Chlorinated Hydrocarbon Concentrations and the Ecology and Behavior of Harbor Seals in Washington State Waters

A Student-Originated Study

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INTRODUCTION

The Pacific harbor seal (*Phoca vitulina richardii*), occurs along the north and west coasts of North America from the Bering Sea to northern Baja California, Mexico (Scheffer 1958). Scheffer and Slipp (1944) have done the most extensive study of the harbor seal in Washington State. More recent research in Washington State has focused on Gertrude Island in Southern Puget Sound and on the outer coast (Arnold 1968, Newby 1971, 1973a, 1973b, Johnson and Jeffries 1977).

Newby (1973a) reported a decline in the Washington State harbor seal population between 1942 and 1972 and the abandonment by this species of the Nisqually Delta, previously a major haul out area of the harbor seal in Southern Puget Sound. Between 1923 and 1960 Washington State paid a bounty on harbor seals; over 10,000 were killed between 1947 and 1960 (Washington State bounty records). The Marine Mammal Protection Act of 1972 includes the harbor seal among the fully protected species.

Harbor seal behavior has been touched upon in most studies, with emphasis on activities at haul out areas (Venables and Venables 1955, 1957, 1959, Newby 1971, Bishop 1967, Scheffer and Slipp 1944). Certain aspects of behavior, e.g. mother-pup interactions, have been studied in detail (Finch 1966, Wilson 1974a), but behavior has not been fully described. Food habits were studied between 1927-1930 by Scheffer and Sperry (1931) but no comprehensive food habit study has since been reported.

The pupping season of harbor seals along the west coast of North America becomes progressively earlier both north and south of Puget Sound (Bigg 1969b). The different seal haul out areas in Puget Sound, a complex network of channels and inlets, provides an excellent opportunity to further research the phenology of harbor seal pupping.

Newby (1971, 1973b) reported a high incidence of prenatal and neonatal deaths, including some associated with birth defects, in harbor seals from Gertrude Island in Southern Puget Sound. Arndt (1973) found significantly higher concentrations of the chlorinated hydrocarbon PCB (polychlorinated biphenyls) in the blubber and liver of harbor seals from Southern Puget Sound than in harbor seals from Northern Puget Sound and Grays Harbor in Washington State, and speculated PCBs might be causing the high pup mortality. The distribution of PCBs in cottids, mussels, and sediment from Southern Puget Sound has been discussed (Mowrer *et al*. 1977). Highest concentrations of PCB were found at sites nearest industrial and populated areas.

Chlorinated hydrocarbons have been shown to cause reproductive failure in a variety of animals; the effects of PCB have been reviewed by Stendell (1976). Chlorinated hydrocarbons have been linked to premature births in California sea lions (*Zalophus californianus*). Interaction between these chemicals and disease agents is a possible mechanism (DeLong *et al*. 1973, Gilmartin *et al*. 1976). Helle *et al*. (1976b) found significantly higher concentrations of PCB and DDE in the blubber of ringed seals (*Pusa hispida*) that had uterine occlusions and stenosis than in females that did not. This population of ringed seals in the Baltic had been experiencing low reproductive success, apparently because of the occlusions. Similar uterine abnormalities were also seen in grey seals (*Halichoerus grypus*) and harbor seals from the Baltic.

We investigated the ecology and behavior of harbor seals and the concentration of the chlorinated hydrocarbons PCB and DDE in harbor seals and their food in Washington State, from March 1977 through January 1978. Our primary objectives were to:

1. Determine the distribution, habitat, and population size of harbor seals in Northern Puget Sound, Hood Canal, and extreme Southern Puget Sound.

2. Examine the reproduction, including the pupping season and birth and mortality rate of harbor seals in these regions.

3. Describe the behavior of harbor seals.

4. Determine the principal fish species eaten by harbor seals in our study areas.

5. Study the effect of human incursion on populations of harbor seals at our study areas.

6. Determine the distribution of PCB and DDE in tissues of harbor seals from different areas of Washington State and examine the possibility that a correlation exists between concentrations of contaminants and reproductive success.

7. Determine the concentration of these contaminants in fish and harbor seal scat and examine the dynamics of contaminant accumulation in the harbor seal.

STUDY SITES

Our study sites are located in northwest Washington in three regions of Puget Sound; Northern Puget Sound (including the San Juan Islands), Hood Canal, and extreme Southern Puget Sound (Fig. 1).

Northern Puget Sound

Our work in Northern Puget Sound took place primarily at Smith Island and the San Juan Islands (Fig. 2). The marine environment typical of the San Juan Island region rocky shores is described by Kozloff (1973). In addition

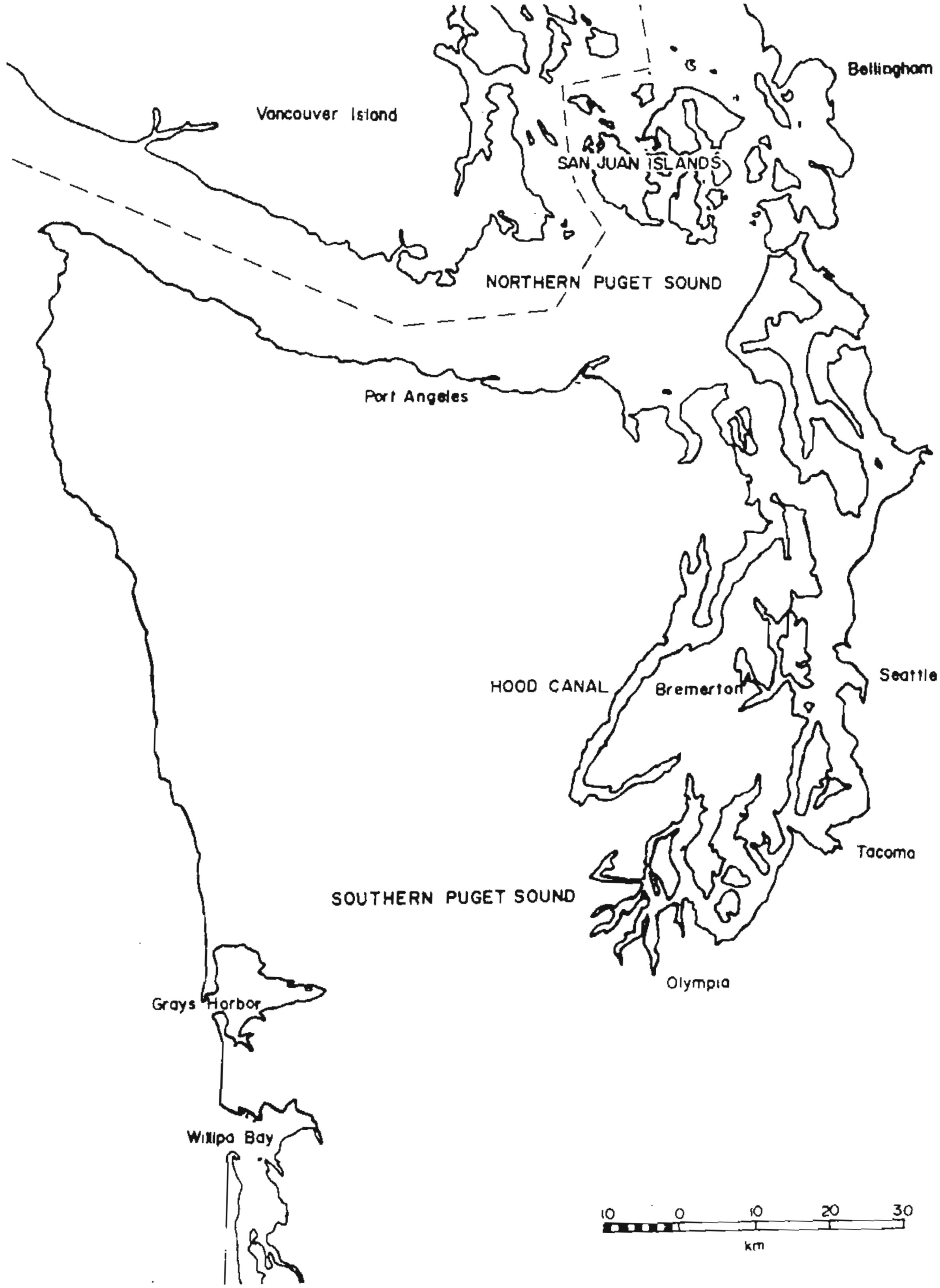

Fig. 1. Map of Northwestern Washington and our 3 study areas.

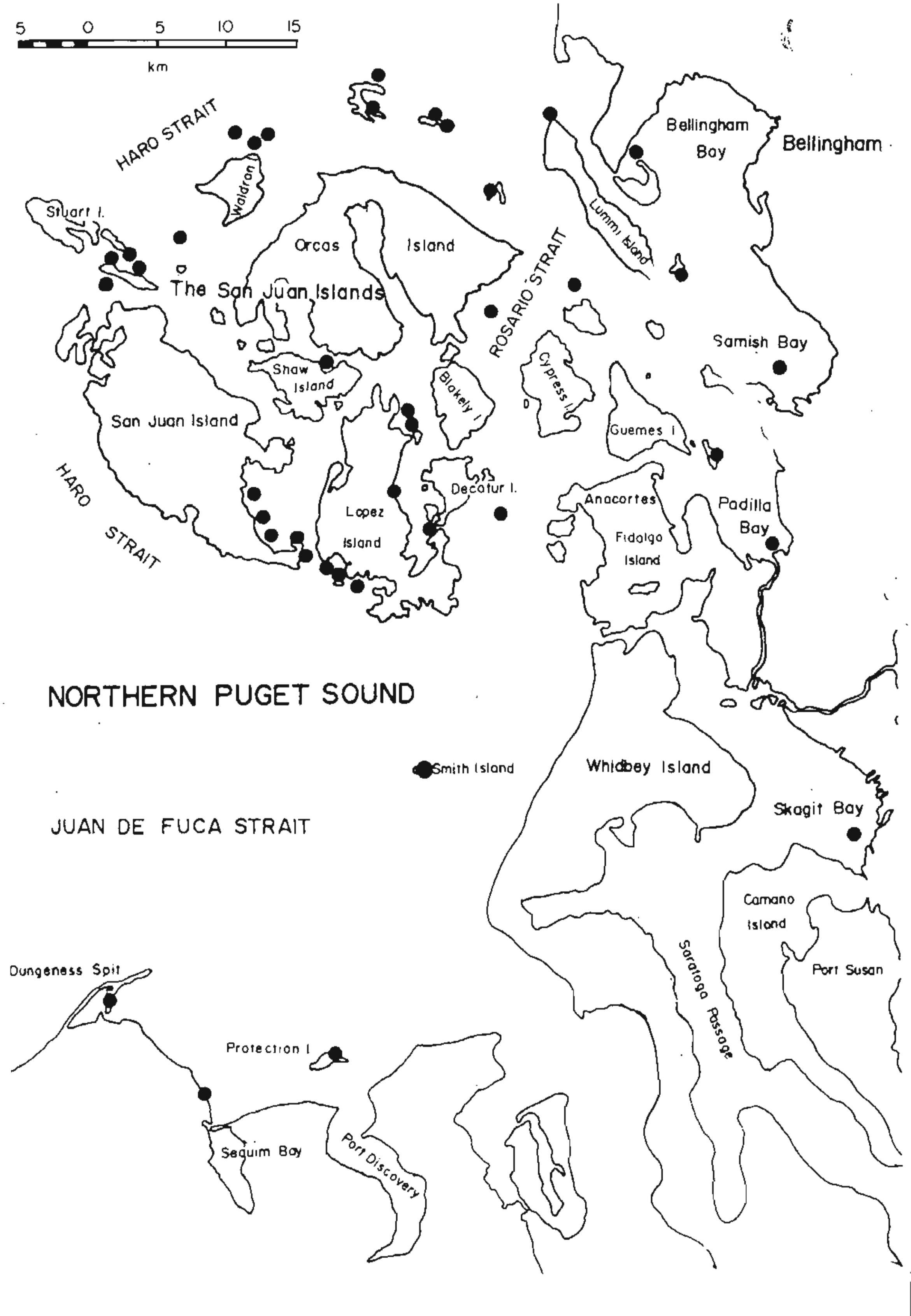

Fig. 2. Seal haul out sites in Northern Puget Sound.

to the harbor seal, other species of marine mammals found in the waters of the San Juan Islands include killer whale (*Orcinus orca*), minke whale (*Balaenoptera acutorostrata*), harbor porpoise (*Phocoena phocoena*) and Steller sea lion (*Eumetopias jubata*). People reside on the larger San Juan Islands throughout the year. An influx of residents and tourists occurs during the summer months, producing a corresponding increase in boat traffic. Topography of Skipjack Island, a study site, is typical of most of the San Juan Island reef landform. The 5.5 ha island is uninhabited.

Smith Island and Minor Island are managed jointly by the U.S. Department of Interior and the U.S. Coast Guard. The islands are closed to the public. They are located in the Juan de Fuca Strait, 9.9 km west of Whidbey Island. Minor Island (0.7 ha) is connected to the larger Smith Island (12.8 ha) at low tide by a 1.3 km cobblestone spit. Until recently a lighthouse keeper was stationed on Smith Island, but the lighthouse is now automated.

Hood Canal

We studied seals at six sites on the Hood Canal: the Skokomish, Dosewallips, Duckabush and Hamma Hamma River Deltas, Quilcene Bay and Jorsted Creek (Fig. 3). The river deltas are characterized by salt marshes, extensive mud flats and eel-grass (*Zostera marina*) beds. A high density of waterfowl is found in these areas during fall, winter, and spring. Anadromus fish, particularly salmon (*Oncorhynchus* sp.), spawn in the rivers and creeks. Much of the land along the canal is sparsely populated.

The Skokomish River Delta is the largest (approximately 200 ha) of the deltas in the Hood Canal. The river has eroded the alluvial substrate at the mouth to form a matrix of sloughs,distributaries,and small islands. The Dosewallips River Delta is owned and managed by the Washington Department of Parks and Recreation. Most of the delta is not easily accessible to visitors.

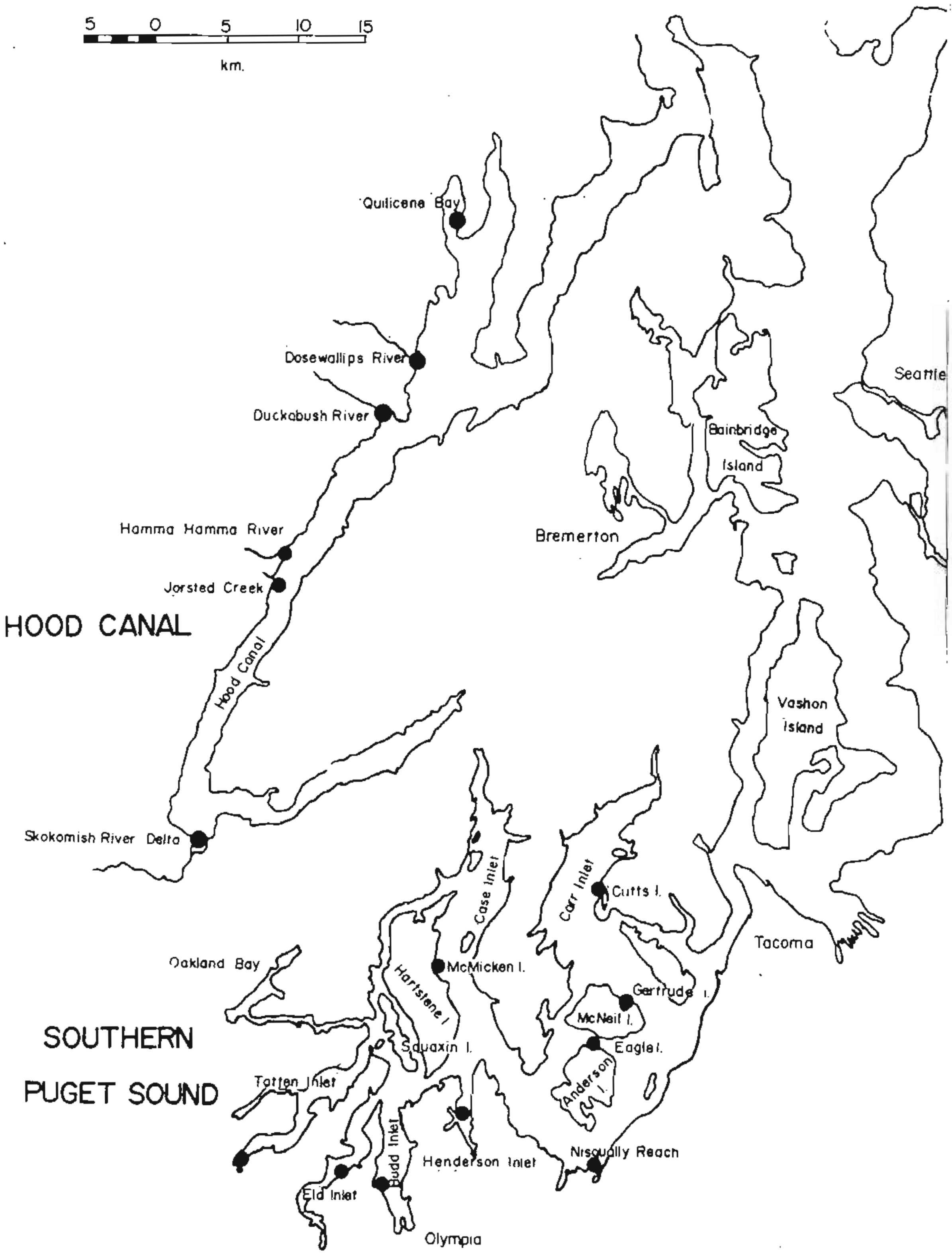

Fig. 3. Seal haul out sites in Southern Puget Sound and Hood Canal.

The Duckabush and the Hamma Hamma River Deltas, both within 25 km of Dosewallips Delta, are crossed by Highway U.S. 101 within 500 m of the canal, and both are privately owned.

At Quilcene Bay and Jorsted Creek,log booms are presently operated. A marsh of approximately 60 ha exists on the northwest side of Quilcene Bay, and shallow portions of the bay are utilized for oyster production. The Jorsted Creek log operation is situated within 50 m of U.S. 101.

Southern Puget Sound

In Southern Puget Sound, research took place in Eld, Budd, Totten, Henderson, and Case Inlets (Fig. 3). Two major human population centers, Tacoma (pop. 116,000) and Olympia (pop. 23,600) are in this region.

Eld Inlet was the most extensively studied site in Southern Puget Sound. The shores of the inlet are primarily residential. Three oyster companies are the only industries on the inlet. The port and city of Olympia are located at the southern tip of Budd Inlet. The shoreline here is densely populated; there is some industry, including plywood and lumber manufacture at the southern end.

The shores of Totten and Henderson Inlets are less developed than Budd or Eld Inlets. An oyster company and log storage facilities are the only industries. McMicken Island in Case Inlet is managed by the Washington Department of Parks and Recreation and only one residence is maintained on the island. Boat campers, mooring offshore, are common during the summer months.

METHODS

Observation and Census

We made 615 visits(not including aerial surveys)to study sites (Table 1). During land-based observation, vegetation and topographic features were used

Table 1. Number of visits and length of each visit to each study site by members of the research group. Half-day visits include one haul out cycle.

Site	Full Day	Half Day	Brief Visit	Total Visits
Southern Puget Sound				
Henderson Inlet	2	2	7	11
McMicken Island		1	10	11
Eld Inlet		180		180
Budd Inlet			21	21
Totten Inlet		1	12	13
Nisqually Delta			7	7
Eagle Island			1	1
Wycoff Shoals			1	1
Cutts Island			1	1
Northern Puget Sound				
Smith Island	37	3	1	41
Skipjack Island	36	11	2	49
Hood Canal				
Skokomish Delta	43	44	21	108
Duckabush Delta	8	29	25	62
Dosewallips Delta	8	27	29	64
Quilcene Bay		2	33	35
Hamma Hamma Delta			6	6
Jorsted Creek			3	3
Rocks South of Duckabush			1	1

for concealment. At the Skokomish River Delta we built a 7 m high tower and blind to aid in observing seals on the extensive salt marsh. A small portable blind concealed researchers on Smith and Minor Islands. We observed seals from small boats in areas where we could not view them from land. Binoculars, spotting scopes, and cameras aided observation and documentation. Land-based censuses of seals were usually taken at 30 minute intervals through the haul out period. Counts of seals in the water were made by scanning an area repeatedly for up to 1 hour.

A total of 19 aerial surveys were flown between 27 June and 23 October to confirm land counts and to get near simultaneous counts for entire regions. We usually circled harbor seals in a four-seat,high wing single engine plane (Cessna 172) at an altitude of approximately 244 m while two observers made counts with the help of binoculars. Photographs were taken with 125 mm and 200 mm telephoto lenses to check counts. The optimal airplane survey time (time when the highest number of seals were hauled) relative to time and hour, was determined by earlier land and water based observations.

Reproduction

The onset of the pupping season at each of our sites was determined by the date of the first pup seen or the first birth evidence(lanugo coat, fetal sack, or placenta) found. We called a seal a pup if it was nursing or making pup vocalizations or if it met a combination of the following criteria: small size, nearness to an adult seal, close association to an adult seal, and pup pelage. All sites were observed regularly and five sites (Eld Inlet, Smith Island, and Skokomish, Dosewallips and Duckabush River Deltas) were searched regularly for evidence of births. All evidence was removed when found to avoid duplication. The end of the pupping season at sites that were visited frequently was designated using the following criteria: the last birth evidence found, the day of the highest pup count, or 4 weeks earlier than the date the last nursing pup was seen (based on the approximately 4-week lactation of harbor seals, Scheffer and Slipp 1944, Newby 1973b, Venables and Venables 1955).

Behavior

Behavior of the harbor seal was described and recorded at all sites. Underwater behavior was most often visible at Skipjack Island in Northern Puget Sound. Positions and duration of resting in the water were timed. Resting on land was timed by recording the number of seconds that eyes were open and closed in a three-minute period every 30 minutes after an individual hauled out. Mother-pup behavior was observed and timed primarily at Skipjack Island, Eld Inlet and Dosewallips Delta. Some individuals were recognizable by distinctive pelage patterns or obvious scars.

Sample Collection

We recovered dead harbor seals found at our sites during the study. Necropsy and histopathology were completed when possible. Stomach contents were identified and recorded. Tissues routinely collected for chlorinated hydrocarbon analysis included blubber, liver, spleen, muscle, and kidney. Samples of blubber for chlorinated hydrocarbon analysis from 22 harbor seals that had been found dead in Puget Sound or on the outer coast and from 28 harbor seals that had been collected from Grays Harbor were received from Steven Jeffries and Murray Johnson of the Museum of Natural History, University of Puget Sound, Washington. Fish were collected by beach seine, hook and line, and otter trawl. Mussels (*Mytilus edulis*) were collected from pilings and beaches at several sites.

At most haul out sites, seal scat was collected for otolith identification and for chlorinated hydrocarbon analysis. All samples for residue analysis were wrapped in aluminum foil and frozen until time of analysis.

Food Habits

Diet of harbor seal populations was determined through identification of fish otoliths in seal scat collected at the study sites. We screened scat through nested sieves (.4-.099 cm) and grouped recovered otoliths by two-week periods before identification. All otoliths were identified by John Fitch of the California Department of Fish and Game.

Chlorinated Hydrocarbons

Mussels (shucked) and harbor seal scats were freeze-dried to determine the dry weight as well as the wet weight. Between 0.5 g and 100 g of sample was digested in BFM solution (glacial acetic and perchloric acid) and extracted with hexane (Stanley and LeFavoure 1965). Lipid weights were determined by evaporation to dryness of a portion of the hexane-lipid extract. A portion of the hexane extract was cleaned up with concentrated sulfuric acid (Murphy 1972) and injected on a Hewlett-Packard electron capture gas chromatograph equipped with a ¼" x 6' glass column packed with 10% DC-200 on gas chrom Q 80/100 mesh. Most samples were injected at least twice, once on a column with a 1" alkaline precolumn (KOH and NaOH) (Miller and Wells 1969) and once on a column without the alkaline precolumn to check for the presence of DDT and its metabolites other than p,p'-DDE. Peak areas were determined by integrators connected to the gas chromatograph.

PCB peaks were quantified by individual homolog analysis using mean weight percent figures reported by Webb and McCall (1973) for 21 peaks. When less than five peaks could be quantified, quantification was made by extrapolating the remaining peaks based on an Aroclor 1254 (trade name for a Monsanto Co. PCB mixture) standard. A PCB standard (mixture of Aroclor 1242, 1254, and 1260) was injected daily. DDE was quantified after subtraction of the estimated overlapping PCB peak assumed to be roughly equal to the preceding PCB peak.

