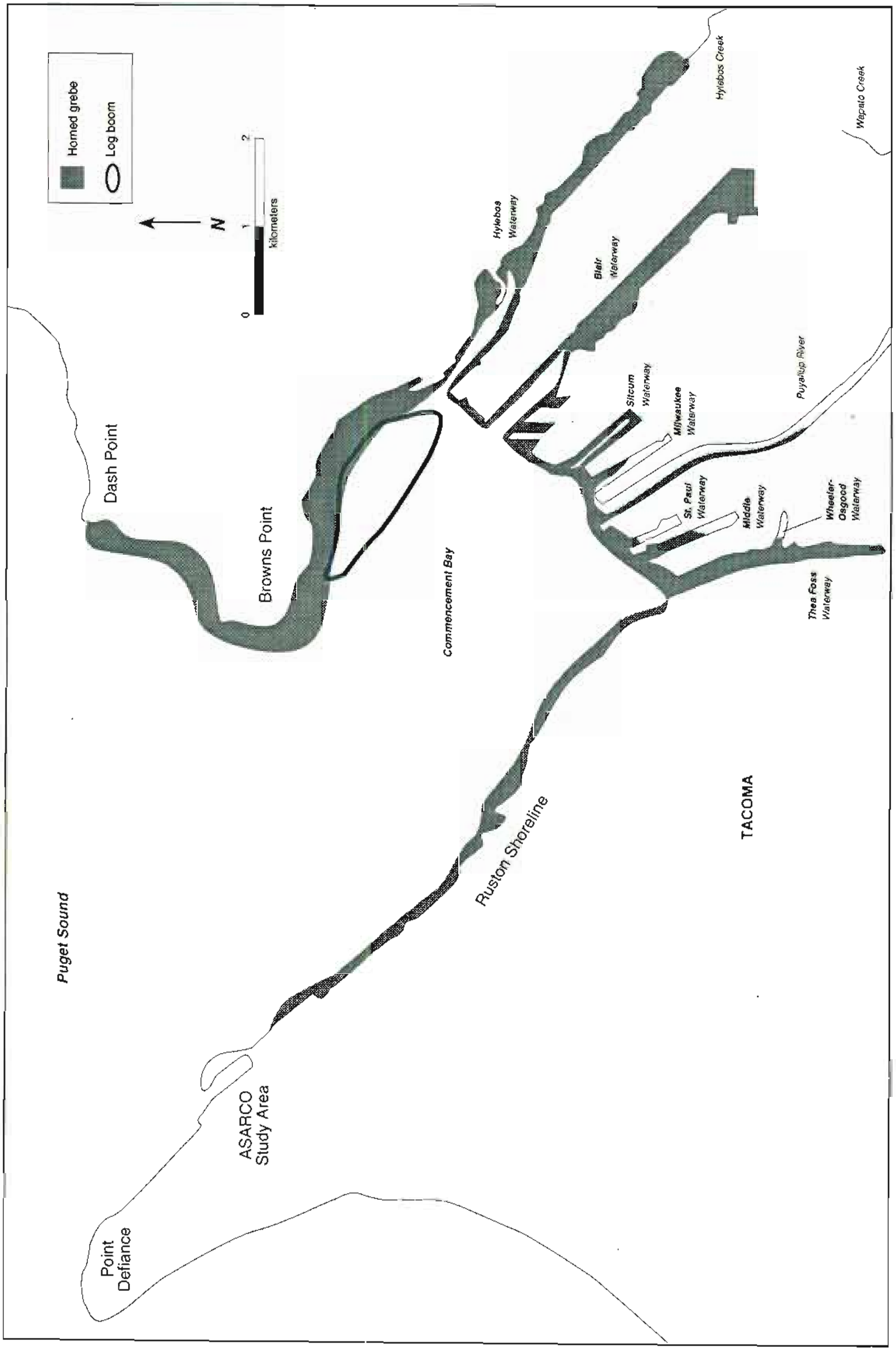

Figure 4-10. Distribution of the horned grebe in Commencement Bay.

Benthivores

Goldeneyes, scaup, and surf scoters are the most abundant benthivores that use the Injury Study Area. Because of their feeding habits, these birds are primarily found in shallower areas, particularly the shallower waterways. These diving ducks are winter residents of the Injury Study Area with individuals arriving from September (for the scoters) to November (for the goldeneyes). Individuals remain in the area until April. Figure 4-11 illustrates the areas of usage typical of these diving ducks.

Carnivores

The most common carnivore in the Injury Study Area is the great blue heron. The great blue heron is a year-round resident that uses the Injury Study Area for feeding and nesting. Antecdotal evidence indicates that individuals feeding in Commencement Bay are associated with the colony from Dumas Bay; however, a small colony exists in Point Defiance Park and individuals from this colony also use the Injury Study Area for foraging. Site usage is concentrated in shallow areas. Log booms along Browns Point shoreline and at the mouth of the Hylebos Waterway provide a major feeding and roosting area (Figure 4-12).

The bald eagle is not an abundant resident species. There are reports of several eyries within 10 km of Commencement Bay, but breeding birds may not winter in the area. Hunt et al. (1992) reports that during winter months individual eagles may range from California to Alaska following salmon spawning. During this time, individuals might use the entire Injury Study Area for foraging (Figure 4-13).

Omnivores

The most common omnivorous bird in the Injury Study Area is the glaucous-winged gull. Glaucous-winged gulls are year-round residents, using the entire Injury Study Area for roosting and feeding. However, their activities are concentrated in shallow waters and in the waterways (Figure 4-14).

