and quantified by combination of capillary gas chromatographic (GC) and capillary gas chromatographic/ mass spectrometric (GC/MS) techniques.

Preliminary Screening of Sediment for Aromatic Hydrocarbons and Halogenated Organic Compounds. Samples of sediment from central and southern Puget Sound were screened for the presence of halogenated organic compounds using a Hewlett-Packard 5840 gas chromatograph equipped with a 50 m SE-54 quartz capillary column and electron capture or flame ionization detector. Individual samples showing significant detector response were then evaluated for possible GC/MS analysis.

Characterization of Aromatic Hydrocarbons and Halogenated Organic Compounds in Sediment by GC/MS. Characterization of aromatic hydrocarbons and halogenated organic compounds associated with sediment was conducted using a Hewlett-Packard 5840-A gas chromatograph containing a 50 m SE-54 quartz capillary column operating in the splitless mode and coupled to a 5985 mass spectrometer equipped with 7900A and 7920 disc drives and operating in the electron impact mode. Samples contained in heptane were injected into the gas chromatograph at 70°C, held at that temperature for 4 min and programmed at 4°/min to a final temperature of 260°C. Assignments of structure were based on comparison to literature spectra. For organic compounds containing chlorine, the number of atoms of chlorine contained in a compound was established by comparison of chlorine isotope ratios of detected compounds to those reported by McLafferty (1967).

Quantification of Selected Aromatic Hydrocarbons and Halogenated Organic Compounds in Sediment. Individual aromatic and halogenated organic compounds were separated and quantitated using a Hewlett-Packard 5840 gas chromatograph equipped with a 50 SE-54 quartz capillary column and flame ionization detector. The aromatic hydrocarbons that were quantified were naphthalene, 2-methylnaphthalene, 1-methynaphthalene, biphenyl, 2,6-dimethylnaphthalene, 2,3,5-trimethylnapthalene, fluorene, dibenzothiophene, phenanthrene, anthracene, 1-methylphenanthrene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benz(e)pyrene, benz(a)pyrene and perylene.

Response factors for individual components in standard mixes of halogenated organic compounds consisting of hexachlorobutadiene, two chlorinated benzene isomers and a standard Arochlor (polychlorinated biphenyl) were used to quantify these classes of compounds in the sediment extracts.

Preparation and Analysis of Bird Tissue Samples for Inorganic Components. Bird tissues were freeze-dried to constant weight, homogenized, and then analyzed by NAA for Co, Fe, Cr, Zn, Se, Sb, and Sc; and AA for Ni, Cu, As, Ag, Cd, Hg, and Pb. Dried tissue was neutron-activated and processed the same as sediment. Before analysis by AA, 0.5 g dry tissue was digested using 10 ml of 15.4 m HNO_3 in open Pyrex® volumetric flasks.

Preparation of Bird Tissue Samples for Analysis of Aromatic Hydrocarbons and Halogenated Organic Compounds. Bird tissue samples (~1-13 g wet wt.) were weighed into 150 ml Corex tubes. Fifteen ml of 2% NaCl were added to the tubes and the mixtures were homogenized using Tekmar Tissumizer®. 50 ml of methylene chloride/methanol (2/1, V/V) was added to a homogenate. The sample was homogenated again and then centrifuged. The aqueous/organic supernatant was transferred to a 250 ml separatory funnel. The tissue pellet was re-extracted with an additional 50 ml of methylene chloride/methanol and the supernatant from this was combined along with 50 ml of 2% NaCl with the supernatant present in the separatory funnel. The mixture was shaken and the layers were allowed to separate. In case of an emulsion, the mixture was centrifuged to obtain layer separation. The methylene chloride layer was drained into an erlenmeyer flask. The aqueous phase was washed with an additional 10 ml of methylene chloride. The methylene chloride layer from this extraction was combined with what was present in the erlenmeyer flask. The combined extract was dried by passing through a glass column packed with 7 grams of anhydrous sodium sulfate and eluting with an additional 20 ml of CH_2Cl_2. The extract was concentrated (~4 ml) using a Snyder column (water bath ~60°C). The extract was transferred to a Solu-vial concentrated under a stream of dry nitrogen (~1 ml) and subjected to silica gel separation as described for sediments. Following silica gel chromatography, the eluted aromatic fraction was subjected to gas chromatographic and/or gas chromatographic/mass spectrometeric analysis as described for sediments.

Preparation of Egg Sample for Analysis of Aromatic Hydrocarbons and Halogenated Organic Compounds. The contents of the bird egg (~10 g) in a beaker was mixed with anhydrous sodium sulfate (~1½ to 2 volumes). This mixture was then transferred to a Soxhlet thimble and then Soxhlet extracted overnight with 200 ml of hexane. The hexane extract was concentrated using a Snyder column (water bath ~70°). The concentrate was transferred to a Solu-vial® and subjected to silica gel chromatography as described for sediments. Following silica gel chromatography, the eluted aromatic fraction was subjected to gas chromatographic and/or mass spectrometeric analysis as described for sediments.

APPENDIX D

Elements in Standard Reference Materials and Sediments of Central and Southern Puget Sound

Table D-1

Quality assurance standards analyzed during this study. Concentrations of elements in Canadian reference marine sediments numbered MESS and BCSS. Certified values supplied by NRCC (1981). Other lines of data generated during this study.

Sample ID	Major Constituents, Percent Dry Weight								
	Al	K	Ca	Ti	Mn	Fe	P	Si	Sr
MESS-1 (this work)	5.1	1.92	0.513	0.497	0.0497	3.10	<0.29	27.1	0.0082
Certified Values	5.8	1.86	0.482	0.543	0.0513	3.09	0.064	31.6	0.0089
BCSS-1 (this work)	6.3	1.89	0.664	0.420	0.0263	3.42	<0.29	27.0	0.0093
Certified Values	6.3	1.80	0.543	0.440	0.0229	3.28	0.067	30.9	0.0096

Sample ID	Trace Components, Parts Per Million Dry Weight													
	Co	V	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Hg	Sc	Pb
MESS-1 (this work)	10.9	57	72	30	28	170	10.5	2.5	0.105	0.67	0.80	0.175	11.1	36.8
Certified Values	10.8	72	71	30	25	191	10.6	(0.4)[a/]	--	0.59	0.73	0.171	--	34.0
BCSS-1 (this work)	11.1	76	126	55	20	99	11.3	1.2	0.065	0.21	1.15	0.135	12.3	22.3
Certified Values	11.4	93	123	55	19	119	11.1	(0.4)[a/]	--	0.25	0.59	0.129	--	22.7

[a/] Not a certified value.

Table D-2

Quality assurance standards analyzed during this study. Elemental concentrations for U.S. National Bureau of Standards standard reference materials, SRM 1571 Orchard Leaves, SRM 1566 Oyster Tissue and SRM 1577 Bovine Liver. Certified values supplied by U.S. NBS. Other lines of data generated during this study.

Sample ID	Trace Components, Parts Per Million Dry Weight													
	Co	Fe	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Hg	Sc	Pb
Orchard L #1	0.213	430	3.1	--	--	27	--	0.08	<0.003	--	3.06	0.124	0.070	--
Orchard L #2	0.128	344	2.9	1.22	12.4	--	13.7	0.14	<0.003	0.128	3.23	0.117	0.080	42.7
Orchard L #3	0.142	316	2.5	1.37	12.4	24	11.3	0.07	<0.003	0.125	3.20	0.119	0.076	48.2
Certified Values	(0.2)[a/]	300	(2.3)[a/]	1.3	12	25	14	0.08	--	0.11	--	0.155	--	45
Oyster #1	0.301	163	0.8	1.08	57	792	7.6	2.37	0.898	2.97	0.05	0.039	0.070	0.44
Oyster #2	0.356	182	0.8	1.14	61	830	14.2	2.13	0.930	3.35	0.08	0.040	0.077	0.51
Oyster #3	0.297	137	1.3	1.06	52	810	11.2	2.51	0.904	3.15	0.02	0.039	0.083	0.44
Certified Values	(0.4)[a/]	195	0.69	1.03	63	852	13.4	2.1	0.89	3.5	--	0.057	--	0.48
Bovine Liver	0.263	292	0.6	0.01	200	120	0.23	0.84	0.074	0.35	<0.02	0.014	<0.006	0.32
Certified Values	(0.18)[a/]	268	0.088	--	193	130	0.055	1.1	(0.06)[a/]	0.27	(0.005)[a/]	0.016	--	0.34

[a/] Not a certified value.

Table D-3

Concentrations of elements in sediment. Chemistry of East Passage and baseline sediments are eight fine-grained sediments (<10% sand) analyzed by Crecelius and Bloom, unpublished data.

Sample ID	Major Constituents, Percent Dry Weight								
	Al	K	Ca	Ti	Mn	Fe	P	Si	Sr
NG-1	5.5	1.24	1.75	0.36	0.081	4.1	<0.29	24	0.024
NG-2	6.3	1.11	2.46	0.30	0.050	2.9	<0.30	29	0.034
NG-3	5.0	1.10	2.35	0.30	0.075	3.0	<0.30	26	0.033
NG-4	6.2	1.10	2.63	0.27	0.047	2.5	<0.31	29	0.035
NG-5a	4.8	1.00	2.14	0.19	0.032	1.6	<0.30	33	0.033
NG-5b	--	--	--	--	--	1.5	--	--	--
NG-5c	5.4	0.96	2.15	0.20	0.033	1.5	<0.33	34	0.033
NG-6	5.4	0.95	2.03	0.23	0.033	1.8	<0.31	30	0.031
NG-7	5.8	1.01	2.36	0.30	0.041	2.4	<0.30	27	0.034
NG-8	5.6	1.00	2.58	0.35	0.044	2.7	<0.31	27	0.035
NG-9	6.4	1.09	2.33	0.33	0.050	3.2	<0.30	26	0.034
NG-10	6.2	1.19	2.56	0.36	0.069	3.8	<0.30	24	0.034
NG-11	5.7	1.15	2.32	0.33	0.063	3.5	<0.30	24	0.032
NG-12	5.1	1.05	2.26	0.26	0.073	2.7	<0.30	31	0.032
NG-13a	6.4	1.12	2.99	0.33	0.044	2.5	<0.31	29	0.041
NG-13b	6.1	1.10	2.91	0.32	0.042	2.4	<0.31	29	0.040
NG-13c	6.4	1.06	2.82	0.31	0.042	2.4	<0.32	28	0.039
NG-14	6.2	1.13	2.52	0.39	0.061	3.7	<0.29	24	0.034
NG-15	6.6	1.07	2.57	0.35	0.066	3.5	<0.30	24	0.035
NG-16	5.9	1.14	2.09	0.34	0.069	3.7	<0.29	24	0.026
East Passage Surface Sediment	6	1.3	1.6	0.37	0.07	4.3	--	--	--
Baseline[a/]	6	1.1	2	0.4	0.06	4	--	--	--

[a/] Elemental concentrations for Puget Sound muddy sediments deposited approximately 100 years ago.