RESULTS AND DISCUSSION

Distribution and Habitat

Harbor seal haul out habitat is characterized by three conditions: protection from approach by land, access to deep water, and proximity to food (Scheffer and Slipp 1944). Haul out pattern varies according to habitat and other factors discussed in Behavior-Haul out. The haul out areas we studied can be divided into five categories: gently sloping cobble or sandy beaches including spits; rocky reefs and ledges; salt marshes; mudflats; and human made environments, including log booms, rafts, and floats. Photographs of the different habitats are shown in Fig. 4.

Gently sloping cobble/sand beaches are found at five sites: Smith Island, Dungeness Spit, Protection Island and Sequim Bay in Northern Puget Sound, and McMicken Island in Southern Puget Sound. At McMicken Island the seals haul out on the flood tide, then follow the water line down as the tide recedes. The topography of the Smith Island Spit allows haul out at almost all tidal heights.

Rocky reefs and rock ledges along shoreline cliffs are important haul out sites in the San Juan Islands and less commonly on Hood Canal. Haul out on reefs is usually limited to low tide exposure. Reefs and small cliff ledges that remain exposed at high tide are occasionally used.

Salt marshes, with banks up to 2 m above the surrounding mudflat are utilized for haul out at the Skokomish, Dosewallips, and Duckabush Deltas. The seals haul out at high tide when the water level approximates the marsh level.

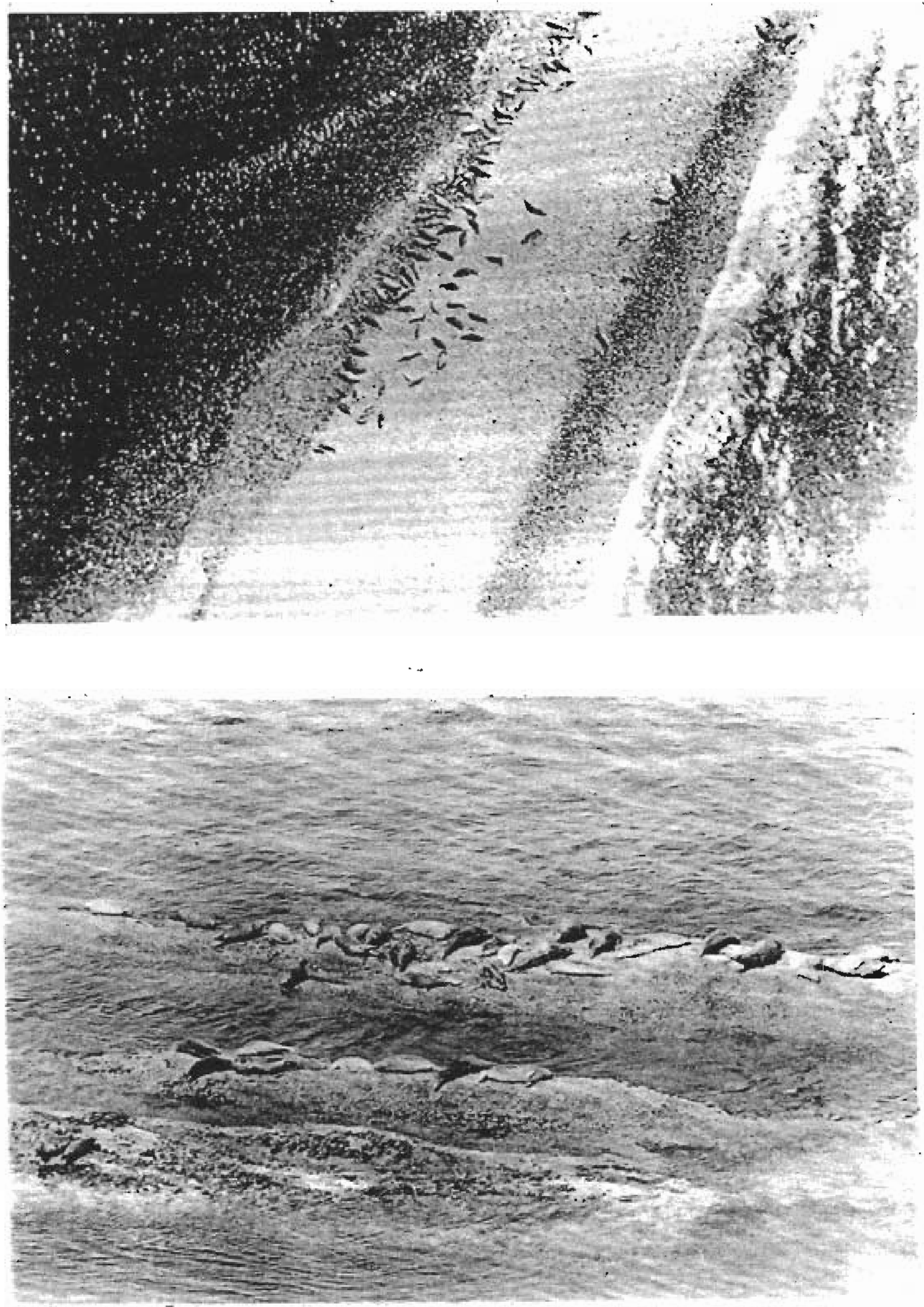

Fig. 4a. Seal haul out habitat. Top: cobble spit, bottom: tidal reef.

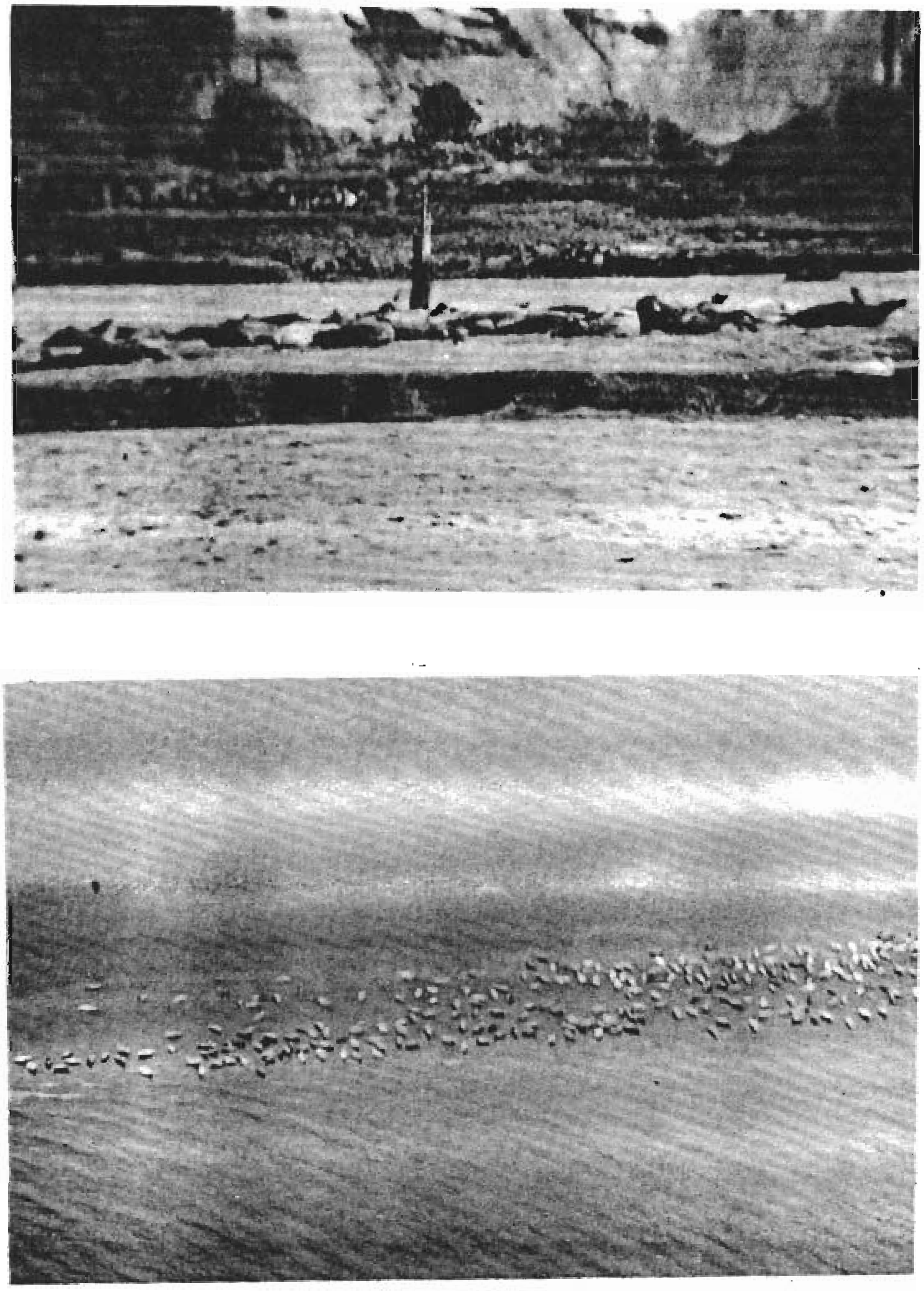

Fig. 4b. Seal haul out habitat. Top: salt marsh, bottom: mud flat.

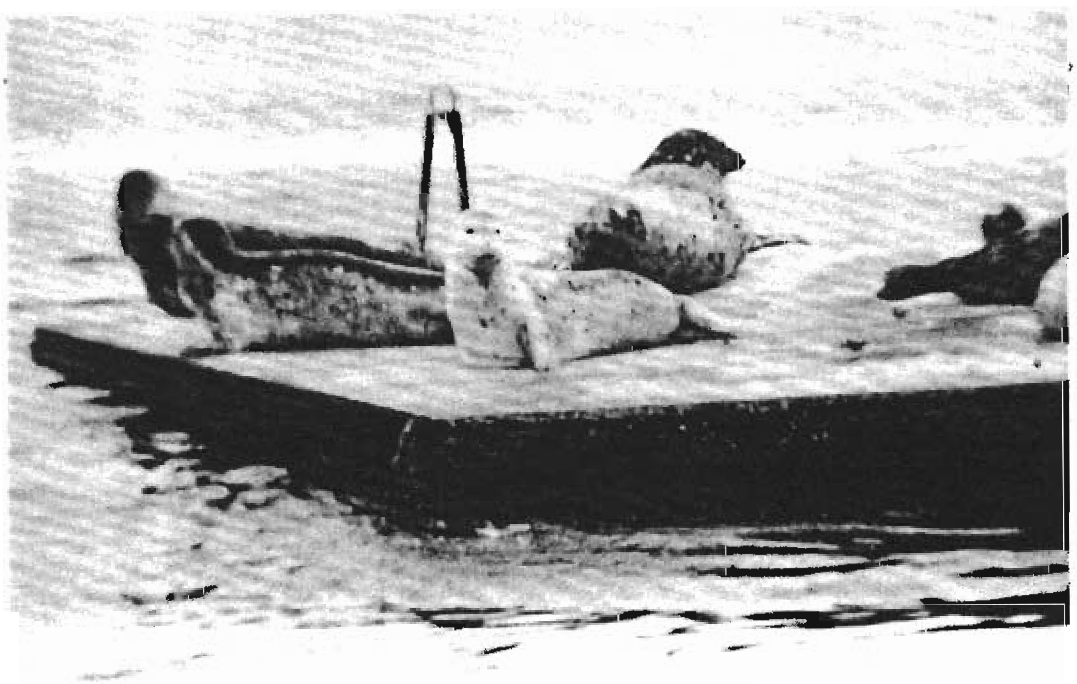

Fig. 4c. Seal haul out habitat. Top: log booms, bottom: recreational float.

Mudflats are used as the primary haul out habitat at Samish, Skagit, and Padilla Bay in Northern Puget Sound. At these sites we found seals hauled out at low tides when the mudflats were exposed. Seals have occasionally been seen to haul out in a similar pattern on the mudflats at Skokomish Delta and Dungeness Spit.

Human-made environments include log booms. These are utilized by seals at Quilcene Bay, Henderson, Budd and Totten Inlets; rafts, oyster floats and barges utilized year-round in Eld and Totten Inlets and seasonally in Quilcene Bay and at the Hamma Hamma River Delta. The log boom habitat is capable of accomodating larger numbers of seals than rafts or floats. Human disturbance, rather than tidal influence, is generally the most important factor influencing haul out pattern in these environments, where seals generally haul out at night when disturbance is minimal. At Quilcene Bay and Totten Inlet, logs are in water too shallow to permit access by seals at low tide.

Population

Since the proportion of the harbor seal population hauled out at a given time is unknown, even high counts of seals represent the minimum number of seals in the area at that time. High counts of harbor seals at our study sites and our highest near simultaneous regional counts from both land and aerial censuses are shown in Table 2. The results of aerial survey counts for each region are shown in Tables 3-5. The locations of haul out areas in Northern Puget Sound, Hood Canal, and Southern Puget Sound are shown in Figs. 2 and 3.

The Northern Puget Sound region was censused primarily from the air. The largest haul out area was on Smith Island, where 245 seals were counted on 18 July 1977. Collectively, the highest count on the San Juan Islands, west of Rosario Strait, was 648 seals on 11 September 1977. There were 28 haul out

Table 2. Short-term regional and site high counts.

Site	Short-term Regional Count Date	Short-term Regional Count Number	Site High Count Number	Site High Count Date
Northern Puget Sound	11 Sept. - 15 Sept.			
San Juan Islands	11 Sept.	648	648	(11 Sept.)
Smith Island	"	163	245	(18 July)
East of Rosario Strait	"	165	165	(11 Sept.)
Protection Island	15 Sept.	165	165	(15 Sept.)
West Sequim Beach	"	36	36	(15 Sept.)
Dungeness Spit	"	60	175	(15 Oct.)
Klaus Rocks			22	(15 Oct.)
Regional Minimum Population		1237		
Site High Count Total			1456	
Hood Canal	15 Sept. - 16 Sept.			
Quilcene Bay	15 Sept.	106	168	(4 April)
Dosewallips River Delta	"	134	160	(8 Oct.)
Duckabush River Delta	"	154	163	(5 June)
Rocks South of Duckabush			33	(15 Oct.)
Hamma Hamma River Delta	15 Sept.	11	17	(17 Oct.)
Jorsted Creek	"	8	30	(3 April)
Skokomish River Delta	16 Sept.	319	342	(30 Sept.)
Regional Minimum Population		732		
Site High Count Total			913	
Southern Puget Sound (South of McNeil Island)	16 Aug. - 26 Aug.			
McMicken Island	16 Aug.	32	44	(14 June)
Eagle Island Reef	"	10	10	(16 Aug.)
Eld Inlet	24 Aug.	23	30	(1 March)
Budd Inlet	"	29	29	(24 Aug.)
Henderson Inlet	26 Aug.	35	40	(13 Aug.)
Nisqually River Delta	18 Aug.	8	17	(3 Nov.)
Totten Inlet			11	(14 June)
Regional Minimum Population		137		
Site High Count Total			182	

Table 3. Aerial survey counts of harbor seals in San Juan Islands (west of Rosario Strait), Northern Puget Sound. Counts include number of pups; shown in parentheses. * = Site not surveyed.

NORTHERN PUGET SOUND

San Juan Islands (U.S. waters, west of Rosario Strait)

Date Time of flight Tide at Friday Harbor	27 June 0555-0937 Low/0832/-0.5	28 June 0850-0952 Low/0923/-1.6	18 July 1105-1204 Low/1300/-0.6	3 August 1158-1237 Low/1415/1.1	11 August 0750-0900 Low/0938/-0.2	11 September 0857-1103 Low/1017/0.6
Middle Channel	*	60	*	15	57(4)	51
Harbor Rock	0	0	2(1)	0	0	4
North Pacific Rocks	*	*	*	*	3	*
Half-tide Rocks	0	15	13	13(2)	33(2)	25
Dinner Island	0	33	43(4)	28(5)	42(2)	72
Sentinel Rocks	56	39	49(2)	24	48(5)	38
Gulf Reef	0	0	6(1)	0	15	23
Cactus Island	0	0	5	0	0	58
Ripple Island	0	0	32	58(2)	71(4)	22
White Rocks	41	31	20	23(3)	12(3)	17
Skipjack Island	22	22	11(2)	25(5)	20(2)	39
Bare-Skipjack Reefs	21	10	40	0	0	0
Ware Island	25	26	0	40(3)	33(2)	45
Clements Reef	75	65	*	46(1)	37(3)	39
Sucia Island	0	8	27(1)	0	24	58
Matia Island	*	*	0	0	0	10
Puffin Island	*	69	36	28	40(4)	68
Barnes Island	*	*	3(1)	0	23(6)	18
Peapod Rocks	*	*	0	50(2)	6	46
Leo Reef	*	*	*	*	*	14
Flower Island	*	*	*	*	*	1
Small Island	*	*	8(3)	5	*	*
Total	220	378	295(15)	355(23)	461(37)	648

Table 4. Aerial survey counts of harbor seals in Northern Puget Sound. Counts include number of pups; shown in parentheses. * = Site not surveyed.

East of Rosario Strait		
Date	11 September	23 October
Time of flight	1010-1140	0758-0930
Tide at Anacortes	Low/0954/0.6	Low/0819/2.6
Lummi Island	67	*
Bellingham Bay	0	23
Eliza Island	3	14
Boulder Reef	36	*
Sammish Bay	45	0
Padilla Bay	0	18
Hat Island	14	53
Bird Rocks	*	6
Skagit Bay	0	14
Total	165	128

Date	27 June	18 July	1 August	3 August	11 August	11 September	15 September	15 October
Smith Island	194(13)	245(37)	43(4)	132(4)	81(1)	163	*	125
Time of flight Tide at Smith Island	1558 Low/1508/5.6	0603 High/0500/5.6	1445 Low/1153/-0.6	0900 High/0718/5.2	0726 Low/0828/-0.2	1735 High/2012/5.9		0935 Low/1209/3.9
Protection Island	*	*	*	*	*	82(1)	165(6)	151
Time of flight Tide at Port Townsend						1140 Low/0919/0.6	0926 Low/1153/2.3	0945 Low/1221/4.7
Kulakala Point	*	*	*	*	*	*	36(5)	0
Time of flight Tide at S Bay entrance							0920 Low/1148/0.6	0951 Low/1216/4.6
Dungeness Spit	*	*	*	*	79(18)	30(1)	60(2)	175
Time of flight Tide at Dungeness					0726 Low/0804/-0.2	0755 Low/0843/0.5	0942 Low/1117/2.1	1007 Low/1145/4.3
Klas Rocks	*	*	*	*	*	*	*	33
Time of flight Tide at Port Ludlow								0919 Low/1203/4.1

Table 5. Aerial survey counts of harbor seals in Hood Canal and Southern Puget Sound. Counts include number of pups; shown in parentheses. * = Site not surveyed.

HOOD CANAL

Date Time of Flight Tide at Pleasant Harbor	18 July 0636-0712 High/0550/9.9	18 August 0640-0820 High/0729/10.1	22 August 1405-1415 Low/1728/6.1	15 September 0727-0907 High/0636/11.0	15 October 0746-0857 High/0728/12.0
Quilcene Bay	7	[illegible]	*	106(7)	83(6)
Dosewallips Delta	106	97(4)	*	134(23)	136
Duckabush Delta	148	147(11)	*	154(18)	80
Rocks S. of Duckabush	*	*	*	*	33
Hamma Hamma Delta	4	0	*	11	1
Lersted Creek	16(1)	0	*	8	0
Skokomish Delta	171	341(2)	73	67	298
Total	[illegible](1)	640(6)		480(30)	631

SOUTHERN PUGET SOUND

Date Time of Flight Tide at Dofflemyer Point (Budd Inlet)	22 July 0602-0721 High/1019/11.5	1 August 0605-0728 High/0643/13.6	13 September 0720-0847 High/0543/13.4
McMicken Island	4	1	13(4)
Totten Inlet	3	5	4(1)
Eld Inlet	9	9(1)	15(1)
Budd Inlet	17(1)	15(1)	15
Gertrude Island	9	15	*
Nisqually Delta	5	8	*
Henderson Inlet	*	*	18
Total	47(1)	53(2)	65(6)

areas in the San Juan Islands with a maximum of 72 seals counted at a single area. Northern Puget Sound, east of Rosario Strait, has a minimum of eight haul out areas, with a maximum of 67 seals counted at a single area. On an aerial survey of this entire area 165 seals were counted. The entire Northern Puget Sound region has a minimum population of 1,237 seals based on counts between 11-15 September 1977. The sum of the high counts at the sites and areas in Northern Puget Sound is 1,459 seals.

The most frequent and extensive censuses were made on the Hood Canal. Principal attention was given to the four major haul out areas. At Skokomish Delta, on 30 September 1977, we counted 342 seals, the highest number seen at any of the haul out areas studied. The minimum population for the region was estimated to be 732 seals and was determined through counts on 15 and 16 September 1977. High counts of the individual sites total 913 seals.

Five inlets were censused regularly in Southern Puget Sound (south of McNeil Island). The highest number of seals seen at any of the haul out areas in this region was 44 on McMicken Island in Case Inlet on 14 June 1977. Since haul out patterns are variable in this region, it was difficult to obtain an accurate simultaneous count. Our minimum population estimate of 136 seals is based on counts made between 16 and 30 August. Summation of high counts for all sites is 180 seals.

Adding our counts to those reported by Johnson and Jeffries (1977) for the outer coast areas and for Gertude and Cutts Island in Southern Puget Sound yields an estimated Washington State harbor seal population (excluding the Columbia River, which borders with Oregon) of approximately 6,300 (Table 6). The Washington State harbor seal population has been estimated at a minimum of 5,000 by Scheffer and Slipp (1944), 1,710 for 1965-1972 by Newby (1973a), and 5,150 (subtracting their estimate for the Columbia River) by Johnson and Jeffries (1977).

Table 6. Estimate of Washington State harbor seal population, excluding Columbia River.

Grays Harbor/Willapa Bay	2000	Johnson and Jeffries (1977)
Outer Coast	2000	Johnson and Jeffries (1977)
Northern Puget Sound (Juan de Fuca Strait, San Juan Islands, waters east of Rosario Strait)	1237	Present Study
Hood Canal	732	Present Study
Southern Puget Sound		
Gertrude Island and Cutts Island	195*	Johnson and Jeffries (1977)
Budd, Eld, Totten, and Henderson Inlets, Eagle Island, Nisqually Delta and McMicken Island	129	Present Study
Total	6293	

*Calculated from Johnson and Jeffries (1977) and our data.

The number of seals we saw in our study areas was higher than those reported by Newby (1973a) and Johnson and Jeffries (1977). Newby did not report any seals in the Hood Canal and Johnson and Jeffries reported 250 seals, compared to our minimum regional population of 732. Newby estimated 600 seals and Johnson and Jeffries reported 650 seals for the Northern Puget Sound region; our minimum estimate is over 1,200. In their Southern Puget Sound estimates neither Newby nor Johnson and Jeffries reported seals from McMicken Island or Henderson, Budd, or Totten Inlets, which are included in our estimate. We believe that the larger number of seals we found does not necessarily indicate a recent increase in the size of these populations, but reflects instead the greater number of land and aerial counts we were able to make in these areas. Some of the methodological problems involved in estimating harbor seal populations are discussed later in this section.

At several sites conversations with old bounty hunters and long time residents provided information on the history of the harbor seal populations in certain areas. In the Hood Canal populations appear to growing. A resident near Skokomish Delta told us there had been a three-fold increase in the number of seals at the delta in the last 20 years. Old bounty hunters from Quilcene said as few as 10 seals were counted in Quilcene Bay in the late 1940's and early 1950's following an intensive period of hunting. This population now numbers over 100. In Southern Puget Sound populations appear stable with evidence of decreases at some sites. A resident told us the number of seals in Eld Inlet was about the same now as in the bounty years. We were told a group of up to 50 seals utilized log booms near Squaxin Island north of Budd Inlet through the 1960's before these booms were removed, apparently dissipating this group. There were conflicting accounts concerning population trends at McMicken Island and Henderson Inlet.

The apparent abandonment of the Nisqually Delta by harbor seals was described by Newby (1973a). The delta was a major haul out site from at least 1927 through the early 1940's (Scheffer and Sperry 1931, Scheffer and Slipp 1944) with up to 284 seals counted by a resident bounty hunter in the 1940's (Newby 1973a). Few seals were reported to be using the delta by 1968 (Newby 1973a), up to 16 seals were seen between November 1972 and April 1976 (Steve Shanewise pers. comm.), and observations in 1977-1978 indicate up to 17 seals presently may be seen at this delta (Klotz _et_ _al_. 1978). Counts at Gertrude Island, the present major breeding colony in Southern Puget Sound, from 1965 to 1976 (Arnold 1968, Newby 1971, 1973a, Johnson and Jeffries 1977) do not show any discernable change in numbers over the years.

Many investigators have reported daily fluctuations in numbers of harbor seals hauled out at a site (Bartholomew 1949, Venables and Venables 1955, Tickel 1970, Newby 1971, Vaughan 1971, Bonner 1972). Van Bemmel (1956) reported that counts of harbor seals in the Waddenzee on consecutive days at similar times and tides yielded the same number of seals. Though we sometimes found nearly the same number of seals hauled on different days at some sites, more often we found that the number of seals hauled fluctuated on a day to day basis. At sites in the Hood Canal, we found up to 100% variation in counts taken 24 hours apart at equivalent tides. Counts of seals in relation to tide and time at Skokomish Delta over a two week period are shown in Fig. 5.

