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LONG-TERM CHANGES IN THE AREAL EXTENT OF TIDAL MARSHES, EELGRASS MEADOWS AND KELP FORESTS OF PUGET SOUND

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KEY WORDS

Eelgrass meadows, kelp forests, long-term changes, Puget Sound, tidal marshes.

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EXECUTIVE SUMMARY

Historical and present-day records on the distribution of marshes, eelgrass meadows and kelp forests are compiled and compared to evaluate historical changes in these nearshore habitats. The findings of the study are as follows:

- The most comprehensive records were for tidal marshes, which have decreased 71% in area since records made in the 1800s. Much of the loss is due to diking, filling and dredging.
- Records of eelgrass meadows from before the major influx of humans in the late 1800s were not comprehensive. However, eelgrass losses of 30% and 15% were estimated for Bellingham Bay and the Snohomish River delta, respectively.
- Eelgrass cover may have increased by approximately fivefold in Padilla Bay.
- Kelp has apparently increased approximately 58% in Puget Sound and the Straits. The greatest increases in kelp distribution were documented in the most populated areas including the Main Basin and south Puget Sound.
- Anecdotal observations indicate that eelgrass and kelp have decreased in distribution in selected subregions of the Main Basin and south Puget Sound.
- Invading species of algae and flowering plants have had a major impact on the distribution of eelgrass and kelp, tideflat and estuarine marsh in some subregions.

Recommendations based on the study results are as follows:

- Monitor habitats in a quantitative manner.
- Investigate causal factors related to dramatic changes in kelp distribution.
- Develop methods to quantify subtidal eelgrass distribution.
- Investigate the factors affecting eelgrass distribution, especially subtidal meadows.
- Incorporate only new quantitative habitat records into a Geographic Information System (GIS) which includes information on water quality and physical site conditions.

INTRODUCTION

The amount of coastal wetlands in the United States has decreased dramatically over the past 70-100 years (Tiner 1984). Of note is the national loss of approximately 120,000 ha of relatively rare estuarine wetlands due to diking, dredging and filling for agriculture and port development (Puget Sound Water Quality Authority 1986). Puget Sound has also experienced substantial loss in the amount of estuarine wetlands for the same reasons (Boulé et al. 1983). Intertidal wetlands of Puget Sound, especially those near urban centers such as Seattle and Tacoma, have suffered most (Bortleson et al. 1980). Loss of wetlands in this region has taken place primarily over the past 100 years; concomitant with the period of most rapid human settlement and population increase. Canning and Stevens (1989) estimated that 58 ha (144 acres) of estuarine wetlands were being lost in Washington State annually.

A growing awareness of the the unique ecological role of wetlands has resulted in the passage of federal, state, and local regulations that limit wetland destruction (Canning and Stevens 1989). Whether the rate of loss of wetlands has occurred in response to these regulations is not known.

To date, studies of the changes in estuarine wetlands of Puget Sound have focused on emergent marshes, tidal freshwater swamps and, to a lesser extent on, unvegetated intertidal flats (Bortleson et al. 1980, Boulé et al. 1983, Hutchinson 1988). Vegetated habitats that are widespread and important to Puget Sound food webs also include macroalgal beds, eelgrass meadows and kelp forests. These latter habitats dominate nearshore areas outside of the direct influence of the major rivers that enter Puget Sound. Fish and shellfish utilize these habitats extensively for food and refuge, and recreational and commercial harvesting of biological resources is heavy in these habitats (Thom 1987). Loss of eelgrass and kelp due to man's activities in Puget Sound has occurred, yet it is not known if these habitats have suffered dramatic declines similar to tidal marshes.

This report summarizes the the spatial extent of the wetland and nearshore plant assemblages in Puget Sound and contrasts this with historical distributions. Analogous to this study is that of Orth and Moore (1984) in Chesapeake Bay. Orth and Moore documented widespread changes in submerged aquatic vegetation (SAV) (i.e., eelgrass, water milfoil) over the past several hundred years. Causes for recent declines in SAV may be related to increased eutrophication and turbidity (Orth and Moore 1984, Davis 1985). Also relevant to the present study is the well-documented decline and regeneration of the kelp forests of southern California, which has been linked to changes in water temperature, grazing pressure and sewage pollution in that region (Harger 1983).

STUDY REGIONS AND HABITATS

We included in the present study the Strait of Juan de Fuca, the San Juan Islands and Puget Sound (Fig. 1). Inclusion of the Strait and San Juan Islands provides sources of data on target habitats from areas which have received relatively less development and disturbance from man as compared with Puget Sound. Hence, these areas serve as the best available reference for evaluating man-caused changes in the habitats of Puget Sound. Information on historical wetland habitat coverage was available for the Strait, San Juan Islands and Puget Sound, although information on all habitat types were not available from all regions.

The study area is broken up into five regions: (1) the Strait, which includes the shorelines from Cape Flattery, the San Juan Islands, and the coast north of Admiralty Inlet; (2) northern Puget Sound, which encompasses the region of Admiralty Inlet and south to approximately the southern tip of Whidbey Island; (3) Hood Canal; (4) the Main Basin, which stretches from the southern tip of Whidbey Island (Possession Point) to Point Defiance; and, (5) southern Puget Sound, which is the area south of Point Defiance (Fig. 1). These regions were further divided into 94 subregions for the purpose of convenience in illustrating eelgrass and kelp bed information on a more local scale (Table 1). The divisions are geographically defined bays, islands or stretches of shoreline. Finally, we identified 33 other areas representing points, banks, shoals and portions of shorelines because of historical references to these specific places (Table 1).

Various schemes have been used to classify vegetated aquatic habitats. The national system developed by Cowardin et al. (1979) has been applied to Puget Sound. This system has been recently "regionalized" by Dethier (1989). Albright et al. (1980) utilized a more traditional scheme, which was applied to all of Puget Sound. Here, we define estuarine wetland and nearshore habitats, those areas included in our study, as tidally influenced shallow water areas containing macrophytic vegetation. Although variously defined in the past, these habitats generally include tidal swamps and marshes, seaweed beds, eelgrass meadows and kelp forests. Tidal flats (i.e., sandflats, mudflats) containing no macroscopic vegetation, but commonly with abundant microalgae, were also included in our analysis areas where data were available. Tidal marshes encompass salt and brackish marshes, which contain a large number of plant species. Eelgrass meadows are formed by the native species *Zostera marina* and the introduced species *Zostera japonica*. The brown alga *Nereocystis luetkeana* forms the kelp forests in the region. We did not include other seaweed beds in our analysis. Our classification scheme generally follows that of Albright et al. (1980).

A general habitat distribution by elevation is shown in Fig. 2. Tidal swamps and marshes are most extensively developed at the mouths of rivers that empty into Puget Sound. Due to the relatively steep topography of much of Puget Sound's shoreline, tidal flats are either found near river mouths or in embayments containing small streams. Seaweed beds develop on cobble,