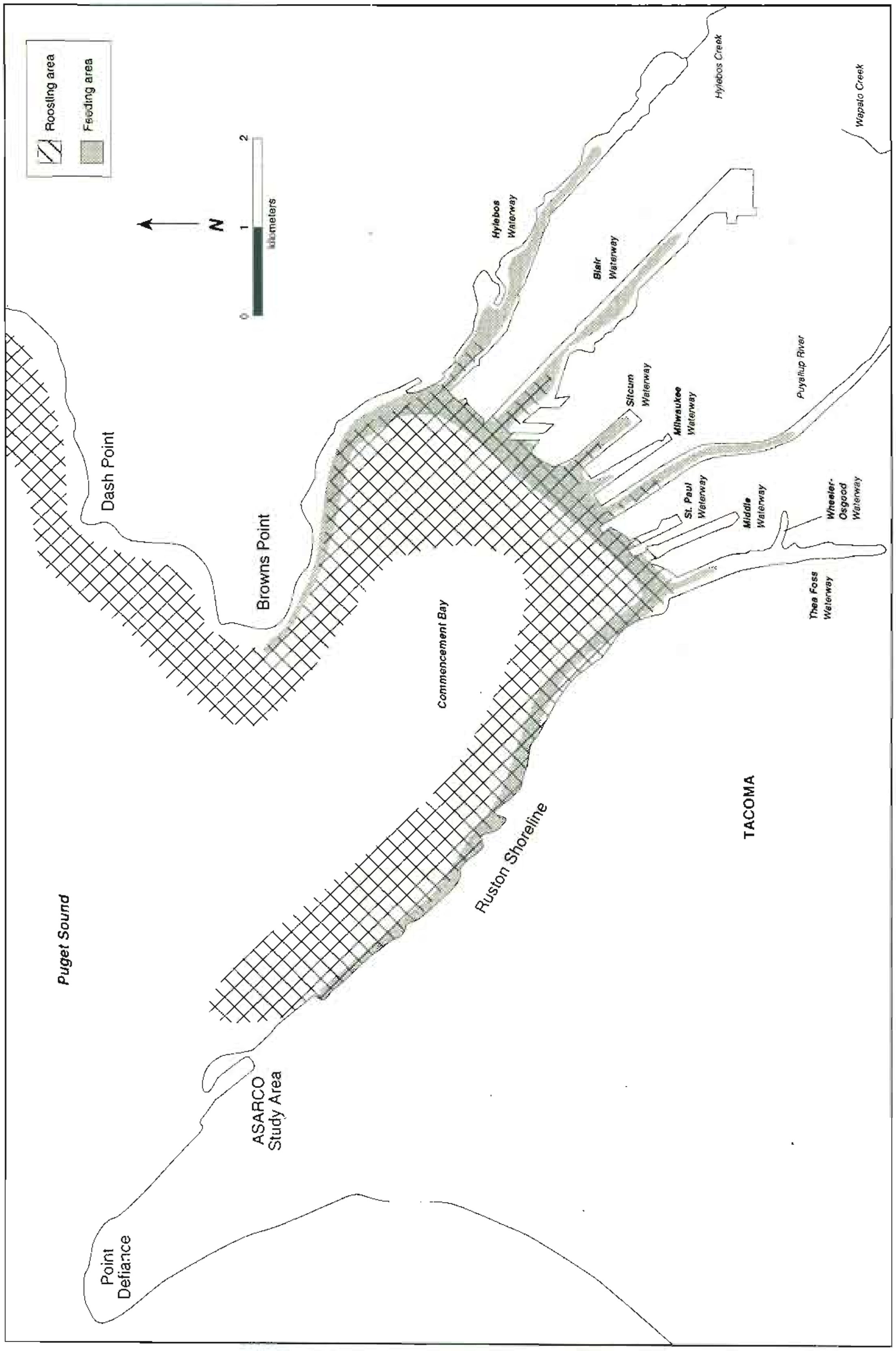

Figure 4-11. Distribution of benthivorous ducks in Commencement Bay.

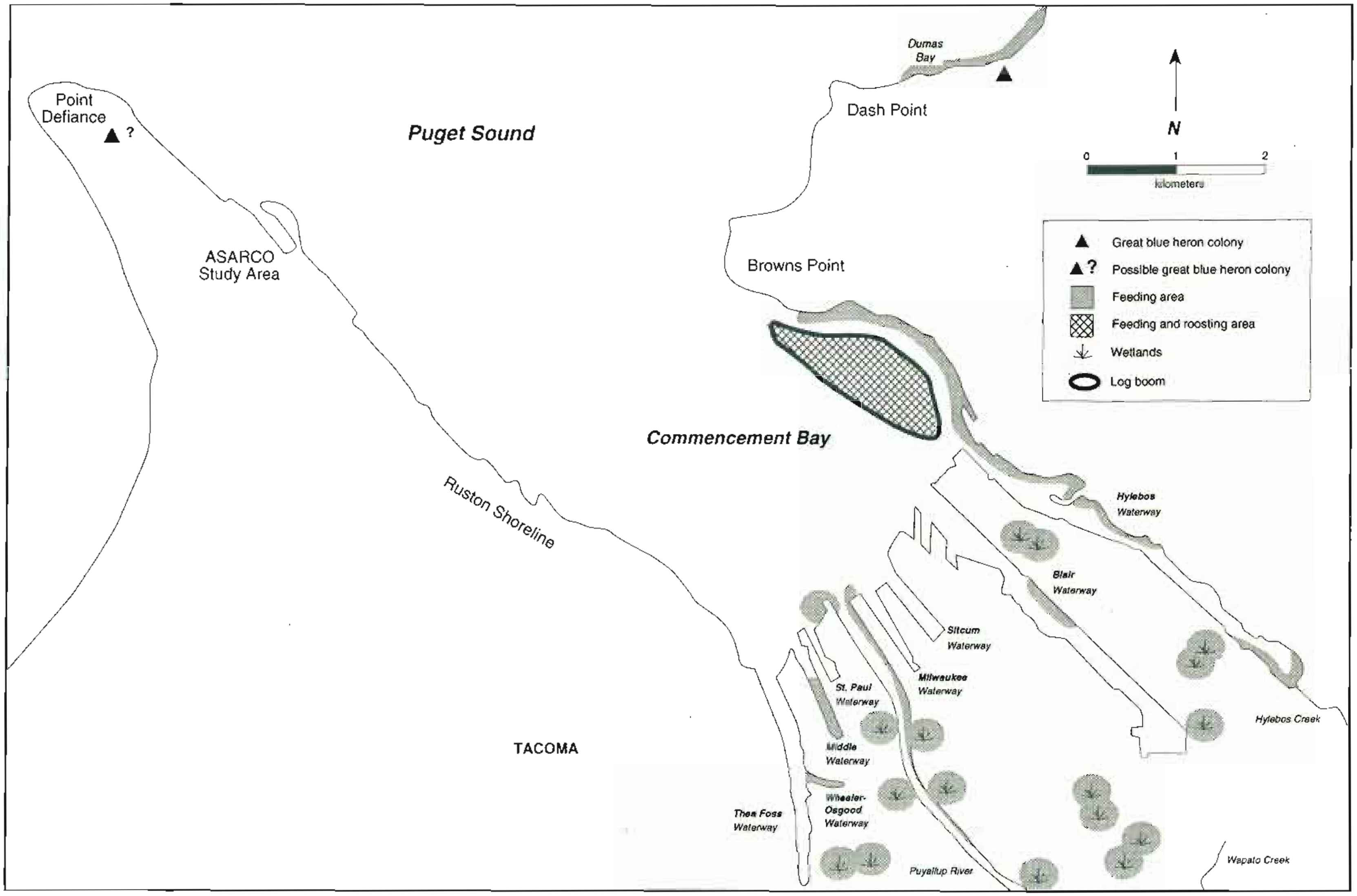

Figure 4-12. Distribution of great blue herons in Commencement Bay.

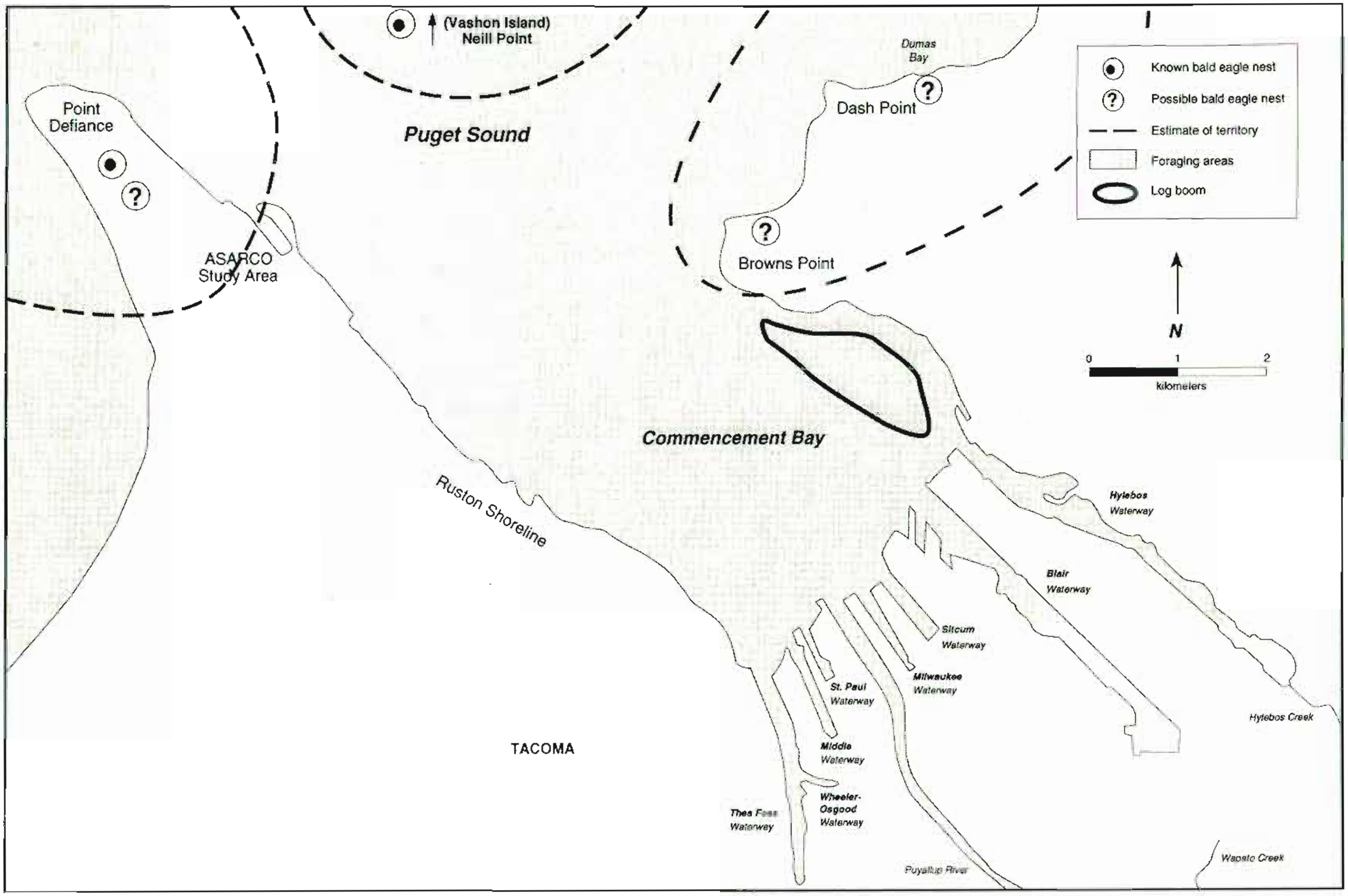

Figure 4-13. Distribution of bald eagles in Commencement Bay.