The average daily high count and the range of daily high counts at sites where frequent observations were made are shown in Table 7. The greatest range of daily high counts was seen at Skokomish Delta and the smallest range at Skipjack and Bare Islands, though Skipjack and Bare were only checked in summer and early fall. Fig. 6 shows changes in the monthly average of daily

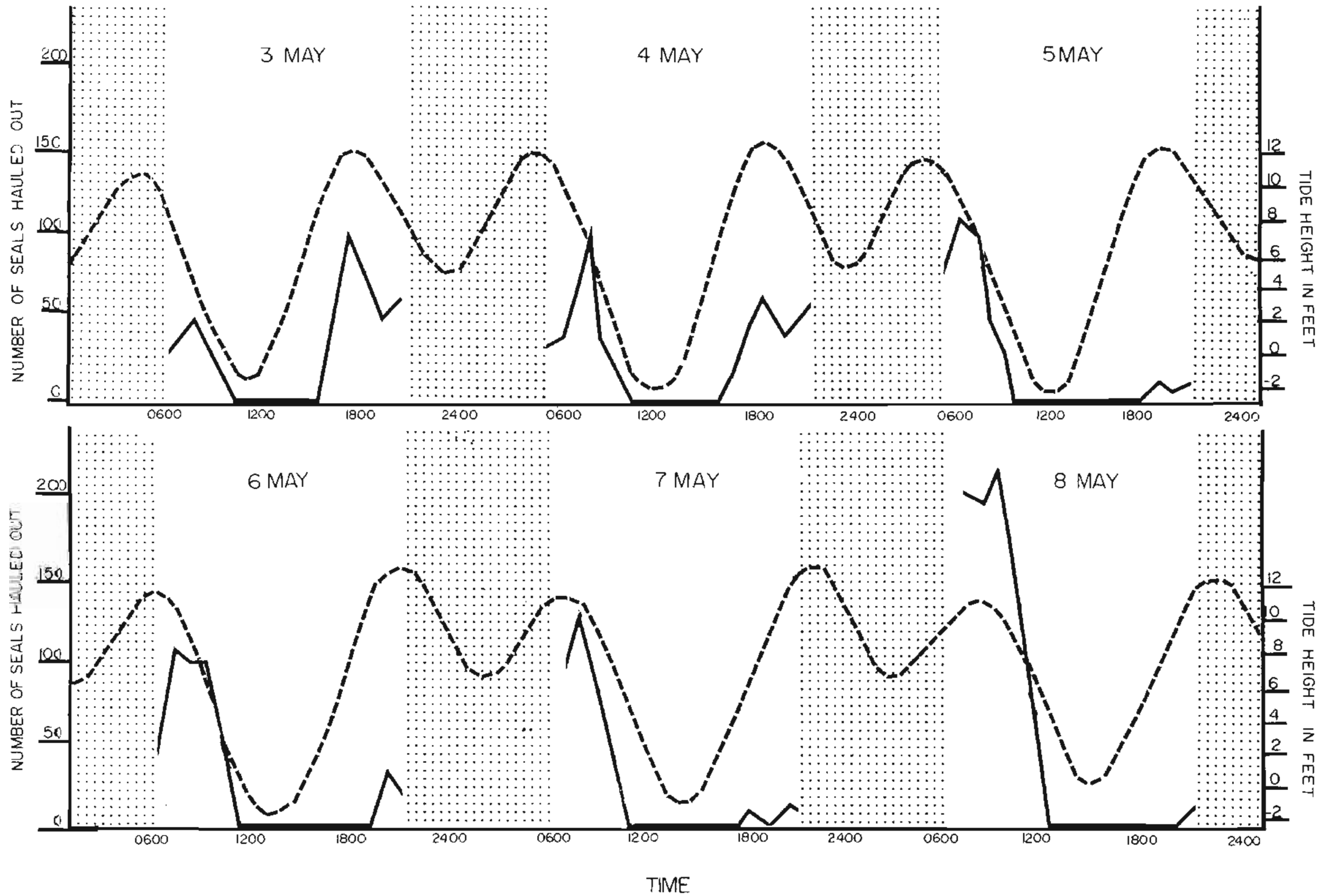

Fig. 5a. Fluctuations in numbers of seals hauled out at the Skokomish River Delta (solid line) and corresponding tidal heights (dashed line).

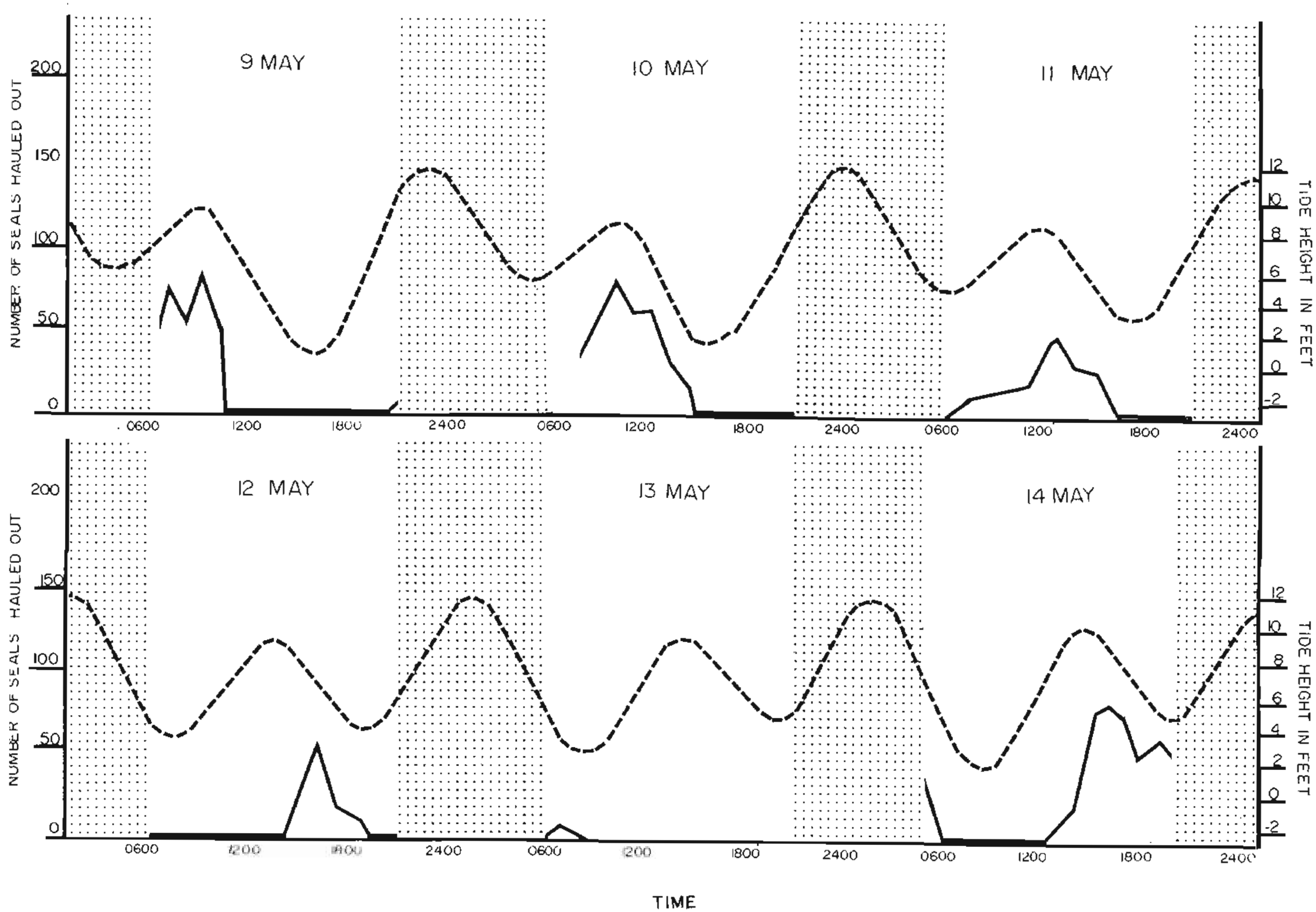

Fig. 5b. Fluctuations in numbers of seals hauled out at the Skokomish River Delta (solid line) and corresponding tidal heights (dashed line).

Table 7. Harbor seal numbers and ranges at selected haul out sites. N = Sample size.

Site	N	Average Daily High Count	Range of High Counts
Northern Puget Sound			
Smith Island 18 June - 15 Oct.	23	123	52 - 245
Skipjack and Bare Islands 26 June - 10 Oct.	40	72	41 - 93
Hood Canal			
Quilcene Bay 18 April - 26 Oct.	18	88	39 - 168
Dosewallips River Delta 17 June - 24 Oct.	27	98	41 - 160
Duckabush River Delta 20 May - 17 Oct.	29	103	28 - 163
Skokomish River Delta 4 Feb. - 15 Nov.	73	147	27 - 342

high counts and monthly high count of seals at haul out areas in the Hood Canal over a 6 month period. At all sites but the Skokomish River Delta, both the average high count and the monthly high count increased following the first full month of each site's pupping season. This increase is due in part to the addition of new pups to the population. In August, we found a sudden increase in the number of hauled seals counted at Skokomish. Seasonal fluctuations in numbers of harbor seals hauled out at a site have been reported by Johnson and Jeffries (1977), Scheffer and Slipp (1944), Wipper (1975), Sergeant (1951), Newby (1971), Bartholomew (1949), Van Bemmel (1956), Fischer (1952), and Rosenthal (1968). Johnson and Jeffries (1977) review some of the possible causes for seasonal fluctuations in numbers of seals hauled out at a specific site. Some factors that may relate to the causes for these fluctuations are discussed in subsequent sections of this paper.

The daily and seasonal fluctuations in numbers of harbor seals hauled out at different sites complicates the determination of population size, particularly if only a small number of counts are made. Boulva (1971) demonstrated the unreliability of a few aerial censuses in determining harbor seal population size at Sable Island, Nova Scotia. Pitcher (1974) and Pitcher and Calkins (1977) have pointed out the difficulty of assigning population sizes from present aerial survey techniques, since the proportion of a population hauled out at any given time is unknown. Johnson (1974) used a linear regression plot of number of harbor seals in the water compared to those on land to extrapolate the estimated population size. Bonner _et al._ (1973) found it necessary "to apply arbitrary corrections, based on subjective assessments of each survey area, to the counts made in the field" to determine the estimated harbor seal population in Shetland. Havinga (1933) and

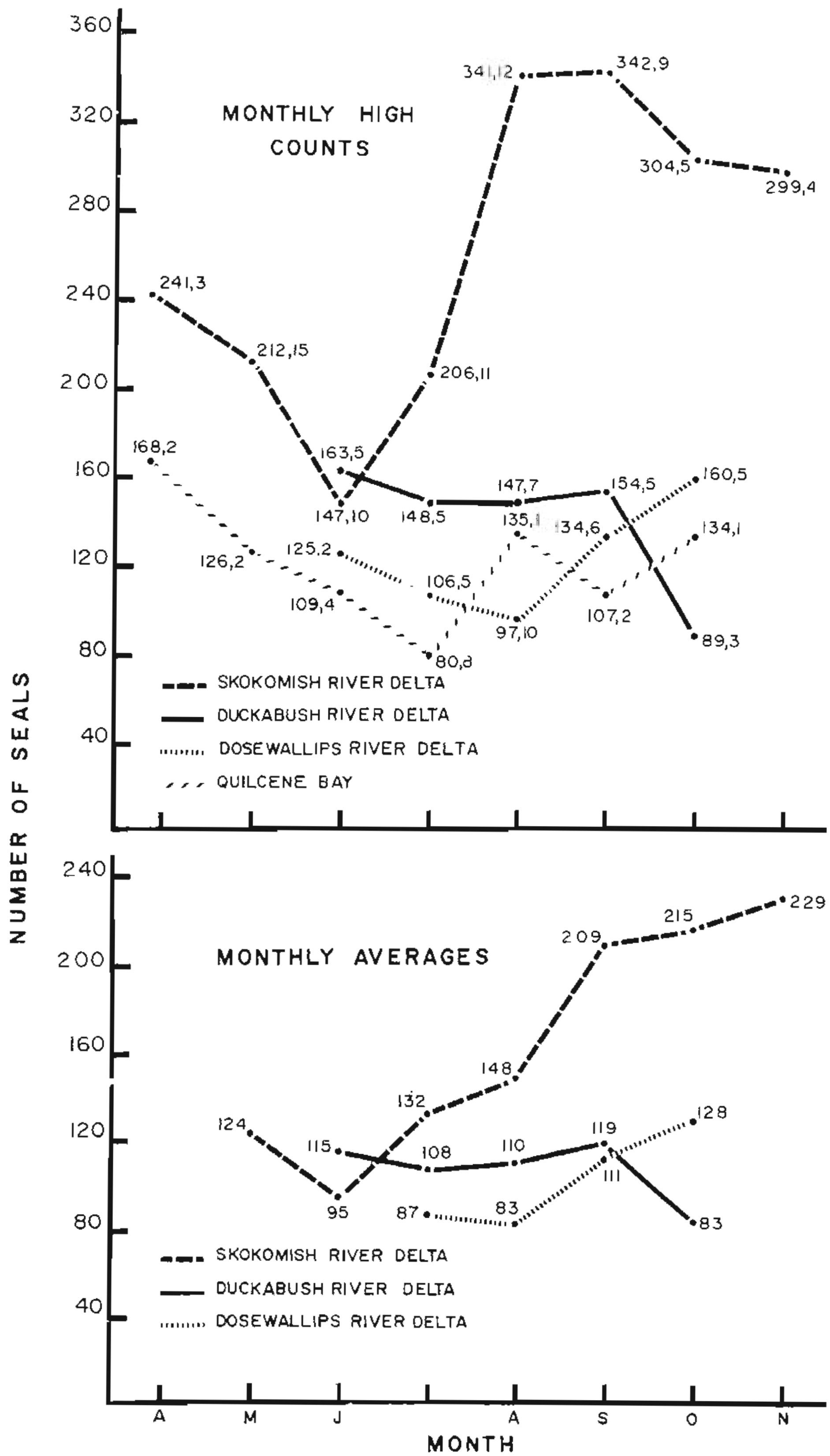

Fig. 6. Monthly high counts and monthly averages of high counts of seals hauled out at Hood Canal sites; numbers following comma = N.

Bigg (1969a) used figures on the number of harbor seals killed by hunters to estimate population size. Estimates of population size in the Wash, England, have been made by both direct counting and extrapolations from estimated total pup production based on mark and recapture methods (Bonner 1972, Vaughan 1971, Summers and Mountford 1975). Estimates of all age population size based on the mark-recapture method indicated a population of at least 4,000 harbor seals in the Wash, while the highest number of harbor seals seen by direct count of the entire region was under 2,000.

We believe that most population estimates based on direct count, including our own, tend to underestimate the actual population size, particularly if based on a small number of counts.

Movement

Harbor seals are considered non-migratory (Scheffer and Slipp 1944), but the nature of their movements are poorly understood. Our evidence and those of other researchers suggest that both long distance movement and year round site loyalty occur in different populations.

We observed fluctuations in numbers of seals at some sites that may have indicated movement to or from these sites. No patterns of increase and decrease, however, were such that we were able to identify sites between which the seals had moved. No discernable trend in fluctuations of numbers of seals in Eld Inlet was noted during the full year we made observations at the site. Kretchmar (unpublished manuscript) identified seven individuals of the small Eld Inlet population, and observed these intermittently over a 5 month period. We were able to identify three of these individuals and continue observation of them over 10 months in the case of one seal and 8 months with the other two seals. Other of the originally identified individuals may have remained in the area but only these three had markings distinct enough to allow easy identification. Venables and Venables (1955) noted the faithfulness of individual harbor seals to a hauling area in Shetland, where one individual occupied a particular rock day after day. Regional differences in chlorinated hydrocarbon concentrations and pupping seasons, both discussed in more detail later, suggest limited interchange between some areas,particularly in the inland waters.

Results of tagging studies in Europe by Bonner and Witthames (1974) and Wipper (1975) have shown harbor seal pups are capable of long distance movement within a year of birth; tagged pups have been found up to 500 km away from the area they were tagged. Divinyi (1971) reported the recovery of a female harbor seal at Tugidak Island, Alaska, 3 miles from where it had been tagged 3 years earlier. Of eight recoveries of newborn harbor seal pups tagged on Gertrude Island in Southern Puget Sound in 1970 and 1972, six were recovered either on Gertrude Island or within 10 km of Gertrude Island from 1 to 369 days after tagging, one was recovered a little over 50 km away 49 days after tagging (Newby unpublished data). Boulva (1971) reported that harbor seals utilize Sable Island, Nova Scotia year round in stable numbers with little apparent interchange with other populations. Wipper (1975) reported that harbor seals completely abandon the Waddenzee in Europe in January and February, apparently because of heavy human fishing activities and bad weather. Pearson and Verts (1970) suspected that heavy hunting pressure led to the absence of resident harbor seals in the Columbia River, and that those seen in the area were visiting. Johnson and Jeffries (1977) suggested emigration as a possible explanation for the seasonal fluctuations in counts of harbor seals in Grays Harbor and Willapa Bay, Washington.

Scheffer and Slipp (1944), on the basis of information available at that time, concluded that the movements of harbor seals "are regulated largely by conditions of the local environment rather than by any inherent urge to wander."

Reproduction

Newby (1971) suggested that Gertrude Island, in Southern Puget Sound, and Smith Island and Fidalgo Bay, in Northern Puget Sound, were the breeding colonies for their respective geographic regions. Johnson and Jeffries (1977) noted reports of pupping in other areas of Southern Puget Sound besides Gertrude Island and suggested that the possibility that pupping occurred at other areas besides Gertrude warranted further investigation. We observed pupping at all haul out areas we studied, regardless of size, with no single site serving as the sole breeding colony for the region. Though breeding was not restricted to specific areas within a region, we did observe that females with pups often used specific areas within a given haul out site (discussed in Behavior).

Pupping season

The variable pupping season of the harbor seal along the west coast of North America reported by Bigg (1969b) ranges from early March at the northern and southern ends of its range to late September in Southern Puget Sound. These variations in pupping season may reflect genetic differences evolved in response to seasonal variations in food (Bigg 1973) and are at least partly controlled by photoperiod (Bigg and Fisher 1975).

The pupping seasons for our principal study sites are shown in Fig. 7. In Northern Puget Sound two distinct pupping seasons were observed. The earliest pupping at any of our sites occurred at Smith Island, and extended from mid-June to late July. The pupping season at Skipjack Island extended from July to early August, and was typical of all the small breeding groups seen in the San Juan Islands. The pupping seasons we observed in Northern Puget

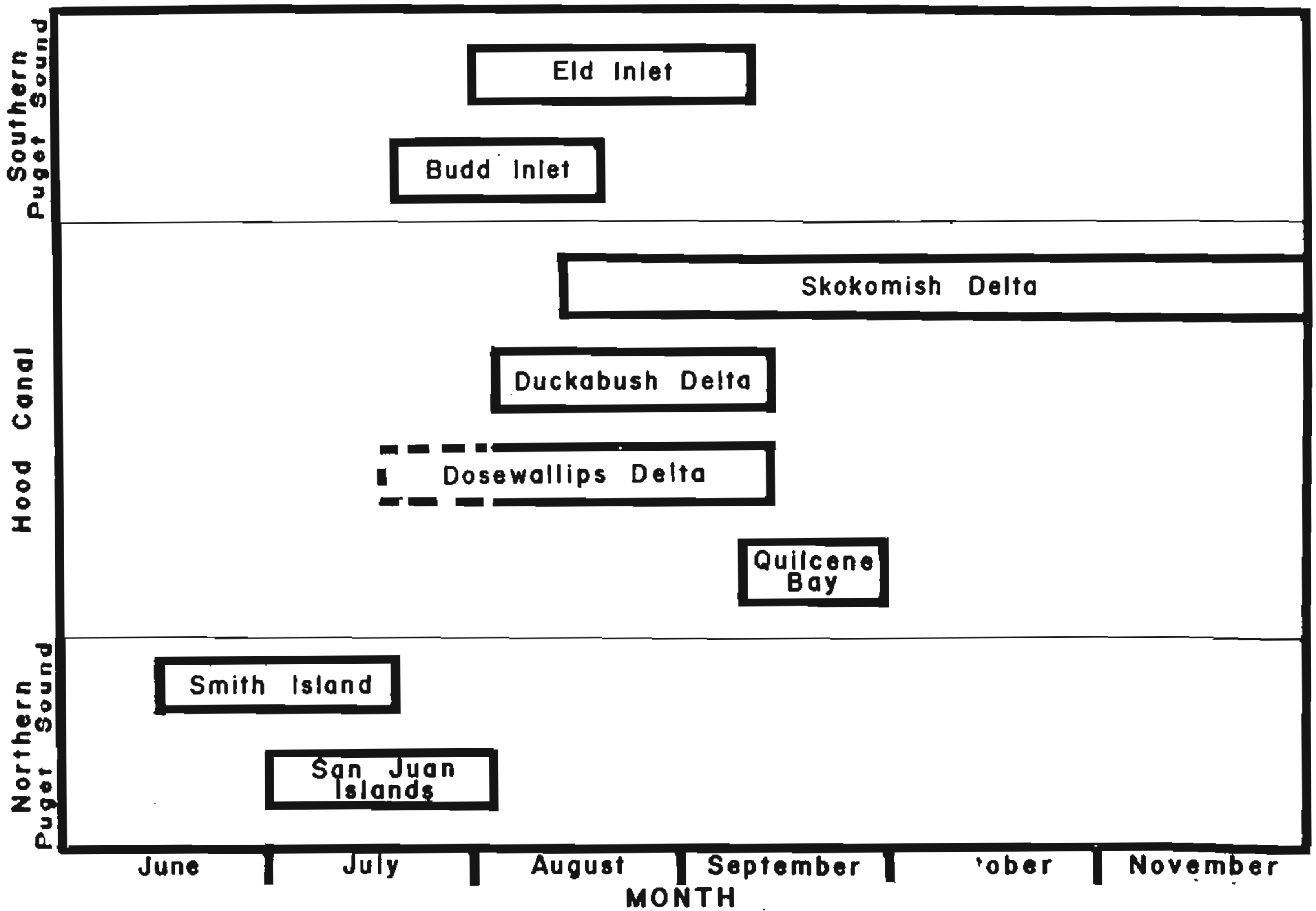

Fig. 7. Pupping phenology of our three study regions.

Sound were earlier than the late July through August season reported by Newby (1973b) for Skagit Delta and Fidalgo Bay.

In Hood Canal, the range of pupping seasons at different haul out sites extended from initial pupping at the Dosewallips Delta in mid-July to approximately mid- to late January at Skokomish Delta. At Doswallips Delta fresh birth evidence was found on 18 July and a pup was seen 20 July. These were isolated occurrences and although we visited the site frequently the next pup was not seen until 4 August. The pupping season at Skokomish Delta has not followed patterns found at our other sites or reported in the literature. A mother-pup pair was first seen on 15 August. At least one nursing pup was seen every week through 15 November and on four more occasions up to 30 January. The maximum number of mother-pup pairs seen at a time was four, on 14 and 30 January. Portions of the parturition sequence were seen on 27 August and 31 October. A premature pup found stillborn at Skokomish Delata on 8 October was determined to be approximately two months premature, using prenatal growth figures reported by Bigg (1969a). To our knowledge such a late and extended pupping season has not been reported previously. The latest pupping season previously reported for the harbor seal on the west coast of North America is mid-August to late September at Gertrude Island, Southern Puget Sound (Bigg 1969b, Newby 1973b, Johnson and Jeffries 1977).

The pupping season at our study sites in Southern Puget Sound ranged from late July to early September. In Eld Inlet the first pup was seen on 30 July and the last birth occurred in early September. Of the eleven pups observed, however, ten were born before 14 August. In Budd Inlet the first pup was seen on 22 July, and the high count of four pups was made on 21 August. Nursing pups were seen at McMicken Island from 5 August to 15 September, and at Henderson Inlet from 11 August to 5 September, but observations at these two sites were too infrequent to allow a conclusion about the duration of pupping season. The largest population in Southern Puget Sound, at Gertrude Island, is reported to have a pupping season extending from mid-August to late September (Newby 1973b, Johnson and Jeffries 1977). Scheffer and Slipp (1944) reported the pupping season for Nisqually River Delta to be 1 June to early August.