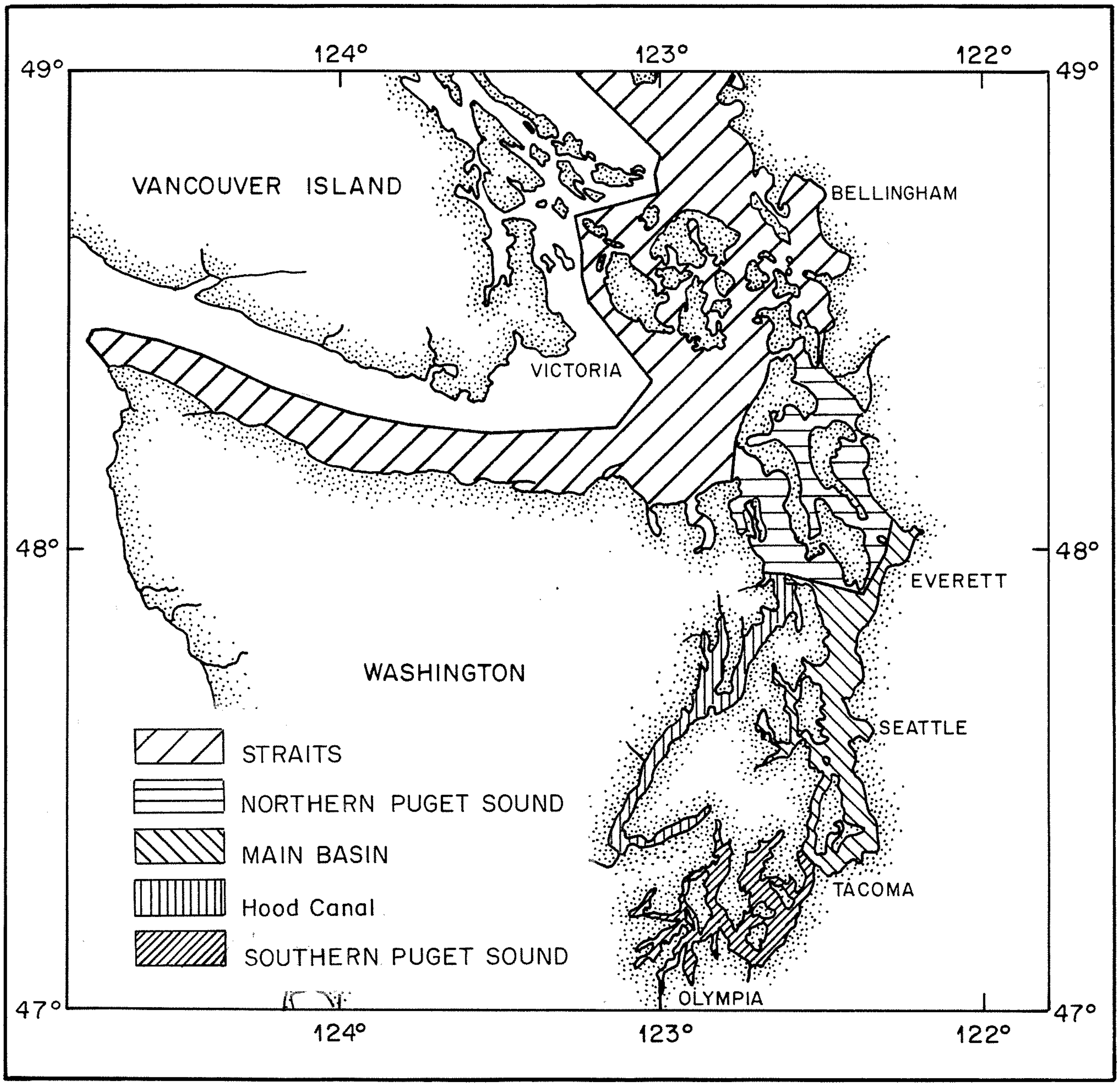

Figure 1. The study area showing the five subregions.

Table 1. Regions, subregions and total shoreline lengths.

Subregion ser. no.	Region	Subregion	Shoreline length (m)
1	Straits	Cape Flat. to Angeles Pt.	98400
2	Straits	Angeles Pt. to NW entr. Sequim Bay	64000
3	Straits	NW entr. Sequim Bay to Diamond Pt.	27150
4	Straits	Diamond Pt. to Cape George	32250
5	Straits	Cape George to McCurdy Pt.	5100
6	Straits	Protection Is.	5550
7	Straits	Smith Is.	675
8	Straits	McCurdy Pt. to Pt. Wilson	6150
9	Straits	Pt. Roberts (US portion)	10400
10	Straits	US-CAN border to Sandy Pt.	45000
11	Straits	Sandy Pt. to SW tip Lummi Peninsula	15400
12	Straits	Portage Is.	11000
13	Straits	SW tip Lummi Penin. to William Pt.	54800
14	Straits	William Pt. to Anacortes Pt.	38000
15	Straits	Anacortes Pt. to Deception Pass	21000
16	Straits	Lummi Is.	29000
17	Straits	Eliza Is.	4800
18	Straits	Hat Is.	1800
19	Straits	Guemes Is.	20600
20	Straits	Sinclair Is.	7600
21	Straits	Cyprus Is.	20200
22	Straits	Burrows Is.	5520
23	Straits	Alan Is.	3480
24	Straits	Barnes Is.	1500
25	Straits	Clarke Is.	2700
26	Straits	Matia Is.	2940
27	Straits	Sucia Is.	10680
28	Straits	Patos Is.	4680
29	Straits	Waldron Is.	15600
30	Straits	San Juan Is.	71800
31	Straits	Orcas Is.	85400
32	Straits	Obstruction Is.	3000
33	Straits	Blakely Is.	15800
34	Straits	James Is.	9480
35	Straits	Decatur Is.	14200
36	Straits	Lopez Is.	64000
37	Straits	Center Is.	2940
38	Straits	Shaw is.	22000
39	Straits	Spieden Is.	8400
40	Straits	Stuart Is.	18000
41	Straits	Henry Is.	12000
42	Straits	Crane Is.	8000
43	Straits	Jones Is.	3540
44	Straits	Vendovi Is.	3000
45	Straits	Flattop Is.	1200
46	Straits	Deception Pass to Rocky Pt.	58400
47	Straits	Hope Is.	3120
48	Straits	Goat Is.	2400
49	Straits	Ika Is.	1920
50	Straits	Deception Pass to Polnell Pt.	26000
51	Straits	Deception Pass to Pt. Partridge	22900
52	Straits	Swinomish Channel	20200
53	N. Sound	Rocky Pt. to Camano Head	29400

Table 1—cont.

Subregion ser. no.	Region	Subregion	Shoreline length (m)
54	N. Sound	Camano Head to NW pt. Tulalip Bay	54000
55	N. Sound	Polnell Pt. to Sandy Pt.	83775
56	N. Sound	Sandy Pt. to Possession Pt.	15225
57	N. Sound	Pt. Partridge to Possession Pt.	63000
58	N. Sound	Pt. Wilson to W. edge Indian Island	16875
59	N. Sound	W. edge of Indian Is. to Tala Pt.	20250
60	N. Sound	Indian Is.	17025
61	N. Sound	Marrowstone Is.	26775
62	N. Sound	Gedney Is.	5025
63	Hood Canal	Tala Pt. to W. pt. Oak Head	45300
64	Hood Canal	W. pt. Oak Head to Dosewallips R.	54450
65	Hood Canal	Dosew. R. to W. shore due W. Ayes Pt	43725
66	Hood Canal	W. shore due W. Ayes Pt. to Ayes Pt.	56400
67	Hood Canal	Ayes Pt. to pt. due E. Hazel Pt.	52275
68	Hood Canal	pt. due E. Hazel Pt. to Foulw. Bluff	43200
69	Main Basin	Foulweather Bluff to Pt. Jefferson	29250
70	Main Basin	Pt. Jefferson to entr. Dyes Inlet	52500
71	Main Basin	Dyes Inlet + Port Wash. Narrows	35625
72	Main Basin	Sinclair Inlet	14250
73	Main Basin	NE Sinclair Inlet to Pt. Southworth	19275
74	Main Basin	Bainbridge Is.	60150
75	Main Basin	Blake Is.	5325
76	Main Basin	Vashon Is. + Maury Is.	71550
77	Main Basin	NW pt. Tulalip Bay to Elliott Pt.	26625
78	Main Basin	Elliot Pt. to Pier 91 (Elliott Bay)	42000
79	Main Basin	Pier 91 to Alki Pt.	15525
80	Main Basin	Alki Pt. to Browns Pt.	39600
81	Main Basin	Browns Pt. to Pt. Defiance	20250
82	Main Basin	Pt. Southworth to Gig Harbor.	22875
83	S. Sound	Pt. Defiance to Johnson Pt.	43500
84	S. Sound	Fox Is.	18225
85	S. Sound	McNeil Is.	16800
86	S. Sound	Anderson Is.	22500
87	S. Sound	Ketron Is.	4500
88	S. Sound	Johnson Pt. to Devils Head	233250
89	S. Sound	Squaxin Is.	14550
90	S. Sound	unnamed Is. S. of Squaxin Is.	1800
91	S. Sound	Herron Is.	3600
92	S. Sound	Stretch Is.	4125
93	S. Sound	Hartstene Is.	36975
94	S. Sound	Devils Head through Gig Harbor	97050
95	Straits	Alden Bank	
96	Straits	Hein Bank	
97	Straits	Partridge Bank	
98	Straits	Barker Reef	
99	Straits	Lawson Reef	
100	Straits	West Bank	
101	Straits	Skipjack Is.	
102	Straits	Davidson Rock	
103	Straits	Bird Rocks	
104	Straits	Salmon Bank	
105	Straits	Speiden Channel Rocks	
106	Straits	White Rock	

Table 1—cont.

Subregion ser. no.	Region	Subregion	Shoreline length (m)
107	Straits	Turn Rock	
108	Straits	rocks W. of Crane Is.	
109	N. Sound	Klas Rock	
110	Main Basin	Blakely Rocks (Bainbridge Is.)	
111	S. Sound	shoal S. of Gibson Pt. Fox Is.	
112	Straits	Pillar Pt. to Low Pt.	
113	Straits	Crescent Rock to Observatory pt.	
114	Straits	Greene Pt. to Dungeness Spit	
115	Main Basin	Restoration Pt. to Pt. White	
116	Straits	Pt. Partridge	
117	N. Sound	Admiralty Bay to Lagoon pt.	
118	N. Sound	Possession Pt.	
119	N. Sound	Alki Pt.	
120	Main Basin	Edwards Pt.	
121	Main Basin	Pt. Vashon	
122	Main Basin	Pt. Defiance	
123	S. Sound	Pt. Evans	
124	S. Sound	Gibson Pt. (Fox Is.)	
125	S. Sound	Brisco Pt. (Hartstene Is.)	
126	S. Sound	Dickenson Pt.	
127	S. Sound	Balch Pass (Anderson is.)	
128	Main Basin	Fauntleroy Cove	
		TOTAL (m)	2622050
		Mean (m)	27894
		TOTAL (km)	2622
		TOTAL (miles)	1626
		Total Straits (km)	1044
		Total N. Sound (km)	331
		Total Hood Canal (km)	295
		Total Main Basin (km)	455
		Total S. Sound (km)	497