Table D-4

Concentrations of trace components in sediment

	Trace Components, Parts Per Million Dry Weight													
SAMPLE ID	Co	V	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Hg	Sc	Pb
NG-1	13.7	112	84	50	60	129	16.0	1.7	0.713	0.34	2.63	0.254	14.1	44
NG-2	13.7	78	120	38	33	72	9.7	<0.5	0.218	0.28	2.49	0.109	14.4	22
NG-3	14.7	61	129	40	34	77	11.5	<0.6	0.276	0.32	3.33	0.129	12.6	26
NG-4	14.0	63	154	35	23	57	9.6	<0.6	0.126	0.25	2.46	0.081	11.3	17
NG-5a	5.6	<30	81	20	16	33	4.2	1.2	0.092	0.20	0.78	0.041	7.2	12
NG-5b	5.7	--	86	--	--	--	--	<0.5	0.100	0.17	1.06	0.036	7.5	--
NG-5c	5.8	<30	93	21	14	32	4.0	1.5	0.092	0.24	0.84	0.075	7.6	11
NG-6	5.7	40	123	32	13	47	2.7	<0.5	0.065	0.06	0.45	0.021	8.6	10
NG-7	7.7	42	110	28	43	68	7.9	0.6	0.273	0.43	1.58	0.208	--	33
NG-8	9.4	69	121	32	30	62	6.3	<0.5	0.164	0.29	1.27	0.126	12.1	21
NG-9	12.4	84	100	41	42	85	10.1	<0.6	0.270	0.60	1.88	0.159	13.1	29
NG-10	14.7	65	81	39	76	133	26.2	0.5	0.545	0.67	9.47	0.231	12.9	44
NG-11	14.6	79	82	41	66	117	24.7	2.5	0.496	0.43	7.76	0.213	13.1	40
NG-12	12.8	81	110	35	21	55	8.3	0.8	0.138	0.09	1.51	0.058	11.0	15
NG-13a	9.3	57	80	21	22	51	6.2	<0.5	0.115	0.40	0.63	0.058	11.7	10
NG-13b	8.7	52	77	21	21	48	7.0	<0.5	0.115	0.31	0.53	0.055	11.0	10
NG-13c	9.4	53	83	23	22	48	6.3	1.8	0.091	0.34	0.76	0.064	11.6	10
NG-14	12.2	108	78	41	46	100	10.7	1.1	0.332	0.70	1.54	0.143	13.5	25
NG-15	12.4	77	68	35	48	92	9.7	<0.5	0.295	0.42	1.61	0.153	12.6	27
NG-16	12.8	73	72	46	53	110	13.3	2.2	0.328	0.90	1.27	0.162	14.0	28
East Passage	--	100	110	50	65	120	30	1.1	0.65	0.35	3.0	0.35	--	55
Baseline*	--	80	90	40	40	70	8	1.0	0.04	0.40	0.5	0.05	--	8

*Elemental concentrations for Puget Sound muddy sediments deposited approximately 100 years ago.

APPENDIX E

Aromatic Hydrocarbon and Halogenated Organic Compound Concentrations in Sediments from Selected Locations in Central and Southern Puget Sound

Table E-1

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg dry wt)		
	N.E. of Blake Island (NG-1)	N. of Blake Island (NG -2)	Rep of NG-2 (NG-3)
naphthalene	22	14	10
benzothiophene	<1	<1	<1
2-methylnaphthalene	9	4	4
1-methylnaphthalene	8	4	3
biphenyl	15	6	6
1+2-ethylnaphthalene	<1	<1	<1
2,6+2,7-dimethylnaphthalene	14	5	4
1,3+1,6-dimethylnaphthalene	12	5	4
1,7-dimethylnaphthalene	9	4	3
1,4+2,3+1,5-dimethyl-naphthalene	11	2	1
1,2-dimethylnaphthalene	4	1	1
2,3,5-trimethylnaphthalene	10	4	3
fluorene	9	2	2
dibenzothiophene	12	1	<1
phenanthrene	29	12	7
anthracene	38	24	10
1-methylphenanthrene	17	6	4
fluoranthene	128	47	33
pyrene	132	43	40
benz(a)anthracene	195	36	62
chrysene	184	30	55
benz(e)pyrene	132	36	34
benz(a)pyrene	96	16	26
perylene	110	29	30
Total	1,196	331	342

Table E-2

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg dry wt.) West of Blake Island (NG-4)	Yukon Harbor (NG-5)	Olalla Bay (NG-6)
naphthalene	<1	3	16
benzothiophene	<1	<1	<1
2-methylnaphthalene	<1	1	4
1-methylnaphthalene	<1	1	3
biphenyl	6	3	10
1+2-ethylnaphthalene	<1	<1	<1
2,6+2,7-dimethylnaphthalene	5	1	6
1,3+1,6-dimethylnaphthalene	2	1	5
1,7-dimethylnaphthalene	2	1	5
1,4+2,3+1,5-dimethyl-naphthalene	1	<1	2
1,2-dimethylnaphthalene	<1	<1	<1
2,3,5-trimethylnaphthalene	1	<1	7
fluorene	1	1	2
dibenzothiophene	<1	<1	<1
phenanthrene	6	9	12
anthracene	12	6	32
1-methylphenanthrene	4	1	8
fluoranthene	40	<1	58
pyrene	30	2	48
benz(a)anthracene	34	<1	44
chrysene	17	<1	20
benz(e)pyrene	13	<1	<1
benz(a)pyrene	7	<1	<1
perylene	8	<1	<1
Total	189	30	282

Table E-3

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg, dry wt.) Gig Harbor (NG-7)	Wollochet Bay (NG-8)	Carr Inlet N. (NG-9)
naphthalene	15	<1	10
benzothiophene	<1	<1	<1
2-methylnaphthalene	5	<1	4
1-methylnaphthalene	4	<1	4
biphenyl	9	6	12
1+2-ethylnaphthalene	<1	<1	<1
2,6+2,7-dimethylnaphthalene	10	5	9
1,3+1,6-dimethylnaphthalene	6	2	6
1,7-dimethylnaphthalene	5	2	5
1,4+2,3+1,5-dimethyl-naphthalene	3	<1	2
1,2-dimethylnaphthalene	1	<1	1
2,3,5-trimethylnaphthalene	7	1	7
fluorene	14	1	4
dibenzothiophene	15	<1	7
phenanthrene	93	6	10
anthracene	47	12	18
1-methylphenanthrene	56	4	8
fluoranthene	17	40	43
pyrene	1	30	44
benz(a)anthracene	337	34	213
chrysene	366	17	63
benz(e)pyrene	235	63	151
benz(a)pyrene	162	13	86
perylene	76	18	129
Total	2,154	254	836

Table E-4

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg, dry wt.) Carr Inlet S. (NG-10)	Rep of NG-10 (NG-11)	East of Anderson Island (NG-12)
naphthalene	16	32	4
benzothiophene	<1	<1	<1
2-methylnaphthalene	4	10	1
1-methylnaphthalene	3	7	1
biphenyl	10	25	8
1+2-ethylnaphthalene	<1	<1	<1
2,6+2,7-dimethylnaphthalene	6	12	2
1,3+1,6-dimethylnaphthalene	5	10	1
1,7-dimethylnaphthalene	5	9	1
1,4+2,3+1,5-dimethyl-naphthalene	2	3	<1
1,2-dimethylnaphthalene	<1	3	<1
2,3,5-trimethylnaphthalene	7	11	<1
fluorene	2	6	1
dibenzothiophene	<1	8	<1
phenanthrene	12	21	3
anthracene	32	21	14
1-methylphenanthrene	8	15	2
fluoranthene	58	89	35
pyrene	48	82	9
benz(a)anthracene	44	133	6
chrysene	20	97	4
benz(e)pyrene	39	76	18
benz(a)pyrene	<1	42	<1
perylene	11	55	<1
Total	332	767	108

Table E-5

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg, dry wt.)	
	Oro Bay (NG-13)	Henderson Inlet (NG-14)
naphthalene	2	11
benzothiophene	<1	<1
2-methylnaphthalene	1	4
1-methylnaphthalene	1	4
biphenyl	8	18
1+2-ethylnaphthalene	<1	<1
2,6+2,7-dimethylnaphthalene	2	8
1,3+1,6-dimethylnaphthalene	1	6
1,7-dimethylnaphthalene	1	5
1,4+2,3+1,5-dimethyl-naphthalene	<1	2
1,2-dimethylnaphthalene	<1	1
2,3,5-trimethylnaphthalene	1	6
fluorene	1	2
dibenzothiophene	<1	<1
phenanthrene	2	11
anthracene	7	18
1-methylphenanthrene	2	10
fluoranthene	10	50
pyrene	9	33
benz(a)anthracene	4	17
chrysene	4	22
benz(e)pyrene	<1	53
benz(a)pyrene	<1	18
perylene	2	23
Total	98	322

Table E-6

Concentrations of selected aromatic hydrocarbons
in sediments from Colvos Passage and southern Puget Sound

Compound	Concentration (µg/kg, dry wt.) S. Case Inlet (NG-15)	N. Case Inlet (NG-16)
naphthalene	8	11
benzothiophene	<1	<1
2-methylnaphthalene	3	5
1-methylnaphthalene	3	5
biphenyl	7	23
1+2-ethylnaphthalene	<1	<1
2,6+2,7-dimethylnaphthalene	5	13
1,3+1,6-dimethylnaphthalene	5	8
1,7-dimethylnaphthalene	5	7
1,4+2,3+1,5-dimethyl-naphthalene	1	3
1,2-dimethylnaphthalene	1	2
2,3,5-trimethylnaphthalene	6	8
fluorene	1	2
dibenzothiophene	3	<1
phenanthrene	9	11
anthracene	23	32
1-methylphenanthrene	8	10
fluoranthene	33	17
pyrene	27	59
benz(a)anthracene	54	18
chrysene	23	32
benz(e)pyrene	59	56
benz(a)pyrene	5	<1
perylene	31	49
Total	320	371

Table E-7

Concentrations of total polychlorinated biphenyls (PCB), chlorinated butadienes (CBD), trichlorobenzenes and hexachlorobenzene in sediment from Colvos Passage and southern Puget Sound. N designates that PCB were not present at measureable concentrations.