Bigg (1973) found that apparent genetic differences between populations were partly responsible for the regional variations in the timing of pupping. Genetic differences could not be responsible for differences in pupping seasons we observed between harbor seals at nearby sites. In Southern Puget Sound, for example, the majority of pups were born in Eld Inlet before pupping began at Gertrude Island, though these two sites are less than 40 km apart by water. Boulva (1975) found that the time of implantation of female harbor seals at Sable Island, Nova Scotia appeared to remain constant over a 3 year period. The length of gestation and thus the birth date, however, varied from year to year, possibly in response to air and sea water temperatures. Tickell (1970) reported that human disturbance delayed the timing of pupping of harbor seals in Shetland but Boulva (1975) did not find any effect at Sable Island.

Bigg and Fisher (1975) showed that an external stimulus, photoperiod, had an effect on the reproductive timing of captive seals. It is possible that nearby populations may not be genetically distinct, but that proximate factors differentially stimulate reproductive timing. These local environmental and behavioral conditions - such as habitat, haul out pattern, and degree of disturbance - may be involved in different reproductive timing between populations. In Eld Inlet, where seals haul out on rafts at night, their perception of the external stimuli that influence the timing of reproduction may be different than the perception by seals at Gertrude Island, where haul out is at low tide on a spit, with time of day playing a minimal role. Likewise, if air and sea water temperatures affect the length of gestation and thus the pupping date, as suggested by Boulva (1975), then local variations in these proximate factors could similarly affect pupping seasons.

For these differences to have a cumulative effect on the reproductive timing of a population would require a minimal amount of movement between areas. Our observation of identified individuals in the Eld Inlet area (discussed further in Movement) indicate that at least a portion of the seals seen in the Inlet are present regularly.

We were unable to explain the extended pupping season at Skokomish Delta, given what is presently known about the nature of reproductive timing in the harbor seal. Whether this phenomenon occurs every year or whether this is an anomaly that has occurred only this year or only the last few years is also unknown.

Birth rate

Birth and mortality rates of harbor seals at two sites in Northern Puget Sound, three sites in the Hood Canal, and three sites in Southern Puget Sound are shown in Table 8. Birth rates (% of population producing a pup) ranged from 15.2% to 24% with the exception of Eld Inlet where 11 pups were born in an estimated pre-pupping population of 17 seals. The unusually high figure for Eld Inlet may be due in part to both our probable underestimation of population size and the unusual population structure at this site. Seals in Eld Inlet are difficult to census because of their nocturnal haul out pattern and their shifting use of haul out floats. Observation of small groups

Table 8. Observed pup mortality and birth rates at study sites. Population size is the highest number of seals observed during the pupping season, excluding pups; minimum pup mortality is the number of dead pups found.

Site	(a) Pup yield (alive and dead)	(b) Population size	(c) Minimum birth rate (a/b)	(d) Minimum pup mortality	(e) Observed pup mortality rate (d/a)
Skipjack Island	7	46	15.2%	1	14.3%
Smith Island	41	208	19.7%	5	12.2%
Quilcene Bay	23	99	23.2%	1	*
Dosewallips Delta	25	111	22.5%	2	8.0%
Duckabush Delta	21	136	15.4%	3	14.3%
Henderson Inlet	8	35	22.9%	4	50.0%
Budd Inlet	6	25	24.0%	3	50.0%
Eld Inlet	11	17	64.7%	1	9.1%

* not calculated, site infrequently searched

of hauled seals on floats indicated the population was composed of a high percentage of females. The unusually extended pupping season at Skokomish Delta made determination of pup yield difficult. A rough estimate based on numbers of nursing pups seen and pupping season duration indicates a probable birth rate of 10% or more.

In life table calculations from harbor seals collected in British Columbia, Bigg (1969a) found the population contained 53% females, 55% of these mature, and 88% of the mature females pregnant. These figures indicate an expected birth rate of 26%. Boulva (1975) reported that an average of 20.5% of a population of harbor seals in Nova Scotia produced a pup. Venables and Venables (1955) reported figures indicating a birth rate of 22%. Bishop (1967) reported that 32% of the harbor seals in the Gulf of Alaska produced pups. Bishop's figure may be higher than normal due to an unbalanced population structure caused by heavy hunting of pups in the populations he studied in the years before he conducted his study.

Pup mortality

Minimum pup mortality (including stillbirths) in the first three months of life totaled 14% for the areas mentioned above (Table 8). Minimum pup mortality in different regions totaled 12.5% at Smith Island and Skipjack Island in Northern Puget Sound, 8.7% at Quilcene Bay, Dosewallips Delta, and Skipjack Island in Northern Puget Sound, and 32% at Henderson, Budd, and Eld Inlets in Southern Puget Sound. Success at recovering dead pups is partly dependent on the type of habitat, environmental conditions, frequency of search, and extent of human activity in the area. Since these factors were variable between sites, mortality rates should be evaluated as minimums only. The perception of mortality rates is also affected by movement in and out of an area by pups in the first three months of life. Measurements and examination results of the pups we found dead are included in Table 9.

At Smith and Minor Islands, five pups were found dead, representing 12.2% of the pups born. On two of these the umbilicus was still present, and at least one of these appeared to have been a stillbirth. This pup had a mass of fetal hair measuring 30-40 cm long and 4.0-5.5 cm in diameter, lodged in the lower colon. It is unclear whether this contributed to the death. Bigg and Tarasoff (1969) found a similar, though longer, obstruction in a harbor seal pup that died shortly after capture, and suggested it was the cause of death. The poor condition by the time of autopsy of most of the pups found on Minor Island precluded a determination of the cause of death in most of these animals. In the San Juan Islands one pup was found dead at Skipjack Island prior to the pupping season by a local resident.

In the Hood Canal, one pup was found dead at Quilcene Bay though the land surrounding this haul out area was rarely checked. This pup still had a large portion of the lanugo pelage and had a deformed interdigital web on the right rear flipper. Two dead pups were found at Dosewallips Delta and three at Duckabush Delta, representing 8.0% and 14.3%, respectively, of the total pups born at each site. Two of these pups were stillbirths. None of the other pups had milk in their stomachs and cause of death could not be determined. At the Skokomish Delta, one premature pup was found dead in October. Prenatal growth charts published by Bigg (1969a) indicate this pup was roughly 2 months premature. The extended pupping season at this site did not allow us to search this site adequately, and no estimate of pup mortality can be made.

Table 9. Measurements of harbor seals found dead during study.
* = Autolysis prevented comprehensive necropsy.

Age class	Catalog number	Sex	Standard length (cm)	Total weight (kg)	Blubber thickness (mm)	Location found	Date	Comments
Pup	PvES1	F	61.0	9.8	25	Budd Inlet	Oct. 72	Found on log boom, no milk in stomach.
	PvES2	F	86.4	11.7	13	Minor Island	19 June 77	Stillbirth, umbilicus not retracted, fetal sack and shed lanugo present. Portion of lanugo coat in lower intestine.
	PvES7	-	72.0	-	18	Willapa Bay	30 June 77	Lanugo pelage. *
	PvES8	M	84.0	11.3	13	Minor Island	14 July 77	*
	PvES9	F	77.0	7.7	9	" "	" " "	*
	PvES10	F	82.0	10.0	13	" "	16 July 77	Umbilicus present. *
	PvES11	M	79.0	7.5	13	" "	21 July 77	Lungs aerated, no milk in stomach.
	PvES12	M	89.0	10.9	13	Dosewallips Delta	13 Aug. 77	No milk in stomach.
	PvES13	M	91.0	13.2	9	Duckabush Delta	15 Aug. 77	Stillbirth, right kidney enlarged.
	PvES14	M	94.0	13.5	13	" "	28 Aug. 77	Lungs aerated, no milk in stomach. Histopathology results: pulmonary congestion and edema.
	PvES15	M	76.0	8.3	13	Quilcene Bay	30 Aug. 77	Deformed interdigital web prevented right rear flipper from spreading open, trachea appeared underdeveloped. *
	PvES16	M	88.5	11.2	12	Dosewallips Delta	1 Sept. 77	Lungs aerated, no milk in stomach. Maxilla, nasal and portions of frontal bones shattered (possibly post-mortem).
	PvES17	M	81.0	8.8	7	Duckabush Delta	8 Sept. 77	Stillbirth. *
	PvES18	F	74.0	6.3	6	Eld Inlet	14 Aug. 77	Lungs aerated.
	PvES20	M	92.0	16.4	15	Willapa Bay	7 Oct. 77	Lacerations on body. Histopathology results: perirenal hemorrhages.
	PvES21	F	62.0	3.1	4	Skokomish Delta	8 Oct. 77	Stillbirth, lanugo pelage.
Sub-adult	PvES4	M	120.0	31.7	25	Twin Harbor	22 June 77	Probably shot, heartworms.
	PvES19	F	119.0	23.6	3	Eld Inlet	12 Sept. 77	Emaciated, stomach empty, lice and heartworms present.
Adult	PvES5	M	162.0	-	22	Twin Harbor	23 June 77	*
	PvES6	M	136.8	64.1	17	Hoodsport	1 July 77	Shot.
	PvES22	M	153.3	61.4	16	Dosewallips Delta	8 Oct. 77	Histopathology results: pulmonary hepatic fibrosis, mild chronic multifocal interstitial nephritis.

We found 50% pup mortality at Budd and Henderson Inlets in Southern Puget Sound. None of the seven dead pups reported at these two sites were examined by us. In Henderson Inlet four dead pups found on the log booms during the pupping season were reported to us by the log boom workers. In Budd Inlet one premature dead pup was seen on a log boom two months before pupping season began. Another premature pup was netted accidentally by a fisherman on 5 August. It died in captivity shortly thereafter and the pathology report indicated it had an intracerebral teratoma, a congenital defect (Johnson and Cargol 1977). A third pup was discovered on 30 October after having been observed in a weak condition for several days by residents. It was heavily infested with heartworms and lice and died shortly thereafter in captivity (Thomas Gornal pers. comm.). The mortality rate in Eld Inlet was 9.1%, with a single pup found dead during the pupping season. Dead pups found which had breathed but had no milk in their stomachs were probably separated from or abandoned by their mothers and died from starvation.

Boulva (1971, 1975) reported mortality in the first month of life of from 12% to 21% for harbor seals on Sable Island, Nova Scotia in three successive years. Van Bemmel (1956) assumed a pup mortality of 20% in the first year of life for harbor seals in the Netherlands. Bigg (1969a) calculated a 20% mortality rate for each of the first five years of life for harbor seals in British Columbia. Wipper (1975) reported a 40% mortality in the first year for harbor seals in the Waddenzee area of Europe. The pup mortality we found at Budd and Henderson Inlets appears to be abnormally high.

High pup mortality has been reported for Gertrude Island in Southern Puget Sound. Newby (1971, 1973b) found eight dead pups at Gertrude Island in 1970. Three of these had birth defects, including one with a skeletal deformity and two with omphaloceles. An additional pup with omphalocele was captured (Newby 1971). A total of 38 pups in 1970 and 26 pups in 1972 were estimated to have been born at Gertrude; nine pups found dead there in 1972 (Newby unpublished data). Six of these dead pups and two pups that were captured had birth defects; four had omphaloceles, two had deformed tails (includes one which also had an omphalocele), two had gut lesions, and one had a deformed body. Johnson and Jeffries (1977) have found stillborn and abandoned pups in their studies of harbor seals in Washington State. Bonner (1972) reported that stillbirths are usually seen at large breeding colonies of harbor seals in Europe. Bonner also reported that starving pups are also commonly seen and are probably associated with disturbance of haul out areas by hunters, who cause mother-pup separation. Desertion-starvation of pups was reported to be a principal cause of mortality of harbor seals in the Gulf of Alaska (Bishop 1967) and Sable Island, Nova Scotia (Boulva 1971). Johnson (1977) found starvation after desertion of pups to be the principal cause of pup mortality at Tugidak Island, Alaska and estimated that 10% of the pups may have been deserted and starved as a direct result of disturbances from low flying aircraft. He also reported abortion to be one of the causes of death in pups. Boulva (1975) found that stillbirths accounted for 10% and 29% of the pup mortality in successive years at Sable Island. This difference appeared due to differences in average size and gestation period of the pups in the two different years. Bigg (1969a) reported abortion to be one of the causes of reproductive failure in British Columbia harbor seals. Van Bemmel (1956) reported bad weather increased pup mortality and found infestations of lungworms and other endoparasites to be a cause of mortality in young seals.

Parturition and birth evidence

Descriptions of parturition in harbor seals have been given by Bishop (1967), Klinkhart (1967), and Johnson (1977). We saw one complete and two incomplete births in the course of our observations. The single complete birth we observed occurred on 1 September at Gertrude Island. In the following summary all times (negative and positive) are in relation to the time the pup was born (1624). Starting a little before -7 hrs, a pregnant seal was observed hauled away from the group for varying durations at three different locations. This seal was re-identified by its pregnant condition (most adult females had already given birth), its unusual behavior, and its general appearance. At -24 minutes this seal hauled out at the periphery of a group of approximately 130 seals. Contractions were first noted at -6 minutes and occurred at 8 second intervals. At -4 minutes the seal turned its hind quarters away from us for 5 minutes and the timing of the birth was determined from the contractions and appearance of the mother's ventrum. The pup, first seen out of the mother at 1 minute, was covered by the fetal sac and some lanugo. The mother turned and the two touched noses several times. At 7 minutes the pup expelled a dark smooth stool. At 11 minutes the mother moved so as to bring her nipples directly in front of the pup and after probing the nipple vicinity the pup nursed for 4 minutes before the mother terminated nursing by shifting her position. At 18 minutes the placenta was expelled and at 28 minutes the pair entered the water.

Two occurrences of extended parturition were seen at Duckabush Delta. During the first occurrence, a seal was seen with a pup head protruding from its vulva. Five times in 1.5 minutes the seal raised and lowered the rear portion of her body. For 16 minutes the female occasionally raised her head and changed her resting position from side to stomach. She entered the water after 39 minutes of observation and then rehauled 1 minute later and remained still for 32 minutes. At this time a contraction occurred, and more of the pup emerged. No movement by the fetus was noticed. After 68 minutes of observation, the female entered the water, birth still not complete, and we did not observe her again.

During the second occurrence, a seal was seen with a partly emerged pup. For 15 minutes the seal constantly moved the rear portion of her body horizontally back and forth but the pup had not emerged further when the female entered the water and observation ended.

Details of the birth evidence found at different sites are shown in Table 10. The yellowish white lanugo coat that is normally shed in utero and expelled with the pup and with the afterbirth was the primary evidence found. The lower recovery of fetal sacs and placentas compared to lanugo is partly due to removal by gulls and other scavengers, and to the departure of females from the hauling area before the afterbirth is expelled. Blood stains were commonly seen at newer birth sites.

The number of birth evidence found as a percent of the highest pup count ranged from 44% at the Dosewallips Delta and Smith Island to 91% in Eld Inlet. Eld Inlet is the only site searched where the haul out areas are not regularly flooded. At all sites except possibly Eld Inlet the birth remnants recovered represent only a minimum of the births that occurred on land at the haul out areas.

At Dosewallips and Duckabush Delta the birth locations found appeared to be evenly distributed among the areas seals commonly hauled at. In Eld Inlet all the birth sites seen were on recreational floats and on one dock. No two births apparently occurred at the same location. We had never observed seals hauled at three of the locations where birth evidence was found.

Table 10. Number of birth remnants found, number of birth sites represented, and recovery rate of birth remnants at selected sites.

Site	Number Found			No. of birth sites represented	No. of births at site	Recovery rate	Range of dates found	Habitat where found
	Lanugo	Placenta	Fetal sac					
Smith Island	18	1	2	18	41	44%	6/19-7/21	Cobble
Dosewallips Delta	9	1	7	11	25	44%	7/18-9/16	Saltmarsh, mudflat
Duckabush Delta	12	1	7	14	21	67%	8/15-9/2	Saltmarsh
Eld Inlet	10	4	1	10	11	91%	8/4-8/18	Floats

A resident, however, recalled seeing what appeared to be a single pregnant female hauled out at one of these locations, a dock, one day during the pupping season. Another resident had witnessed a birth at sunset in the summer of 1976 on a float near floats where we found birth evidence in 1977.

The number and location of births we found evidence of indicate that births usually occur on land. This appears to be the case in most harbor seal populations (Scheffer and Slipp 1944, Bishop 1967, Kinkhart 1967, Newby 1973b, Johnson 1977). Venables and Venables (1955) reported evidence of birth in the water, though this evidence was questioned by Newby (1973b). Johnson (1977) reported the birth of a harbor seal in water, in captivity.

Mortality

During the course of the study, 20 harbor seals were found dead and portions of their tissues collected. The location, date, sex and measurements of each seal found dead are shown in Table 9. Of those collected, 15 were pups (discussed in Reproduction), 3 were subadults, and 2 were adults. One adult from the Hood Canal (PvES6) was shot in the head and one subadult from the outer coast (PvES4) also appeared to have been shot in the head. Histopathology results of an adult seal found at Dosewallips River Delta (PvES22) indicated pulmonary hepatic fibrosis and mild chronic multifocal interstitial nephritis. A subadult found in Eld Inlet (PvES19) was emaciated and the upper portion of its body covered with louse eggs.

Johnson and Jeffries (1977) found that the major causes of mortality in seals in Washington State were human related and included shooting, underwater blast and propeller wounds.

Bigg (1969a) estimated mortality of harbor seal populations to be 20%. The number of dead seals recovered during the course of this study falls well below that level.

Behavior

Haul out

Fisher (1952), Bishop (1967), Scheffer and Slipp (1944) and Johnson and Jeffries (1977) describe haul out behavior of harbor seals in different localities. Haul out areas are generally utilized by harbor seals year round with haul out usually occurring once or twice every 24 hours depending on the location. Little is known about haul out requirements of individual seals but daily fluctuations in number of seals at a haul out area indicate that not all seals haul out on all cycles. Haul out behavior varies from site to site. Variations are due primarily to differences in habitat, environmental conditions, level of disturbance and population size. The role of these factors is discussed in the following sections.

Haul out pattern: Tide is the most important environmental factor affecting haul out pattern at most sites. Tide influences the availability of and access to the haul out area.

A low tide haul out cycle is most commonly reported. Low tide haul out patterns have been described for Gertrude Island in Southern Puget Sound by Newby (1971) and Johnson and Jeffries (1977). We observed low tide haul out primarily in Northern Puget Sound on tidal shelves and rocks in the San Juan Islands and on mudflats in Northern Puget Sound bays. At these locations haul out areas are exposed only at low tide.

High tide haul out cycles have not been well described in the literature. High tide haul out areas in our study regions occurred primarily on marshes of Hood Canal river deltas. The number of seals hauled out and tide height at Skokomish River Delta during 12 continuous days of observation are shown in Fig. 5. Daily high counts of seals occurred primarily at high tide or shortly after the high tide. During these observations, harbor seals began hauling out at tide heights between 3.2' and 10.5' above mean lower, low water. Groups of seals left the haul out area at tide heights between 0.3' and 6.5'. The difference between mean lower low water and mean higher high water is 11.8' at this site.

At some sites, including the Hood Canal river deltas and the San Juan Islands, where tide is the principal factor influencing haul out, time of day also has an effect. The number of seals hauled at these sites during the morning high or low tides is generally higher than on afternoon tide cycles. At Skokomish Delta nine out of 10 monthly high counts of seals occurred at early morning high tides. Johnson (1974) also found higher numbers of harbor seals during the morning at Otter Island, Alaska.

At Quilcene Bay, use of log booms by seals is dependent on tide and time of day and week. The boom where seals haul out most of the year is not afloat and is therefore not accessible at most low tides. Diurnal human activity on the log booms during weekdays allows seals to haul undisturbed only at night.

Nocturnal haul out cycles independent of tides were seen at human-made haul out sites in Southern Puget Sound. At these sites, tide has little effect on access or availability of the haul out area. Human activity is at a lower level during the night, allowing seals to haul undisturbed. Nocturnal haul out under similar circumstances for harbor seals in San Francisco has been reported by Paulbinsky (1975).

Haul out patterns can be affected by wave action at exposed haul out areas. Venables and Venables (1955) report harbor seals in Shetland would not haul on tidal rocks and shingle beaches during onshore swells. Newby (1971) reports above normal numbers of seals hauled in stormy weather at Gertrude Island in Puget Sound. At Skipjack Island in the San Juan Islands, fewer seals hauled out when the haul out area was exposed to heavy swells.

Occasional disturbances of haul out areas by humans also affect haul out pattern and are described in a later section of this paper.

Alteration of harbor seal habitat affects haul out pattern, especially where man-made haul out areas are used. In Quilcene Bay most seals shifted their haul out site from a log boom to newly placed oyster rafts 3.6 km away. These rafts were disturbed less frequently than the log booms. Changes, such as removal of log booms and floats, also affect haul out pattern. Seals utilized log booms at Brinnon near Dosewallips Delta and at Squaxin Island in Southern Puget Sound before the booms were removed. At Dosewallips Delta seals now haul out on the marsh but at Squaxin Island seals no longer haul out. Floats used by seals in Eld Inlet were occasionally removed, resulting in seals shifting usage to other floats. Scheffer and Kenyon (1966) reported that 50 seals utilized Steamboat Island in Southern Puget Sound. This site is presently not used by seals, possibly as a result of the residential construction there. Newby (1973a) described the abandonment of Nisqually Delta by harbor seals possibly because of hunting and human disturbance. Many major haul out areas appear traditional. The Twana Indians traditionally hunted seals at the Skokomish Delta (Elmendorf 1960) and this site was historically called "seal resting place" by the Skokomish Indians (Karen James pers. comm.).

Different stages in the life cycle of harbor seals, such as pupping (see <u>Mother-pup interaction</u>) and moult affect haul out. Gol'tsev (1971) and Pitcher and Calkins (1977) reported harbor seals to spend more time hauled out during moult. We observed longer periods of haul out during moult at Skipjack Island and Eld Inlet.

Haul out activity: Seals generally arrive at the haul out area singly or in small groups. Seal numbers increase as conditions become optimal for haul out. Up to 100 seals have been counted in the water at Skokomish Delta preceding haul out. The number of seals congregrating differs according to site conditions and population size. From night observations in Eld Inlet it appeared solitary seals hauled out before any seals had congregated, and others hauled as the night progressed.

The presence of hauled seals stimulates other seals to haul out nearby. In the most rapid hauling sequence seen at Skokomish Delta, 45 seals were observed to haul out in 12 minutes after the first seal had hauled, 66 were hauled in 32 minutes and 75 had hauled in 45 minutes, all in the same vicinity. Numbers regularly increase in this manner as more seals come into the haul out area until a peak is reached. After a varying amount of time when numbers remain stable,numbers of seals begin to decline as conditions become less optimal for haul out. This pattern changes when extreme high tides inundate marshes on Hood Canal. Numbers of hauled seals drop as seals rest or swim in the water near the marsh. Numbers rise again as the tide recedes and seals rehaul.

Seals often hauled in groups even though there were other areas available. At Eld Inlet, seals occasionally approached and rejected empty floats before approaching and hauling on an occupied float.

Seals often rehaul after a disturbance if conditions are similar to those needed for initial haul out. At Dosewallips Delta 47 seals rehauled within 3 minutes after all seals present on land had entered the water. After a haul out on the marsh at Skokomish Delta, a group of seals rehauled four times, each successively further out on the partly submerged mudflat 100 to 200 m from the marsh. Seal numbers decreased at each subsequent haul out. A variation of this pattern occurs at sites where the haul out area is gently sloping. Here seals often move in a direction perpendicular to the water line to remain on land but close to water with the changing tide.

Termination of haul out: At sites where the haul out cycle is dependent on low tide exposure of haul out area as in the San Juans, inundation by water will terminate the haul out. High tide haul out cycles in the Hood Canal are affected by the receding tide because seals generally leave before becoming isolated from water. Seals leave a haul out area when disturbed regardless of environmental conditions, and at sites where human influence is great, this is the major factor terminating haul out. Occasionally groups of seals leave the haul out area for no apparent reason. Generally, this behavior occurs in the latter half of the haul out period.

Seals leave the haul out site gradually at sites where low tide is the key factor and disturbance is minimal. As the tide rises most seals move up, keeping on land; some, however, enter the water and either remain near the haul out area or disperse slowly. Departure is generally more abrupt at sites where haul out occurs at high tide. At the Hood Canal Delta individual seals slide down the mud banks of the marsh and enter the water when tide recedes but the final exodus usually involves a group of seals traveling quickly. A group of seals entering the water at one time may swim quickly by moving underwater for 20 to 40 m before surfacing and often Spyhopping (rising up out of the water to chest level and looking around). At some sites groups of seals enter the water and disperse so quickly that only a few seals are seen thereafter near the haul out area. After leaving Skokomish marsh, seals have been seen swimming as a group for 15 minutes, traveling approximately 3 km until they disperse or disappear from sight.

Activities of individual seals in the water

Activities in the water which we observed can be categorized into swimming, diving, splashing, and leaping.