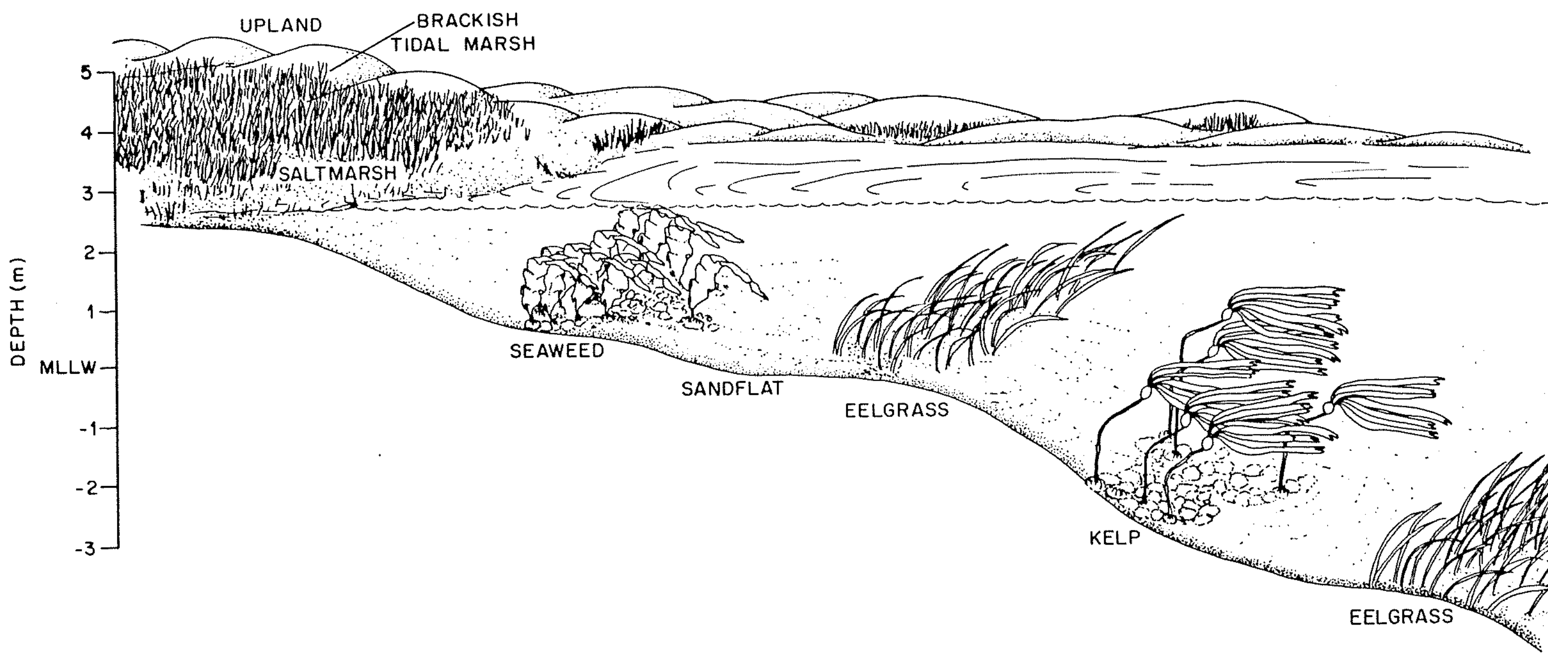

Figure 2. A composite illustration of the general distribution of nearshore habitats in the study area.

boulder and bed-rock substrata along much of the shoreline of Puget Sound. Eelgrass meadows occur on finer unconsolidated substrata, in protected or semi-exposed areas, at elevations 1.8 m above MLLW down to depth of as great as 30 m MLLW (Phillips 1984). Kelp forests are confined to the shallow subtidal zone (down to a depth of approximately 10 m MLLW) in areas where rocky substrata is available for the attachment of the haptera (holdfast) of the plants.

METHODS AND MATERIALS

SOURCES OF INFORMATION

The search for sources of information was initiated through discussions with approximately 50 State and Federal agency personnel, researchers and others familiar with Puget Sound habitats. Literature was searched through the computerized system at the University of Washington. Approximately 400 references found in the search appeared to be pertinent, and were then reviewed. We have largely utilized published information and other documented information (e.g., aerial photographs) in assessing the historical extent of the habitats. Our discussions with many people revealed anecdotal information on specific sites. Some of these sites had been observed, many times by individuals interested in waterfowl and shorebirds, over extended periods of time. These individuals had observed changes (declines) in the extent of kelp and eelgrass which were not related to direct disturbance (e.g., marine dredging). These types of observations are valuable records of habitat changes, and were the basis for the analysis of massive declines in the aquatic vegetation of other estuaries (Orth and Moore 1984). Where appropriate below, we note anecdotal observations but do not include these observations in calculations of quantitative changes in habitat distributions.

Two comprehensive habitat mappings have been done for Puget Sound. The first of these, the Coastal Zone Atlas, is a series of folio sized maps which show the distribution of major nearshore habitats, along with soil and substrata types, land use and other information for the coastal zone of the State. Marshes, eelgrass and kelp were mapped based on observations from aircraft, aerial photographs, and groundtruthing. Aerial photographs were taken in 1973-74, and groundtruthing was carried out in 1977 and 1978 (Richard Albright, pers. comm., telephone, 19 June 1989). The objective of the Atlas was to provide regional estimates that could be used in initial habitat assessments of specific project sites. It was not meant to provide a method or format for routine inventory. The minimum polygon mapping unit for wetlands data is approximately 0.1 $inch^2$, which corresponds to about 1 acre. While certain data such as beach sediment composition were gathered at a larger scale, heterogeneous areas were lumped together. The widths of boundary lines within the Atlas are equivalent to about 50 ft at 1:24,000 scale. Therefore, areas near boundaries must be field-verified to ensure accuracy (Albright et al. 1980). The classification system used was derived from a combination of other schemes and was further modified based on field experience. It was hoped that the maps would be used in conjunction with the wildlife descriptions contained within the two-volume Land Cover/Land Use Narratives published by the Washington State Department of Ecology (WDOE) in 1980 (Albright et al. 1980).

The second comprehensive mapping was performed by the U.S. Fish and Wildlife Service (USFWS 1987). This group produced a series of maps, referred to as the NWI (National Wetland Inventory) maps at a scale of 1:12,000 (7.5-ft USGS quadrangle) on aquatic habitats based on 1:58,000-scale aerial photographs done in the early 1980s and limited groundtruthing. The NWI maps are digitized for Washington State and are recognized as base maps for federal and state inventory work. Our examination and that of Mumford et al. (1990) of these maps indicated that estuarine marshes were generally accurately depicted, but eelgrass meadows and kelp forests were either absent on the maps or underepresented in terms of areal extent. Mumford et al. (1990) found that NWI maps contained only presence or absence information and did not include whether aquatic beds were drift or attached vegetation or what types of vegetation were present.

Several significant sources of marine habitat distribution exist, including aerial photographs taken periodically by the Seattle District Corps of Engineers. In addition, Washington Department of Transportation and Washington Department of Natural Resources (WDNR) have aerial photographs from many areas in Puget Sound. Photos from satellites (LANDSAT) are also available, and have been used to map some habitats in Puget Sound (Webber et al. 1987). The difficulty with these records is that season, tidal elevation and area of coverage vary among the records. These factors affect the accuracy of mapping for plants that show strong seasonality in abundance or cover, and plants that are at lower intertidal to subtidal depths (e.g., eelgrass meadows and kelp forests).

The U.S. EPA produced aerial photographs of a large portion of the Puget Sound shoreline that were taken in May and June of 1982 (Duggan 1982). The true-color vertical photographs are produced at a scale of 1:6,000, are contained in seven folio-sized volumes, and cover the northern shore of Fidalgo Island, a portion of the Straits (from Low Point east), the west shoreline of Admiralty Inlet, Hood Canal, Commencement Bay and south Puget Sound. Vegetation habitat types are outlined on acetate overlays. The vegetation/habitat types delineated include the following: forest wetlands, shrub wetlands, marsh wetlands, mudflats, beach, rocky shore, rooted aquatics and floating aquatics. Because the photographs were taken early in summer, kelp forests are not well represented.

In 1988, approximately 66% of the Puget Sound shoreline was photographed by the Environmental Monitoring Systems Laboratory in Las Vegas (EMSLV, U.S. Environmental Protection Agency (EPA)) for the purpose of developing a protocol for mapping and monitoring wetland and nearshore habitats in Puget Sound (Mumford 1988). The protocol is being developed by WDNR for the Puget Sound Ambient Monitoring Program (PSAMP). Color infrared photographs were taken at several scales (1:12000; 1:24000; 1:36000) during minus tides in July 1988. In addition, multispectral scanning imagery was gathered from the same areas. We relied on the aerial photographs (9- x 9-in prints) from this survey to help verify changes at selected areas in Puget Sound. A report on the protocol is in preparation (Mumford et al. 1990).

Tidal Marshes and Swamps

Changes in the distribution of the tidal marshes of Puget Sound have received considerable attention. The most comprehensive early report on areal coverage of tidal marshes and swamps is Nesbit (1885). These surveys were done to assess the amount of land that could be reclaimed for agriculture in the region. Nesbit apparently utilized navigation maps, interviews with residents and field observations to document the extent of the tidal marshes throughout Washington State as of about 1883.