Location (Sample Number)	Concentration (µg/kg, dry wt.)			
	PCB	CBD	Trichloro-benzenes	Hexachloro-benzene
N.E. of Blake Island (NG-1)	36	86	<0.3	<0.1
N. of Blake Island (NG-2)	N	25	<0.3	<0.1
Rep of NG-2 (NG-3)	N	42	<0.2	<0.1
W. of Blake Island (NG-4)	N	30	<0.2	<0.1
Yukon Harbor (NG-5)	N	20	<0.1	<0.1
Olalla Bay (NG-6)	N	1	<0.2	<0.1
Gig Harbor (NG-7)	27	33	<0.3	<0.1
Wollochet Bay (NG-8)	N	2	<0.2	<0.1
Carr Inlet N. (NG-9)	N	51	<0.4	<0.1
Carr Inlet S. (NG-10)	N	89	<0.5	<0.1
Rep. of NG-10 (NG-11)	N	58	<0.4	<0.1
E. Anderson Island (NG-12)	N	22	<0.2	<0.1
Oro Bay (NG-13)	N	8	<0.2	<0.1
Henderson Inlet (NG-14)	N	41	<0.6	<0.1
S. Case Inlet (NG-15)	N	39	<0.4	<0.1
N. Case Inlet (NG-16)	N	38	<0.6	<0.1

APPENDIX F

Concentrations of Selected Elements in Tissues of Birds Collected from the Puget Sound Region

Table F-1

Concentrations of selected elements in bird tissue

	Trace Components, Parts Per Million Dry Weight													
SAMPLE ID	Co	Fe	Cr	Ni	Cu	Zn	As	Se	Ag	Cd	Sb	Hg	Sc	Pb
HTL-1	0.055	1362	0.5	0.01	35.6	112	0.08	4.02	0.114	0.040	<0.02	11.7	<0.006	0.17
HTK-1	0.211	1115	<0.4	<0.01	7.99	60	0.60	4.69	<0.003	0.103	0.08	6.45	<0.006	0.24
HTF-1	<0.016	16	<0.4	0.01	0.52	1.6	0.04	0.02	<0.003	0.084	<0.02	0.136	<0.006	<0.05
HTL-2	0.118	2686	<0.4	0.02	48	119	0.61	6.15	0.581	0.149	0.05	16.4	<0.006	1.55
HTK-2	0.179	1244	<0.4	0.10	9.26	50	1.07	18.36	0.011	0.522	0.05	2.38	<0.006	0.29
HTF-2	<0.016	20	<0.4	<0.01	0.19	0.9	0.16	0.16	<0.003	<0.006	<0.02	0.081	0.015	0.30
GTL-1	0.192	332	0.4	0.07	14.5	95	0.69	2.74	0.034	0.147	<0.02	0.84	<0.006	0.25
GTK-1	0.380	296	0.6	0.06	10.83	85	1.28	5.39	<0.003	0.375	<0.02	0.742	<0.006	0.84
GTL-2	0.320	565	<0.4	<0.01	29.1	97	0.37	3.00	0.286	0.399	0.07	0.78	<0.006	0.64
GTK-2	0.425	444	0.5	0.11	12.41	86	0.94	4.88	<0.003	0.465	<0.02	0.841	<0.006	0.84
GTL-3	0.246	560	<0.4	0.06	25.6	99	1.12	3.61	0.242	0.142	0.09	0.826	<0.006	0.20
GTK-3	0.352	385	<0.4	0.05	11.5	94	1.83	5.47	0.008	0.382	0.03	0.869	<0.006	0.46
GTL-4	0.304	976	<0.4	<0.01	47	99	0.46	2.47	0.457	0.122	0.08	0.542	<0.006	0.34
GTK-4	0.473	583	0.6	0.05	12.5	101	1.10	7.80	<0.003	0.321	0.07	0.65	<0.006	0.72
HSL-1	0.119	1420	<0.4	0.04	47.	135	0.24	4.44	0.933	0.045	0.07	3.26	<0.006	0.27
HSK-1a	0.337	1141	<0.4	0.07	7.35	49	0.79	5.58	0.014	0.098	0.05	1.91	<0.006	0.29
HSK-1b	0.317	1235	<0.4	0.06	7.48	51	1.00	4.89	<0.003	0.120	0.05	1.83	<0.006	0.22
HSK-1c	0.311	1196	<0.4	0.02	7.43	47	0.97	5.09	<0.003	0.076	0.06	2.13	<0.006	0.24
HSF-1	<0.016	114	<0.4	0.06	1.10	7.6	0.23	0.25	<0.003	<0.006	<0.02	0.192	<0.006	<0.05
HSL-2	0.186	871	0.7	<0.01	33.5	174	0.60	7.50	0.265	0.130	0.38	8.98	<0.006	0.27
HSK-2	0.382	919	<0.4	0.04	9.13	52	0.60	6.00	<0.003	0.159	0.16	4.19	<0.006	0.58
HSF-2	<0.016	33	<0.4	0.01	0.45	3.7	0.23	0.14	<0.003	0.006	0.04	0.271	<0.006	0.25
GSL-1	0.248	1119	1.0	<0.01	31.7	86	1.01	3.66	0.551	0.119	<0.02	0.894	<0.006	0.37
GSK-1	0.416	732	0.6	0.02	10.4	90	0.60	8.70	<0.003	0.129	0.08	0.674	<0.006	1.23
GSL-2	0.236	807	1.1	<0.01	36.8	92	1.34	4.90	0.272	0.045	0.05	1.33	<0.006	0.37
GSK-2	0.404	603	<0.4	0.04	14.5	89	0.86	7.32	<0.003	0.103	0.09	0.92	<0.006	1.47
GSL-3	0.240	103	<0.4	<0.01	33.4	95	1.75	3.90	0.272	0.025	0.06	1.20	<0.006	0.54
GSK-3	0.296	664	0.6	<0.01	10.7	85	0.50	6.24	<0.003	--	0.08	0.954	<0.006	1.79
GSL-4	0.246	927	<0.4	<0.01	28.9	96	0.24	5.46	0.208	0.027	<0.02	0.70	<0.006	0.44
GSK-4	0.194	720	0.7	0.02	11.0	80	0.97	6.85	<0.003	0.085	<0.02	0.69	<0.006	1.40
PGSL-1	<0.016	1257	0.8	0.05	21.3	77	1.82	3.11	0.034	0.039	0.04	0.94	<0.006	0.20
PGSK-1	0.065	856	0.7	0.50	8.34	60	3.02	5.24	<0.003	0.111	0.07	0.686	<0.006	0.82
HSqL-1	0.131	2842	<0.4	<0.01	65	280	0.28	7.31	0.645	0.035	0.05	2.75	<0.006	0.10
HSqK-1	0.516	312	0.7	0.08	11.5	71	0.41	10.03	<0.003	0.116	<0.02	1.41	<0.006	0.11
HSqF-1	0.053	213	1.5	0.79	7.1	112	0.26	2.94	<0.003	0.046	0.42	0.465	<0.006	0.68
PGPIL-1	0.073	664	<0.4	0.02	15.5	54	0.69	2.27	0.084	0.065	<0.02	0.699	<0.006	0.12
PGPIK-1	0.185	633	0.9	0.13	10.7	59	1.00	5.01	<0.003	0.558	0.08	0.490	<0.006	0.12
GPIL-1	0.392	1092	<0.4	0.01	97	91	0.44	6.92	0.725	0.045	0.16	0.174	<0.006	<0.05
GPIK-1	1.43	629	0.5	0.07	12.8	87	1.07	12.30	<0.003	0.103	0.08	0.29	<0.006	0.25
GPIL-2	0.289	1016	0.5	0.04	17.6	92	0.42	6.53	0.090	0.031	0.04	0.132	0.008	<0.05
GPIK-2	1.032	532	<0.4	0.14	13.3	92	0.85	11.72	0.017	0.177	0.06	0.160	0.006	0.46
GPIL-3a	0.520	1258	0.8	0.01	78.	82	0.35	7.25	0.584	0.026	0.04	0.182	0.009	<0.05
GPIL-3b	0.411	1193	0.5	0.02	74.	78	0.51	6.51	0.547	0.165	<0.02	0.163	<0.006	<0.05
GPIL-3c	0.416	1118	0.6	0.04	71.	78	0.55	6.72	0.510	0.029	0.05	0.151	<0.006	<0.05
GPIK-3	1.31	643	<0.4	0.10	8.4	74	1.32	9.55	0.008	0.068	0.07	0.377	0.014	<0.05
GPIL-4	0.381	1391	0.6	<0.01	62.	90	1.32	7.84	0.635	0.045	<0.02	0.154	<0.006	<0.05
GPIK-4	0.873	709	<0.4	0.02	17.8	82	1.14	12.74	<0.003	0.164	0.12	0.166	<0.006	0.07

APPENDIX G

Concentrations of Selected Aromatic Hydrocarbons in the Tissue of Birds Collected from the Puget Sound Region

Table G-1

Concentrations of selected aromatic hydrocarbons in liver of Great Blue Heron from the Puget Sound

Compound	Concentration (µg/kg, wet wt)				
	Seattle		Tacoma		Sequim Bay
	Bird 1	Bird 2	Bird 1	Bird 2	
naphthalene	<3	<1	<3	<2	<6
benzothiophene	-	<9	<5	<3	<9
2-methylnaphthalene	<2	-	<3	<1	<5
1-methylnaphthalene	<2	-	<8	-	-
biphenyl	<2	<6	<3	<1	<5
1+2-ethylnaphthalene	<2	<6	<3	<1	<5
2,6+2,7-dimethylnaphthalene	-	<6	<3	<1	<5
1,3+1,6-dimethylnaphthalene	-	<6	<3	<1	<5
1,7-dimethylnaphthalene	-	<6	<3	<1	<5
1,4+2,3+1,5-dimethyl-naphthalene	-	<6	<3	<1	<5
1,2-dimethylnaphthalene	-	<6	<3	<1	<5
2,3,5-trimethylnaphthalene	<2	<6	<3	<2	<5
fluorene	-	-	-	-	-
dibenzothiophene	<3	<12	<4	<2	<7
phenanthrene	<2	<6	<2	-	-
anthracene	-	<6	-	-	-
1-methylphenanthrene	-	-	-	-	-
fluoranthene	-	-	-	-	-
pyrene	<3	<8	<4	-	<6
benz(a)anthracene	<3	<9	<5	<2	<8
chrysene	-	<11	<6	<3	<11
benz(e)pyrene	-	-	-	-	-
benz(a)pyrene	-	-	-	-	-
perylene	-	-	-	-	-
Total	<24	<109	<64	<22	<92

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-2

Concentrations of selected aromatic hydrocarbons in kidney of Great Blue Heron from Puget Sound