Swimming: Scheffer and Slipp (1944) described the basic swimming motion of harbor seals, which involves use of the rear flippers in a side to side motion with each flipper alternately providing power on the inside stroke. The front flippers are used only minimally for power. On occasion seals swim with the front flippers, when the head and rear flippers are held out of the water, called U-position Floating. When swimming singly or in groups, seals alternate swimming underwater with swimming at the surface with the head held horizontal above the water surface. We observed seals to Chest Swim for short periods usually when seals were swimming quickly, by rising to chest level out of the water at an angle of approximately 30^0 then submerging either at the same angle or in a head first Porpoise Dive. After leaving the haul out area groups of seals often Chest Swim and Porpoise Dive together in a partially synchronized manner.

Diving: Forms of diving observed include: Sinking, where the nose of the seal is the last part to submerge, as described by Scheffer and Slipp (1944) as the most common; Roll Diving, where the head is first to go under and the body then curls forward and down, exposing different portions of the back; the Porpoise Dive is accomplished from a Chest Swim position by rising and almost clearing the water then arching the back and submerging the head, the body curling forward as in the Roll Dive. At Skipjack Island, seals were seen to occasionally continue their dives underwater by twisting downward in a corkscrew fashion, using all flippers to rotate the body.

Splashing: Seals splash by slapping the water with fore flippers and hind flippers. The Fore Flipper Splash is executed most commonly as the seal swims on its side, bringing the fore flipper perpendicular to the water surface and lowering it to slap the water. This activity often occurs several times in succession. Seals occasionally swim on their backs and clap the fore flippers over their chest. We have observed the Hind Flipper Splash most commonly at the end of a Roll Dive, as the seal positions its hind flippers perpendicular to the water surface then brings its torso and hind flippers to one side and slaps the water. This activity is often alternated with dives. A seal in shallow water may position its body vertically, nose pointed down, and slap the water with hind flippers while rotating its body. We observed a seal to splash 33 consecutive times in this manner, bringing its head out of the water twice. Splashing by individual seals seems to have significance to groups of seals. The Alarm Splash has been described by several researchers (Scheffer and Slipp 1944, Newby 1971) and we also observed it at most study sites. An example of this behavior was seen at Skipjack Island when hauled seals entered the water as human divers approached. A group of seals Spyhopped, looking in the direction of the divers, and an individual seal slapped the water with a fore flipper as it dived; other seals immediately did the same.

Leaping: Seals Salmon Leap (Hewer 1974), often clear of the water, before reentering the water head first. A Breech is a slight variation; the seal rises straight up out of the water up to the chest or abdomen and submerges by falling backwards or to the side, at only a slightly different angle. Salmon Leaps and Breeches have been observed most frequently during haul out periods. Seals were observed to Salmon Leap several times in succession, the leaps approximately 5 m apart. At Skokomish, a seal alternately hauled and entered water 10 times in succession, each time swimming 1 to 5 m from the marsh and Salmon Leaping and Breeching. A male seal at Eld Inlet also hauled out 10 times in a 6 minute period, executing Salmon Leaps while in the water. Both instances eventually ended with the seal remaining hauled and resting. Wilson (1974b) describes leaping and splashing as common activities of young seals before hauling out and asserts that seals may engage in this type of activity as a group, resulting in a more rapid haul out than the normal social haul out. Hewer (1974) suspected Salmon Leaping was part of male pre-mating behavior.

Resting on land

Harbor seals on land rest primarily on their stomach or side. In nine timings at Skipjack Island the time individual seals spent hauled ranged from 60 to 270 minutes with an average of 180 minutes. In 52 timings of the activities of individual hauled out seals, the average time spent resting with eyes closed in a 3 minute period was 82 seconds and ranged from 45 to 114 seconds.

Resting in shallow water

Seals observed resting in shallow water, while still in contact with the ground, commonly are in one of two positions depending on water depth. In water up to approximately 1 m deep, seals often rest with the head and rear flippers arched up above the water in a U-position, with their stomachs or sides touching the ground. The probable thermoregulatory function of this position is discussed in Resting in the water. In water 1-1.5 m deep, seals often rest with the head out of the water and the body vertical, with the rear flippers together, turned to the side, and in contact with the ground. Both of these positions have been noted by Scheffer and Slipp (1944) and U-position resting is described by Bartholomew (1949).

Resting in water

Seals were observed resting in the water in four positions: Bottom

Resting, Bottling, Head and Back Floating, and U-position Floating. Three of these positions have been noted by Scheffer and Slipp (1944) and Venables and Venables (1959).

Bottom Resting: At Skipjack Island seal movements underwater were seen clearly enough to document and time Bottom Resting. The behavior of seals on the surface at other sites indicated Bottom Resting occurred at other sites with only slight variations, according to habitat. Seals Bottom Resting lie on the bottom on their back, stomach or side. At Skipjack Island seals usually Bottom Rest in a rock crevice, possibly to prevent them from drifting with the current. Seals usually alternate Bottom Resting with resting at the surface or swimming slowly with the head above water.

We saw seals Bottom Resting in groups as well as singly. At Skipjack Island up to five seals Bottom Rested in a one-meter wide and less than ten-meter long crack under approximately 10 m of water. During two aerial surveys of Skokomish Delta and Quilcene Bay in Hood Canal, groups of 73 and 65 seals, respectively, were seen Bottom Resting on a mudflat covered by 1 to 3 m of water.

In 124 timings of Bottom Resting at Skipjack Island, the average time spent underwater was 4 minutes 45 seconds (range - 1 minute 30 seconds to 8 minutes 20 seconds) and the average time spent on the surface was 49 seconds. While at the surface each time seals inhaled 15 to 27 times, averaging 18 breaths in 10 observations. In 27 timings of seals Bottom Resting at Skokomish River Delta, the average time spent underwater was 4 minutes 13 seconds (range - 39 seconds to 6 minutes). Averages of series of at least four timings for individual seals ranged from 1 minute 45 seconds to 5 minutes 30 seconds. The maximum time a seal was seen Bottom Resting was 8 minutes 20 seconds, and the longest time a seal was seen alternating Bottom Resting with brief periods on the surface was 3 hours; both observations were made at Skipjack Island. Scheffer and Slipp (1944) describe a seal sleeping on the bottom of a pool at an aquarium and give timings of 3.5 to 4.5 minutes on the bottom with 45 seconds on the surface. The nostrils opened and closed 15 times while on the surface.

Bottling: Seals that are Bottling float vertically in the water with the head (or sometimes just the snout), out of the water and directed upwards. The seal usually floats without use of flippers, though treading water with the fore flippers was seen. At river deltas in the Hood Canal, groups of up to 50 seals were seen, predominantly in this position. Bottling was the most common of the surface resting positions used by seals in the water. In Eld Inlet one seal was timed in this position for 55 minutes.

Bottling, and the two other surface resting positions are probably maintained by retaining air in the lungs; seals are negatively buoyant and often sink when shot while in the water (Scheffer and Slipp 1944, Imler and Sarber 1947).

Head and Back Floating: Seals that are Head and Back Floating rest at the water's surface with the top of the head (head horizontal), snout, and a portion of the mid-back above the water. The back occasionally rises and falls slightly in the water, an apparent result of breathing. Seals did not remain in this position for prolonged periods but were seen floating for short periods, particularly between Bottom Rests. Head and Back Floating was observed less frequently than Bottling.

U-position Floating: When U-position Floating a seal rests at the surface with its back in an inverted arch or U-position, with the head and rear flippers above the water. The rear flippers are held together and compressed. This position is frequently seen immediately after seals enter the water undisturbed. Seals in this position occasionally swim for short periods using the fore flippers. U-position Floating was less frequently seen than the other surface resting positions.

The hind flippers of harbor seals are vascularized with the major blood vessels located superficially on the plantar surface, and appear to play an important role in thermoregulation (Tarasoff and Fisher 1970).

Interactions in the water

All prolonged interactions we observed between seals in the water involved pairs. Rolling (Venables and Venables 1957, 1959) was the most commonly seen interaction between pairs. When Rolling a pair of seals maintains frequent body contact while diving over each other, twisting and turning in the water. During Rolling, seals often slapped the water with fore and hind flippers and occasionally bit at each others' hind flippers while swimming in circles.

Other activities between seals during Rolling included mouthing the head and neck, pair bubble blowing, mounting for brief periods and simultaneous Fore and Hind Flipper Splashes by both seals of the pair.

On six occasions in the field, between 13 July and 5 August at Skipjack Island, and on one occasion in captivity at Point Defiance Aquarium, the sex of both members of a Rolling pair was known or determined. In all cases both participants were males. Four of the six observations were of the same pair on different days in a 1 week period. Wilson (1974b) observed two male subadults in captivity to form static pairs which engaged in Rolling. During three of our six observations the penis of one seal was extruded and one seal mounted the other on several occasions. Johnson and Johnson (1977) and Johnson (1974) also observed only males engaging in Rolling activities.

At Skipjack Island our observations continued through the mating season, which is reported to occur soon after the annual moult (Fisher 1954, Bigg 1969a, Venables and Venables 1957) and coincide with the weaning of the first pups (Bishop 1967). During this period suspected mating was seen on only one occasion, though the sex of both seals was not positively determined. On this occasion, after extended pair Rolling, a male with extruded penis was seen mounting the other seal on several occasions before both sank out of view.

Venables and Venables (1957) have described mating in the harbor seal in detail. They reported Rolling pair behavior between males and females in the spring prior to pupping (Venables and Venables 1959) and in September and October during moulting with coition seen on several occasions after Rolling (Venables and Venables 1957).

During the moult at Skipjack Island in late August, a pair of seals were observed to fight briefly with both seals tumbling into the water from where they were hauled out. One of the seals was then seen bleeding from the neck and right fore flipper. This was our only observation of seals fighting in which a seal was injured. During the mating season up to half of the seals at Skipjack appeared to be bleeding from small cuts. We frequently observed adult male harbor seals with a large number of scars on the chest and neck. Other investigators have reported scars around the chest and neck of male harbor seals (Bigg 1969a, Scheffer and Slipp 1944). Bishop (1967) reported increased male aggressiveness during the breeding season. Bigg (1969a) found a higher mortality in adult males than adult females, possibly as a result of fighting between males in the breeding season.

There are few reports in the literature of fighting between harbor seals and we rarely observed fighting that resulted in any injury to the participants. The evidence listed in the preceding paragraph, however, suggests that fighting between seals may be part of the breeding behavior of harbor seals. The rare observations of mating and possibly fighting indicate they must take place in an inconspicuous manner or at times or locations that researchers have not usually studied.

Interactions on land

Interactions between hauled seals are few and usually involve spacing at the haul out area. We observed motions made by hauled seals which appeared to discourage one seal from hauling or moving close to another seal on land. When seals increased their distance from each other the motions generally stopped. Interactions included the Foreflipper Flail, a waving motion of the fore flipper directed towards an approaching seal; the Head Thrust, where a seal jerks its head and chest at another seal; and light contact with the fore flipper. Seals also vocalized, described by Scheffer and Slipp (1944) as a "squall, bawl, or throaty grunt", during interactions at the haul out area. We observed these types of interactions most frequently at the beginning and end of the haul out period. When seals first hauled out they generally remained alert and reacted to seals which hauled nearby. When seals rested interactions were much less frequent. When haul out space is limited, as at Skipjack Island, when haul out rocks are inundated, and at Hood Canal haul out areas during extreme high tides which cover the marsh, seals move closer together to remain hauled. This usually results in increased flipper flailing and vocalizing as they shift positions. Bishop (1967) describes this type of "mild, intraspecific strife" at Tugidak Island, Alaska.

Mother-pup interactions

Mother-pup interactions of the harbor seals have been described. The nursing period has been reported to last 3 weeks (Finch 1966, Wilson 1974a) and 4 weeks with a maximum of 6 weeks (Newby 1973b, Venables and Venables 1955). Close association between mother and pup occurs only during the nursing period (Wilson 1974a, Newby 1971, Venables and Venables 1955) and decreases during weaning (Finch 1966).

Nursing and contact: We observed nursing on land and in the water. On land, nursing was more frequently seen by mother-pup pairs that had recently hauled out than in pairs that were already hauled. Wilson (1974a) observed nursing just after haul out in 89% of the total observations of nursing. Our observations of duration of nursing bouts on land ranged from 2 minutes 45 seconds to 12 minutes, with 2-3 second interruptions. Nursing underwater was observed on eight occasions, seven at Skipjack Island and one at Eld Inlet. At Skipjack Island pups often suckled underwater when haul out space was accessible. In Eld Inlet pups were rarely seen hauled out in the first week after birth necessitating nursing in the water during that time. Newby (1973b) reported nursing to occur at 3 to 4 hour intervals and to last 25 to 160 seconds per feeding. Underwater nursing has been described by Venables and Venables (1955) and Finch (1966) but was not observed by Wilson (1974a). Though Bishop (1967) mentions the possibility of underwater nursing, he and Newby (1973b) describe mothers and pups hauling out to nurse their pups on smooth beaches of islands. These differences in nursing locations may be due to contrasting environments (Bishop 1967) including limited accessibility of the haul out area to mother-pup pairs as Venables and Venables (1955) observed in Shetland and we observed in Eld Inlet.

Haul out and activity in the water: The haul out pattern of mothers with pups during lactation is different than that of the rest of the population. At Eld Inlet pups appeared unable to haul out on floats in the first week after parturition. Females with pups were seen to haul out briefly if at all during this first week. Venables and Venables (1955) discuss the difficulty pups have hauling out during the first few days due to weak hind quarters. They observed that females generally stayed in the water with their pups.

We observed mother-pup pairs to form nursery groups during the nursing period at four sites. At Eld Inlet, one float was utilized consistently as haul out area by five to six mother-pup pairs; three single seals were also often present on this float. A group of near shore rocks west of the main haul out area at Skipjack Island was utilized often by mainly mother-pup pairs and occasionally by only mother-pups. During several observation periods at Dosewallips Delta, a group of three to four mother-pup pairs and one single seal hauled out at a slough away from the main group of hauled seals. Within the main group, mother-pups also formed groups of three to four pairs. At Smith Island study site, the ratio of mother-pup pairs to single seals hauled out on the southeast side of Minor Island was as high as 59%. Formation of nursery groups has also been reported by Newby (1973b) and Johnson (1974). We occasionally observed single mother-pup pairs to haul out alone from other seals.

Mothers and pups generally moved together during haul out, though different pairs exhibited slightly varied behavior patterns. Mothers, rather than pups,ordinarily initiated haul out. Wilson (1974a) also describes this sequence as the more common one. The pup often followed the mother to the land edge but would not haul out, and the mother turned back to the water. For specific pairs this occurred several times in succession before they remained hauled out. Bishop (1967) describes cows leading their pups to the beach on Tugidak Island before the pups would remain hauled out. Pups occasionally did not follow their mothers into the water after haul out; the mother then commonly splashed the water with her fore flipper or rehauled and nosed the pup, in a way similar to that described by Wilson (1974a). The pup then ordinarily followed, but occasionally the pup remained hauled.

The identification of mother-pup pairs at Skipjack Island provided information on the variable interactions of different pairs. One pup was seen less frequently with its mother than other pups throughout 2 weeks of observation. The pup was normal size, and when it was with its mother, interactions were typical of close mother-pup associations. This pup was heard vocalizing often and was seen to approach and sniff other seals on 12 occasions. The reactions elicited were usually flipper flails and lunges, which the pup often reciprocated. It was also seen investigating the abdomen of males.

In the water, pups generally follow their mothers. The pup may circle its mother, swimming away and returning to the female as she swims. In Eld Inlet, a mother and pup were observed diving together; subsequently the mother brought a fish to the surface. The pup stayed close by but was not seen eating any of the fish. Mothers and pups were seen Bottom Resting together at Skipjack Island, though the pups did not spend as much time underwater and could often be seen drifting directly above their respective mothers as they Bottom Rested.

Pups were sometimes separated briefly from their mothers in the water. Activities of pups during these periods include: floating with head submerged and back slightly above water surface; floating and swimming on their backs and then diving; Bottling and U-position Floating as described for adults; and manipulating sticks, pieces of algae and on one occasion a bivalve. The manipulation of objects by pups is considered an important stage in learning to catch and eat fish (Finch 1966).

The results of mother-pup behavior timing in Eld Inlet are contained in Table 11. The mothers spent from 53-63% of their time while in the water below the surface while the pups spend 4-5% less time underwater. The portion of time spent underwater was not necessarily concurrent; they often dove together. The four positions on the surface varied in duration and frequency. U-position Floating was seen only once, though it was a prolonged activity. The Back Only Floating occurred much more often in the pup's activities, often while the mother was underwater.

Desertion and separation: The role of desertion and separation of mother-pups in pup mortality is discussed in Reproduction - Pup mortality. In Eld Inlet a pup regularly hauled out alone on a tire for over 2 weeks during the pupping season. This identified pup also hauled with another mother-pup pair and unsuccessfully attempted to nurse several times. The pup appeared to be surviving during the two week period, though it remained visibly thin. Mothers with pups at Skipjack Island generally reacted to the approaches of pups other than their own by growling and Foreflipper Flailing; they occasionally entered the water. These actions are similar to those described by Bishop (1967).

We observed instances of pups separated from their mothers for periods of several hours to over 2 weeks. At Skipjack Island pups remained alone for up to 4.5 hours before being rejoined by a female. Here, deep water was never far from the haul out site, so mothers could leave the pups unattended through haul out periods. On the Hood Canal marshes, where tides are extreme, nursing pups were not observed separate from their mothers for entire haul out periods. At Dosewallips Delta, a mother attempted to induce her pup to enter the water, by rehauling and nosing, for 24 minutes after the hauled group left; then she swam nearby for another 13 minutes before swim-

Table 11. Underwater and on the surface behavior of mother-pup pairs in Eld Inlet, Southern Puget Sound. Number of bouts (#), mean duration of bout (X), and ratio of duration of bout to total seconds observed are shown.

	Mother 1			Pup 1			Mother 2			Pup 2		
Position	#	$\bar{X}$	%	#	$\bar{X}$	%	#	$\bar{X}$	%	#	$\bar{X}$	%
Underwater	23	79	63	17	101	59	7	77	58	6	89	53
Surface	43	24	37	32	36	41	21	21	42	18	26	48
head*	26	12	11	17	15	9	7	22	15	7	28	20
head and back floating	13	25	11	10	40	14	7	40	27	4	27	11
U-position floating	3	140	15									
back	1	1	1	5	99	18				1	168	17
Total seconds observed		2860			2766			1050			1012	

* includes bottling position and swimming

ming out to deeper water, leaving her pup at the haul out site.

Interactions with other seals: Most interactions of mothers and pups with other seals were observed during haul out. Both mothers and pups were seen Foreflipper Flailing when attempting to haul out near other seals, including other mothers. Mothers of pairs that were already hauled were seen to Head Thrust and growl at seals beginning to haul out near them. Occasionally pups were knocked into the water during an interaction between the female and another seal. When this occurred, mothers usually followed their pups into the water immediately.

Disturbances and interactions with humans, birds, and killer whales

Humans have historically hunted seals in Washington State. The Twana Indians traditionally hunted harbor seals in the Hood Canal (Elmendorf 1962). From 1923 to 1960 Washington State paid a bounty on harbor seals and over 10,000 seals were killed between 1947 and 1960 (Washington State bounty records). Johnson and Jeffries'(1977) summary of the bounty records indicates that Northern and Southern Puget Sound and the outer coast bays and harbors were the main seal hunting areas. Scheffer and Slipp (1944) and Paulson (1946) discuss some of the hunting methods used in Washington. Seals are still occasionally shot though they have been legally protected from human harassment by the Marine Mammal Protection Act of 1972.

During this study, interactions observed between seals and humans were most often in the form of disturbance to seals at haul out areas. Table 12 indicates the number of disturbances of hauled seals, where the cause was seen by us, for six study sites. Human related disturbance ranged from 50% of all disturbance at Dosewallips Delta, where birds often caused disturbances, to 81% at Smith Island, where seals were rarely disturbed except by boats and low flying aircraft. Human caused disturbance came primarily from

Table 12. Number of disturbances where cause was observed and proportion of disturbances caused by humans.

Site	Total Disturbances	No. Human Caused	%	Total Days Observed
Smith Is.	16	13	81	38
Skipjack Is.	20	14	70	41
Skokomish	51	38	75	69
Duckabush	19	12	63	28
Dosewallips	14	7	50	26
Eld Inlet	22	15	68	90

* Total days observed was computed by the addition of the following conversions: full day = 1; 2 half-days = 1; 5 brief visits = 1.

approach to the haul out area by boat or vehicles, and from duck hunting near the haul out area.

Birds also caused disturbances. Great Blue herons (Ardea herodias) caused seals to enter the water on eight occasions by landing nearby or flying low over a group of hauled seals. A crow (Corvus brachyrhynchos) and merganser (Mergus sp.) elicited the same reaction. In most cases, seals remained hauled when birds approached and on one occasion rehauled after being disturbed by a great Blue heron, although the heron was still present. On five occasions, gulls nipped at seals' rear flippers. The presence of a gull on floats where seals were hauled out caused seals to shift positions, growl and Front Flipper Flair; on one occasion a seal entered the water following a bout of this sort.

Scheffer and Slip; (1944) reported the killer whale as one of the few natural predators of harbor seals in Washington State. They provide an account of whales attacking seals at Nisqually Delta. We observed three encounters between harbor seals and killer whales, all in Northern Puget Sound, none involving predation. On 22 August, two whales travelled past a haul out area at Skipjack Island. Seals in the water moved closer to the seals hauled out. The killer whales turned back, this time passing within 5 m of seals in the water. Some seals previously underwater came to the surface and Spyhopped toward the whales. On a second occasion at Skipjack a seal near the island moved into a cove as two killer whales approached. On 17 July at Smith Island, 13 killer whales swam past a group of seals, both hauled and in the water. The seals in the water Spyhopped in the direction of the whales, as at Skipjack Island, but the whales did not approach. Participants in Orca Survey, a current study of killer whales in Washington State inland waters (Balcomb 1978), have not observed killer whale predation on harbor seals, or other interspecific interactions (James Boran, pers. comm.). A resident reported seeing a killer whale feeding on a harbor seal in the Straits of Juan de Fuca, west of Port Angeles, during the summer, several years ago.

Food Habits

Diet

Fitch and Brownell (1968) have discussed the value of identification of otoliths from cetacean stomachs in determining food habits. Experimental studies on the Baikal seal (*Pusa sibirica*) showed it is possible to determine the species spectrum of feeding and the size, weight, and age of fishes on the basis of otoliths recovered from scat (Pastukhov 1975). Identification of otoliths from seal scat is valuable as a method of determining feeding habits because it does not require the killing or disturbing of the seals and also allows a larger,more extensive sampling.

We recovered over 1700 fish otoliths (representing a minimum of 951 fish) from harbor seal scat collected between April and October. The breakdown of species recovered at different sites is shown in Table 13. At least 20 species of fish are eaten by harbor seals in our study areas. There were regional differences; a maximum of 12 species were recovered in any one of the three regions we studied. Fragments of crustaceans were also found in scat but were not identified.

At the three river deltas studied in Hood Canal, the Skokomish, Dosewallips, and Duckabush, Pacific hake (*Merluccius productus*) comprised 81% of the otoliths found and plainfin midshipman (*Porichthys notatus*) was second in abundance with 8%. At Skokomish Delta, Pacific hake comprised 76% of the species taken, followed by plainfin midshipman, blackfin sculpin (*Halacocottus zonurus*) and walleye pollack (*Theragra chalcogramma*) which

Table 13. Number of otoliths recovered from harbor seal scat.

Species	Skokomish River Delta		Duckabush River Delta		Dosewallips River Delta		Hood Canal Region Total		Eld Inlet		McMicken Island		Budd Inlet		S Puget Sound Region Total		Smith Island (N Puget Sound Region)		All Region Total	
	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%	no.	%
Pacific hake *Merluccius productus*	744	76	236	86	244	97	1224	81	30	23	1	8	1	25	32	21			1256	73
plainfin midshipman *Porichthys notatus*	101	10	8	3	6	2	115	8	1	.8	5	39			6	4	2	3	123	7
shiner perch *Cymatogaster aggregata*	27	3	29	11			56	4	1	.8					1	.7	1	1	58	3
blackfin sculpin *Malacocottus zonurus*	49	5					49	3											49	3
walleye pollock *Theragra chalcogramma*	39	4					39	3	2	2					2	1			41	2
slender sole *Lyopsetta exilis*	8	.8			1	.4	9	.6											9	.5
staghorn sculpin *Leptocottus armatus*	7	.7					7	.5	99	74					99	66			106	6
English sole *Parophrys vetulus*	6	.6			1	.4	7	.5			1	8			1	.7	2	3	10	.6
striped seaperch *Embiotoca lateralis*	2	.2					2	.1			1	8			1	.7			3	.2
Pacific tomcod *Microgadus proximus*	1	.1					1	.1			4	31	1	25	5	3	3	4	9	.5
Pacific herring *Clupea harengus*			1	.4			1	.1									8	11	9	.5
white seaperch *Phanerodon furcatus*													1	25	1	.7			1	.1
sand sole *Psettichthys melanostictus*													1	25	1	.7			1	.1
eulachon *Thaleichthys pacificus*																	2	3	2	.1
blackbelly eelpout *Lycodopsis pacifica*																	34	48	34	2
Pacific sand lance *Ammodytes hexapterus*																	4	6	4	.2
rockfish *Sebastes* sp.																	1	1	1	.1
threadfin sculpin *Icelinus filamentosus*																	1	1	1	.1
flounder unidentified pleuronectid											1	8			1	.7	2	3	3	.2
eelpout *Lycodes* sp.																	9	13	9	.5
Total	984		274		252		1510		134		13		4		150		69		1729	

totaled 19%. These four species represented varying proportions of the take throughout the study period (Fig. 8). Pacific hake was the predominant species during late April and from July to October. The three other species alternately took the place of hake from May to June.