The most often cited reference documenting changes in tidal wetland for Puget Sound is Bortelson et al. (1980). Bortelson et al. measured and mapped the changes in the areal cover of tidal marshes and swamps in 11 major deltas that had taken place since the mid-late 1800s. They used maps produced either by the U.S. Coast Survey or the U.S. Coast and Geodetic Survey between 1884 and 1908 for the baseline data, and largely topographic maps made in the 1970s by the U.S. Geologic Survey for present-day conditions. Bortelson et al. divided tidal wetlands into subaerial wetlands (i.e., those wetlands landward of the general saltwater shoreline, exclusive of intertidal wetlands) and intertidal wetlands (i.e., wetlands covered and uncovered by the daily rise and fall of the tide; the zone between the mean high-water line and the mean low-water line along the coast). Hutchinson (1988) made estimates of pre-European settlement and present-day cover of tidal marshes and swamps for areas outside the 11 deltas.

Temporal trends in the changes for the Snohomish River and Puyallup River deltas were presented by Boule' et al. (1983), and by Blomberg et al. (1988) for the Duwamish River delta. These latter studies utilized navigation charts containing symbols for marshes to calculate habitat areas. Because port development has been extensive in the Snohomish, Puyallup and Duwamish deltas, navigation charts were available very early (e.g., 1854 for the Duwamish) and were revised relatively often since approximately 1900.

Owing to their importance to waterfowl, the Skagit and Stillaguamish River deltas have been the subject of study for over 40 years by wildlife biologists. In 1947, Jeffrey (1947) established transects at 183-m (200-yd) intervals along the entire extent of the marsh in the Skagit and Stillaguamish deltas. The study area extended from Ikai Island in Skagit Bay to Warm Beach in Port Susan. Transects were aligned along compass bearings that ran approximately perpendicular from the landward edge to the seaward edge of the marsh. The species that occurred at each pace (calibrated for distance covered) along a transect line was noted. These transects were resurveyed using identical methods in 1974 (Brewer 1980). Maps of the vegetation distribution were made from each survey, and the areas occupied by the marsh were calculated.

Finally, Burg (1984) illustrated the historical development of the Nisqually River delta. Her work shows the effects of diking and agriculture on the tidal marshes and swamps in that delta.

Eelgrass Meadows

Hydrographic charts provide the earliest record of the distribution of eelgrass in Puget Sound. The information on eelgrass was not nearly as comprehensive as that for kelp or marshes, probably because eelgrass is not used as a navigational aid and there was no economic justification for assessing the extent of eelgrass in Puget Sound. Furthermore, eelgrass is generally restricted to low intertidal to shallow subtidal depths, and, therefore, is not commonly observed. The fact that the symbols for eelgrass and kelp were combined in 1925 complicated the interpretation of historical meadows (Shallowitz 1962). Many of the early navigation charts have the word "grass" or "grs" to designate areas of eelgrass, however. We utilized this latter information for determining historical coverage in Bellingham Bay, Padilla Bay and Snohomish delta; areas for which nineteenth century hydrographic charts showed eelgrass meadows.

Ronald Phillips (Seattle Pacific University) conducted qualitative surveys of eelgrass at 107 sites throughout Puget Sound and Hood Canal in 1962-3. Surveys were made by boat, and the relative density (i.e., sparse, common, dense, very dense) of eelgrass was verified by underwater observations made by divers. In some cases, Phillips noted flowering, kelp forests and seaweeds associated with the eelgrass. Phillips (1974) stated that nine percent of the bottom (within the photic zone) below MLLW in Puget Sound was occupied by eelgrass.

The Washington State Department of Fisheries (WDF) manages the herring (*Clupea harengus pallasi*) fishery and has conducted herring spawning surveys in Puget Sound since 1975 (Gregory Bargman, WDF, pers. comm., May 1990). Herring spawn preferentially on eelgrass and certain seaweed species, and WDF routinely records the vegetation type upon which spawn was found at their survey sites. D. Pentilla of WDF (Seattle) has been involved in these surveys since 1975, and has a comprehensive knowledge of the location of eelgrass. Pentilla was the source of information on eelgrass distribution for WDF. Areas not surveyed or areas surveyed that had no eelgrass were distinguished and noted.

Although eelgrass was mapped on the Coastal Zone Atlas, we found several locations where omissions were apparent in the final maps. In particular, Padilla Bay is shown to contain eelgrass only in the northern one-third of the Bay, with cover in the remaining portion of the Bay obviously omitted. In addition, the dense and relatively extensive meadows of the Cherry Point region and Lummi Bay did not appear on the Atlas maps. Eelgrass distribution was mapped by tracing the distribution of meadows on mylar overlays of aerial photographs taken in 1973-1974 (William Nelson, Washington Department of Wildlife, WDW, Vancouver, WA, pers. comm., April 1990). Virtually all of the shoreline was groundtruthed in 1977, with the exception of the San Juan Islands, to verify the presence of eelgrass. According to Richard Albright (Environmental Protection Agency, pers. comm., 1989), the WDW project leader, only the meadows which extended into the intertidal zone were accurately represented. In addition, some areas were not groundtruthed because of access problems (e.g., Lummi Bay). We obtained the original mylar habitat maps from W. Nelson and compared the information on the mylars with the Coastal Zone Atlas maps. The distribution of eelgrass according to the Coastal Zone Atlas, as supplemented by information on the original mylar field maps, form the most comprehensive distributional information for eelgrass in the study region. Eelgrass extends into the subtidal zone, especially in areas where water clarity is high (Phillips 1984). Therefore, the distributions based on the Coastal Zone surveys are low.

We examined changes in eelgrass distribution for three areas for which detailed 19th century hydrographic charts showed eelgrass: Bellingham Bay (U.S. Coast Survey, Preliminary survey of Bellingham Bay, scale = 1:20,000, Register No. 502, August 7-11, 1855, Commander James Alden U.S.N.), Padilla Bay (U.S. Coast and Geodetic Survey, Padilla Bay, scale = 1:20,000, Register No. 1815, August 8 - October 28, 1887, Lieut. C.T. Forse, U.S.N.) and Snohomish delta (U.S. Coast and Geodetic Survey, Possession Sound, scale = 1:20,000, Register No. 1728, July 6 - September 1, 1886, Lieut. C.T. Forse, U.S.N.). Bellingham Bay and Snohomish delta have undergone extensive port development which has affected the distribution of eelgrass. Padilla Bay has been subject to agricultural diking landward of the eelgrass meadow, which has affected freshwater and sediment input in that Bay. The accuracy and precision of eelgrass distribution on these maps cannot be totally verified. However, three factors suggest that eelgrass distributions on the maps are somewhat accurate: (1) all surveys were done during the season of maximum standing stock of eelgrass; (2) the density of points where depths were recorded along with substrata observations is high; and (3) relatively small (i.e., <0.1 ha) patches of eelgrass noted on the Snohomish delta chart are present in the same location on the 1988 photographs.

A straight line was drawn to connect the outermost symbols on the hydrographic charts where it was apparent to us that the symbols represented a contiguous eelgrass patch. As eelgrass distribution extends to the subtidal and may not have been easily observed by during these early surveys, we felt that the area enclosed by the lines was a conservative (i.e., low) estimate of the actual area occupied by the patch. The area of each patch within each bay or delta was then measured using a calibrated polar planimeter. For comparison, present day meadows in Snohomish delta were determined from color infra-red aerial photographs (scale = 1:6,000) taken during low tides in July 1988. These 1988 photographs were used to develop the protocol for mapping and monitoring nearshore habitats in Puget Sound (Mumford et al. 1990). Photographs were not available for Bellingham Bay. Information in the Coastal Zone Atlas and discussion with WDF biologists (D. Pentilla, K. Fresh) indicated that little eelgrass was present in the vicinity of the Port of Bellingham. We relied on data from Webber et al. (1987) for the eelgrass meadow in Padilla Bay. In addition, an estimate of seagrass cover in Padilla Bay was made in 1989 using aerial photographs and groundtruthing by Douglas Bulthuis (Padilla Bay Estuarine Research Reserve, Mount Vernon, WA). The areas of the patches were determined using a polar planimeter.

The location of eelgrass as indicated on hydrographic charts between 1852 and 1899, Phillips' notations, Coastal Zone Atlas (including information from the original mylar overlay maps), WDF herring spawning survey information and other limited observations on eelgrass distribution were transferred to two U.S. Department of Commerce (NOAA) navigation charts: (A) Strait of Georgia and Strait of Juan de Fuca, map no. 18400, 35th edition, Nov. 22, 1986, scale 1:200,000; and, (B) Puget Sound, map no. 18440, 18th edition, Jan. 3, 1987, scale 1:150,000. Hereafter these maps are referred to as base maps (see Appendix 1).

The 1988 aerial photographs, WDF, Coastal Zone Atlas photographs in Duggan (1982) and Phillips' observations indicated that early information available on eelgrass was probably not comprehensive for Puget Sound. We did measure the length of shoreline occupied by eelgrass meadows on the base maps based on the data from WDF and the Coastal Zone Atlas. Observations by Phillips in 1962-3 are wide-spread and allow an estimate of range of distribution at that time. The data available did not allow us to develop an estimate, comparable to that for kelp, of the total amount of eelgrass in Puget Sound prior to the major influx of people in the 20th century. Hence, we can only show changes in selected subregions and not for the all Puget Sound regions.