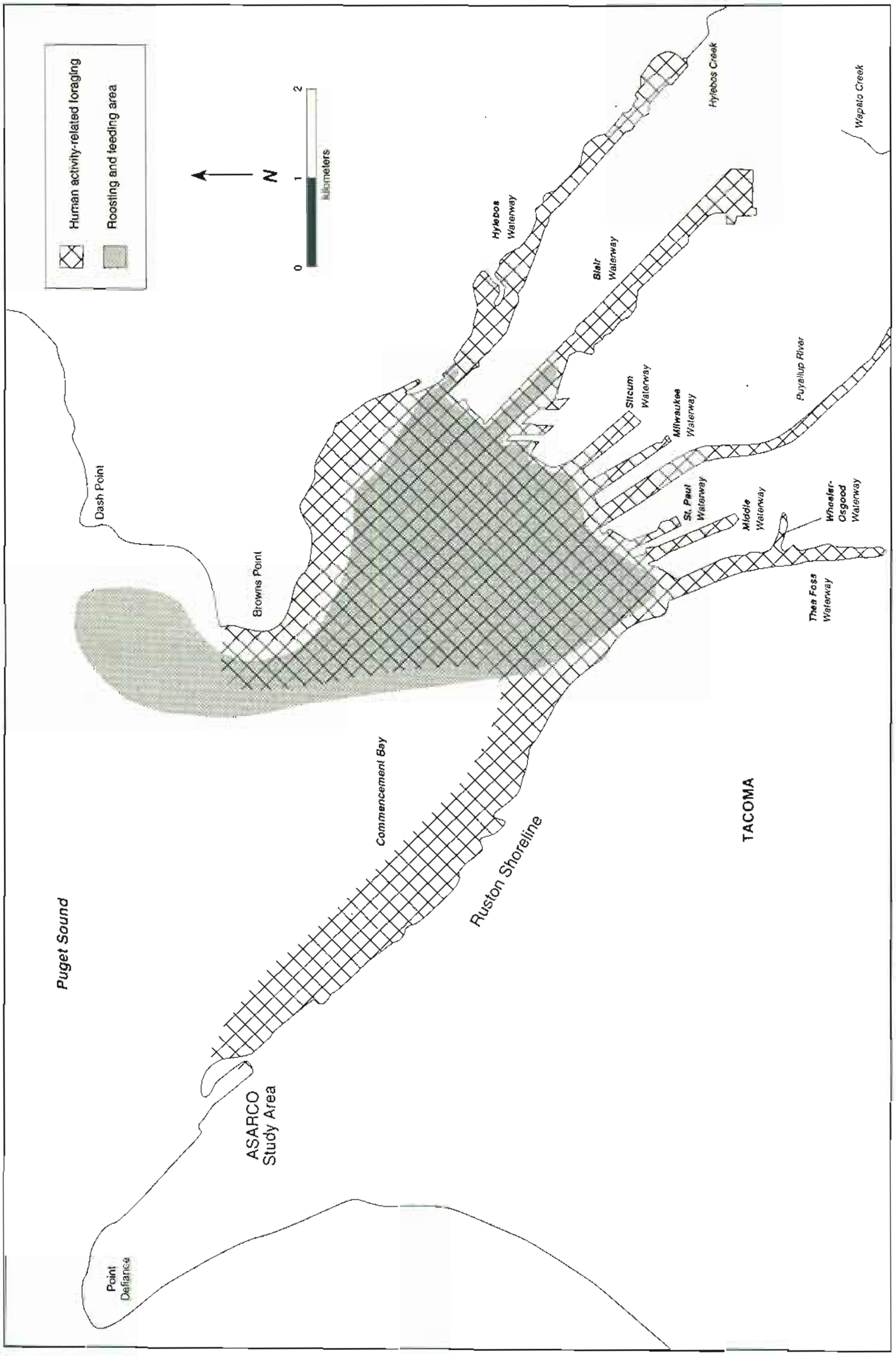

Figure 4-14. Distribution of glaucous-winged gulls in Commencement Bay.

4.4.2 Potential Areas of Exposure

Information on the distribution of key biological resources presented in Section 4.4.1 was compared to the distribution of SOCs in sediments to provide an indication of exposure. Sections 4.1, 4.2, and 4.3 establish the mechanisms and pathways of exposure to the key biological resources. This section demonstrates that the key biological resources use areas where contamination is present and, therefore, exposure likely occurs through the pathways outlined in Sections 4.2 and 4.3.

4.4.2.1 Summary of Distribution of Substances of Concern

The areal distribution of SOCs in surface sediments of the Injury Study Area was presented in detail in Section 2.0. The SOCs were grouped as either metals/metalloids, aromatic hydrocarbons, or chlorinated hydrocarbons. The metals/metalloids distribution represents arsenic, copper, and mercury. The chlorinated hydrocarbon distribution includes hexchlorobenzenes, hexachorobutadienes, and total PCBs. The aromatic hydrocarbon distribution represents LPAHs and HPAHs. These three chemical groups were selected based on the following factors:

- The selected SOCs were generally detected in sediments over a wide area of Commencement Bay
- The selected SOCs co-occurred with a number of the SOCs that have been identified in Commencement Bay sediments and are reasonably representative of their distribution
- Several of the selected SOCs represent groupings of compounds that are widely distributed in Commencement Bay sediments, are covariant, and probably share the same types of sources

The areal distribution of the chemical groups was mapped to indicate general areas where they were detected as well as areas where higher concentrations were found (see Appendix A).

Concentrations of the metals/metalloids had the largest area of exceedance of the SQS within the Injury Study Area. Sediments contaminated above the SQS with these SOCs were found in most of Hylebos, Thea Foss, Sitcum, and Milwaukee Waterways; a portion of Middle and

Blair Waterways; the inner bay near the mouths of Middle and St. Paul Waterways; the mouth of the Puyallup River; and the vicinity of the ASARCO property (Figure 4-15). A similar areal distribution was observed for the chlorinated hydrocarbons (Figure 4-16) with two exceptions: 1) the SQS for chlorinated hydrocarbons were exceeded in a larger area near the mouths of the Hylebos and Thea Foss Waterways; and 2) the SQS for chlorinated hydrocarbons were not exceeded in sediments offshore of the ASARCO property. Aromatic hydrocarbons exceeded the SQS in the smallest area, with exceedences primarily in Blair, Sitcum, and Milwaukee Waterways (Figure 4-17).

The following sections discuss the areal extent of potential exposures to the SOCs (shown in Figures 4-15 to 4-17) for selected key resources identified in Section 4.4.1. To help illustrate the areas of exposure, transparent overlays that show the distributions of metals/metalloids, chlorinated hydrocarbons, and aromatic hydrocarbons (similar to Figures 4-15, 4-16, and 4-17, respectively) are provided in a pocket in Appendix G. These overlays are provided to allow the reader to compare the distributions of SOCs to the distribution of the key biological resources (shown in figures in Section 4.4.1) as evidence of the potential for exposure.