Otoliths collected from Southern Puget Sound (Budd Inlet, Eld Inlet, and McMicken Island) represented 10 species. At McMicken Island, plainfin midshipman and Pacific tomcod (Microgadus proximus) made up 65% of the take. In Eld Inlet, staghorn sculpin (Leptocottus armatus) comprised 74% of the fish taken, with hake next in abundance. Starry flounder (Platichthys stellatus), was not found in the otolith analysis, but we did observe a seal eating an individual of this species.

Otoliths were collected in July and August from Smith Island in Northern Puget Sound. Of the 12 fishes found, eelpouts (Zoarcidae) were most numerous; the blackbelly eelpout (Lycodes pacifica) constituted 48%, and eelpouts contributed 13%.

There are several limitations in the use of scat analysis. The consumption of cartilaginous fish cannot be determined from otolith identification in scat. Though the beaks of squid and octopus and remains of crustaceans probably can be recovered from scat, quantitative determinations would be more difficult than with fish. Scat analysis may also be biased due to poorer otolith recovery of fish with small otoliths or due to the rejection of the seals of the heads of gillnetted salmon (Scheffer and Slipp 1944). Stomach content analysis may also be biased by these factors when food remains are partly digested.

We examined stomachs of the 21 dead seals recovered during the study. The stomachs of all 16 pups were empty. Of the five non-pup seals found dead, four had no distinguishable food items in their stomach. In an adult

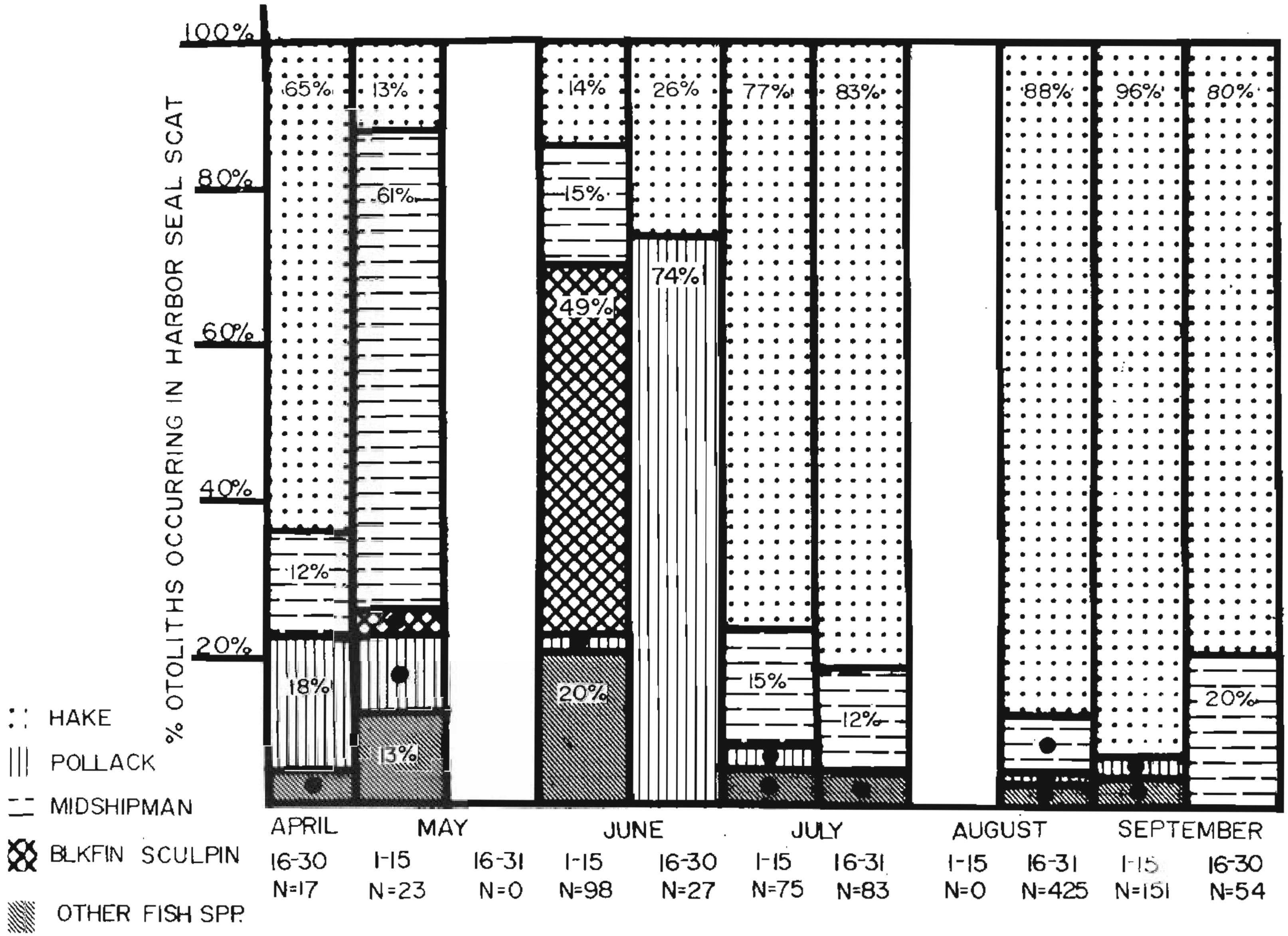

Fig. 8. Seasonal changes in otoliths occurring in harbor seal scat at Skokomish River Delta, April-September 1977. N = number of otoliths, • = less than 10%.

male found shot near a salmon hatchery on 1 July in the Hood Canal, 16 otoliths from Pacific hake, 3 from Pacific tomcod, 2 from chinook salmon (Oncorhynchus tshawytscha), and 1 from white seaperch (Phanerodon furcatus), along with fish vertebrae and nematodes, were found in the stomach. The chinook salmon otoliths were the only salmonid remains found in association with harbor seals in the course of this study. On five occasions, however, we observed seals eating red-fleshed fish, which we concluded were salmon.

Seal predation on salmon has been an important issue and was the reason that Washington State maintained a bounty on harbor seals from 1923-1960 (Washington State bounty records). Scheffer (1928a, 1928b) and Scheffer and Sperry (1931) pointed out the unfairness of the bounty system. Scheffer and Sperry (1931) report that of 81 stomachs of Washington harbor seals they examined, and which contained food, only two held salmon. They note seals may reduce juvenile salmon mortality in estuaries by eliminating or scaring away predators of salmon fry. Scheffer (1928a) found salmon in 2 of 14 stomachs of harbor seals from Washington that contained food other than milk. Pitcher and Calkins (1977), also, report minimal occurrences of salmon in stomachs of harbor seals from the Gulf of Alaska. In British Columbia coastal waters salmon occurred in 16% of harbor seal stomachs in summer and in 30% of harbor seals taken mostly near salmon spawning streams in fall, when salmon were moving into the streams (Spalding 1964). Fisher (1952) reported salmon occur in 25% of harbor seals taken primarily in the summer near the Skeena River, British Columbia. Scheffer (1928a) and Spalding (1964) report that small fish are probably eaten underwater; only the larger fish, such as salmon, are eaten at the surface. Spalding (1964) calculated that harbor seal predation on salmon in British Columbia equaled less than 1% of the commercial catch and concluded that predation at that level was not a significant factor in salmon mortality.

Scheffer and Sperry (1931) report stomach contents of seals at Nisqually Delta in Southern Puget Sound. All families of teleosts (bony fishes) reported in that study (except Stichaeidae) were found in this study. Data from the Scheffer and Sperry study was adapted by Scheffer and Slipp (1944) and lists flounder, Pacific herring, Pacific tomcod, Pacific hake, and sculpins as the descending order of frequency of occurrence in 100 harbor seal stomachs collected in Southern Puget Sound. A large number of stomachs contained squid, a food item without otoliths. Arnold (1963) reported that Pacific cod, sculpins, and Pacific hake occurred in two seal stomachs collected at Gertrude Island, Southern Puget Sound. Other food habit studies of harbor seals have shown gadids, pleuronectids, clupeids, salmonids, cottids, mackerel, and molluscs to be some of the major food items (Imler and Sarber 1947, Fisher 1952, Godsil 1933, Spalding 1964, Wilke 1954, Kenyon 1965, Rae 1968, Gol'tsev 1971, Pitcher and Calkins 1977).

Feeding behavior

Reports of feeding are rare. We saw seals eating fish at the surface 17 times during the study period. Large fish, held in the jaws, were shaken violently in a back-and-forth motion, that often raised spray, until pieces of the fish were torn off. This behavior was reported by Scheffer and Sperry (1931), Scheffer and Slipp (1944), and Fisher (1952). Seals also bit off pieces of large fish while underwater, as evidenced by a seal surfacing with a fish that had been whole prior to a dive. Chunks of flesh and small fish were chewed or swallowed whole. Two seals used their foreflippers to push a fish away from their jaws and thereby dismember the prey. One seal ate while hauled partly out of the water; the others ate fish only while they were in the water. Non-feeding seals were close to feeding seals in five instances, and in one case a non-feeding seal approached within half a meter of a feeding individual. However, there was no stealing or sharing of food though chunks of fish floated away from feeding seals. We saw seals eat the heads of fish four times. Gulls congregated around feeding seals, and obtained chunks of fish in the vicinity of one seal.

Chlorinated Hydrocarbons

Concentration in harbor seals

Detectable concentrations of PCB and p,p'-DDE were found in all samples analyzed. The concentration (ppm, wet weight) of PCB and p,p'-DDE (hereafter referred to as DDE) in the blubber of harbor seals from different sites is shown in Tables 14-16, and summarized in Table 17. Arithmetic mean concentrations of PCB and DDE in the blubber of seals found dead were; 171 ppm and 15.2 ppm, respectively, in 20 seals from Southern Puget Sound, 31.0 ppm and 4.38 ppm in 9 seals from the Hood Canal, 16.3 ppm and 8.34 ppm in 6 seals from the outer coast, and 14.8 ppm and 4.64 ppm in 8 seals from Northern Puget Sound. The 28 seals collected from Grays Harbor had an average concentration of 18.8 ppm PCB and 9.0 ppm DDE.

Results of statistical analysis for differences between regional (including Gertrude Island) mean concentrations of PCB and DDE and their ratio are shown in Table 18. PCB concentrations in seals from Southern Puget Sound are significantly higher than in seals from all other regions ($p < .05$ in all cases). The concentration of PCB in the eleven seals from Gertrude Island (also included in the Southern Puget Sound mean) were higher than the concentration in seals from other regions, with the difference highly significant ($p < .001$ in all cases). DDE concentrations were also significantly higher in both the Gertrude Island seals and in seals from the whole Southern Puget Sound region ($p < .05$, in all cases), with the exception of

Table 14. Concentrations of PCB and DDE in harbor seals found dead in Southern Puget Sound.

Site (date collected)	Age class	Sex	wt. (kg)	Blubber thickness (mm)	Concentration (ug/g, wet wt.) PCB	p,p'-DDE	PCB/DDE	Comments
				Southern Puget Sound				
Gertrude Island (24 Feb. 76)	A	M	100.	-	208.	17.9	12.	
" " (6 Dec. 76)	"	M	90.	-	270.	19.4	14.	
" " (16 Jan. 77)	"	M	-	-	250.	15.3	16.	
" " (30 Sept. 75)	S	F	14.1	-	216.	27.0	8.0	
" " (4 Jan. 76)	"	M	20.9	21	152.	13.1	12.	
" " (4 Jan. 76)	"	F	32.2	20	146.	18.2	8.0	
" " (21 Jan. 76)	"	M	25.0	15	86.5	7.5	12.	
" " (16 May 76)	"	F	14.6	-	287.	30.0	10.	
" " (30 Sept. 75)	P	M	15.0	-	66.7	7.1	9.4	
" " (30 Sept. 75)	"	F	8.8	6	57.6	7.1	8.1	Stillbirth
" " (18 Sept. 76)	"	F	6.8	-	141.	13.0	11.	
Mean (SD) Gertrude Island					171 (81.0)	16.0 (7.7)	11. (2.6)	
Adults only					243 (31.6)	17.5 (2.1)	14. (2.0)	
Subadults only					178 (76.5)	19.2 (9.4)	10. (2.0)	
Pups only					88.4 (45.8)	9.1 (3.4)	9.5 (1.5)	
Rosedale (3 July 77)	S	F	35.0	18	529.	37.7	14.	
" (7 Dec. 77)	P	M	8.25	-	15.4	0.89	17.	Stillbirth
Vaughn Bay (17 July 75)	A	F	128.	42	20.5	1.34	16.	
Nisqually Delta (8 Feb. 77)	S	M	-	-	58.5	5.54	11.	
" " (25 Oct. 77)	S	M			34.7	3.69	9.4	
Budd Inlet (- Nov. 72)	P	F	9.8	25	160.	25.3	6.3	
" " (5 Aug. 77)	P	M	5.75	8	28.1	2.84	10.	Lanugo coat*
Eld Inlet (12 Sept. 77)	S	F	23.6	3	615.	42.1	15.	
" " (14 Aug. 77)	P	F	6.31	6	68.8	9.89	7.0	
Mean (SD) Southern Puget Sound					171 (162)	15.2 (12.0)	11 (3.2)	

*Cerebral teratoma, died in captivity

Table 15. Concentrations of PCB and DDE in harbor seals found dead in Northern Puget Sound and Hood Canal.

Site (date collected)	Age class	Sex	wt. (kg)	Blubber thickness (mm)	Concentration (ug/g, wet wt.) PCB	p,p'-DDE	PCB/DDE	Comments
				Northern Puget Sound				
Smith Island (19 June 77)	P	F	11.7	13	7.52	2.46	3.1	Stillbirth
" " (14 July 77)	P	F	11.4	12	6.73	0.75	9.0	
" " (14 July 77)	P	F	6.4	9	18.9	6.82	2.8	
" " (14 July 77)	P	F	10.0	12	6.00	1.73	3.5	
" " (21 July 77)	P	M	7.5	12	9.75	2.56	3.8	
Mean (SD) Smith Island					9.78 (5.29)	2.86 (2.33)	4.4 (2.6)	
Bellingham Bay (- Dec. 76)	A	M	88.3	32	28.7	8.72	3.3	
" " (17 Aug. 77)	S	F	23.3	39	15.8	3.8	4.2	
Dungeness Spit (17 Jan 76)	A	M	48.6	23	24.9	10.3	2.4	
Mean (SD) Northern Puget Sound					14.8 (8.73)	4.64 (3.52)	4.0 (2.1)	
				Hood Canal				
Quilcene Bay (17 Aug. 77)	P	M	8.3	13	10.1	1.51	6.7	Lanugo coat
Dosewallips Delta (8 Oct. 77)	A	M	61.8	16	101.	13.7	7.4	
" " (13 Aug. 77)	P	M	10.9	11	9.27	1.14	8.1	
" " (1 Sept. 77)	P	M	11.2	12	12.5	1.61	7.8	
Duckabush Delta (15 Aug. 77)	P	M	13.6	9	8.00	1.35	5.9	Stillbirth
" " (28 Aug. 77)	P	M	13.5	13	11.0	1.84	6.0	
" " (2 Sept. 77)	P	M	8.8	7	33.4	5.34	6.3	Stillbirth
Skokomish Delta (1 July 77)	A	M	64.1	17	85.3	11.9	7.2	
" " (8 Oct. 77)	P	F	3.10	4	8.25	0.98	8.[illegible]	Premature
Mean (SD) Hood Canal					31.0 (36.3)	4.38 (5.00)	7.1 (0.92)	
Adults only					93.2 (11.1)	12.8 (1.27)	7.3 (0.[illegible])	
Pups only					13.2 (9.04)	1.97 (1.51)	7.0 (1.[illegible])	

Table 16. Concentrations of PCB and p,p'-DDE in harbor seals collected in Grays Harbor and found dead on the outer coast. Grays Harbor seals collected by Jeffries and Johnson.

Site (date collected)	Age class	Sex	wt. (kg)	Blubber thickness (mm)	Concentration (ug/g, wet wt.) PCB	p,p'-DDE	PCB/DDE	Comments
				Grays Harbor (collected)				
Grays Harbor (30 July 76)	A	M	60.8	22	17.5	8.41	2.1	
" " (30 July 76)	"	M	57.7	25	12.7	10.2	1.2	
" " (27 Aug. 76)	"	M	55.4	24	27.0	18.7	1.4	
" " (17 March 77)	"	F	68.4	47	7.77	1.60	4.9	Pregnant (fetus 1)
" " (20 May 77)	"	F	99.0	44	5.80	2.56	2.3	Pregnant (fetus 2)
" " (20 May 77)	"	F	120.	64	22.4	7.92	2.8	Lactating (pup 1)
" " (20 May 77)	"	F	70.3	65	6.01	3.51	1.7	Lactating (pup 2)
" " (20 May 77)	"	F	101.	38	13.7	4.65	2.9	
" " (10 June 77)	"	M	81.8	30	34.7	13.4	2.6	
" " (22 July 77)	"	F	65.8	16	63.3	19.4	3.3	
" " (15 Aug. 77)	"	M	80.6	18	16.3	9.06	1.8	
" " (15 Aug. 77)	"	F	53.3	12	11.0	2.73	4.0	
" " (15 Aug. 77)	"	M	82.5	30	30.7	14.2	2.2	
" " (6 Oct. 77)	"	M	63.3	28	34.5	19.3	1.8	
" " (6 Oct. 77)	"	M	83.8	34	30.8	10.0	3.1	
" " (3 Dec. 76)	S	M	26.5	35	28.7	14.5	2.0	
" " (3 Feb. 77)	"	M	39.2	45	17.3	10.3	1.7	
" " (17 March 77)	"	F	25.4	32	22.0	12.9	1.7	
" " (10 June 77)	"	M	29.3	32	5.33	3.12	1.7	
" " (10 June 77)	"	F	42.3	20	48.7	22.2	[illegible]	
" " (22 July 77)	"	F	27.3	27	13.8	8.87	1.6	
" " (22 July 77)	"	M	48.3	22	16.4	10.7	1.5	
" " (22 July 77)	"	M	53.2	32	10.4	6.55	1.6	
" " (15 Aug. 77)	"	M	27.3	15	17.8	10.7	1.7	
" " (20 May 77)	P	M	15.3	20	3.19	1.56	2.0	Pup 1
" " (20 May 77)	"	M	11.4	9	4.17	2.14	1.9	Pup 2
" " (20 May 77)	F	F	8.	-	1.85	0.77	2.4	Fetus 1
" " (20 May 77)	"	M	12.3	18	3.78	2.12	1.8	Fetus 2
Mean (SD) Grays Harbor					18.8 (14.5)	9.00 (6.17)	2.2 (0.82)	
Adults only					22.3 (15.2)	9.71 (6.19)	2.5 (1.00)	
Subadults only					20.0 (12.6)	11.1 (5.34)	1.7 (0.22)	
Pups only					3.68 (0.70)	1.85 (0.41)	2.0 (0.07)	
Fetuses only					2.82 (1.36)	1.45 (0.96)	2.1 (0.42)	
				Outer Coast (found dead)				
Grayland (- Aug. 76)	P	M	47.7	8	39.4	14.8	2.7	
Grays Harbor (9 May 76)	P	M	5.9	-	13.3	3.6	3.7	
Twin Harbor (22 June 77)	A	M	-	21	11.6	11.1	1.0	
" " (22 June 77)	S	M	31.7	25	11.2	5.60	2.0	
Willapa Bay (30 June 77)	P	-	-	18	8.87	6.23	1.4	
" " (7 Oct. 77)	P	M	16.4	15	13.3	8.73	1.5	
Mean (SD) Outer Coast (found dead)					16.3 (11.4)	8.34 (4.10)	2.1 (1.0)	

Table 17. Sample size and mean concentrations of PCB and p,p'-DDE in blubber of harbor seals from different regions. All seals were found dead, except where noted.

Site	Sample size				Concentration (ug/g, wet weight) mean (SD)		
	Total	Ad.	Subad.	Pups	PCB	p,p'-DDE	PCB/DDE
S. Puget Sound	20	4	9	7	171. (162)	15.2 (12.0)	11. (3.2)
Gertrude Island*	11	3	5	3	171. (81.0)	16.0 (7.7)	11. (2.6)
N. Puget Sound	8	2	1	5	14.8 (8.73)	4.64 (3.5)	4.0 (2.1)
Hood Canal	9	2	0	7	31.0 (3.63)	4.38 (5.0)	7.1 (0.92)
Grays Harbor (collected)	28	15	9	4**	18.8 (14.5)	9.00 (6.2)	2.2 (0.82)
Outer Coast	6	1	1	4	16.3 (11.4)	8.34 (4.1)	2.1 (1.0)

*Included in S. Puget Sound.

**Includes two fetuses.

Table 18. Confidence limits for differences between mean PCB and DDE concentrations and their ratio in blubber of harbor seals from different regions using Student's T-test (two tailed). NS indicates differences were not significant to the .05 level.

	Gertrude Is. S. Puget Sound			S. Puget Sound			N. Puget Sound			Hood Canal			Grays Harbor (collected only)			Outer Coast (found dead only)		
	PCB	DDE	PCB/DDE	PCB	DDE	PCB/DDE	PCB	DDE	PCB/DDE	PCB	DDE	PCB/DDE	PCB	DDE	PCB/DDE	PCB	DDE	PCB/DDE
Gertrude Is. S. Puget Sound				NS	NS	NS	.001	.002	.001	.001	.002	.001	.001	.01	.001	.001	.04	.001
S. Puget Sound							.02	.04	.001	.02	.02	.002	.001	.04	.001	.04	NS	.001
N. Puget Sound										NS	NS	.002	NS	NS	.001	NS	NS	NS
Hood Canal													.04	.05	.001	NS	NS	.001
Grays Harbor (collected only)																NS	NS	NS

the DDE concentration of seals in Southern Puget Sound compared to seals from the outer coast. The highest PCB to DDE ratio was also found in seals from Southern Puget Sound and in the Gertrude Island subsample, with the differences highly significant in all cases ($p < .002$).

Concentrations of PCB were lowest in seals from Northern Puget Sound, but differences in the concentration of PCB in seals from the Hood Canal, the outer coast, and Grays Harbor (collected) were not significant ($p > .05$). Concentrations of DDE were lowest in seals from Northern Puget Sound and the Hood Canal. In all but two cases either the concentration of PCB or DDE, or their ratio, were significantly different between regions. The figures from the six seals found dead on the outer coast (including Grays Harbor and Willapa Bay) were not significantly different from the figures for seals collected from Grays Harbor or the seals found dead in Northern Puget Sound. The lack of a statistically significant difference between the outer coast and the Northern Puget Sound groups appears to be partly due to the small sample sizes and the variable concentrations of both groups. The lack of a significant difference between the residue concentrations in seals found dead on the outer coast and those collected from Grays Harbor is discussed in Variations in concentrations due to health and blubber thickness.

The mean concentration of PCB we found in the blubber of harbor seals found dead at Gertrude Island is 31% higher than the 130 ppm PCB that Arndt (1973) found in seals collected at Gertrude Island in 1972. The concentration of PCB we found in adults only is 39% higher than those found by Arndt. In both cases, however, the differences are not statistically significant ($p > .05$). The voluntary restriction of PCB to use in closed systems in 1971 has apparently not yet lowered the concentration of this chemical found in Southern Puget Sound harbor seals. The PCB concentrations we found in seals from Northern Puget Sound and Grays Harbor were lower than those found by Arndt (1973) in 1972, but again the differences were not statistically significant. Differences in the concentration of DDE found by Arndt and us are harder to interpret because of differences in analytical and quantitative methods for DDE analysis that could have affected the results. Young et al. (1977) found only minor decreases in the concentration of PCB and DDT in fish and sediment in Southern California over a 3 year period despite major decreases in the emissions of these chemicals. These results reflect the persistence of these chemicals in portions of the marine ecosystem.

Anas (1974) is the only other investigator to have reported chlorinated hydrocarbon concentrations in harbor seals from Washington State. He found concentrations of 459 and 1620 ppm PCB plus DDE in the blubber of two harbor seals from Southern Puget Sound. The mean concentrations in the Puget Sound seals were greater than the concentrations he found in harbor seals from San Miguel Island, California; Columbia River, Oregon; and the Pribilof Islands, Alaska. The mean concentration of PCB plus DDE found by Anas in Puget Sound seals is considerably higher than the concentrations found by us or Arndt (1973) and may be partly due to the small sample size and different quantitative methods employed.