Kelp Forests

Kelp, because it is used as a navigation aid, and because of its commercial importance as a source of potash, had an extensive amount of historical information on kelp presence. The oldest information on kelp was found on early navigation maps (1841) made by the Wilkes expedition. Hydrographic survey maps available as far back as 1852 (U.S. Department of Commerce, Coast and Geodetic Survey) were examined for kelp. Those produced between 1892 and 1924 had symbols distinguishing kelp and eelgrass (Shallowitz 1964), although the symbols were very similar in appearance. From 1925 on, one symbol was used to represent both kelp and eelgrass. Kelp was noted at several places in Puget Sound in the Coast Pilot, a serial publication used to aid navigation, since its first publication late in the 1800s. Some information on the distribution of kelp is summarized by Scagel (1957) based on collections made by phycologists.

The most comprehensive early documentation of the location of kelp forests was developed for the Department of Agriculture (Cameron 1915) as part of the inventory of fertilizer resources of

North America. Surveys were made by George B. Rigg (Rigg 1915) of the entire shoreline in the Straits of Georgia and Juan de Fuca, Puget Sound and Hood Canal by boat in September and October of 1912, and the location of kelp was defined on maps. In addition, a density value of plants within each forest was given. The series of nine maps (sheet numbers 1, 2, 4 to 8, 11, 14) Rigg produced are 44 cm x 30 cm in size with a scale of 1:100,000. These maps are contained as a portfolio separate from Cameron's (1915) narrative of the surveys and supersede three preliminary maps, with a scale of 1:300,000, which were based upon initial surveys conducted by Rigg in the summer of 1911 (Senate Document no. 190, 62nd Congress, 2nd session). In August and September of 1978, the location and areal extent of kelp forests were again mapped, this time from the air, by the Washington Department of Wildlife (WDW). We obtained the original copies of the navigation charts upon which WDW biologists marked kelp forests. This information was used in developing the Coastal Zone Atlas.

A comprehensive mapping of kelp forests was carried out by WDNR in October 1989 using aerial photographs. The region of coastline included the outer coast from Cape Flattery south a distance of approximately 100 km, and the mainland portion of the Straits from Cape Flattery east to Point Wilson. Protection Island was also included. The maps were produced at 1:12,000 scale by projecting color infrared slides onto base maps of the coastline and marking the location of the kelp canopy on the base maps. A total of 25 maps entitled the Washington Coastal Kelp Resource maps (WCKR) were produced. According to documentation provided by WDNR (T. Mumford, pers. comm.), very sparse (i.e., individual kelp plants) can be resolved using this imagery. In general, the maps show kelp as small (<1-mm diameter) specks to larger dark patches on the base maps.

Kelp data were treated as follows. First, all records of kelp location, except the WCKR maps, and the areal coverage of forests were transferred onto base maps (see Appendix 2). A different symbol was used to distinguish each data set (e.g., Rigg 1911-12) on the base maps. The location of forests as drawn on all of the 19th century hydrographic charts we reviewed was transferred onto the base maps. We combined the data from these maps primarily because it was apparent that surveys of shoreline areas became more detailed during the 19th century and the location of kelp beds was among the details added to the maps. The fact that a bed was added did not mean that it had suddenly appeared. In the case of the Coast Pilot information, only the records up until 1926 were transferred. It appeared to us that notes on kelp location were not systematically updated for all regions for each issue of the Coast Pilot. By 1926, however, records on kelp existed for essentially all of Puget Sound. We, therefore, arbitrarily defined 1926 as the cutoff year for comparisons of old (pre-1927) records. New (post-1926) records using the Coast Pilot information was taken from the 1951 publication.

We utilized the two comprehensive kelp surveys to quantify changes in kelp distribution. To do this, we measured the length of shoreline spanned by kelp within the regions of Puget Sound using distributions on maps produced by Rigg in 1911 and 1912 and the 1978 WDW survey (see above). In most cases, kelp formed a linear band that followed the contour of the shoreline. In cases (e.g., Hein Bank) where the forest shape was approximately circular, we recorded the widest dimension. In addition, we measured the shoreline spanned by kelp in the WCKR maps from 1989.

Finally, for locations where either large differences (i.e., >50%) were found between records made in 1911-12 and 1978 in subregions 1-94 or between early chart records and modern records for other subregions, observations on the location of kelp were checked against available aerial photographs taken in 1982 (Duggan 1982) and 1988 by EPA (Mumford et al. 1990).

INTRODUCED SPECIES

Spartina spp.

Cordgrass (*Spartina* spp.) was transplanted into several river deltas in Washington for the purpose of stabilizing dikes and for duck habitat (Parker and Aberle 1979). Much of this planting was done during the 1940s. Since then, *Spartina* has spread and may adversely affect the distribution of native marsh taxa (e.g., *Scirpus* spp.). We summarize what is presently known regarding the distribution of *Spartina* in Puget Sound. At present there is an interagency task force established to develop information on *Spartina* and to investigate ways to manage it (T. Mumford, pers. comm., WDNR, 1989). A map of the locations where *Spartina* spp. has been documented was provided by T. Mumford. B. Aberle provided a summary of distribution as of 1990 (letter dated October 23, 1990 to M. Rylko).

Zostera japonica

Zostera japonica was introduced to the northwest through the importation of oyster seed. The first report from the United States was in Willapa Bay in 1956 (Harrison 1976). This annual species generally is found on mudflats at tidal elevations overlapping, but generally higher than, the native perennial eelgrass *Z. marina* (Harrison 1976, Thom 1990). Competition for space does occur between the two species (Harrison 1982). The ecology of the non-native species is just beginning to be studied. Hence, concern among biologists about the effects of the invader on our native systems has not developed to the degree it has regarding *Spartina*.

Only limited data exists on the spread of *Z. japonica* in Puget Sound. This species has been observed as far south as the Snohomish delta (Thom, pers. observation) where it forms small patches. *Z. japonica* forms extensive stands in Padilla Bay (Webber et al. 1987) and Drayton Harbor (Thom et al. 1989). This species has not been observed in southern Puget Sound.

Sargassum muticum

The brown seaweed *Sargassum muticum* was introduced to British Columbia and Washington with the importation of oyster seed from Japan in approximately 1902 (Scagel 1957). This species has gained world-wide attention because it has displaced other prominent native seaweed species because of its invasive characteristics (Norton 1977).

The first report of *Sargassum* in Washington waters was from Rocky Bay and Andrews Bay, San Juan Island, in 1955 (Scagel 1957). There, were indications that this species was also present in Hood Canal and Willapa Bay at this time (Scagel 1957). *Sargassum* has invaded Puget Sound, although not much is known regarding the pattern of spread throughout the region. Studies by Phillips and Fleenor (1970) in Hood Canal, Harlin (1969) at Steamboat Island in southern Puget Sound and the notes of Phillips from 1962-63 indicate the widespread distribution of *Sargassum* in the region.

The primary concern here is that *Sargassum* has displaced *N. luetkeana*, *Z. marina* and other species, primarily in the low intertidal and shallow subtidal zone (DeWreede 1978). Quantitative data on the percent cover of seaweeds along a rocky intertidal transect at Alki Point have been taken in May for most years between 1979 and 1989 (Thom, unpublished data). These data are summarized here to show the influence of *S. muticum* on the distribution of *N. luetkeana* at that site. *Sargassum* requires bare space for initial colonization (DeWreede 1978). Harvesting of seaweeds, in particular *Nereocystis*, in the study area may have hastened the decline of kelp and the spread of *Sargassum* at this site.

RESULTS

TIDAL MARSHES AND SWAMPS

On the basis of the surveys in the 1880s by Nesbit (1885), tidal marshes and swamps in the 1880s covered a total of 26,792 ha in 7 of the 9 counties bordering Puget Sound (Table 2). Nesbit estimated that less than 405 ha (1,000 ac) of land which would normally be submerged at high tides was diked prior to his survey. The original Skagit-Stillaguamish tidelands covered approximately 520 km^2 (200 mi^2) within 20 km (12 mi) of the present shoreline. Swinomish tide marsh flats, now behind dikes, was 14.5 km (9 miles) long connecting the Skagit delta with Padilla Bay. The tide marshes greatly exceeded the tide flats in area on Puget Sound. Nesbit noted that several rivers including the Skagit, Nooksack, White, Puyallup and Nisqually carried extensive glacial sediments during periods of heavy runoff. These sediments were responsible for maintaining and prograding the deltas and marshes. Nesbit estimated that freshwater marshes of the Puget Sound area were 3-4 times as great in extent as compared to the tide marshes.

Table 2. Area of tidal marshes and swamps and linear length of dikes in counties bordering Puget Sound in 1883 (from Nesbit 1885). (-- = no data)

County	Tideland Area (ha)	Tideland Dikes (mi)
Pierce	2,590	--
King	486	6
Snohomish	7,285	37
Skagit	12,950	150
Whatcom	1,619	--
Island	1,619	6
San Juan	243	--
Total	26,792	

Hydrographic maps from the era of Nesbit's survey for eleven deltas in the study region when contrasted with recent maps indicated substantial changes in wetland distribution in several deltas. Intertidal wetland area had decreased from 7%-100% in 6 of the 8 deltas for which both old and recent data existed (Table 3). The most urbanized deltas (i.e., Snohomish, Duwamish and Puyallup Rivers) had the greatest decline, and the least urbanized (i.e., Dungeness and Nooksack) showed increases in area (Table 3). Subaerial wetlands (i.e., those wetlands landward of the general saltwater shoreline, exclusive of intertidal wetlands) in 8 of the 11 deltas decreased in area, with percentage decreases of 17%-100% (Table 4). Again, non-urbanized deltas showed increases in subaerial wetlands, and highly urbanized deltas showed the greatest losses. On the basis of data from Bortelson et al. (1980) plus data on other areas of Puget Sound as summarized by Hutchinson (1988), total subaerial wetland area in the deltas has decreased by 73% since the late 1800s.