4.4.2.2 Areal Extent of Potential Exposure for Salmonids

As discussed previously, beach seine and tow net data from Commencement Bay indicate that all of the nearshore subtidal waterways, as well as most of the nearshore off Ruston Shoreline and Browns Point, are used by juvenile chinook, coho, chum, and pink salmon. These same areas have also been found to contain sediment having the highest concentrations of SOCs, indicating a high degree of potential exposure (Figure 4-3). Data from the Injury Study Area and the literature indicate that temporal exposure can be more than 12 weeks for juvenile chinook salmon, the predominant species.

Exposure to contaminated sediment is expected to be less for adult salmonids than for the juveniles. Adults have been reported infrequently within the contaminated waterways, apparently preferring open-water areas along the Ruston Shoreline and Browns Point, and the mouth of the Puyallup River. Some overlap of contaminated sediments and the distribution of adult salmonids is observed near the ASARCO property, the mouth of the Puyallup River, and along the Browns Point shore.

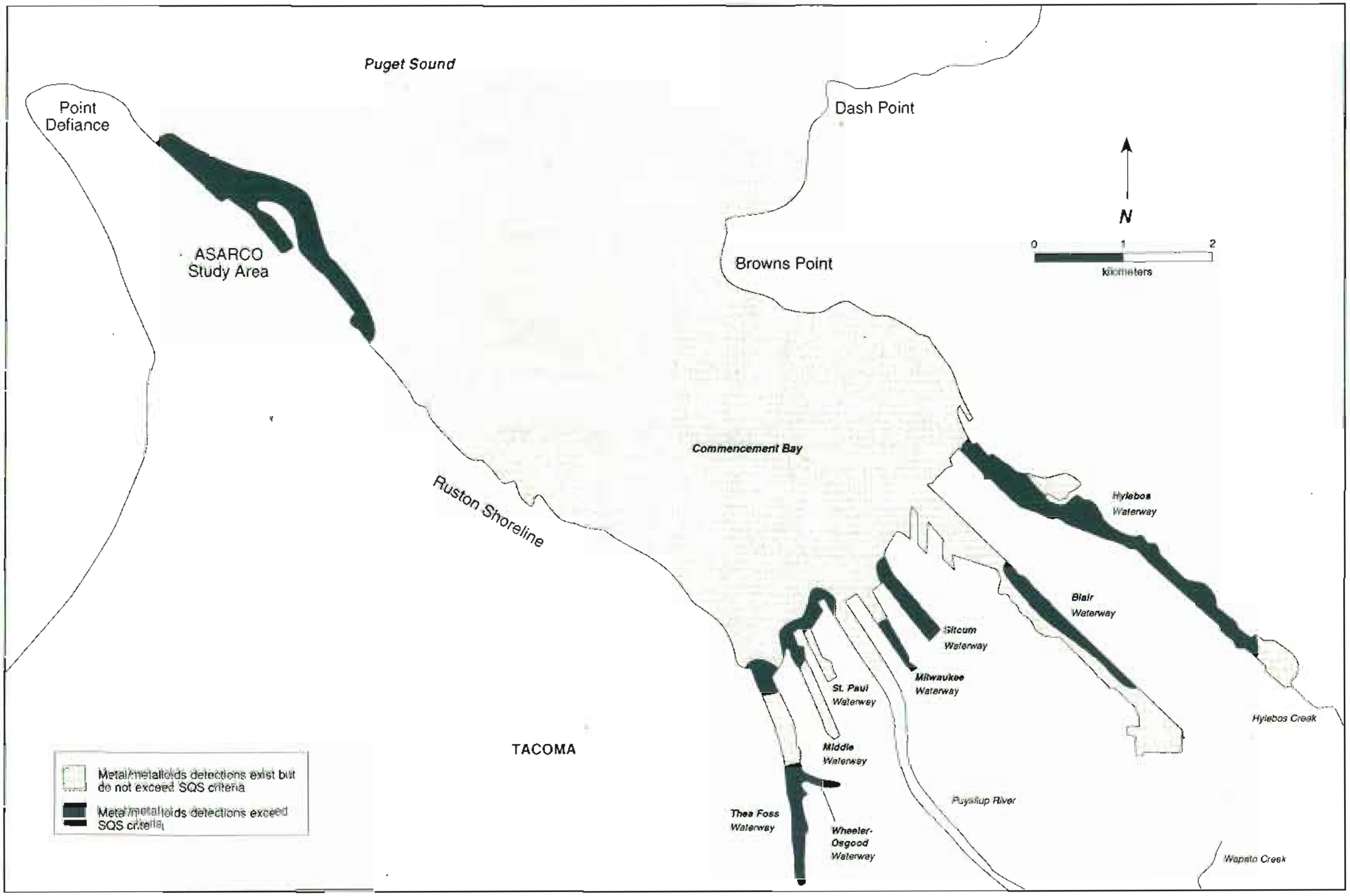

Figure 4-15. Distribution of selected metals/metalloids in Commencement Bay.

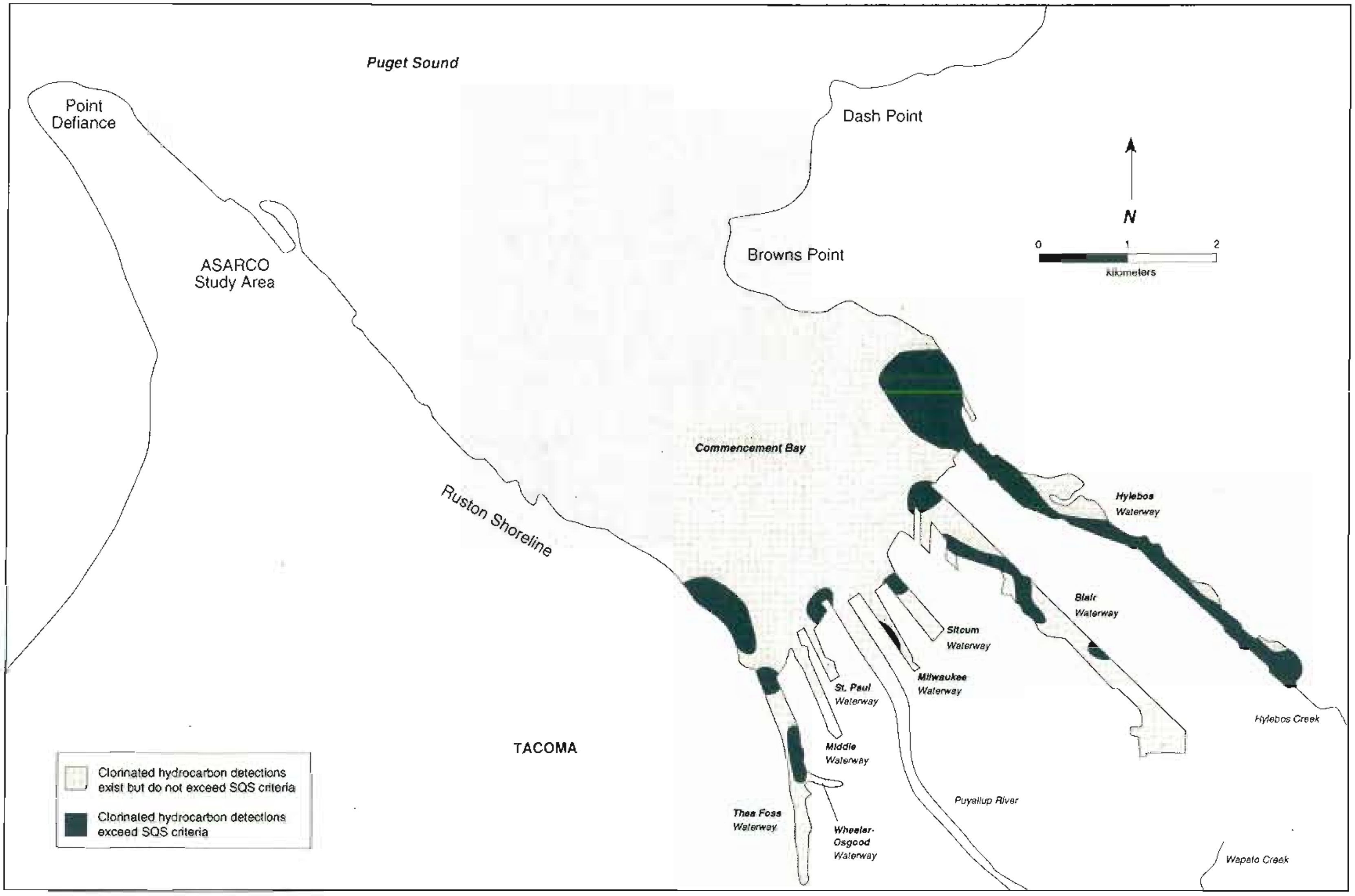

Figure 4-16. Distribution of chlorinated hydrocarbons in Commencement Bay.