Compound	Concentration (µg/kg, wet wt)				
	Seattle		Tacoma		Sequim Bay
	Bird 1	Bird 2	Bird 1	Bird 2	
naphthalene	< 20	< 21	-	-	-
benzothiophene	< 30	< 32	< 7	< 8	< 12
2-methylnaphthalene	< 20	< 21	< 4	-	< 8
1-methylnaphthalene	< 21	< 22	-	-	-
biphenyl	< 20	< 21	< 4	< 5	< 8
1+2-ethylnaphthalene	< 21	< 21	< 4	< 5	< 8
2,6+2,7-dimethylnaphthalene	< 21	< 21	< 4	< 5	< 8
1,3+1,6-dimethylnaphthalene	< 21	< 21	< 4	< 5	< 8
1,7-dimethylnaphthalene	< 21	< 21	< 4	< 5	< 8
1,4+2,3+1,5-dimethyl-naphthalene	< 21	< 21	< 4	< 5	< 8
1,2-dimethylnaphthalene	< 21	< 21	< 4	< 5	< 8
2,3,5-trimethylnaphthalene	< 21	< 22	< 5	< 5	< 8
fluorene	< 22	< 23	-	-	-
dibenzothiophene	< 41	< 42	< 10	< 11	< 17
phenanthrene	-	-	< 5	< 6	< 9
anthracene	-	-	-	-	-
1-methylphenanthrene	-	< 24	-	-	-
fluoranthene	< 26	-	-	-	-
pyrene	< 29	< 30	< 6	< 7	< 11
benz(a)anthracene	< 31	< 32	< 6	< 7	< 11
chrysene	-	< 39	< 8	< 9	< 14
benz(e)pyrene	-	-	-	-	-
benz(a)pyrene	-	-	-	-	-
perylene	-	-	-	-	-
Total	< 407	< 455	< 79	< 88	< 146

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-3

Concentrations of selected aromatic hydrocarbons
in fat of Great Blue Heron from Puget Sound

Compound	Concentration (µg/kg, wet wt)				
	Seattle		Tacoma		Sequim Bay
	Bird 1	Bird 2	Bird 1	Bird 2	
naphthalene	-	-	-	-	< 154
benzothiophene	< 12	-	-	-	< 235
2-methylnaphthalene	< 6	< 24	< 26	< 32	< 155
1-methylnaphthalene	< 6	-	-	-	< 162
biphenyl	< 6	< 24	< 26	< 31	< 151
1+2-ethylnaphthalene	< 6	< 25	< 26	< 32	< 156
2,6+2,7-dimethylnaphthalene	< 6	< 25	< 26	< 32	< 156
1,3+1,6-dimethylnaphthalene	< 6	< 25	< 26	< 32	< 156
1,7-dimethylnaphthalene	< 6	< 25	< 26	< 32	< 156
1,4+2,3+1,5-dimethyl-naphthalene	< 6	< 25	< 26	< 32	< 156
1,2-dimethylnaphthalene	< 6	< 25	< 26	< 32	< 156
2,3,5-trimethylnaphthalene	< 7	< 26	< 30	< 33	< 162
fluorene	< 7	< 27	-	< 35	< 167
dibenzothiophene	-	-	-	-	< 313
phenanthrene	< 5	-	-	-	-
anthracene	-	-	-	-	-
1-methylphenanthrene	-	-	-	-	< 180
fluoranthene	-	-	-	-	< 199
pyrene	< 8	< 35	-	-	< 221
benz(a)anthracene	-	-	< 40	< 49	< 239
chrysene	-	< 46	-	-	-
benz(e)pyrene	-	-	-	-	-
benz(a)pyrene	-	-	-	-	-
perylene	-	-	-	-	-
Total	< 93	< 332	< 278	< 372	< 3,274

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-4

Concentrations of selected aromatic hydrocarbons
in liver, kidney and egg of Pigeon Guillemot from Puget Sound

Compound	Concentration (µg/kg, wet wt)				
	Seattle			Protection Island	
	Liver	Kidney	Egg	Liver	Kidney
naphthalene	< 4	< 15	< 3	< 3	< 4
benzothiophene	< 6	< 23	< 5	< 4	< 6
2-methylnaphthalene	< 3	< 15	< 3	< 2	< 4
1-methylnaphthalene	< 3	< 16	< 3	< 2	< 4
biphinyl	< 3	< 15	< 3	< 2	< 4
1+2-ethylnaphthalene	< 3	< 15	< 3	< 2	< 4
2,6+2,7-dimethylnaphthalene	< 3	< 15	< 3	< 2	< 4
1,3+1,6-dimethylnaphthalene	< 3	< 15	< 3	< 2	< 4
1,7-dimethylnaphthalene	< 3	< 15	< 3	< 2	< 4
1,4+2,3+1,5-dimethyl-naphthalene	< 3	< 15	< 3	< 2	< 4
1,2-dimethylnaphthalene	< 3	< 15	< 3	< 2	< 4
2,3,5-trimethylnaphthalene	< 4	< 16	< 3	< 2	< 4
fluorene	< 4	< 17	< 3	< 2	< 5
dibenzothiophene	< 5	< 31	< 4	< 3	< 8
phenanthrene	< 3	< 16	< 2	< 2	< 4
anthracene	-	< 17	< -	-	< 5
1-methylphenanthrene	-	< 18	< 4	-	-
fluoranthene	-	< 20	-	-	-
pyrene	< 4	< 22	-	< 3	< 6
benz(a)anthracene	< 6	< 24	< 5	< 4	< 6
chrysene	< 7	< 29	-	< 5	< 8
benz(e)pyrene	-	-	-	-	-
benz(a)pyrene	-	-	-	-	-
perylene	-	-	-	-	-
Total	< 70	< 384	< 56	< 46	< 92

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-5

Concentrations of selected aromatic hydrocarbons
in liver of Glaucous-Winged Gull from the Tacoma area

Compound	Concentration (µg/kg, wet wt) Tacoma			
	Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	-	< 3	< 3	< 3
benzothiophene	< 5	< 6	< 5	< 5
2-methylnaphthalene	< 3	< 3	< 2	< 2
1-methylnaphthalene	-	-	-	< 3
biphenyl	< 3	< 3	< 2	< 2
1+2-ethylnaphthalene	< 3	< 3	< 3	< 2
2,6+2,7-dimethylnaphthalene	< 3	< 3	< 3	< 2
1,3+1,6-dimethylnaphthalene	< 3	< 3	< 3	< 2
1,7-dimethylnaphthalene	< 3	< 3	< 3	< 2
1,4+2,3+1,5-dimethyl-naphthalene	< 3	< 3	< 3	< 2
1,2-dimethylnaphthalene	< 3	< 3	< 3	< 2
2,3,5-trimethylnaphthalene	< 3	< 3	< 3	< 3
fluorene	-	< 3	-	< 3
dibenzothiophene	< 4	< 5	< 4	< 4
phenanthrene	< 2	< 3	< 2	< 2
anthracene	-	-	-	-
1-methylphenanthrene	-	-	-	-
fluoranthene	-	-	-	-
pyrene	< 4	< 4	< 3	< 3
benz(a)anthracene	< 5	< 5	< 4	< 4
chrysene	< 8	< 7	< 5	< 5
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	< 55	< 63	< 51	< 51

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-6

Concentrations of selected aromatic hydrocarbons
in liver of Glaucous-Winged Gull from the Seattle area

Compound	Concentration (µg/kg, wet wt) Seattle			
	Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	<3	<3	<2	<2
benzothiophene	<4	<4	<3	<4
2-methylnaphthalene	<2	<2	<1	<2
1-methylnaphthalene	<2	<2	<2	<2
biphenyl	<2	<2	<1	<2
1+2-ethylnaphthalene	<2	<2	<2	<2
2,6+2,7-dimethylnaphthalene	<2	<2	<2	<2
1,3+1,6-dimethylnaphthalene	<2	<2	<2	<2
1,7-dimethylnaphthalene	<2	<2	<2	<2
1,4+2,3+1,5-dimethyl-naphthalene	<2	<2	<2	<2
1,2-dimethylnaphthalene	<2	<2	<2	<2
2,3,5-trimethylnaphthalene	<3	<2	<2	<2
fluorene	<3	<2	<2	<2
dibenzothiophene	<4	<3	<2	<3
phenanthrene	<2	<2	<1	<2
anthracene	-	-	-	-
1-methylphenanthrene	-	-	-	-
fluoranthene	-	-	-	-
pyrene	<3	<3	<2	<3
benz(a)anthracene	<4	<4	<2	<3
chrysene	<5	<5	<3	<4
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	<49	<46	<35	<43

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-7

Concentrations of selected aromatic hydrocarbons in liver of Glaucous-Winged Gull from the Protection Island area

Compound	Concentration (µg/kg, wet wt) Protection Island Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	<2	<4	<4	<4
benzothiophene	<3	<6	<6	<5
2-methylnaphthalene	<2	<3	<3	<4
1-methylnaphthalene	<2	<3	<3	-
biphenyl	<2	<3	<3	<3
1+2-ethylnaphthalene	<2	<3	<3	<3
2,6+2,7-dimethylnaphthalene	<2	<3	<3	<3
1,3+1,6-dimethylnaphthalene	<2	<3	<3	<3
1,7-dimethylnaphthalene	<2	<3	<3	<3
1,4+2,3+1,5-dimethyl-naphthalene	<2	<3	<3	<3
1,2-dimethylnaphthalene	<2	<3	<3	<3
2,3,5-trimethylnaphthalene	<2	<3	<3	<4
fluorene	<2	<3	<3	-
dibenzothiophene	<2	<5	<4	<8
phenanthrene	<1	<2	<2	<4
anthracene	-	-	-	-
1-methylphenanthrene	-	-	-	-
fluoranthene	-	-	-	-
pyrene	<2	<4	<4	<5
benz(a)anthracene	<3	<5	<5	<5
chrysene	<4	<7	<6	<6
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	<39	<66	<64	<62

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-8

Concentrations of selected aromatic hydrocarbons
in kidney of Glaucous-Winged Gull from the Tacoma area

Compound	Concentration (µg/kg, wet wt) Tacoma			
	Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	< 7	< 4	< 4	< 5
benzothiophene	< 11	< 7	< 6	< 7
2-methylnaphthalene	< 7	< 4	< 4	< 5
1-methylnaphthalene	< 7	< 5	< 4	< 5
biphenyl	< 7	< 4	< 4	< 5
1+2-ethylnaphthalene	< 7	< 4	< 4	< 5
2,6+2,7-dimethylnaphthalene	< 7	< 4	< 4	< 5
1,3+1,6-dimethylnaphthalene	< 7	< 4	< 4	< 5
1,7-dimethylnaphthalene	< 7	< 4	< 4	< 5
1,4+2,3+1,5-dimethyl-naphthalene	< 7	< 4	< 4	< 5
1,2-dimethylnaphthalene	< 7	< 4	< 4	< 5
2,3,5-trimethylnaphthalene	< 7	< 5	< 4	< 5
fluorene	-	< 5	< 4	< 5
dibenzothiophene	< 14	< 9	< 7	< 10
phenanthrene	< 7	< 5	< 4	< 5
anthracene	-	< 5	< 4	< 5
1-methylphenanthrene	-	-	-	-
fluoranthene	-	-	-	-
pyrene	< 10	< 6	< 5	< 7
benz(a)anthracene	< 11	< 7	< 6	< 7
chrysene	< 13	< 8	< 7	-
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	< 143	< 98	< 87	< 101