There appears to be differences in tidal marsh and swamp area estimates made by Bortelson et al. (1980) and Nesbit (1885), especially for the Duwamish River (Tables 2, 4). Of Nesbit's estimate of 486 ha for King county, the Duwamish marshes account for 405 ha. In comparison, Bortelson et al. reported 260 ha. These, and perhaps other discrepancies, may be partially explained by the fact that different maps were used to produce the estimates and that interpretations of habitat on historical maps can be speculative. Nesbit had the benefit of groundtruthing the areas in the mid-1880s. However, his interpretation of the boundaries and definitions of tidal marshes are also subject to speculation.

Most of the tidal wetland losses in the three most urbanized deltas took place between about 1910 and 1950 (Figs. 3-5). In the Snohomish delta, Boule et al. (1983) found that most of the losses occurred prior to 1940, and a slight increase occurred between 1940 and 1960 due to marsh establishment in previously unvegetated areas (Fig. 3). Tidal swamps, marshes and flats exhibited dramatic declines in the Duwamish River delta between 1910 and 1940 (Fig. 4). There has been a continued decline in these habitats in that delta since 1940. Unvegetated flats were initially lost

Table 3. Comparison of historical and present day intertidal wetland areas in major river deltas (from Bortelson et al. 1980). (-- = no data)

River Delta	Area (km^2) Historical	Area (km^2) Present	Change Area (km^2)	Change Percent
Nooksack	6.7	8.5	+1.8	+26.9
Lummi	14.0	13.0	-1.0	-7.1
Samish	--	15.0	--	--
Skagit	--	55.0	--	--
Stillaguamish	--	20.0	--	--
Snohomish	13.0	8.8	-4.2	-32.3
Duwamish	8.5	0.0	-8.5	-100.0
Puyallup	7.4	0.1	-7.3	-98.6
Nisqually	7.4	5.8	-1.6	-21.6
Skokomish	5.0	4.5	-0.5	-10.0
Dungeness	5.9	6.0	+0.1	+1.7
Total				
8 of 11 deltas	67.9	46.7	-21.2	-31.2
11 of 11 deltas	--	136.7	--	--

Table 4. Comparison of historical and present subaerial wetland areas in major river deltas according to Bortelson et al. 1980. Data on other areas from Hutchinson (1988). Values in parentheses indicate wetland area estimated to exist prior to dike construction and prior to the initial C&GS topographic surveys (Bortelson et al. 1980).

River delta	Area (km^2) Historical	Area (km^2) Present	Change Area (km^2)	Change Percent
Nooksack	4.5	4.6	+0.1	+2.2
Lummi	5.8	0.3	-5.5	-94.8
Samish	1.9 (11)	0.4	-1.5 (-10.6)	-79.0 (-96.4)
Skagit	16.0 (29)	12.0	-4.0 (-17.0)	-25.0 (-58.6)
Stillaguamish	3.0 (10)	3.6	+0.6 (-6.4)	+20.0 (-64.0)
Snohomish	39.0	10.0	-29.0	-74.4
Duwamish	2.6	0.03	-2.57	-98.8
Puyallup	10.0	0.0	-10.0	-100.0
Nisqually	5.7	4.1	-1.6	-28.1
Skokomish	2.1	1.4	-0.7	-33.3
Dungeness	0.5	0.5	0.0	0.0
Other areas	3.0	2.5	-0.5	-16.7
Total	94.1(144.1)	39.4	-54.7(-88.7)	-58.1(-72.7)

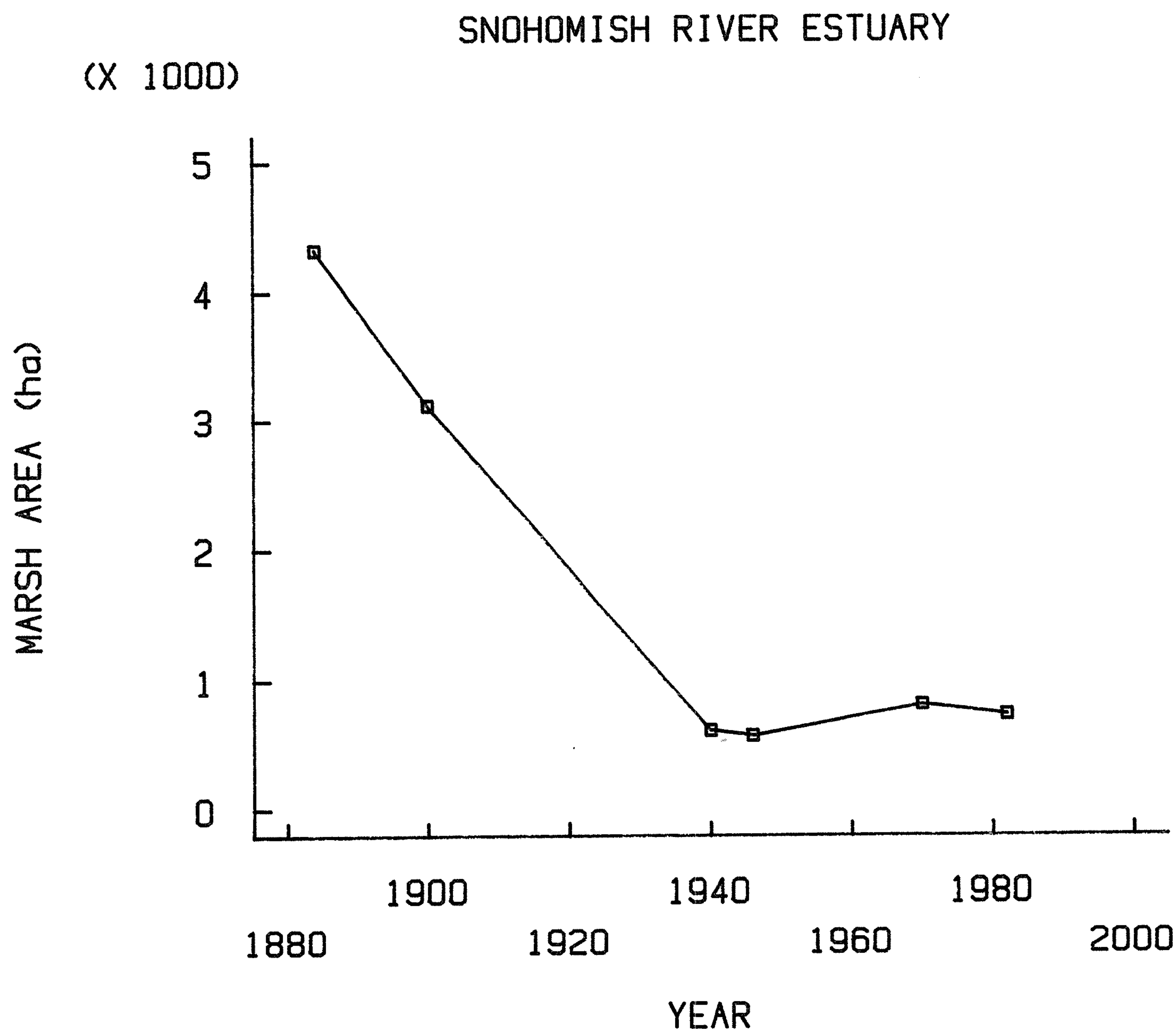

Figure 3. Changes in wetland area in the Snohomish River estuary (from Boulé et al. 1983).