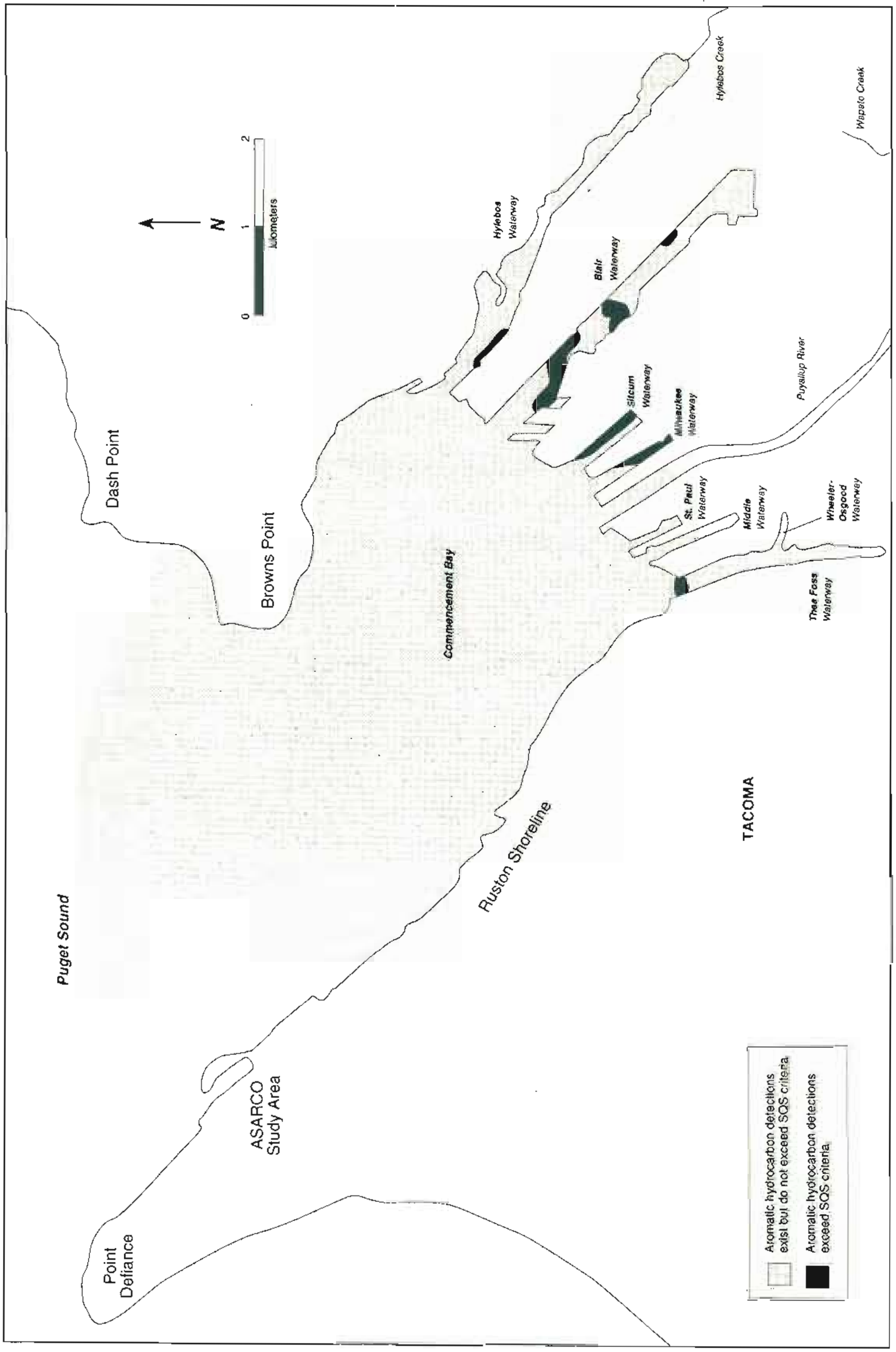

Figure 4-17. Distribution of aromatic hydrocarbons in Commencement Bay.

The areal and temporal distribution of juvenile salmonids in Commencement Bay has been fairly well characterized. The only apparent lack of sampling data for juvenile salmonids within nearshore areas of the Injury Study Area is for approximately 1 km of shoreline south of the ASARCO property, an area where substantial contamination has been observed. It is not known to what extent juvenile salmonids use the area as juvenile rearing habitat. Sampling of juvenile salmonids has not occurred in offshore waters either; however, concentrations of SOCs are lower in offshore areas of Commencement Bay.

Few data on the distribution of adult salmonids in Commencement Bay have been collected, which presents a principal data gap for confirming exposure for these species. The limited data indicate that areal and temporal exposure of adult salmonids to contaminated sediment may be minimal. However, all adult salmonids that migrate up the Puyallup River basin likely occupy areas of the inner bay where higher concentrations of SOCs have been observed, at least for a short time before ascending the river.

Although the limited evidence suggests that direct exposure to contaminated sediments may be minimal, adult salmonids feed actively in Commencement Bay, and principal prey items, such as pandalid and crangon shrimps, have been measured with elevated tissue concentrations of chlorinated hydrocarbons (Malins et al., 1982) (see Section 4.4.3). These concentrations suggest that a primary route of exposure to contaminated sediment may be through the food chain, as opposed to direct proximal and temporal exposure for adult salmonids.

4.4.2.3 Areal Extent of Potential Exposure for Flatfish

The fish trawl transects conducted in Commencement Bay indicate that flatfish reside in all nearshore areas of the bay, including all of the waterways and along both the Ruston Shoreline and Browns Point shore. The Dames & Moore (1981a) transects, which were conducted across all four seasons, indicate that most of the flatfish species, particularly the most dominant (English and rock soles), are present year-round. Because most of the sediments with higher contaminant concentrations are present in nearshore subtidal areas of the waterways and the shorelines, there is the potential that most, if not all, contaminated areas are used by flatfish year-round (Figure 4-4).

The general propensity for flatfish not to move considerable distances (particularly juveniles that predominate in the nearshore subtidal areas) and the fairly comprehensive sampling coverage of previous fish surveys provide convincing evidence of both temporal and areal exposure of this key resource group.

4.4.2.4 Areal Extent of Potential Exposure for Benthic and Epibenthic Invertebrates

Potential areal and temporal exposure of benthic infaunal communities to contaminated sediments has been documented in most of the Injury Study Area. Sampling coverage for benthic infauna within the Injury Study Area has been reasonable, with the exception of the Browns Point shore and deep water, which has been limited. Benthic community studies in Commencement Bay indicate that benthic infauna reside in all of the waterways and along both shores, including those areas where concentrations of SOCs are high (i.e., exceed SQS concentrations). Benthic infauna are sessile and would be expected to occupy contaminated areas until the limits of their tolerance are reached, then disappear from the community.

The potential areal and temporal exposure to epibenthic communities has been documented, but only to a limited extent. Sampling has confirmed the presence of the communities, primarily in the inner bay near the mouths of the waterways. A few epibenthic stations have been sampled in the waterways and off the two shorelines, but these efforts have not been extensive. The areal and temporal distribution of macroinvertebrates in Commencement Bay has also not been fully characterized. Sampling and surveys for macroinvertebrates have focused on economically valued species (i.e., shrimp and crab) and only in a few areas of the bay. It is unlikely, however, that epibenthic communities move considerable distances, and it also not expected that extensive seasonal movements of macroinvertebrates occur in Puget Sound. These data, although limited, suggest that both benthic and epibenthic species are exposed to SOCs in Commencement Bay.