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-9

Concentrations of selected aromatic hydrocarbons
in kidney of Glaucous-Winged Gull from the Seattle area

Compound	Concentration (µg/kg, wet wt) Seattle			
	Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	< 3	< 4	< 6	< 6
benzothiophene	< 4	< 7	< 10	< 9
2-methylnaphthalene	< 3	< 4	< 6	< 6
1-methylnaphthalene	< 3	< 5	< 7	< 6
biphenyl	< 3	< 4	< 6	< 6
1+2-ethylnaphthalene	< 3	< 4	< 6	< 6
2,6+2,7-dimethylnaphthalene	< 3	< 4	< 6	< 6
1,3+1,6-dimethylnaphthalene	< 3	< 4	< 6	< 6
1,7-dimethylnaphthalene	< 3	< 4	< 6	< 6
1,4+2,3+1,5-dimethyl-naphthalene	< 3	< 4	< 6	< 6
1,2-dimethylnaphthalene	< 3	< 4	< 6	< 6
2,3,5-trimethylnaphthalene	< 3	< 5	< 7	< 6
fluorene	< 3	< 5	< 7	< 7
dibenzothiophene	< 5	< 9	< 13	< 12
phenanthrene	< 3	< 4	< 6	< 6
anthracene	< 3	< 5	< 7	< 7
1-methylphenanthrene	-	-	< 7	-
fluoranthene	-	-	< 8	< 8
pyrene	< 4	< 6	< 9	< 9
benz(a)anthracene	< 4	< 7	< 10	< 9
chrysene	< 5	< 8	< 12	< 11
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	< 64	< 97	< 157	< 144

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

Table G-10

Concentrations of selected aromatic hydrocarbons in kidney of Glaucous-Winged Gull from the Protection Island area

Compound	Concentration (µg/kg, wet wt) Protection Island			
	Bird 1	Bird 2	Bird 3	Bird 4
naphthalene	<5	<6	<5	<3
benzothiophene	<8	<10	<8	<4
2-methylnaphthalene	<5	<6	<5	<3
1-methylnaphthalene	<5	<7	<6	<3
biphenyl	<5	<6	<5	<3
1+2-ethylnaphthalene	<5	<6	<5	<3
2,6+2,7-dimethylnaphthalene	<5	<6	<5	<3
1,3+1,6-dimethylnaphthalene	<5	<6	<5	<3
1,7-dimethylnaphthalene	<5	<6	<5	<3
1,4+2,3+1,5-dimethyl-naphthalene	<5	<6	<5	<3
1,2-dimethylnaphthalene	<5	<6	<5	<3
2,3,5-trimethylnaphthalene	<5	<7	<6	<3
fluorene	<6	<7	<6	-
dibenzothiophene	<11	<13	<11	<5
phenanthrene	<5	<6	<5	<3
anthracene	<6	<7	<6	-
1-methylphenanthrene	-	-	-	-
fluoranthene	-	<8	<7	-
pyrene	<7	<9	<8	<4
benz(a)anthracene	<8	<10	<8	<4
chrysene	<10	<12	<10	<5
benz(e)pyrene	-	-	-	-
benz(a)pyrene	-	-	-	-
perylene	-	-	-	-
Total	<116	<150	<126	<58

- Interferences prevented quantification. GC/MS analysis did not indicate the presence of the compound of interest under the interfering peak.

APPENDIX H

Total Ion Chromatogram and Selected
Mass Spectra from the Analysis
Seattle Heron Adipose Tissue

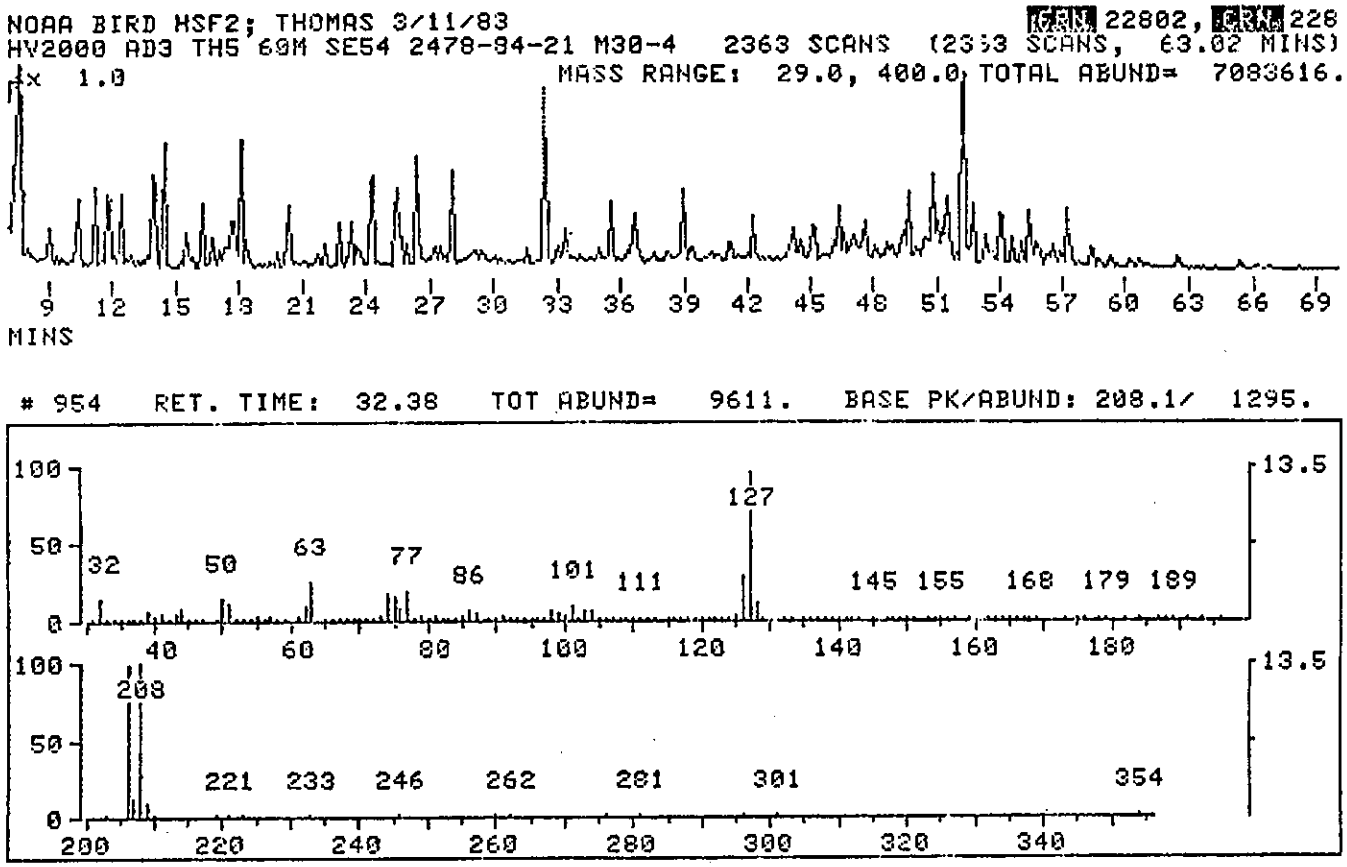

Figure H-1

Total ion mass chromatogram of aromatic fraction isolated from adipose tissue of Seattle Heron. Mass spectrum is that of the internal standard, bromonaphthalene.

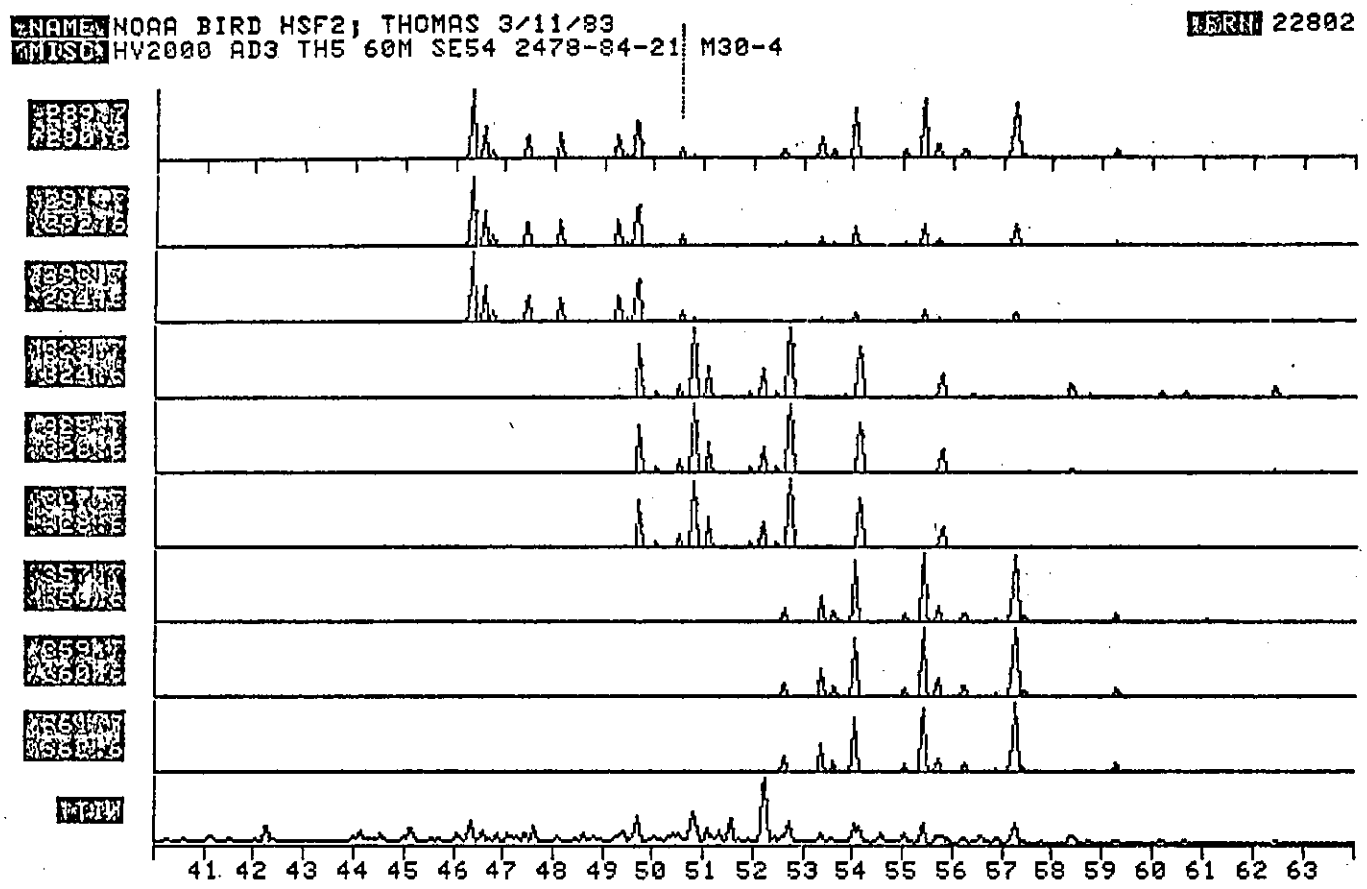

Figure H-2

Single ion scans of Heron adipose tissue identifying the presence of Cl_4 through Cl_6 chlorinated biphenyls.