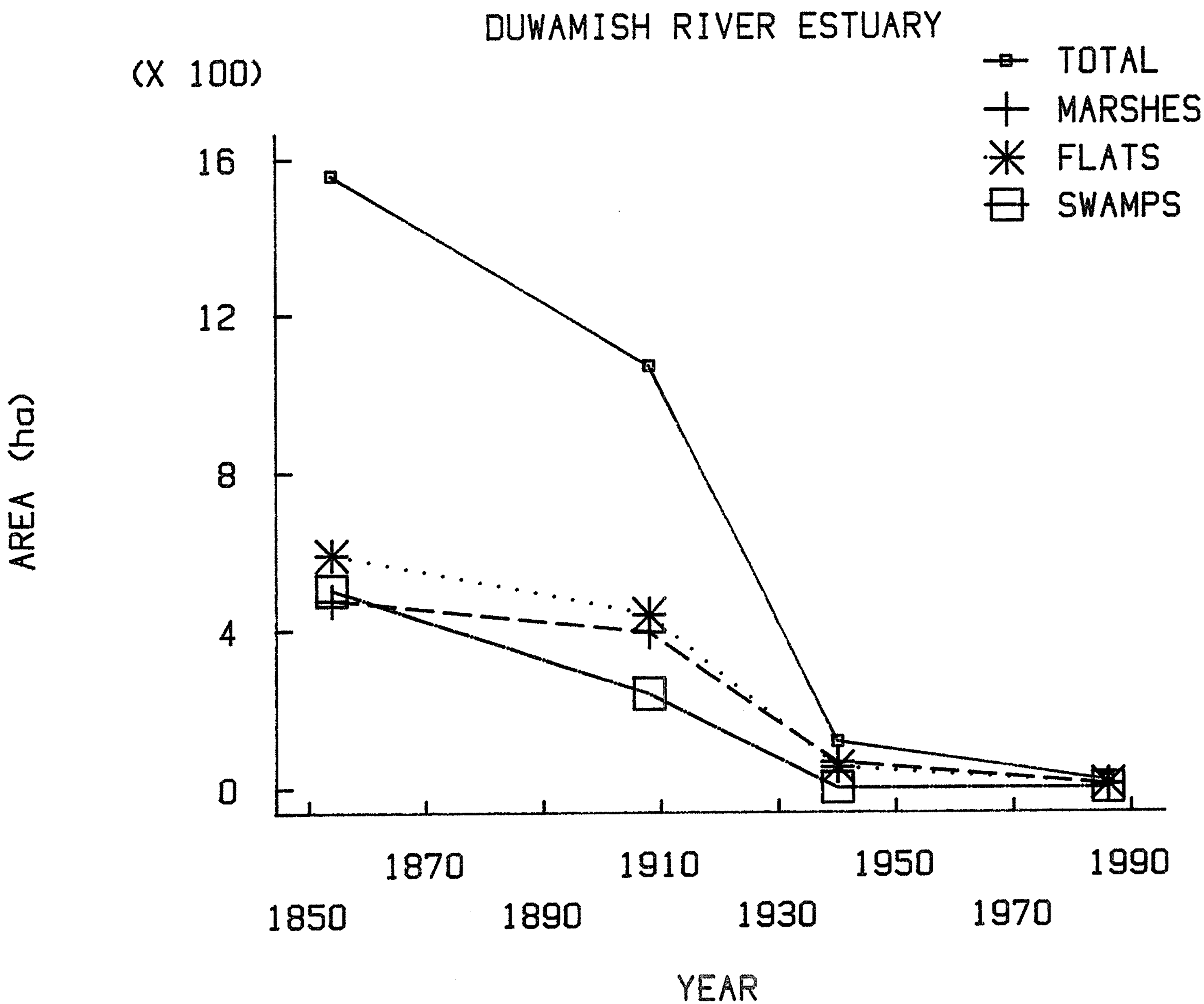

Figure 4. Changes in tidal marshes and swamps, unvegetated shallows and flats and total wetland area in the Duwamish River estuary (from Boulé et al. 1983).

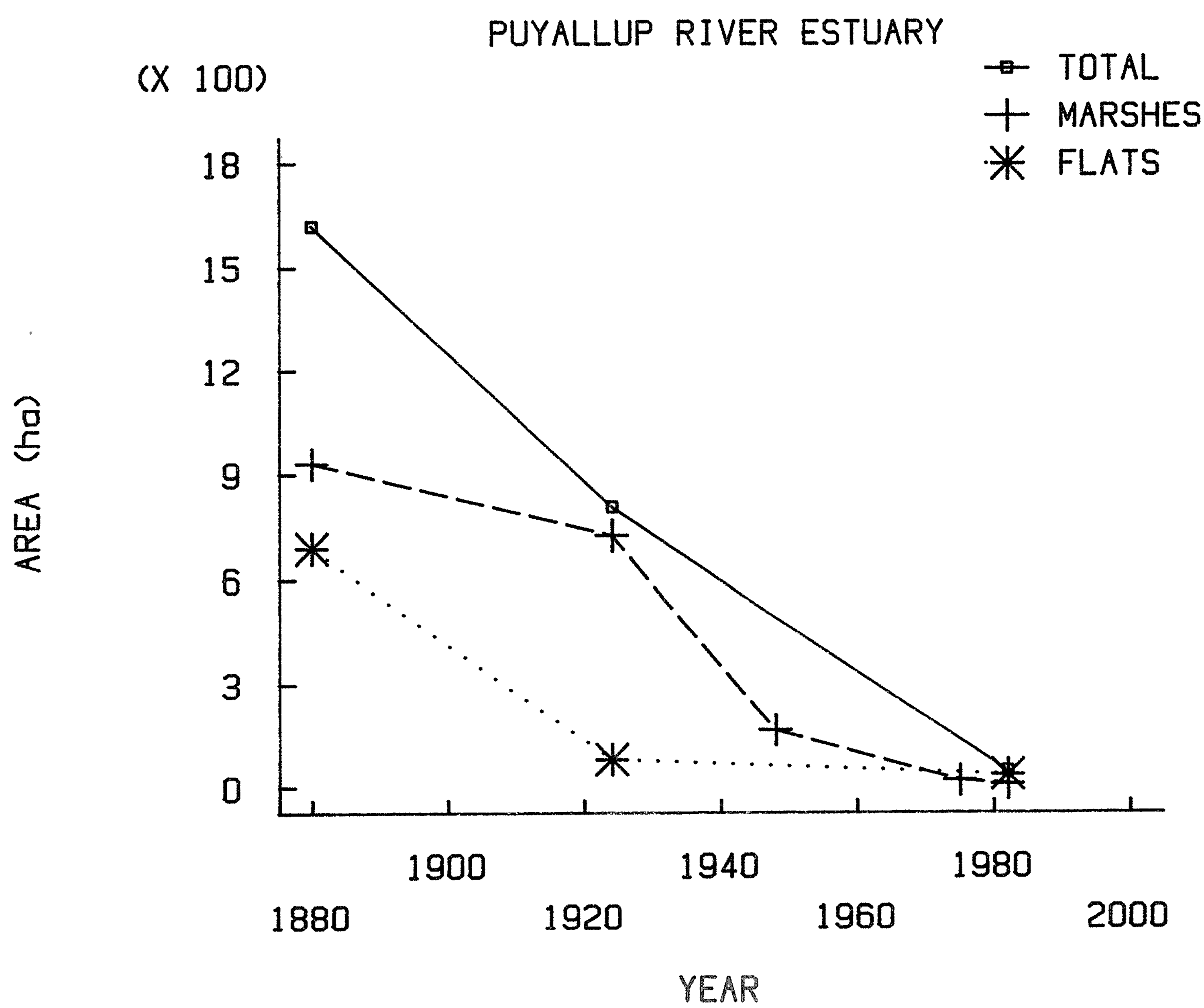

Figure 5. Changes in vegetated wetland, unvegetated flats and total wetland area in the Puyallup River estuary (from Boulé et al. 1983).

between 1880 and 1924 in the Puyallup River delta (Fig. 5). Tidal marshes were most affected by development between 1924 and 1948.

Diking for agriculture was the primary cause for loss of wetlands in the Skagit and Stillaguamish River deltas. Bortelson et al. (1980) showed a decline from 1600 to 1200 ha between 1886 and 1973 in the Skagit delta (Fig. 6). In contrast, the field surveys summarized by Brewer (1980) indicated that 1532 ha of wetland was present in the Skagit it 1947 and that this area increased to 1622 ha by 1974 (Fig. 6). Both Bortelson et al. and Brewer indicated an increase in marsh area in the Stillaguamish over time (Fig. 7). Bortelson et al. showed a change of 300 to 360 ha between the years 1886 and 1973. Brewer's quantitative survey data indicated a change from 506 ha in 1947 to 648 ha in 1974.

Diking in the Nisqually River delta resulted in the conversion of large amounts of unconsolidated shore, emergent wetland and scrub-shrub/forested estuarine wetland to palustrine wetlands since 1878 (Burg 1984; Table 5). Erosion of 160 ha unconsolidated shore had resulted an equal increase in subtidal unconsolidated bottom. A total of 365 ha of subaerial estuarine wetland was lost between 1878 and 1984, most of which took place in the early 1900s.

Boulé et al. (1983) estimated a total area of 422 km^2 estuarine wetlands presently border Puget Sound (Table 6). Of this, approximately 50 km^2 is made up of emergent marshes, scrub-shrub and forested wetlands. The remainder consists of flats, rocky shore and subtidal aquatic bed. Of the 50 km^2 estimated for marshes, scrubshrub and forested wetlands, 39.4 km^2 occur in the seven counties for which Nesbit (1885) provided estimates for a similar set of habitat of 267.9 km^2 (Table 2). The percent wetland loss for these counties based on these estimates is 85.3%.

EELGRASS MEADOWS

Eelgrass was noted on pre-1900s hydrographic charts within only 10 of the 94 defined subregions (Appendix 1). In contrast, Phillips noted eelgrass in 30 subregions, which indicates that the pre-1900 records may be incomplete for eelgrass. Only four of his 107 stations were located in the Straits, where eelgrass is widely distributed based on both the surveys by WDF and the Coastal Zone Atlas (Table 7). Northern Puget Sound, Hood Canal and the Main Basin had the greatest amount of survey information. Eelgrass occurred in all regions, but was noted much less frequently (i.e., only four of 22 stations) by Phillips in South Puget Sound (Table 7). Only a few areas were surveyed by WDF in the Straits and South Puget Sound.