4.4.2.5 Areal Extent of Potential Exposure for Birds

Intertidal Herbivores

Intertidal herbivores feed extensively in the intertidal and shallow subtidal habitats of the Injury Study Area. These areas tend to be those with higher levels of contamination. Comparison of their distribution with that of the SOCs indicates the potential for exposures

(Figure 4-8). Because these species spend extended periods of time, up to year-round, in the Injury Study Area, exposure could be substantial. Because these species are primarily herbivores, they are less likely to be exposed through the food chain but are potentially exposed through incidental ingestion of sediment during feeding. As with the fish-eating birds (piscivores) and diving ducks (benthivores), however, information on site fidelity for these species is lacking.

Piscivores

Fish-eating birds range throughout the Injury Study Area, with some species, such as the western grebe, found over deeper water and others, such as the horned grebe, preferring shallow water. These species use the area for up to 9 months. Comparison of the distribution of the birds to the distribution of SOCs indicates that the potential for exposure does exist (Figures 4-9 and 4-10). The 9- month period of time (i.e., up to 9 months) that these species use the Injury Study Area indicates that considerable exposure could occur.

Even though these species are found in the area for an extended period and have been documented in the Injury Study Area, data on site fidelity are lacking. Therefore, it is not known if these species could be exposed to SOCs in other areas during their winter residency in south Puget Sound.

Benthivores

The diving ducks use shallow-water areas, particularly in the waterways, for feeding during their 6-month winter residency. A comparison of their distribution to that of SOCs indicates that the potential for exposure exists (Figure 4-11). As with the fish-eating birds, information on site fidelity is lacking for these species and estimating the duration of exposure is difficult.

Carnivores

The great blue heron feeds year-round in the shallow areas of the Injury Study Area, particularly along the Browns Point shoreline and the Hylebos Waterway. The areas used by the great blue heron are known to have high concentrations of SOCs (Figure 4-12). The potential for significant exposure to SOCs exists due because of its feeding locations and the fact that it uses the area year-round.

The Injury Study Area also serves as a potential feeding site for bald eagles (Figure 4-13). The potential for exposure to SOCs is unknown, however, because their usage of the Injury Study Area is not well documented.

Omnivores

The glaucous-winged gull is an opportunistic feeder that forages throughout the Injury Study Area, particularly in the shallow, subtidal, and intertidal habitats. A comparison of the site usage to the distribution of contaminants indicates the potential for exposures (Figure 4-14). Because the glaucous-winged gull is a year-round resident, exposure could be significant. This species is known to forage extensively in urban areas, and therefore may be exposed to contaminants outside the Injury Study Area. Specific information on foraging locations is lacking.

4.4.3 Substances of Concern Measured in the Biota of Commencement Bay

Previous sections demonstrated that exposure to SOCs could occur based on:

- Existence of a pathway
- Coincidence of the distribution of the key resources relative to the distribution of SOCs
- Data verifying that exposure exists in some of the key resources in the Injury Study Area

The following section summarizes what is known about the presence of the SOCs in the tissues of the key biological resources in Commencement Bay.

4.4.3.1 Salmonids

Varanasi et al. (1993) sampled juvenile chinook salmon in Commencement Bay and analyzed liver tissue for PCBs, bile for fluorescent aromatic compounds (FACs—which are semiquantitative measures of the products of the metabolism of PAHs), and stomach contents (prey) for selected PCBs, PAHs, and other chlorinated hydrocarbons. Metals/metalloids were not analyzed. Fish were collected in Blair, Milwaukee, St. Paul, Middle, and Thea Foss Waterways.

Varanasi et al. (1993) found concentrations of PCBs (ranging from 39 to 320 µg/kg wet liver weight) and FACs (250 to 400 mg/kg benzo(a)pyrene equivalent in bile protein) that were consistently higher in salmon from the Injury Study Area than those in fish from the Nisqually estuary or in salmon-hatchery reference samples. Concentrations of PCBs in the tissues were found to persist for at least 3 months after removing fish from Commencement Bay and holding them in a laboratory. These findings suggest that the effects of exposure to PCBs in the Injury Study Area could continue after juvenile salmon migrate to an ocean environment.

Concentrations of aromatic hydrocarbons (ranging from 3,600 to 169,000 µg/kg wet weight) and PCBs (94 to 480 µg/kg wet weight) in stomach contents of juvenile chinook salmon from Commencement Bay were significantly higher than those in stomach contents of fish from the Nisqually estuary or in salmon hatchery reference samples. These results also indicate that contaminated diet serves as a potential route of uptake (Varanasi et al., 1993).

Taken together, these data demonstrate the exposure of juvenile salmon from Commencement Bay to SOCs and the subsequent uptake of SOCs into tissues.

Malins et al. (1982) analyzed liver and muscle tissue for selected SOCs in adult chinook and coho salmon collected from Commencement Bay, and found total PCB concentrations in liver and muscle ranging from 63 to 190 µg/kg and 41 to 57 µg/kg wet weight, respectively. These concentrations, however, were generally not elevated compared to those in reference samples from Point Jefferson. Given the migratory nature of adult salmon and the observance of similar concentrations in non-urban embayments, it is not known to what extent PCBs in the tissues of adult salmon are due to exposure within the Injury Study Area.

4.4.3.2 Flatfish

Tetra Tech (1985), Gahler et al. (1982), and Malins et al. (1982) collected flatfish in Commencement Bay and analyzed tissues for a number of SOCs. All three studies found that total PCBs were the most frequently detected and widespread SOCs in the tissues of flatfish, particularly English sole. Total PCBs were detected in flatfish collected from Hylebos, Blair, Sitcum, Milwaukee, St. Paul, Middle, and Thea Foss Waterways, and at Old Town Dock and Pt. Defiance along the Ruston Shoreline. Detected concentrations ranged from 40 to 1,120 μg/L total PCBs (wet weight), with the highest concentrations observed in fish collected from the Hylebos and Thea Foss Waterways. Malins et al. (1982), also analyzed liver samples and reported concentrations ranging from 1,500 to 24,000 μg/kg (dry weight).

Tetra Tech (1985) found copper in flatfish collected from Sitcum Waterway, St. Paul Waterway, and the Ruston Shoreline, and mercury in flatfish from Hylebos Waterway at concentrations statistically higher than those in Carr Inlet reference samples. Gahler et al. (1982) reported arsenic, chromium, lead, and nickel in flatfish fillets collected from the Hylebos and Thea Foss Waterways and along the Ruston Shoreline at concentrations 2 to 5 times higher than concentrations observed in flatfish collected at reference stations.

Tetra Tech (1985) and Gahler et al. (1982) found low concentrations of hexachlorobenzene in English sole muscle tissue (wet weight) collected from the Hylebos Waterway; Tetra Tech (1985) also reported low concentrations of 1,3-dichlorobenzene and hexachlorobutadiene. Malins et al. (1982) reported concentrations of total chlorinated butadienes ranging from 820 to 9,100 μg/kg (dry weight) and hexachlorobenzene ranging from 840 to 3,700 μg/kg (dry weight) in English sole liver tissue collected from the Hylebos Waterway. Naphthalene was detected at high concentrations in muscle tissue of English sole (1,364 μg/kg, wet weight) from the Milwaukee Waterway (Tetra Tech 1985), while total aromatic hydrocarbons were observed in sole liver from the Hylebos Waterway at concentrations ranging from 420 to 1,400 μg/kg (dry weight) (Malins et al., 1982).

U.S. EPA (1992a) collected starry flounder from two sites in Commencement Bay as part of a nationwide study of chemical residues in fish. Fish were collected from the mouths of the Hylebos and St. Paul Waterways. Tissues were analyzed for organic compounds, including PCDDs and PCDFs, and mercury. Starry flounder fillets collected in the Hylebos Waterway contained, on a wet-weight basis, mercury (0.05 ng/g), octachlorostyrene (33.4 ng/g), hexachlorobenzene (29.2 ng/g), transnonachlor (4.39 ng/g), DDE (21.0 ng/g), and total PCBs (525.4 ng/g). Fish collected from the St. Paul Waterway contained, on a wet-weight basis, DDE (4.84 ng/g) and total PCBs (82.01 ng/g). In addition, fish samples from both waterways contained a variety of PCDD and PCDF congeners (Table 4-2).