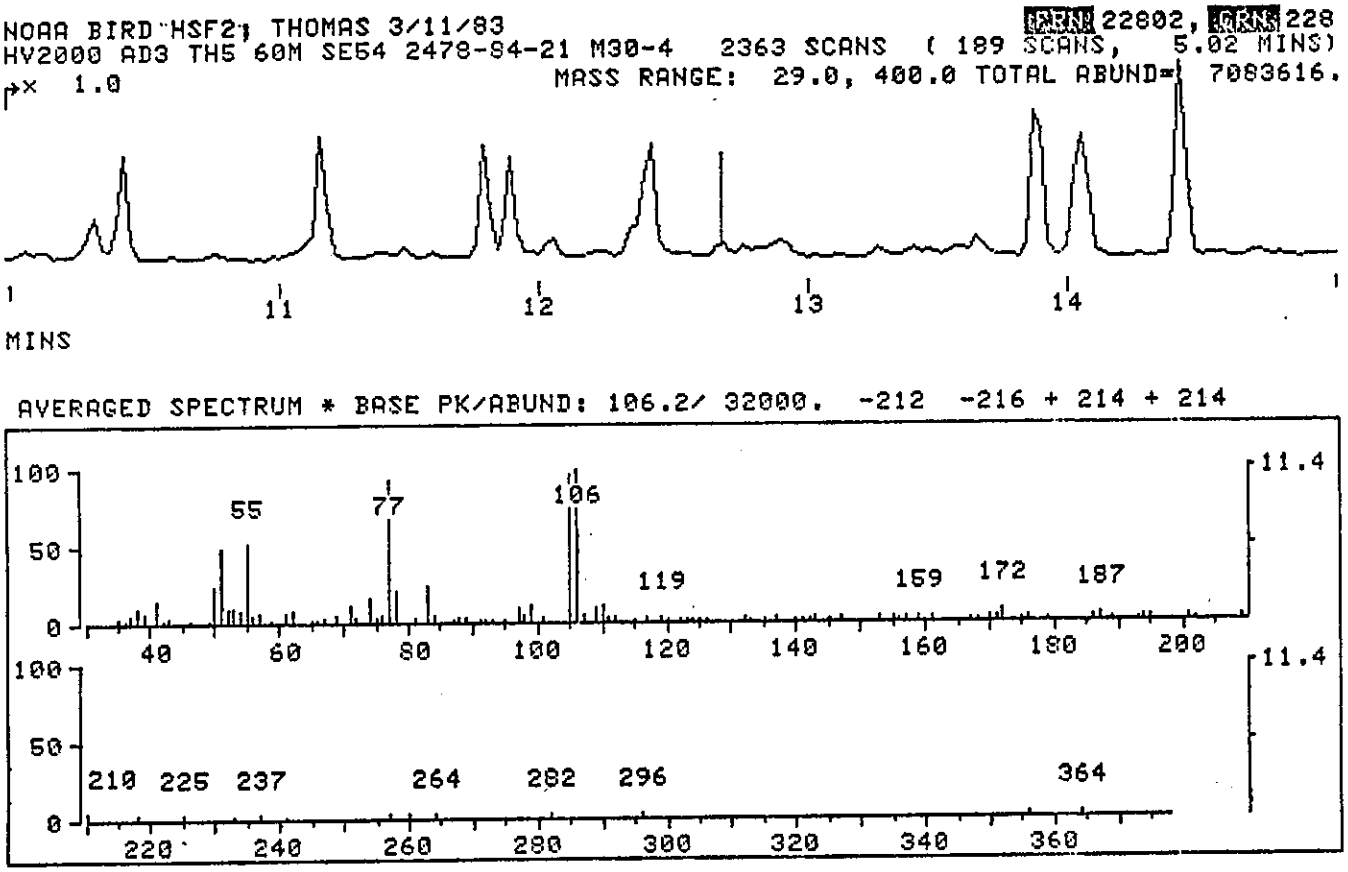

Figure H-3

Mass spectrum of component (RT ~12.6 min) in Heron adipose tissue.
Tentatively identified as benzaldehyde.

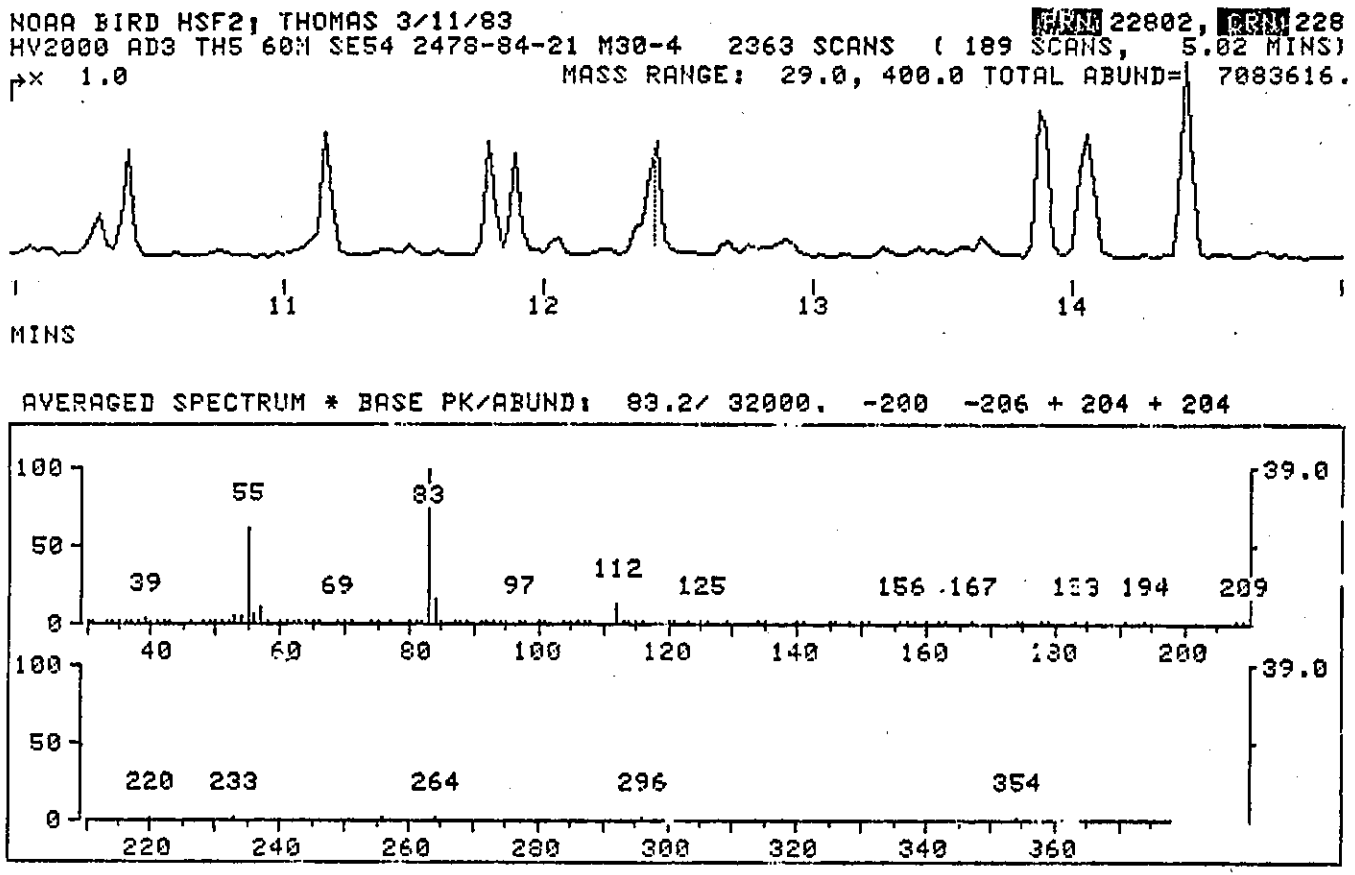

Figure H-4

Mass spectrum of component (RT ~12.3 min) in Heron adipose tissue.
Tentatively identified as C_7 unsaturated ketone.