Concentrations of PCB and DDT in marine mammals have been reviewed by Peakall (1975). The PCB concentrations we found in Southern Puget Sound seals are among the highest reported in pinnipeds. Comparable concentrations have been found in harbor seals and grey seals from parts of England and Wales (Holden 1972, Heppleston 1973) and from the German North Sea coast (Drescher et al. 1977). Concentrations of PCB slightly lower than those we found, but in the same range, were found in harbor seals from the Bay of Fundy and Gulf of Maine, Canada (Gaskin et al. 1973), ringed and grey seals from the Baltic Sea area (Helle et al. 1976a, 1976b) and in California sea lions from the Channel Islands, California (DeLong et al. 1973, Gilmartin et al. 1976). In two of these populations concentrations of PCB and DDT were correlated to reproductive dysfunctions which are discussed later in this paper. A minimum of 10 other researchers have reported PCB concentrations in pinnipeds from different regions that are considerably lower than the concentrations we found in Southern Puget Sound.

DDT and its metabolites have been reported in higher concentrations than those we found. Higher concentrations of DDT have been found in the following pinniped populations; harbor seals from the Bay of Fundy and Gulf of Maine, Canada (Gaskin et al. 1973); California sea lions from the Channel Islands, California (Le Boeuf and Bonnell 1971; DeLong et al. 1973, Gilmartin et al. 1976); ringed and grey seals from the Baltic Sea area (Jensen et al. 1969, Helle et al. 1976a, Helle et al. 1976b); harbor seals from central California (Shaw 1971); and a crabeater seal from the Antarctic (Sladen et al. 1966). Concentrations of DDT and metabolites similar to those we found in Southern Puget Sound seals have been reported in: harbor seals and grey seals from England (Holden 1972, Heppleston 1973); harbor seals from the German North Sea coast (Drescher et al. 1977); from Canadian waters (Holden and Marsden 1967); and from the Wadden Sea (Koeman and van Genderen 1966); grey seals from Nova Scotia, Canada (Addison and Brodie 1977); harp seals from the Gulf of St. Lawrence and Newfoundland front (Addison et al. 1973, Frank et al. 1973); and Northern fur seals from the Pribilof Islands (Anas and Wilson 1970). To our knowledge only four investigators have reported lower concentrations of DDT and metabolites in the blubber of pinnipeds than those we found. Three of these pinniped populations were from the Arctic (Holden 1972, Clausen et al. 1974, Addison and Smith 1974) and one was from the Gulf of St. Lawrence (Jones et al. 1976).

Concentrations of DDT and PCB could not be compared to those reported by Anas (1974) and Anas and Wilson (1970) because they combined the concentrations determined for PCB and DDT.

Association with reproductive difficulties

PCBs and DDT have been shown to cause reproductive difficulties in a variety of animals. Stendell (1976) summarizes some of the recent findings on the effects of PCB on birds and mammals. White-footed mice fed PCB gave birth to a reduced number of litters with no young surviving past 21 days (Merson and Kirkpatrick 1976). Feeding of DDT to rabbits caused prematurity and intra-uterine growth retardation (Hart et al. 1971). The reproductive effects of DDT and PCB on several species of birds has been documented (Peakall 1970, Peakall et al. 1972, Cooke 1973, Cecil et al. 1974). PCBs affect the reproduction of fathead minnows (Nebeker et al. 1974) and were implicated as the cause of stillbirths in big brown bats (Clark and Lamont 1976).

Some animals such as mink (Mustela vison) have been shown to be highly sensitive to PCBs. Aulerick et al. (1973) found that feeding fish with 5 ppm PCB to mink resulted in no reproduction and feeding 1 ppm reduced reproductive success. Platonow and Karstad (1973) found that mink produced no surviving young when fed 0.64 ppm PCB in meat of cows that had been fed PCB. Jensen et al. (1977) conducted a study on the effect of PCB and DDT on mink because of the possible link between these chemicals and the low reproductive success of Baltic seals. The mink was chosen because that species,like seals, feeds on fish and exhibits a delayed implantation. He found PCBs have a much more powerful effect on reproduction than DDT, with PCB-fed minks exhibiting a reduced number of whelps, smaller whelps, an increased number of stillbirths, undersized young, and reduced survival of the young.

Allen and Norback (1976) and Allen and Barsotti (1976) reported that female rhesus monkeys fed dietary levels of PCB as low as 2.5 and 5 ppm for up to 1.5 years developed reproductive dysfunctions (among other symptoms) which included irregular menstrual cycles, early abortions, and stillbirths. Of the infants born of dosed mothers, 50% died within 4 months. Women who injested rice oil contaminated with PCBs in Japan suffered symptoms which included menstrual disturbances, small for the date babies, and unusual pigmentation of young (Kuratsune et al. 1976), as well as a high incidence of stillbirths (Kuratsune et al. 1972).

Both PCB and DDT have been shown to induce hepatic microsomal enzyme activity which may affect the levels of steroid hormones involved in reproduction (Peakall 1967, Conney et al. 1967, Kufner 1969). PCBs altered in vitro steroid hormone biosynthesis in the grey seal (Freeman and Sangaland 1977). Administration of PCB or DDT increased the length of the estrous cycle in mice, probably as a result of increased steroid hormone metabolism (Orberg et al. 1972). The DDT homolog o,p'-DDT was shown to have estrogenic activity in the reproductive tissues of birds and mammals (Bitman et al. 1968). PCB caused reduction of urinary estrogen levels in boars fed PCB, even though there were no detectable pathological alterations (Platonow et al. 1972).

The immunosuppressive properties of PCB and DDT could influence the reproductive success of an animal. Friend and Trainer (1970) reported that mallards fed PCB at doses that caused no apparent clinical intoxication had significantly higher mortality when challenged with duck hepatitis virus. Hansen et al. (1971) reported that pinfish and spot exposed to PCB were more susceptible to disease. The body defense reactions of rats were moderated by ingestion of DDT (Wassermann et al. 1969). Vos and De Roij (1972) demonstrated the immunosuppressive activity of PCB on the humoral immune response in guinea pigs.

Chlorinated hydrocarbon contaminants have been correlated with reproductive dysfunctions in populations of pinnipeds in the Channel Islands, California and in the Baltic Sea region. Odell (1971) first reported a high incidence of premature pups in California sea lions in the Channel Islands off the coast of Southern California. Le Boeuf and Bonnell (1971) reported high concentrations of DDT and PCB in California sea lions from Southern California. DeLong et al. (1973) found PCB and DDE concentrations two to eight times higher in tissues of premature parturient California sea lion females and pups than in similar tissues of full-term females and pups. A second study on this same population also found significantly higher concentrations of PCB and DDE in the blubber and liver of females giving birth prematurely.

Two potential pathogenic microbiological agents, the bacteria Leptospira and a virus indistinguishable from Visicular Exanthema of Swine Virus (both associated with reproductive failures in domestic animals) were recovered from some of the premature-partus animals (Smith et al. 1974, Gilmartin et al. 1976). These results suggest an interrelationship of disease agents and chlorinated hydrocarbon contaminants as the cause of the premature births (Gilmartin et al. 1976).

Helle et al. (1976a) reported a very low reproductive rate in ringed seals from Bothnian Bay in the Baltic Sea area. Concentrations of PCB and DDT were significantly higher in the females of reproductive age that were not pregnant compared to pregnant females. The presence of pathological changes in the seal uteri were correlated to PCB and DDT levels (Helle *et al.* 1976b). The authors suggested that comparison of the concentrations they found with those found in sea lions in the Channel Islands indicated that PCB and not DDT was responsible for the reproductive failures.

The PCB concentration we found in Southern Puget Sound harbor seals was higher than those found in the Channel Island premature-partus California sea lions and in the ringed seals with uterine occlusions from Bothnian Bay. The DDE concentration we found, however, was lower than those in both groups of pinnipeds showing reproductive difficulties. The number of pinniped populations that have higher concentrations of DDT and its metabolites than those we found in our study, and show no obvious health effects indicate these chemicals at their present concentration are probably not a threat to the harbor seals in Southern Puget Sound. The concentration of PCB in the Southern Puget Sound seals, however, is among the highest reported in a population of pinnipeds.

We observed high pup mortality at two sites in Southern Puget Sound (discussed in Reproduction). Newby (1971, 1973b) observed a high incidence of prenatal and neonatal deaths, including birth defects, in harbor seals at Gertrude Island. Arndt (1973) suggested that the high PCB concentrations found in Gertrude Island seals and the high incidence of abortions and birth defects may be linked. The reproductive effects of chlorinated hydrocarbons, the correlation between chlorinated hydrocarbons and reproductive dysfunctions in other pinnipeds, and the presence of high concentrations of chlorinated hydrocarbons and high pup mortality in Southern Puget Sound harbor seals suggests a link between the contaminants and the pup mortality. This link, however, cannot be verified at this time on the basis of our data.

There are distinct differences between both the contaminant concentrations and the type of reproductive dysfunctions that have been found in California sea lions (DeLong et al. 1973, Gilmartin et al. 1976) and ringed seals (Helle et al. 1976a, 1976b), and the dysfunctions and concentrations found in Southern Puget Sound harbor seals.

In Bothnian Bay, reproductive difficulty was caused by occlusions of the uteri, found in 47 out of 109 female ringed seals examined, as well as in a few grey and harbor seals (Helle et al. 1976b). On San Miguel Island, premature pupping occurred in California sea lions with the estimated pup mortality due to premature pupping being as high as 20% of the total pups born (R.L. DeLong, unpublished data reported in Gilmartin et al. 1976). The number of harbor seal pups born full term or prematurely in Southern Puget Sound, found by our study and Newby (1971) indicate a normal rate of pregnancy, eliminating the possibility that there is a high prevalence of uterine occlusions in Southern Puget Sound harbor seals. Birth defects were seen in three of eight dead harbor seal pups found in 1970 on Gertrude Island in Southern Puget Sound (Newby 1973b) and in six out of nine harbor seal pups found dead in 1972 on Gertrude Island (Newby unpublished data). The principal birth defects noted by Newby were omphaloceles and deformities of the tail or body. Birth defects were not reported in the studies on California sea lions and ringed seals. If PCB and DDT are involved in the reproductive difficulties exhibited by these three populations of pinnipeds, their effects appear to be different in these three populations. These differences could be due to interspecific differences in the effects of these contaminants or, if these effects are due to interactions between the contaminants and natural environmental factors such as disease, the differences could be the result of interactions with a different environmental factor in each of the populations.

Variations also exist in the concentrations of PCB and DDT found in the three populations of pinnipeds, indicating that if these chemicals are responsible for the observed effects, there are interspecific differences in the sensitivity to these contaminants. Jensen and Jansson (1976) suggested that the reproductive difficulties in ringed seals may be caused by substances that covariate with PCB and DDT.

There is also a possibility that the reproductive effects are not related to chlorinated hydrocarbons and the variations in contaminants observed are a side effect, or are independent of the reproductive dysfunctions. This is a concern particularly with the Bothnian Bay ringed seal study where differences in concentrations between pregnant and non-pregnant females could be due to the effects of reproductive state on concentrations found in the blubber of females.

Holden (1972) suggested that pinnipeds are put at risk when high concentrations of contaminants are liberated in the body during times of lipid metabolism and stress.

Concentration in fish

Concentrations of PCB and DDE by wet and lipid weight in different species of fish from Southern Puget Sound and from the Hood Canal are shown in Table 19. Concentrations of PCB and DDE in fish from Southern Puget Sound ranged from .014 to .859 ppm PCB and from .001 to .143 ppm DDE by wet weight and from .80 to 15.2 ppm PCB and .058 to 1.69 ppm DDE by lipid weight. The highest concentration by wet weight was found in a herring from Nisqually Reach-Tacoma Narrows are in Southern Puget Sound. The concentration of 0.859 ppm PCB fell well below the federal tolerance limit of 5 ppm PCB in fish for human consumption. The high concentration found in the herring was probably related to the high fat content of this fish, and the concentration of PCB

Table 19. Concentration of PCB and p,p'-DDE in fish.

Site	Date	Species (common name)	Wt. (g)	Concentration (ug/g, wet wt.) PCB	Concentration (ug/g, wet wt.) p,p'-DDE	Concentration (ug/g, lipid wt.) PCB	Concentration (ug/g, lipid wt.) p,p'-DDE	PCB/DDE
			Southern Puget Sound					
Nisqually Reach	3 Nov. 77	Clupea harengus (Herring)	172.*	.859	.143	4.31	.719	6.0
" "	"	Microgadus proximus (Tomcod)	86.2	.224	.019	5.83	.503	11.6
" "	"	Cymatogaster aggregata (Shiner perch)	46.5	.293	.017	2.41	.141	17.2
" "	"	Parophrys vetulus (English sole)	51.4	.154	.009	6.66	.371	17.9
Budd Inlet	21 Nov. 77	Hypomesus pretiosus (Surf smelt)	15.9	.164	.009	9.99	.542	18.4
" "	"	Rhacochilus vacca (Pile perch)	583.*	.304	.034	15.2	1.69	8.9
" "	"	Leptocottus armatus (Pacific staghorn sculpin)	87.7	.077	.005	6.62	.456	14.5
" "	"	L. armatus (Pacific staghorn sculpin)	43.8	.094	.004	7.82	.308	25.4
" "	"	Platichthys stellatus (Starry flounder)	116.*	.097	.003	9.11	.238	38.3
Eld Inlet	4 Sept. 77	Oncorhynchus nerka (Sockeye salmon)	18.2	.036	.006	4.43	.758	5.8
" "	10 June 77	C. aggregata (Shiner perch)	35.0	.294	.017	9.46	.556	17.0
" "	4 Sept. 77	C. aggregata (Shiner perch)	8.6**	.034	.003	.90	.074	12.3
" "	"	L. armatus (Pacific staghorn sculpin)	34.6	.014	.001	.91	.058	15.7
Heron Island	16 Aug. 77	L. armatus (Pacific staghorn sculpin)	43.2	.106	.011	.80	.081	9.9
			Hood Canal					
Skokomish Delta	8 July 77	Porichthys notatus (Plainfin midshipman)	24.3	.319	.031	7.70	.760	10.1
" "	26 Nov. 77	L. armatus (Pacific staghorn sculpin)	50.9	.096	.004	5.82	.262	22.2

* cross section of muscle analyzed

** composite of two fish

and DDE in this fish by lipid weight fell within the range found in other fish.

Mowrer et al. (1977) found concentrations of PCBs ranging from .021 to .84 ppm wet weight in Pacific staghorn sculpin taken from 18 sites in Southern Puget Sound. Risebrough (1969) found .16 ppm PCB and .18 ppm DDT, wet weight, in hake taken from Puget Sound. Otoliths of all but four of the species of fish listed in Table 19 were found in scats of harbor seals and an additional one of these was seen eaten by a seal (see Food Habits). Compared to a mean concentration of 171 ppm PCB in blubber of Southern Puget Sound harbor seals, concentrations of these contaminants in fish eaten by the seals is 200 to 12,200 times lower by wet weight*. DDE concentration differences have a larger range, but are similar to those for PCB.

Concentration factors we found appear to be higher than those reported in the literature. Frank et al. (1973) found captive harp seals concentrate PCB and DDT in their blubber up to ten times the concentration found in their diet on a lipid weight basis. Holden and Marsden (1967) reported an increase of up to about 100 times by wet weight from concentrations of pesticides in fish eaten by grey seals to adult grey seal blubber from E. Scotland. Drescher et al. (1977) reported PCB concentrations approximately 1000 times higher and DDT concentration approximately 100 times higher by wet weight in harbor seals than in fish from the German North Sea. Figures provided by Jensen et al. (1969) indicate an increase in concentration of PCB and DDT from fish to blubber of grey and harbor seals from the Baltic Sea area of approximately ten times by lipid weight, and from 20 to over 1000 times by wet weight. Holden (1972) estimated concentrations of PCB and DDT in blubber of harbor and grey seals from Britain to be 200 times higher by wet weight, and usually less than ten times higher by lipid weight than in

* 20 to 200 times lower by lipid weight.

the fish they feed on.

Body burden in harbor seals and relationship to diet

A rough calculation of the body burden of PCB and DDT and the dynamics of its accumulation can be made. The overall percent composition fat of harbor seals can be roughly estimated at 30% using figures provided by Stirling and McEwan (1975) for the more northern ringed seal and Pitcher and Calkins (1977) for the harbor seal in Alaska. Concentrations of chlorinated hydrocarbons in different tissues of an organism, except brain, usually are similar on a lipid weight basis (Herman *et al*. 1969, Frank *et al*. 1973, Holden and Marsden 1967). A Gertrude Island adult seal (mean concentration in blubber 243 ppm PCB and 17.5 ppm DDE) of 100 kg would be expected to have a body burden of approximately 7.3 g of PCB and .53 g DDE and a whole body concentration by wet weight of 73 ppm PCB and 5.3 ppm DDE.

Estimates of the amount of fish eaten by harbor seals daily based on captive animals range from 5-15 lb (2.3-6.8 kg) and from 5-6% of body weight (Scheffer and Slipp 1944, Finch 1966, Scheffer 1977). From these figures a seal would be estimated to consume its own weight in fish in about 20 days. The mean concentration of PCB and DDE found in four species of fish (eaten by seals) taken at Nisqually Reach near Gertrude Island in Southern Puget Sound was .38 ppm PCB and .05 ppm DDE.

The amount of time required for an adult to reach its body burden of PCB and DDE, assuming complete absorption and no loss, is calculated to be 5-11 years. This figure does not include losses that occur due to incomplete absorption from food, metabolism, excretion and for females, pregnancy and lactation. Losses due to these factors are discussed in later sections. These calculations indicate that seals absorb a majority of the PCB and DDE from their diet and retain a high percentage of it during their life span. Holden and Marsden (1967) estimated that grey seals could reach their body burden in a few years assuming full absorption and no loss. Platonaw and Geissinger (1973) found that the body burden of PCBs in growing piglets (an animal that accumulates large amounts of fat) that had been fed a single dose of PCBs remained nearly static over a 12 week period following the dose.

Regional and local variations in concentrations

Variations in contaminant concentrations and ratios in harbor seals from different areas can be used to gain insights into their ecology. As discussed in the previous section and shown in Tables 17, 18 and Fig. 9, there are significant differences in contaminant concentrations and ratios between most regions. In particular, the differences in the PCB to DDE ratio between most regions is highly significant. Differences in both the PCB and DDE concentrations and their ratios are significantly different between harbor seals from all of Southern Puget Sound, as well as Gertrude Island alone, and all other regions (with a single exception) in DDE concentrations. These differences could be due to differences in degrees of contamination of different areas and the result of regional differences in feeding habits. The former of these probably has the greatest influence on the differences we found. Considering the extended period over which these contaminants build up in the body of seals (discussed in Body burden in harbor seals and relationship to diet) these regional differences indicate that minimal movement of adults occurs between most of the regions examined. In particular the Southern Puget Sound population appears to be reasonably distinct from the other regions.

Frank *et al*. (1973) suggested that differences in chlorinated hydrocarbon concentrations in harp seals from different regions indicated separate sub-population groups. Holden and Marsden (1967) suggested separate breeding grounds and differences in environmental contamination as reasons for regional differences they found in grey and common seals from Scotland. Differences in concentrations of chlorinated hydrocarbons in different age groups of California sea lions in the Channel Islands appears to be due to differences in feeding areas (DeLong et al. 1973, Gilmartin et al. 1976).

In addition to regional differences, within some regions sample size was large enough to examine local site variations. The difference between the PCB to DDE ratio in pups from Dosewallips Delta and Duckabush Delta in the Hood Canal was highly significant ($p < .002$, Student's t-test, two tailed). These sites are separated by approximately 6 km of water. The difference between the PCB to DDE ratio in pups from Willapa Bay and pups and near-term fetuses from Grays Harbor were significantly different ($p < .05$). The difference between PCB and DDE concentrations in two subadults from Nisqually Delta and five subadults from Gertrude Island approached significance ($p < .10$). These sites are approximately 15 km apart.

These differences indicate that seals from these different areas are exposed to different concentrations of contaminants, either due to different feeding areas or habits, and that harbor seals are reasonably philopatric and loyal to a haul out area for a portion of their life span.

Variations in concentrations due to health and blubber thickness

Bonner (1972) recommended caution in interpreting chlorinated hydrocarbon concentrations in seals found dead. The Grays Harbor-Outer Coast region is the only area in which the concentrations of contaminants in animals found dead could be compared to collected animals. The concentration of PCB and DDE and their ratio in the six animals found dead on the outer coast were very similar to the concentrations in the 28 harbor seals collected in

Grays Harbor, though the age class composition of the two groups differed.

Correlation analysis of blubber thickness versus PCB and DDE concentrations indicated there was no significant correlation in the Grays Harbor sample. Sample sizes at other sites were not large enough to allow for correlation analysis. If the Skokomish Delta and Budd Inlet (5 August 1977) pups, which were both born prematurely are excluded, the animals with a blubber thickness of less than 10 mm which apparently would be caused by starvation, tended to have elevated contaminant concentrations.

No significant differences in concentration of chlorinated hydrocarbons in blubber were found in California sea lions (Le Boeuf and Bonnell 1971) and harbor seals (Drescher et al. 1977) found dead, sick, or killed. Bonner (1972) reports finding higher concentrations in poorly nourished grey seal pups than in well nourished pups. Elevated concentrations of chlorinated hydrocarbons in pups found dead that were emaciated and had apparently starved has been reported in harbor seals (Arndt 1973), grey seals (Holden 1972) and captive harp seals (Frank et al. 1973). Addison and Smith (1974) found an inverse correlation between DDT concentration and blubber thickness in male and not female ringed seals, while Addison et al. (1973) found blubber thickness did not account for the variable concentrations found in harp seals. Sladen et al. (1966) found higher DDT concentrations in the blubber of an Adelie penguin after fasting compared to animals collected before fasting. Drescher et al. (1977) found the comparison between blubber thickness and PCB and DDT concentrations to be highly variable.

Our data and most of the literature indicates that blubber thickness does not contribute significantly to differences in the residue concentrations in blubber unless the animal is emaciated or has starved. The concentrations of contaminants in non-emaciated animals found dead usually provide

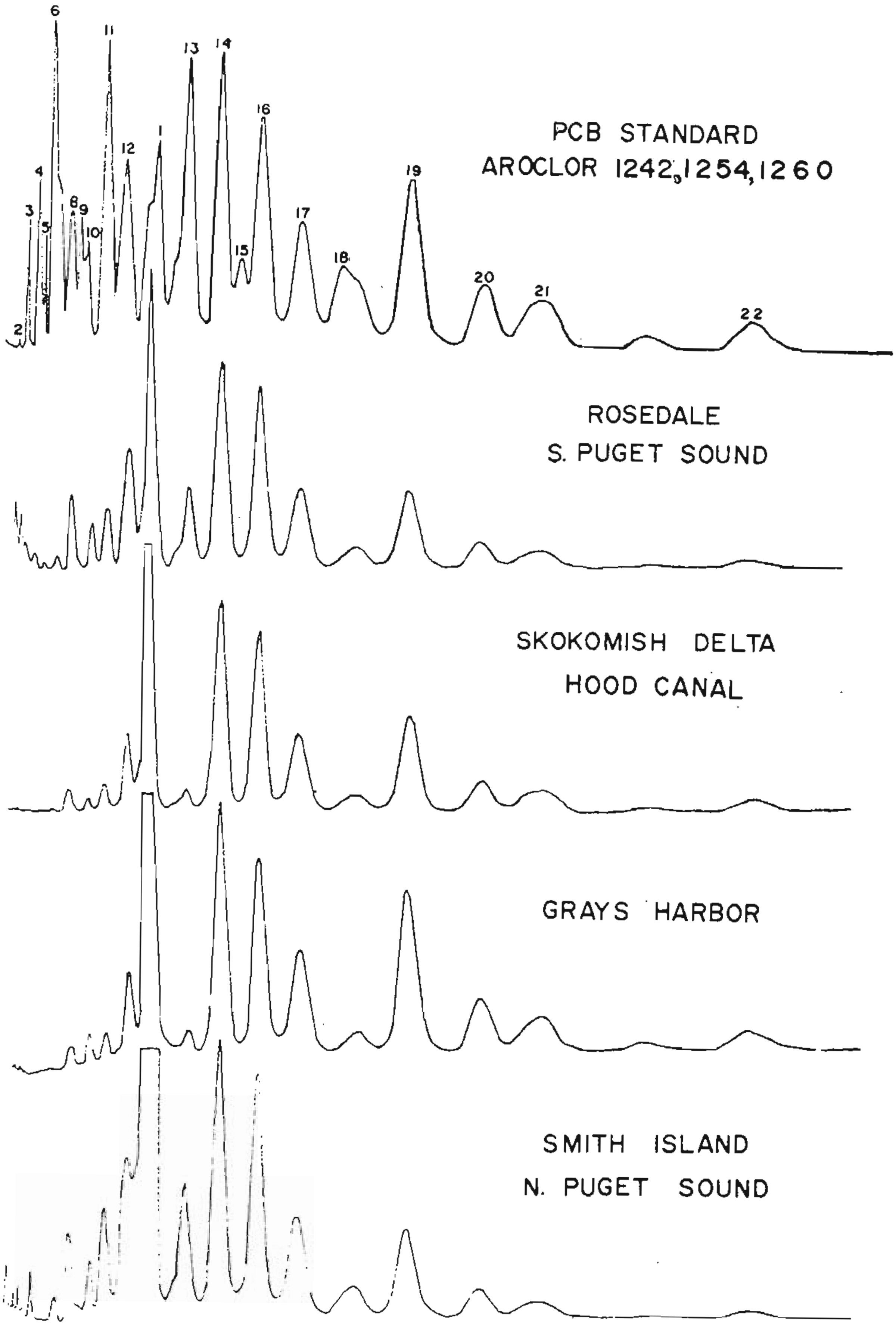

Fig. 9. Chromatograms of regional variations of PCB in blubber of harbor seals. Largest peak in each sample represents p,p'-DDE.

a good indicator of the concentrations in the population provided the contaminant is not contributing to the mortality.