Table 4-2. Concentrations of PCDDs and PCDFs in Fish and Crabs Collected in the Hylebos and St. Paul Waterways

	PCDD/PCDF Concentrations[a] (pg/g wet weight)														
	2,3,7,8-TCDD	1,2,3,7,8-PeCDD	1,2,3,4,7,8-HxCDD	1,2,3,6,7,8-HxCDD	1,2,3,7,8,9-HxCDD	1,2,3,4,6,7,8-HpCDD	2,3,7,8-TCDF	1,2,3,7,8-PeCDF	2,3,4,7,8-PeCDF	1,2,3,4,7,8-HxCDF[b]	1,2,3,6,7,8-HxCDF	1,2,3,78,9-HxCDF	2,3,4,6,7,8-HxCDF	1,2,3,4,6,7,8-HpCDF	1,2,3,4,7,8,9-HpCDF
Hylebos Waterway															
Starry Flounder	2.43	4.72	ND	9.58	0.66	3.48	9.80	5.88	13.58	5.36	2.22	ND	ND	0.93	ND
Dungeness Crab	ND	ND	ND	ND	ND	2.25	26.47	10.81	3.23	3.09	2.12	ND	ND	ND	ND
Crab Hepatopancreas	6.61	10.17	3.46	26.28	5.10	37.12	334.80	99.62	45.72	37.49	27.93	ND	3.35	10.86	ND
St. Paul Waterway															
Starry Flounder	1.51	1.21	ND	2.30	ND	1.11	3.00	ND	1.09	0.19	ND	ND	ND	0.35	ND
Dungeness Crab	5.44	6.43	ND	27.72	ND	15.99	67.41	3.70	4.11	2.28	2.16	ND	ND	3.71	ND
Dungeness Crab	ND	0.94	ND	2.22	ND	1.79	49.18	19.65	6.40	5.80	ND	ND	ND	ND	ND
Crab Hepatopancreas	5.67	6.10	ND	17.82	2.67	15.31	206.62	68.35	34.48	19.73	13.12	ND	ND	4.52	ND

Source: U.S. EPA (1992a).

Note: ND - not detected.

[a] TCDD = Tetrachlorodibenzo-*p*-dioxin; PeCDD = Pentachlorodibenzo-*p*-dioxin; HxCDD = Hexachlorodibenzo-*p*-dioxin; HpCDD = Heptachlorodibenzo-*p*-dioxin; TCDF =Tetrachlorodibenzofuran; PeCDF = Pentachlorodibenzofuran; HxCDF = Hexachlorodibenzofuran; HpCDF = Heptachlorodibenzofuran.

[b] Coelution with 1,2,3,4,6,7-HxCDF on gas chromotograph column (DB5 30Mx).

Taken together, these fish tissue data indicate that exposure to SOCs found in the sediment of the Injury Study Area has occurred, confirming that pathways exist between sediment-associated SOCs and fish resources. Of particular interest because of their persistence and demonstrable toxicological effects, is the presence of PCBs and PAHs in the tissues of English and other species of sole that inhabit the Commencement Bay estuary.

4.4.3.3 Benthic Invertebrates

Malins et al. (1982) collected whole tissue homogenates of marine worms (*Capitella* spp.), clams (*Macoma* spp.), shrimps (mixtures of *Pandalus danae, P. jordani, Crangon alaskensis*), and crabs (*Cancer* spp.) from Hylebos Waterway and analyzed the homogenates for a variety of constituents. Tetra Tech (1985) and Gahler et al. (1982) analyzed muscle tissue from cancrid crabs collected from Commencement Bay. As with flatfish tissue, total PCBs were observed most frequently in the Injury Study Area.

Malins et al. (1985) found total PCBs, total PAHs, and chlorinated butadienes in whole tissue of marine worms, shrimps, and clams collected from Hylebos Waterway at concentrations greater than those found in samples collected from Port Madison and Case Inlet. The maximum concentration of total PCBs detected in shrimps was 3,800 μg/kg dry weight; the maximum concentrations of PAHs and chlorinated butadienes detected in marine worms were 17,000 μg/kg dry weight and 360 μg/kg dry weight, respectively. Tetra Tech (1985) and Gahler et al. (1982) measured total PCBs in crab tissue at concentrations ranging from 40 to 1,120 μg/kg wet weight. The highest concentrations of PCBs were found in species collected from the Hylebos Waterway, followed by the Pt. Defiance dock, Thea Foss Waterway, and Sitcum Waterway. Total PCBs were detected in all waterways except the St. Paul Waterway.

Gahler et al. (1982) detected hexachlorobenzene (150 μg/kg wet weight) in crab collected from the Hylebos Waterway. Chromium, copper, and lead were also detected at concentrations 2 to 5 times greater than reference concentrations in crab tissue from the Hylebos and Thea Foss Waterways.

PTI (1988) collected and analyzed sea cucumbers (*M. intermedia*) from three deep-water stations in Commencement Bay. Tissue analyses detected HPAH and phenol in one sample each. Metals were detected in tissues collected at all stations.

As part of a nationwide study of chemical residues in fish, U.S. EPA collected Dungeness crabs at the entrance of the Hylebos and St. Paul Waterways. Both whole crab and hepatopancreas samples were analyzed for PCDDs and PCDFs. Most of the 2,3,7,8-substituted congeners were detected in the whole crab samples from both waterways (Table 4-2), with 2,3,7,8-TCDF present at the highest concentration (26.47 to 67.41 pg/g wet weight). Hepatopancreas samples also contained detectable concentrations of most of the 2,3,7,8-substituted congeners (Table 4-2), with 2,3,7,8 TCDF found in concentrations up to 334.8 pg/g wet weight (Hylebos Waterway sample). This 2,3,7,8 TCDF concentration was the highest found in any species collected in the nationwide survey.

Similar to the conclusion that can be drawn from the tissue residue data presented for fish, there is sufficient evidence to conclude that the benthic and epibenthic species are being exposed to sediment-associated SOCs in the Injury Study Area. The SOCs found in the sediment of the Injury Study Area, particularly PCBs, are bioavailable and have accumulated in the tissues of benthic invertebrates. The presence of SOCs in the tissue of benthic and epibenthic species is evidence that the accumulation of SOCs in flatfish tissues is, in part, due to contaminated diet. Polychaetes (marine worms) and bivalves are common prey items of flatfish, particularly English sole.

4.4.4 Substances of Concern Measured in Birds

Studies on the residues of contaminants in bird tissues in Commencement Bay are limited to the western grebe, surf scoter, great blue heron, and glaucous-winged gulls.

4.4.4.1 Western Grebe

A study by the U.S. Fish and Wildlife Service was undertaken in 1985 to determine if western grebes were accumulating contaminants while overwintering in Commencement Bay. Contaminant data were obtained for 40 grebes, 20 collected in October 1985 and 20 collected 112 days later in February 1986 (Henny et al., 1990). Results of this study are presented in Tables 4-3 and 4-4. In summary, the concentrations of arsenic and mercury increased in western grebe collected in February relative to those collected in October. Selenium concentrations did not change and copper concentrations decreased significantly. Cadmium concentrations in the kidney of molting grebes were much higher than for other birds, indicating that year-round residence may increase cadmium burden. The concentrations

Table 4-3. Geometric Mean Concentrations of Metals/Metalloids Reported in the Livers and Cadmium in Kidneys of Western Grebes and Surf Scoters Collected from Commencement Bay

Species / Date Sampled	Metals / Metalloid Concentrations (mg/kg)						
	Sample Size	Arsenic	Cadmium	Copper	Mercury	Selenium	Zinc
Western Grebe							
Fall 1985	20 15[a]	0.96 1.10	0.70 0.38	16.26 16.71	1.90	9.25 7.64	NA
Spring 1986	20	2.70	0.85	13.15	2.40	7.89	NA
Surf Scoters							
Fall 1984	6	0.24	5.7	57.7	1.9	26.5	129.6
Spring 1985	10	0.20	5.6	54.9	4.19	43.4	129.5

Source: Henny et al. (1990, 1991).