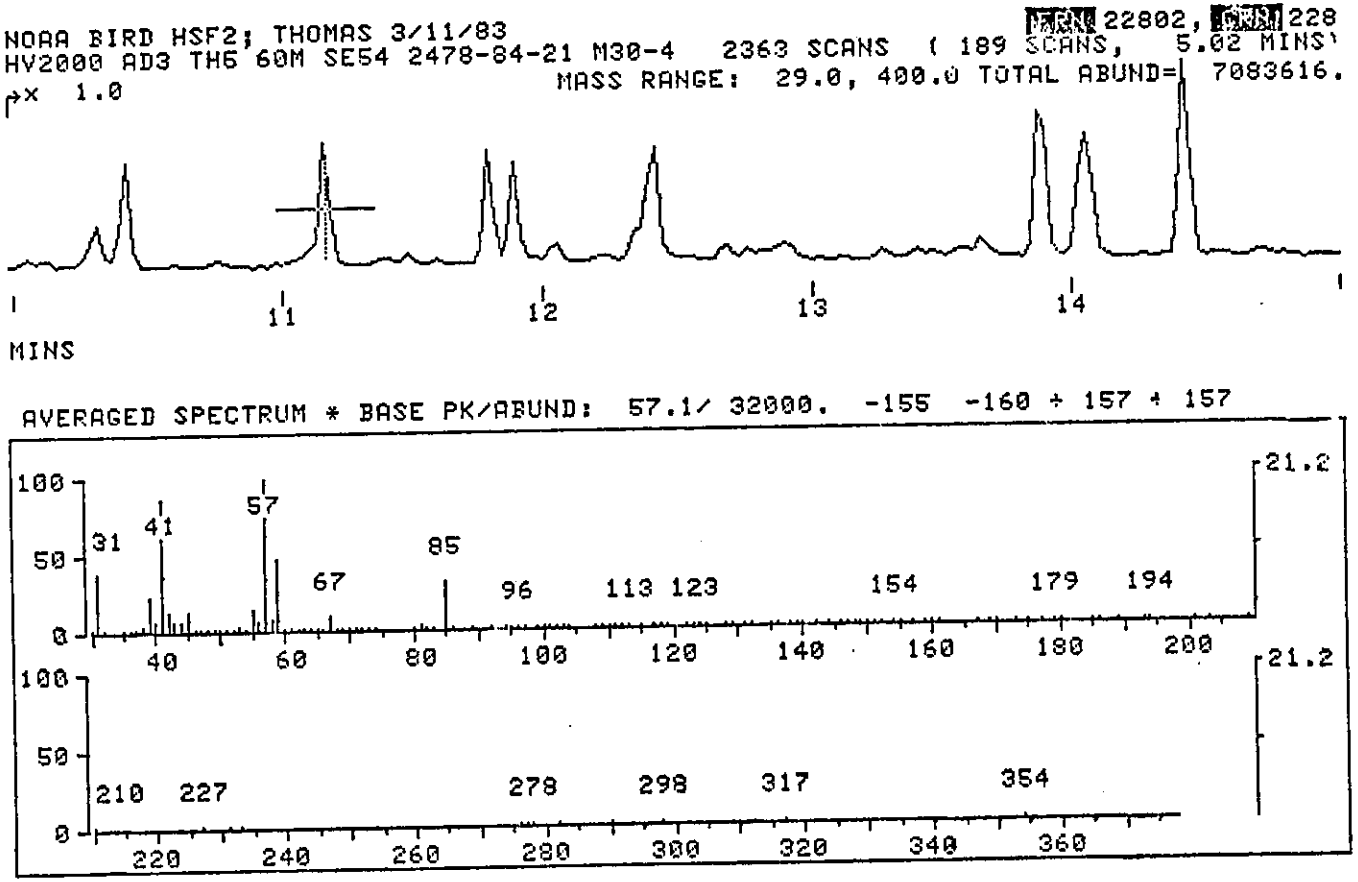

Figure H-5

Mass spectrum of component (RT ~11.2 min) in Heron adipose tissue. Tentatively identified as an alcohol with molecular weight of 118.

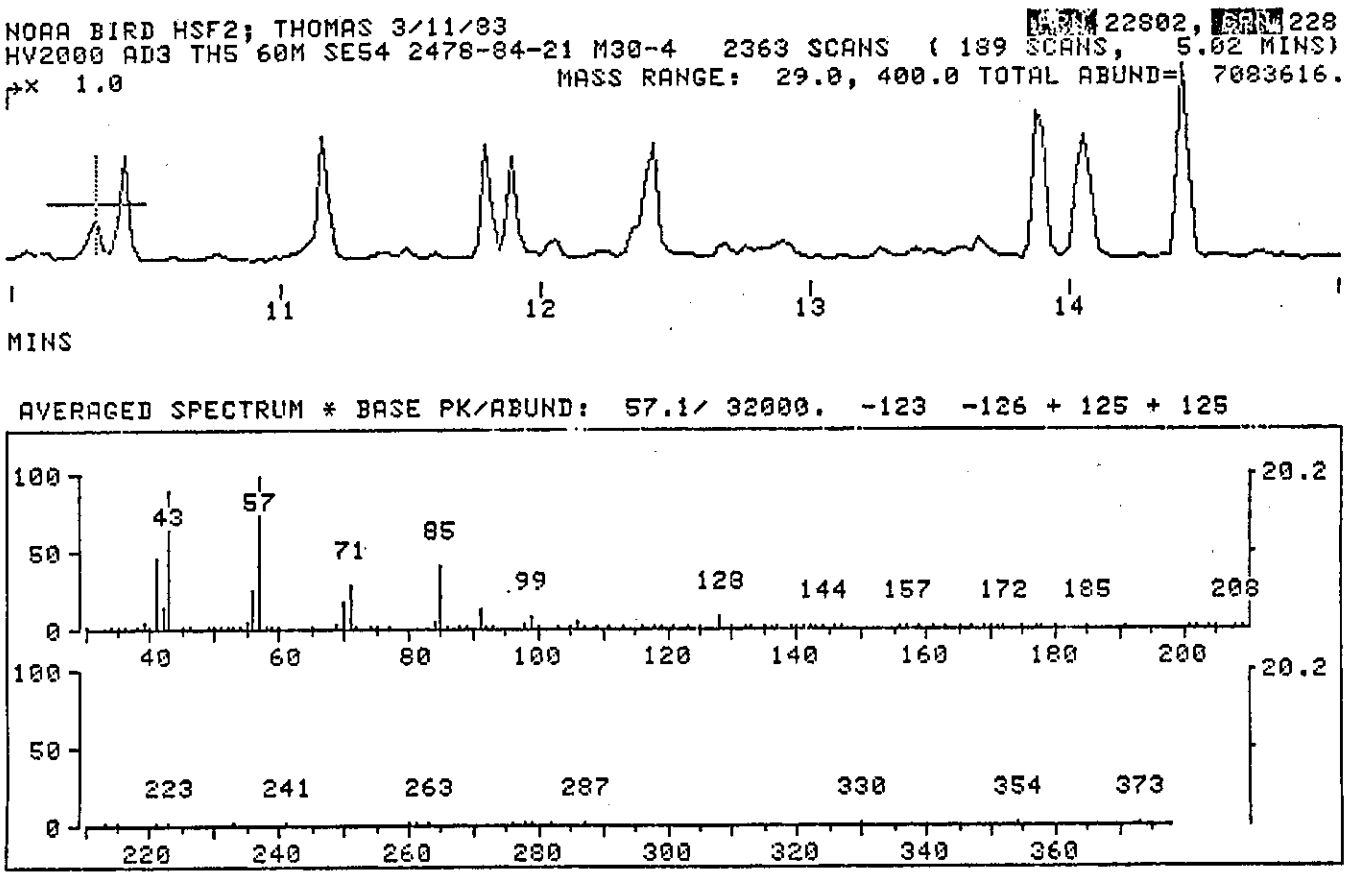

Figure H-6

Mass spectrum of component (RT ~10.3 min) in Heron adipose tissue.
Tentatively identifed as a C_8 saturated ketone.

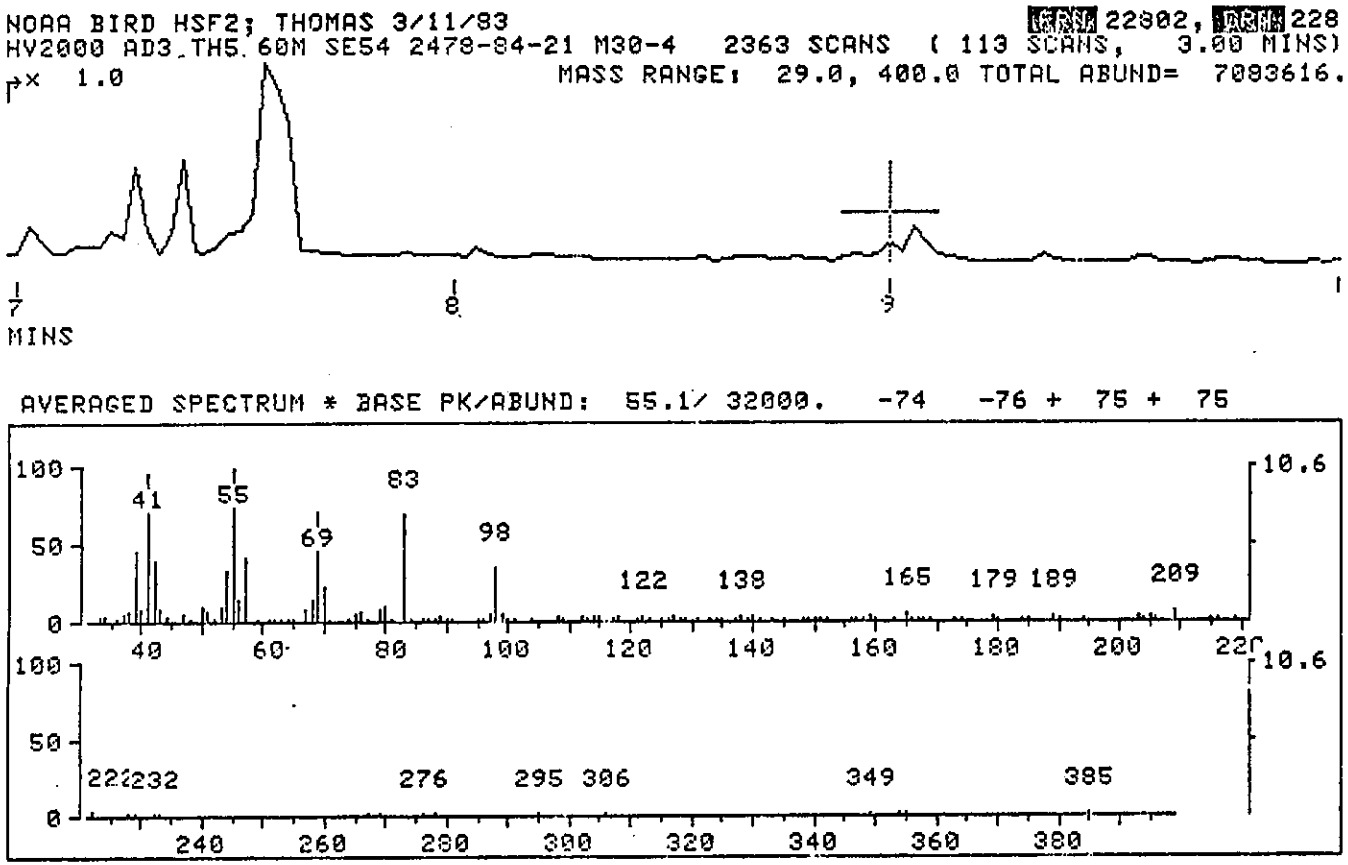

Figure H-7

Mass spectrum of component (RT ~9.0 min) in Heron adipose tissue.
Tentatively identified as a C_6 unsaturated ketone.