Variations in concentrations due to age class, sex, and reproductive condition

In the seals from Gertrude Island, Grays Harbor, Hood Canal, and Northern Puget Sound the concentration of PCB and DDT in adults and pups (including two near-term fetuses from Grays Harbor) could be compared. In all areas the concentration of both PCB and DDT were significantly greater in adults ($p < .05$, Student's t-test, two tailed).

Concentrations ranged from two to seven times higher in adults than in pups in the different areas. In Grays Harbor, two pregnant females had PCB levels 2.4 times higher and DDE levels 1.4 times higher in blubber than in their fetuses and two lactating females had PCB levels 3.8 times higher and DDE levels 3.1 times higher than their pups. Chromatograms of these animals are shown in Fig. 10. Concentrations of PCB in subadults were between those found in adults and pups at sites where this relationship could be examined. DDE concentrations, however, were higher in subadults than adults at Gertrude Island and Grays Harbor. This factor was also reflected in the higher PCB to DDE ratio in adults than subadults which at Gertrude Island was significantly different ($p < .05$).

In the Grays Harbor sample variations in contaminant levels in harbor seals of different sexes and reproductive condition could be compared. Adult males had higher concentrations of PCB and DDE and a lower PCB to DDE ratio. Both the differences in DDE concentration and the PCB to DDE ratio were significantly different ($p < .05$). The PCB to DDE ratio of adult females is higher than both the males and females in the other age classes as well. The concentrations of PCB and DDE were lower in the pregnant and lactating

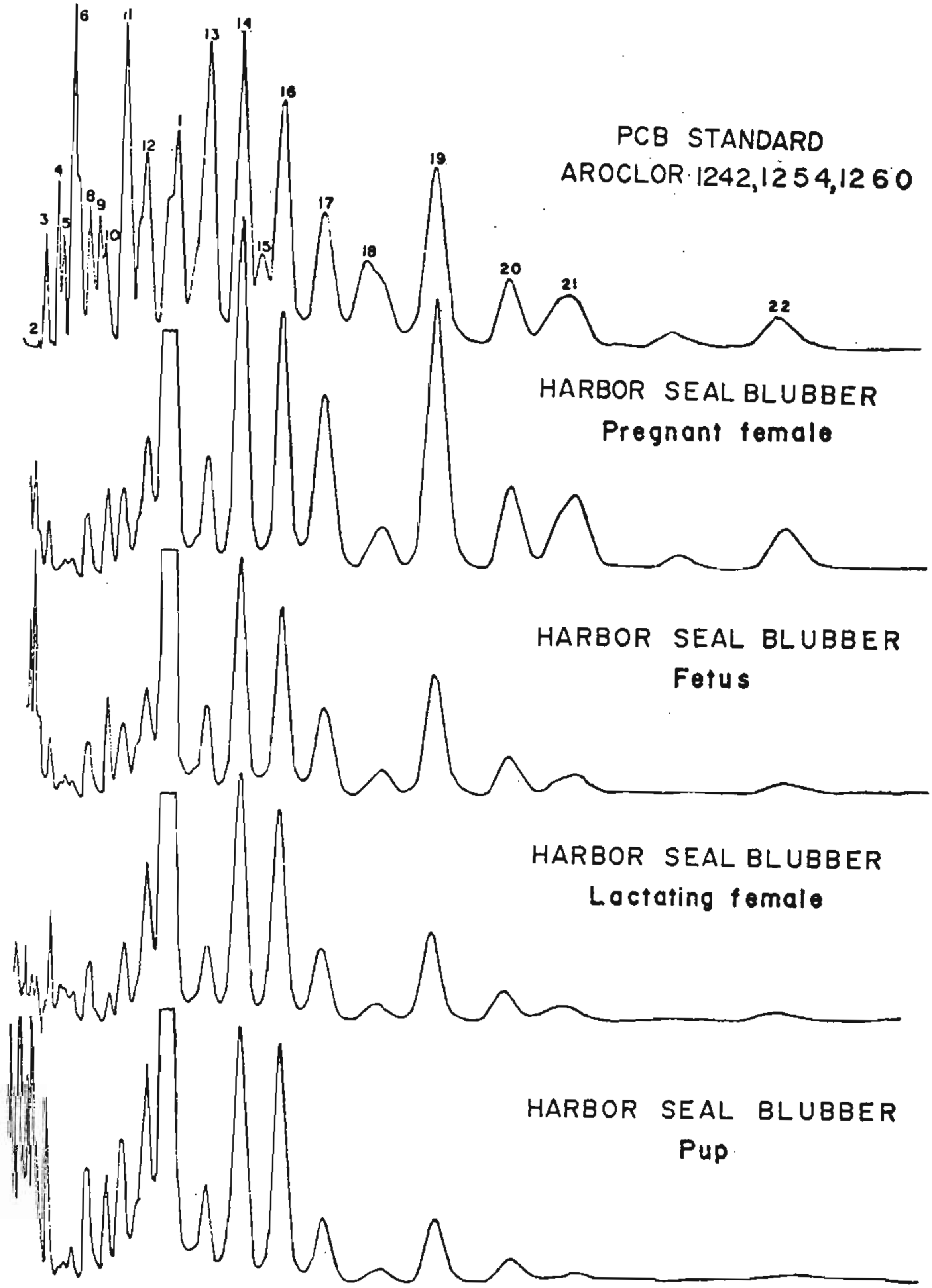

Fig. 10. Chromatograms of PCB in blubber of a pregnant harbor seal and her fetus and a lactating harbor seal and her pup. Largest peak in each sample represents p,p'-DDE.

adult females than in the other adult females, but this difference was not statistically significant ($p > .05$). The blubber thickness of pregnant and lactating females was significantly greater than in the other adult females ($p > .02$) and this factor may be partially responsible for the lower concentration in these animals.

Heppleston (1973) and Addison and Brodie (1967) reported increases in chlorinated hydrocarbon concentrations from grey seal pups to mothers, of approximately two-fold. Holden and Marsden (1967) found concentrations only higher (less than two-fold) in grey and harbor seal adults compared to pups. Jones et al. (1976) reported higher concentrations in harp seal lactating females than in their pups, though the increase was variable. Helle et al. (1976b) found concentrations of PCB and DDT approximately 30% lower in fetuses than in mothers.

Concentrations of PCB and DDE have been correlated to age in male but not female ringed seals (Addison and Smith 1974, Helle et al. 1976b). Addison and Brodie (1977) estimated losses of PCB and DDE due to pregnancy and lactation in female grey seals roughly equaled their yearly intake, and suggested this as an explanation of why concentrations would increase with age in males and not females. Frank et al. (1973) found that concentrations in female harp seals increased with age up to maturity and then leveled off. Losses due to pregnancy and lactation are probably responsible for the lower concentrations of contaminants we found in adult females as compared to males. Addison et al. (1973) using Holden's (1970) data and additional age determination data found only a weak correlation between chlorinated hydrocarbons and age in grey seals, and suggested the large number of lactating females in the sample as a possible cause. Heppleston (1973) reported no correlation to age in grey seals. Arndt (1973) and Drescher et al. (1977)

found no correlation between PCB and DDT concentrations and age in different harbor seal populations. Addison et al. (1973) found no correlation to age in Anas and Wilson's northern fur seal data, but suggested the absence from the sample of animals older than 10 years may have been the cause. A large sample which includes older animals and separate analysis of males and females appears necessary to evaluate the possible correlation of PCB and DDT concentrations to age in pinnipeds.

Though females lose a portion of their chlorinated hydrocarbon burden during pregnancy and lactation there may be other short-term changes during this period that reduce the concentration of contaminants in blubber. Addison et al. (1973) analyzing Holden's (1970) data and new age determinations found reduced residue levels of DDT in lactating female grey seals. Gaskin et al. (1971) found concentrations of total DDT approximately three times lower in pregnant and lactating female harbor porpoises compared to resting and immature females. Helle et al. (1976a, 1976b) found significantly lower concentrations of PCB and total DDT in pregnant ringed seals compared to non-pregnant ringed seals of reproductive age, though the authors suggest contaminant induced reproductive difficulties are responsible for the difference.

Distribution in blubber

Results of the analysis of nine blubber samples taken from different locations on the body of a harbor seal collected in Grays Harbor are shown in Table 20. Concentrations of PCB ranged from 30.3 ppm to 42.0 ppm with a mean of 37.0 ppm. The concentration of DDE ranged from 13.3 ppm to 22.4 with a mean of 17.8 ppm.

Anas and Worlund (1975) analyzed subsamples of the blubber of 12 northern fur seals and found a significantly higher concentration of PCB plus DDT in subsamples taken from homogenized portions of blubber than in subsamples

Table 20. PCB and DDE concentrations in blubber from different portions of the body of an adult male harbor seal taken in Grays Harbor, 6 October 1977.

Location on body	Concentration (ug/g, wet weight) PCB	DDE
ventral-neck	42.04	22.37
" sternum	37.29*	18.37*
" abdomen	30.62	11.27
" pelvic	38.76	17.81
" sternum (inner portion)	30.33*	13.25*
" sternum (outer portion)	38.42*	20.73*
dorsal-thoracic	38.74	18.34
sinistral-thoracic	40.70	20.43
dextral-thoracic	35.70	17.26
Mean	36.96	17.76
Standard deviation	4.10	3.55

* mean of two values

taken before homogenizing. He suggested uneven distribution of chlorinated hydrocarbons or lipids in the blubber as a possible cause. Our results indicate a relatively low degree of variance in chlorinated hydrocarbon concentrations in blubber taken from different locations on the body of a harbor seal.

Excretion and metabolism of contaminants

Concentrations of PCB and DDE in harbor seal scat from three sites is shown in Table 21. Concentrations in scat even from the same site were variable. The concentration of PCB was highest in scat from Skokomish Delta by wet and dry weight but Eld Inlet scat had a higher concentration by lipid weight. DDE concentrations were highest in Skokomish Delta scat.

Chromatograms of the blubber of harbor seals from different areas are shown in Fig. 9 and chromatograms of harbor seal blubber and scat and fish are shown in Fig. 11. Harbor seal samples generally contain a very low peak #13 compared to other samples. Peak #15 is always absent in these samples. In most fish samples, however, peak #13 is one of the principal PCB peaks and peak #15 is sometimes present. As shown in Fig. 11 harbor seal scat chromatograms varied, sometimes resembling the chromatograms of fish, other times those of seal tissues. Since the relative height of peak #13 in scat is generally not higher than in fish the low height of this peak in harbor seal tissues must be the result of selective metabolism of this peak and not selective excretion. The similarity between some of the chromatograms of harbor seal scat and fish indicate incomplete absorption of these compounds from fish also occurs. The degree to which either of these factors contribute to the contaminants in scat varies and is probably partly responsible for the variable concentrations we found in scats.

Metabolites of both PCB and DDE have been found in tissues and scat.

Table 21. Sample size, mean concentrations of PCB and p,p'-DDE in harbor seal scat, and standard deviation.

Site	Sample size	Concentration (ug/g, wet wt.)		Concentration (ug/g, dry wt.)		Concentration (ug/g, lipid wt.)		
		PCB	p,p'-DDE	PCB	p,p'-DDE	PCB	p,p'-DDE	PCB/DDE
Skokomish Delta Hood Canal	6	.45 (.65)	.09 (.17)	1.3 (1.6)	.26 (.41)	18. (14.)	2.9 (1.7)	9.1 (4.4)
Eld Inlet S. Puget Sound	3	.19 (.08)	.017 (.012)	.61	.055	24. (13.)	1.5 (.86)	14. (4.0)
Smith Island N. Puget Sound	1	.079	.012	.28	.043	4.5	.69	6.6

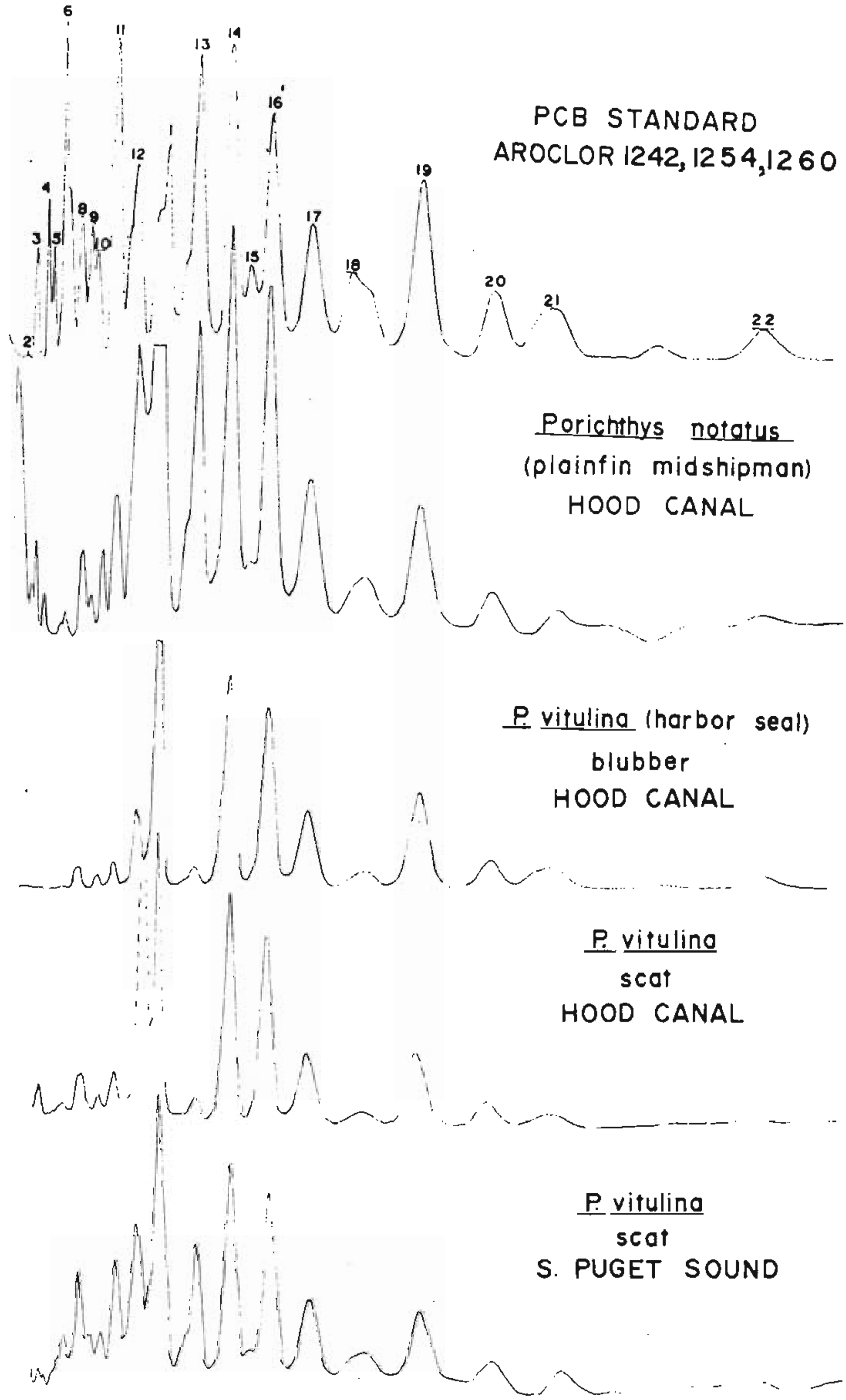

Fig. 11. Chromatograms of PCB in food, blubber and scat of harbor seals. Largest peak in each sample represents p,p'-DDE.

Jensen and Jansson (1976) isolated methyl sulfone metabolites of PCB and DDE in seals from the Baltic. Jansson et al. (1975) identified phenolic metabolites of PCB and DDE in grey seal scat from the Baltic.

The concentration of PCB and DDE found in harbor seal scat by wet weight was similar to the concentration we found in fish eaten by seals. Pastukhov (1975) in experimental studies on the Baikal seal (*Pusa sibirica*), found that the scat weight was 4.2% of the food ration weight. If a similar ratio exists in the harbor seal then the amount of non-metabolized PCB and DDE excreted by harbor seals in scat represents approximately 4% of the seal intake from food. The higher concentration of PCB and DDE by lipid weight in scat compared to fish may be the result of greater absorption of lipids than contaminants in the seal digestive tract. The PCB to DDE ratio in scat from the different areas roughly parallel the ratios found in seals and fish from those areas.

Concentration in other marine mammals

Concentrations of PCB and DDE in three species of marine mammals other than harbor seals, are shown in Table 22. The concentration of both PCB and DDE in the minke whale is considerably lower than the concentrations we found in harbor seal, killer whale, or sea lion. This probably is the result of the diet of plankton and fish of this balleen whale (Hale and Kelson 1959) which likely contain lower concentrations of contaminants than the fish diet of seals, sea lions, and killer whales. The ratio of PCB and DDE also indicates this animal probably had fed predominantly outside of Washington's inland waters. Scheffer and Slipp (1948) report the minke whale only occasionally visits Puget Sound waters south of the Strait of Juan de Fuca.

The killer whale sample we analyzed was of a previously identified whale (L-8) from a pod of whales frequently sighted around the San Juan

Table 22. Concentrations of PCB and DDE in the blubber of some other marine mammals besides harbor seals found dead in Washington State. Tissues of the Minke whale collected by Steven J. Jeffries, Puget Sound Museaum of Natural History and tissues of the killer whale collected by Ken Balcomb, Orca Survey.

Species	Date Collected	Location	Sex	Concentration (ug/g, wet wt.)		
				PCB	DDE	PCB/DDE
Minke Whale Balaenoptera acutorostrata	11 March, 1976	Nisqually Delta S. Puget Sound	M	.15	.55	.27
Killer Whale Orcinus orca	28 Sept., 1977	San Juan Is. N. Puget Sound	M	38	59	.64
Sea Lion (spp. unknown)	24 June, 1977	Twin Harbor Outer Coast	--	2.6	4.8	.54

Islands (Balcomb 1978). The concentration of both PCB and DDE in the blubber of this animal was higher than the concentration we found in any of the harbor seals from Northern Puget Sound. The greater amount of DDE than PCB is probably due either to the killer whale feeding in areas outside of Washington inland waters or to their feeding on migratory fish such as salmon that would not reflect the higher PCB to DDE ratio found in resident fish from inland waters. Scheffer and Slipp (1948) list whales, dolphins, seals, sea otters, squid and fish (including greenling, ling cod, and salmon) as probable food of killer whales. The concentrations of contaminants in this single animal is difficult to evaluate until more is known on this species' biology and on its contaminant concentrations and dynamics.

The concentration of PCB and DDE in the sea lion (sp. unknown) is lower than those reported in California sea lions off Southern California Le Boeuf and Bonnell 1972, (DeLong et al. 1973, Gilmartin et al. 1977).

Recent literature suggested PCB as a possible cause for the decline of harbor porpoise (Phocoena phocoena) populations in the Baltic Sea (Otterlin 1976). Scheffer and Slipp (1948) reported numerous sitings of harbor porpoise in Southern Puget Sound and Elmendorf (1960) lists harbor porpoise as one of the principal marine mammals hunted by the Twana Indians of the Hood Canal area. During our studies in inland waters no harbor porpoises were sighted. Balcomb (1978) in studies of killer whales did not see harbor porpoise south of the Straits of Juan de Fuca in Puget Sound. This evidence suggests a decline of harbor porpoise populations or of their occurrence in Washington inland waters.

Two studies have examined concentrations of chlorinated hydrocarbons in both harbor porpoise and seals from the same area. In the Bay of Fundy total DDT concentrations in the blubber of harbor porpoises (Gaskin et al.

1971) were over two times greater than the concentrations found in harbor seal blubber (Gaskin et al. 1973). Holden and Marsden (1967) found total DDT concentrations roughly three times higher in adult harbor porpoise compared to adult grey and common seals from East Scotland waters.

Several factors may contribute to the higher concentrations found in harbor porpoise. Gaskin et al. (1974) discussed the high metabolic and feeding rate of the harbor porpoise. Fish with high oil and fat content such as herring make up a large portion of the diet of harbor porpoise (Gaskin et al. 1974). Fatty fish would be expected to have higher body burdens of chlorinated hydrocarbons than other fish.

The concentrations of PCB in Baltic Sea seals reported by Helle et al. (1976a, 1976b) are similar to those we found in Southern Puget Sound seals indicating similar levels of contamination by PCB's in these two areas. DDE concentrations, however, are lower in Southern Puget Sound. The apparent decline of harbor porpoise populations in two areas with high PCB contamination warrants further investigations into the potential effects of this contaminant in harbor porpoises.

SUMMARY

Harbor seals utilized five habitats in our study regions: gently sloping cobble or sandy beaches including spits; rocky reefs and ledges; salt marshes; mudflats; and human made environments including log booms, rafts, and floats. Minimum regional populations of harbor seals during the summer were estimated to be 1,237 in Northern Puget Sound (east of Port Angeles), 732 in the Hood Canal, and 136 in extreme Southern Puget Sound (south of McNeil Island). Combining our census data with those of Johnson and Jeffries (1977) yields an estimated harbor seal population in Washington State (not including the Columbia River) of approximately 6,300. Our counts are generally higher than those reported previously.

Pupping occurred at all haul out areas studied. Pupping began in mid-June at Smith Island in Northern Puget Sound, and continued to late January at Skokomish Delta in the Hood Canal. The pupping season at Skokomish has been later and longer than any reported pupping season for harbor seals, to our knowledge. There were often variations in the timing of pupping between haul out areas less than 50 km apart. The percentage of the population producing a pup at eight different haul out sites ranged from 15.2% to 24%, with one exception. Estimated minimum pup mortality (including stillbirths) in the first 3 months of life at different haul out sites ranged from 9.1% to 50%. We found 50% pup mortality at Budd and Henderson Inlets, both in Southern Puget Sound. A high incidence of prenatal and neonatal deaths, some associated with birth defects, at Gertrude Island, Southern Puget Sound, has been reported previously by Newby (1973b). Recovery of birth remnants indicated the majority of births occur on land. Our description of harbor seal behavior complements and extends the information presently available. We focused on haul out, resting in water, and mother-pup behavior.

Identification of otoliths recovered from harbor seal scat indicated at least 20 species of fish were eaten by seals in our study areas. Principal species eaten were blackbelly eelpout at Smith Island in Northern Puget Sound, Pacific hake in the Hood Canal, and staghorn sculpin in Southern Puget Sound. Harbor seal predation on salmon appeared to be minimal.

Concentrations of the chlorinated hydrocarbons, PCB and DDE, in the blubber of 43 harbor seals found dead averaged 171 ppm and 15.2 ppm, respectively, in Southern Puget Sound, 31.0 ppm and 4.38 ppm in the Hood Canal, 14.8 ppm and 4.64 ppm for Northern Puget Sound, and 16.3 ppm and 8.34 ppm on the outer coast. Concentrations of PCB and DDE in the blubber of harbor seals collected by other researchers in Grays Harbor averaged 18.8 ppm and 9.0 ppm, respectively. Though concentrations of PCB and DDE were significantly higher in Southern Puget Sound where we found the highest pup mortality, a link between contaminants and the mortality cannot be verified by our data. Concentrations of PCB and DDE in fish eaten by seals were roughly 200 to 10,000 times lower by wet weight and roughly 20 to 200 times lower by lipid weight than the concentrations in seal blubber. Our results indicate harbor seals absorb a majority of the PCB and DDE in their diet and retain a high percentage of it during their life span.

Concentrations of PCB and DDE were higher in adults than in pups. Analysis of nine blubber samples taken from different parts of the body of a harbor seal indicate a relatively low variance of residues in blubber from different areas of the body. We found .15 ppm PCB and .55 ppm DDE in the blubber of a minke whale found dead in Southern Puget Sound, 38 ppm PCB and 59 ppm DDE in the blubber of a killer whale from Northern Puget Sound, and 2.6 ppm PCB and 4.8 ppm DDE in the blubber of a sea lion from the outer coast.

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