[a] Excluding molters.

Table 4-4. Geometric Mean Concentrations of Pesticides and PCBs in Carcasses of Western Grebes from Commencement Bay

Species / Date Sampled	Sample Size	Concentration (mg/kg wet weight)			Total[a] Chlordanes (mg/kg wet weight)
		DDE	DDD	PCBs	
Western Grebe					
Fall 1985	20	0.90	0.14	3.47	0.13
	15[b]	0.45	0.12	1.94	0.10
Spring 1986	20	1.77	0.24	6.37	0.21

Source: Henny et al. (1990).

[a] Total chlordanes is the sum of oxychlordane, *cis*-chlordane, *trans*-nonachlor, and *cis*-nonachlor.

[b] Excludes molting birds.

of DDE, PCBs, and total chlordanes increased over the study period in the grebes. PCBs tripled in concentration, and DDE increased 4 times. Geometric mean concentrations of 1.77 mg/kg wet weight for DDE and 6.37 mg/kg for PCBs were found in the later collection period. Total chlordanes showed a significant increase between periods when data for molting birds were eliminated.

4.4.4.2 Surf Scoter

In a similar study of surf scoters by the U. S. Fish and Wildlife Service over the winter of 1984-1985, a total of 16 birds were collected from Commencement Bay and analyzed — 6 birds in October and 10 birds in January (Table 4-3). Analyses of metals were performed on the liver and kidney tissue samples, while the breast muscle tissues were analyzed for organochlorine compounds.

The only metal that showed a statistically significant increase in concentration over the study period was mercury. Selenium showed an increase over the winter, but it was not significant. PCBs increased in frequency of detection, as well as concentration, in both adults and juveniles in Commencement Bay over the period of the study and DDE increased in frequency of detection, but was not detected often enough for statistical comparison.

4.4.4.3 Great Blue Heron

Three studies have analyzed tissues of great blue herons from Commencement Bay or from the Dumas Bay colony that is suspected to feed in Commencement Bay. In September 1982, two adult herons were collected, and liver and kidney tissues were analyzed for PCBs, DDE, PAHs, and a suite of metals/metalloids (Riley et al., 1983). Speich et al., (1992) collected six eggs from the heron colony at Dumas Bay in April 1984 and analyzed five for PCBs (quantitated as Aroclor 1260) and DDE. In 1988, the U.S. Fish and Wildlife Service and the WDF collected 15 eggs and 5 nestlings, of which 12 eggs were analyzed for organochlorines and PCBs and 5 eggs were analyzed for mercury and selenium (Norman, 1991; Block, 1992).

Riley et al. (1983) reported elevated mercury concentrations in tissues of great blue heron collected from Commencement Bay compared to those in birds collected from Elliott and Sequim Bays (Table 4-5). In addition, these birds had elevated concentrations of PCBs compared to those found in birds from Sequim Bay (Table 4-5).

Table 4-5. Concentrations of Mercury and PCBs Found in the Tissues of Great Blue Herons Collected from Various Bays in Puget Sound

Location	Mercury (mg/kg dry weight)			PCB (mg/kg wet weight)		
	Liver	Kidney	Adipose	Liver	Kidney	Adipose
Commencement Bay						
Bird 1	11.7	6.45	0.136	1.030	0.384	80.385
Bird 2	16.4	2.38	0.081	1.902	0.500	26.206
Elliott Bay						
Bird 1	3.26	1.96	0.192	1.304	0.536	14.600
Bird 2	8.98	4.19	0.27	5.087	2.080	57.696
Sequim Bay						
Bird 1	2.75	1.41	0.465	0.747	0.235	5.466

Source: Adapted from Riley et al. (1983).

Speich et al. (1992) reported that great blue heron eggs from the Dumas Bay colony contained elevated concentrations of PCBs and total DDT compounds compared to those in eggs collected from the Nisqually colony (Table 4-6). The PCBs were quantified as Anoclor 1260, thus the total PCB concentration may be substantially higher.

Table 4-6. Concentrations of PCBs and Total DDT in Great Blue Heron Eggs from Dumas Bay and Nisqually

Location	PCBs			Total DDT		
	Sample Size	Geometric Mean (mg/kg)	95% Confidence Interval	Sample Size	Geometric Mean (µg/g)	95% Confidence Interval
Dumas Bay	5	5.46	3.34–8.61	5	1.60	1.33–1.90
Nisqually	5	1.44	0.90–2.14	5	0.42	0.13–0.80

Source: Adapted from Speich et al. (1992).
Note: Concentrations are in wet weight.

Norman (1991) and Block (1992) reported the presence of PCBs, as well as the pesticides heptachlorepoxide, dieldrin, DDT, and chlordane, in the tissues of nestlings from Dumas Bay. In addition to these compounds, hexachlorobenzene was detected in the eggs collected from the colony (Table 4-7). The concentrations of hexachlorobenzene, dieldrin, heptachlorepoxide, and total chlordane were significantly higher in eggs from Dumas Bay than those from the reference colony at Nisqually. The total mean DDT concentration was also higher, but not significantly so. PCB concentrations were similar, although the geometric mean was higher at Dumas Bay (2.81 mg/kg wet weight) than at Nisqually (2.34 mg/kg wet weight).

Table 4-7. Geometric Mean Concentrations of Organochlorines, PCBs, and Mercury in Great Blue Heron Eggs and Nestling Breast Tissue Collected from the Dumas Bay and Nisqually Rookeries

Rookery/ Study/ Sample Type	Sample Size	Concentration (mg/kg wet weight)						
		Hexachloro-benzene	Heptachlor-epoxide	Dieldrin	DDE	Total Chlordane[a]	Total PCBs	Mercury
Dumas Bay								
Norman (1991)								
Eggs	7	0.10	NQ	NQ	1.43	NQ	12.33	NA
Nestlings (breast tissue)	5	0.003	NA	NA	0.048	NA	0.467	NA
Block (1992)								
Eggs	5	0.11	0.10	0.13	0.68	0.50	2.81	0.858
Nestlings (breast tissue)	5	ND	0.01	0.02	0.05	0.02	0.12	0.914
Nisqually								
Block (1992)								
Eggs	10	0.01	0.01	0.02	0.43	0.09	2.34	0.796
Nestlings collected from the nest	5	ND	ND	ND	0.03	0.01	0.06	0.82

Source: Adapted from Norman (1991) and Block (1992).
Note: ND - not detected, NQ - not quantified, NA - not analyzed.
[a] Total chlordane is the sum of oxychlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-chlordane, and *cis*-nonachlor.

4.4.4.4 Glaucous-winged Gull

In a 1982 a study in Commencement Bay, Riley et al. (1983) investigated a glaucous-winged gull colony nesting on the roof of the Simpson paper mill. Prefledgling chicks were collected, and tissues were analyzed for 14 metals/metalloids, PAHs, and PCBs. Concentrations of mercury, lead, and PCBs found in the birds' livers and kidneys are summarized in Table 4-8.

Table 4-8. Concentrations Found in Prefledging Glaucous-Winged Gull Chicks from Commencement Bay

TISSUE	SAMPLE SIZE	CONCENTRATION (μg/kg wet weight x±SE)		
		MERCURY	LEAD	PCB
Liver	4	0.75 ± 0.07	0.36 ± 0.10	575 ± 191
Kidney	4	0.78 ± 0.05	0.72 ± 0.09	107 ± 28

Speich et al. (1992) reported that glaucous-winged gull eggs collected from Commencement Bay contained a mean PCB concentration of 2.91 µg/g wet weight (N=6) and total DDT concentration of 0.49 µg/g wet weight (N=6).

4.4.5 Conclusions

Analysis of the principal sources and exposure pathways demonstrate that pathways exist for exposure of biota in Commencement Bay to SOCs. A comparison of the distribution (both areal and temporal) of the key biological resources and the SOCs demonstrates that exposure occurs through these pathways. Existence of exposure is demonstrated by data indicating that all key biological resources (i.e., salmonids, flatfish, benthic invertebrates, and birds) have accumulated a variety of the SOCs in their tissues, although site fidelity is an issue for some species.