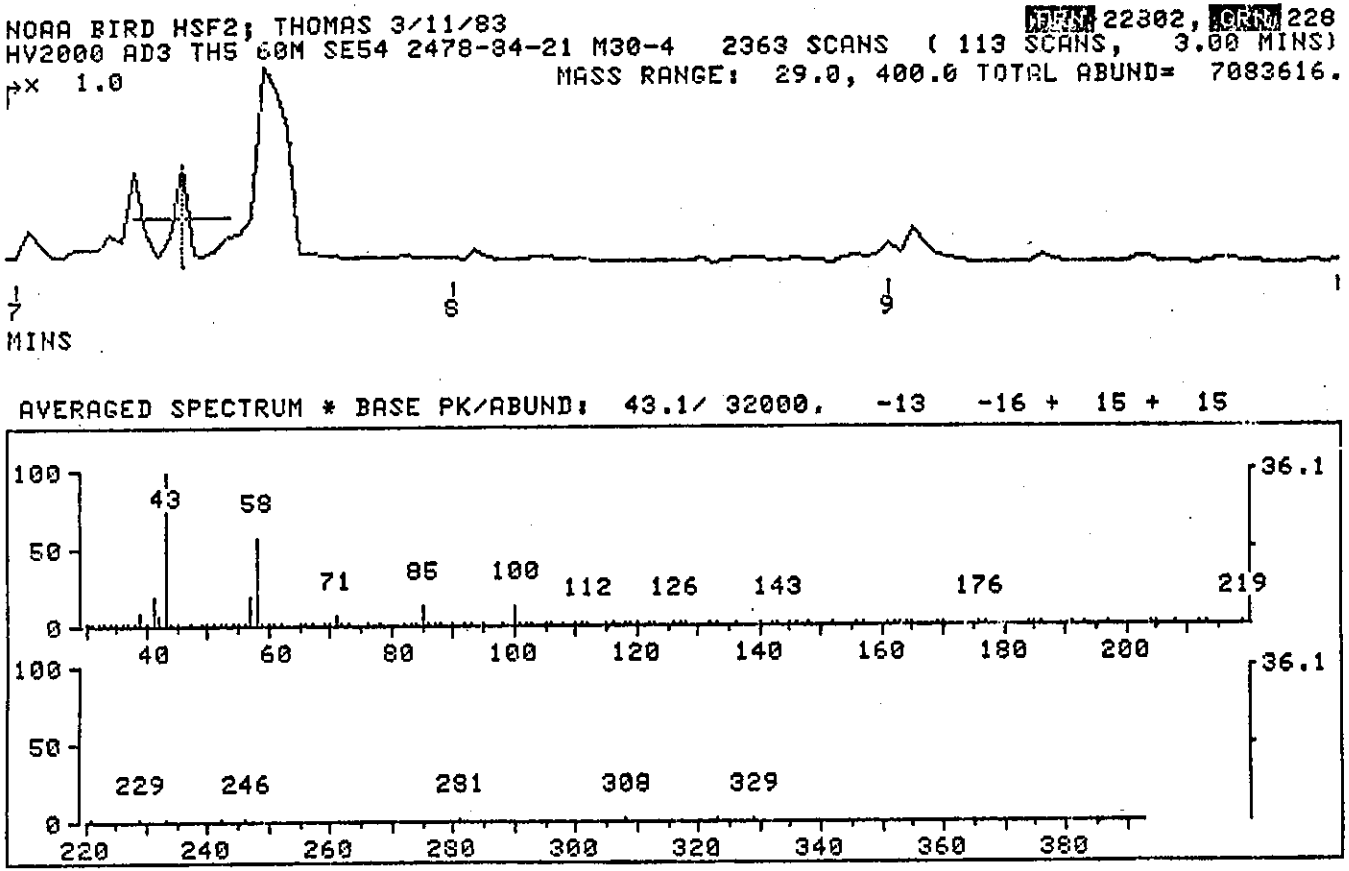

Figure H-8

Mass spectrum of component (RT ~7.4 min) in Heron adipose tissue.
Tentatively identified as a C_6 saturated ketone.

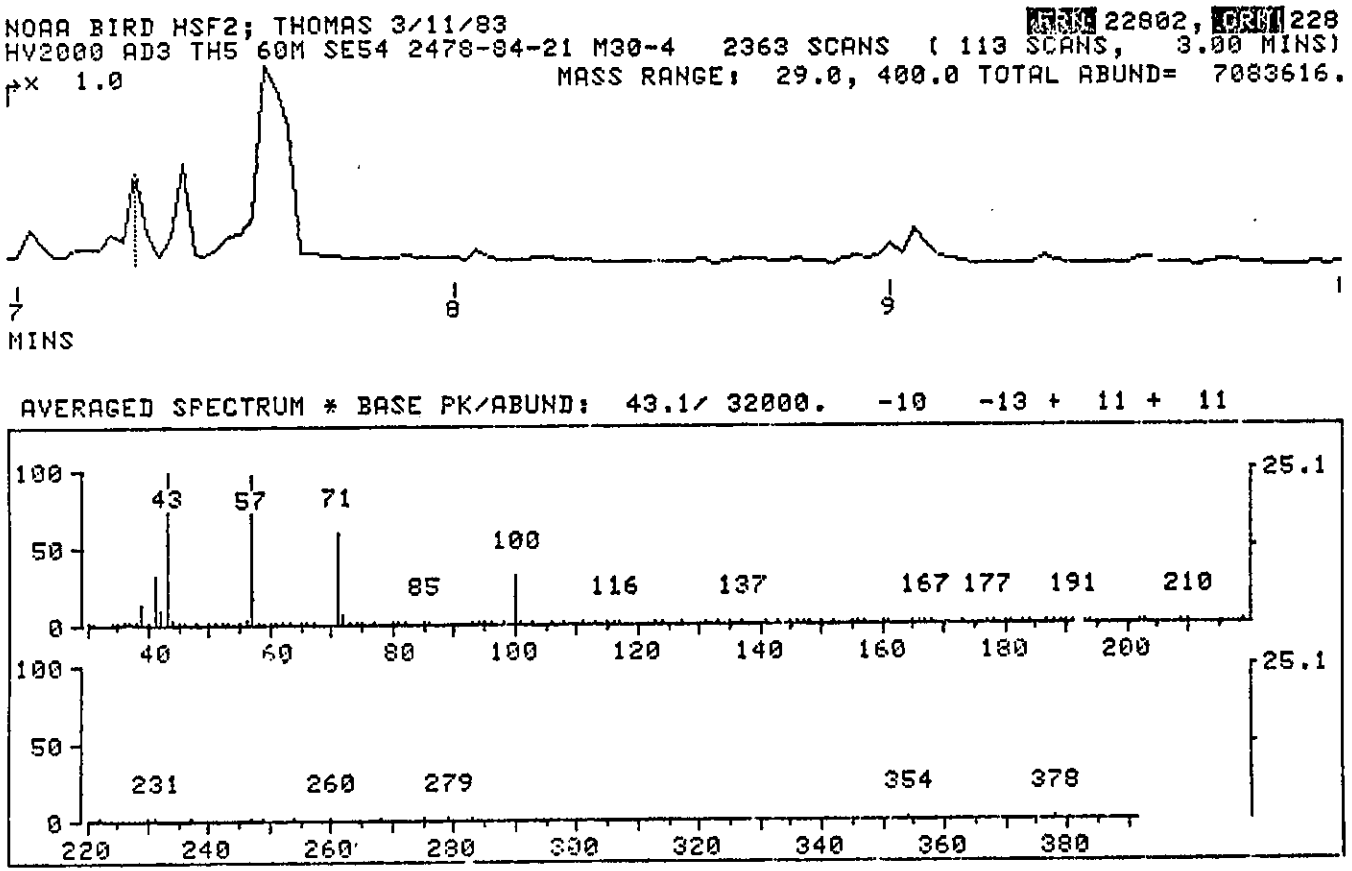

Figure H-9

Mass spectrum of component (RT ~7.3 min) in Heron adipose tissue.
Tentatively identified as a C_6 saturated ketone.

APPENDIX I

Concentrations of Selected Halogenated Organic Compounds in the Tissues of Birds Collected from the Puget Sound Region

Table I-1

Concentration of polychlorinated biphenyls (PCB), chlorinated benzenes and chlorinated butadienes in tissue of Great Blue Heron from Puget Sound

Sample Type	Location	Bird	Concentration (ng/g, wet wt.)			
			Total PCB	Trichloro-benzenes	Hexachloro-benzene	Chlorinated Butadienes
Liver	Seattle	1	1,304	<0.5	<0.5	<0.5
		2	5,087	<0.5	<0.4	<0.4
	Tacoma	1	1,030	<0.5	<0.4	<0.5
		2	1,902	<0.5	<0.4	<0.4
	Sequim Bay	1	747	<0.8	<0.7	<0.7
Kidney	Seattle	1	536	<0.3	<0.2	<0.3
		2	2,080	<0.3	<0.2	<0.3
	Tacoma	1	384	<0.4	<0.4	<0.4
		2	500	<0.3	<0.3	<0.3
	Sequim Bay	1	235	<0.6	<0.5	<0.5
Fat	Seattle	1	14,600	<1.3	<1.1	<1.2
		2	51,696	<0.7	<0.6	<0.7
	Tacoma	1	80,385	<0.8	<0.7	<0.8
		2	26,206	<1.3	<1.1	<1.2
	Sequim Bay	1	5,466	<7.2	<6.1	<6.6

Table I-2

Concentration of polychlorinated biphenyls (PCB), chlorinated benzenes and chlorinated butadienes in tissue and egg of Pigeon Guillemot from Puget Sound

Sample Type	Location	Bird	Concentration (ng/g, wet wt.)			
			Total PCB	Trichloro-benzenes	Hexachloro-benzene	Chlorinated Butadienes
Liver	Seattle	1	387	<0.4	<0.4	<0.4
	Protection Island	1	28	<0.4	<0.3	<0.4
Kidney	Seattle	1	<2.4	<2.1	<1.8	<1.9
	Protection Island	1	<6.4	<5.7	<4.8	<5.2
Egg	Seattle	1	11,262	<1.7	<1.4	<1.6

Table I-3

Concentration of polychlorinated biphenyls (PCB), chlorinated benzenes and chlorinated butadienes in tissue of Glaucous-Winged Gull from Puget Sound

Sample Type	Location	Bird	Concentration (ng/g, wet wt.) Total PCB	Trichloro-benzenes	Hexachloro-benzene	Chlorinated Butadienes
Liver	Seattle	1	142	<0.3	<0.2	<0.2
		2	125	<0.4	<0.3	<0.3
		3	212	<0.3	<0.2	<0.3
		4	281	<0.4	<0.3	<0.3
	Tacoma	1	1,095	<0.4	<0.4	<0.4
		2	474	<0.5	<0.4	<0.4
		3	551	<0.3	<0.3	<0.3
		4	181	<0.3	<0.3	<0.3
	Protection Island	1	75	<0.2	<0.2	<0.2
		2	19	<0.5	<0.5	<0.5
		3	29	<0.5	<0.5	<0.5
		4	182*	<0.4	<0.3	<0.3
Kidney	Seattle	1	29	<0.4	<0.4	<0.4
		2	42	<0.4	<0.3	<0.3
		3	67	<0.4	<0.4	<0.4
		4	68	<0.4	<0.3	<0.4
	Tacoma	1	141	<1.1	<0.9	<1.0
		2	97	<0.9	<0.7	<0.8
		3	158	<0.5	<0.4	<0.4
		4	32	<0.4	<0.4	<0.4
	Protection Island	1	7	<0.7	<0.6	<0.6
		2	<0.8	<0.7	<0.6	<0.6
		3	6	<0.5	<0.5	<0.5
		4	6	<0.4	<0.4	<0.4

*Gas chromatographic peak interference precludes this from being a valid number.