On the basis of the information provided by D. Pentilla, eelgrass meadows have been observed on 393 km of coastline in the study area (Table 8). However, approximately 36% of the coastline has not been surveyed by WDF since the Department began the surveys in 1975. The observations by Phillips in 1962-3 indicate that several subregions not surveyed by WDF do contain eelgrass

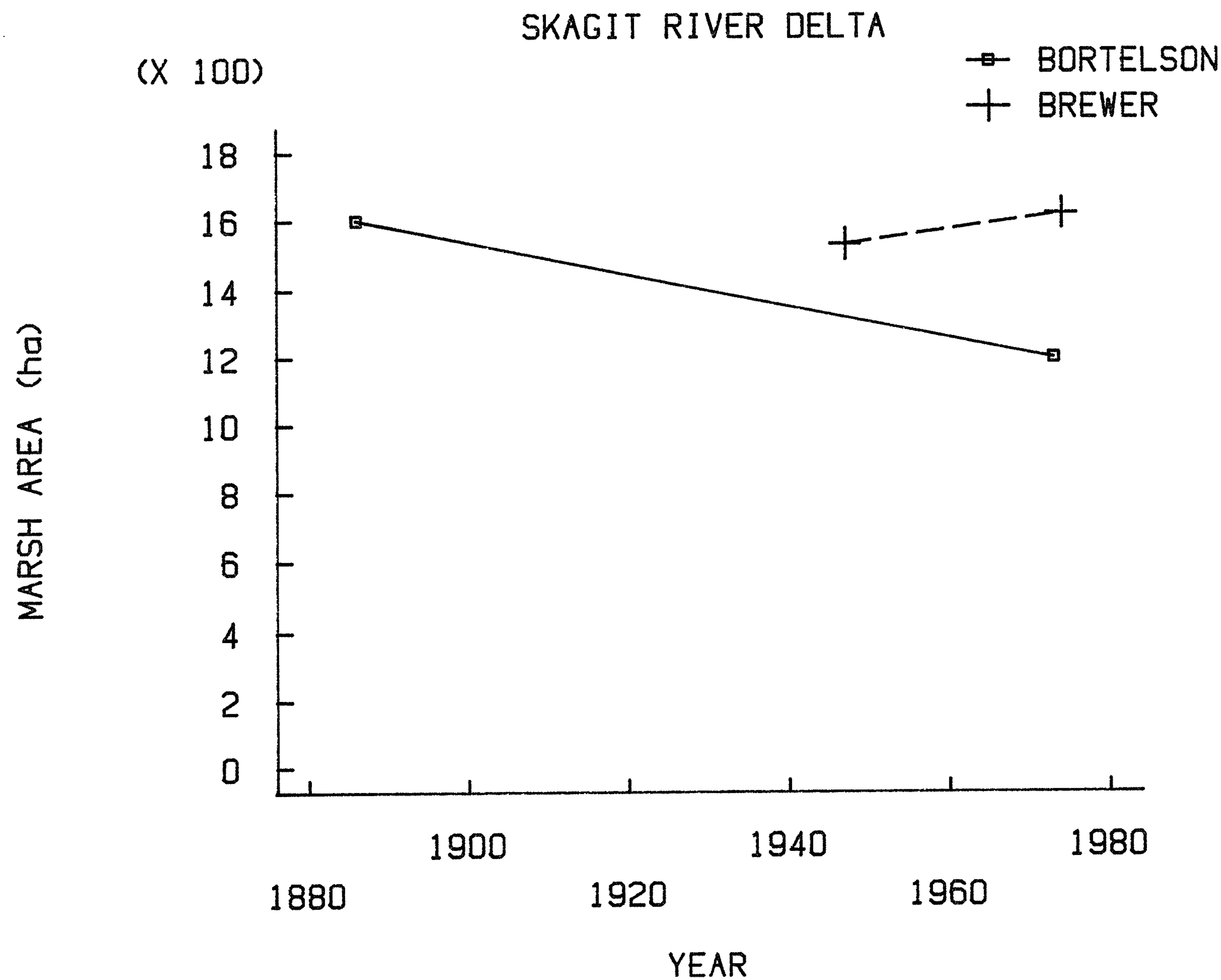

Figure 6. Changes in the tidal marsh area of the Skagit River according to Bortelson et al. (1980) and Brewer (1980).

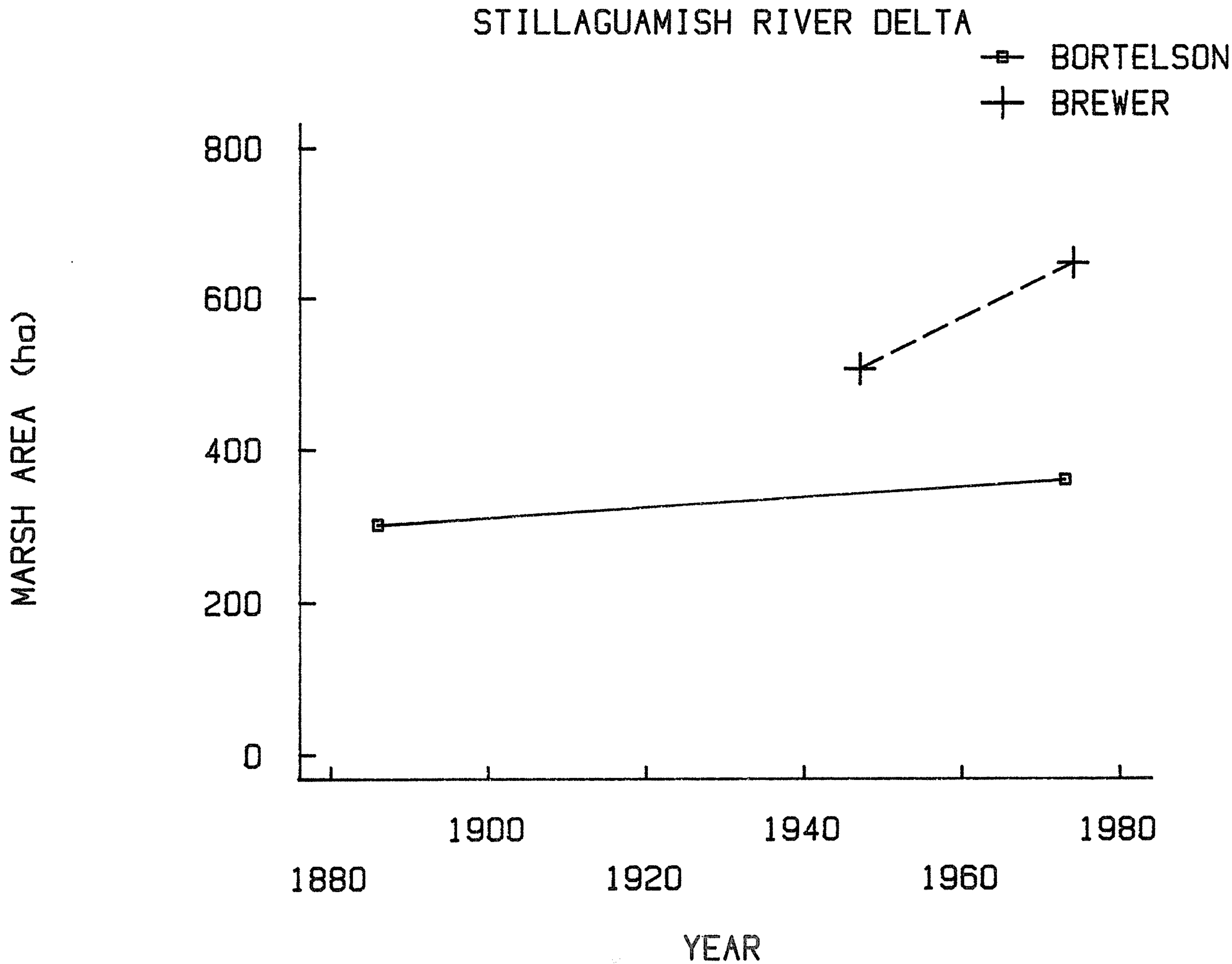

Figure 7. Changes in the tidal marsh area of the Stillaguamish River according to Bortelson et al. (1980) and Brewer (1980).

Table 5. Changes in habitat areas in the Nisqually River delta. Table is from Burg (1984). (-- = not measured.)

Habitats	Area (ha) 1878	Area (ha) 1984	Change Area (ha)	Change Percent
Estuarine:				
Subtidal				
Unconsolidated Bottom	--	--	+160[a]	--
Aquatic Bed	--	--	--	--
Intertidal				
Unconsolidated Shore	740[b]	580[b]	-160	-22
Streambed	--	--	--	--
Aquatic Bed	--	--	--	--
Emergent Wetland	570[b]	250[b]	-320	-56
Scrub-Shrub/ Forested Wetland	95[c]	36[d]	-45	-47
Palustrine:				
Unconsolidated bottom	0	28[d]	+28	+100
Emergent Wetland	0	257[d]	+257	+100
Forested Wetland	0	13[e]	+13	+100
Upland/Palustrine:				
Herbaceous/Emergent	140[c]	216[d]	+76	+54
Upland:				
Herbaceous	0	--	--	--
Scrub-Shrub	0	6[d]	+6	+100
Forested	--	--	--	--
Structures	--	--	--	--

[a]Surface area of Unconsolidated Bottom created by the erosion of the same area of Unconsolidated Shore.
[b]Bortelson et al. (1980)
[c]Grid measurement
[d]USFWS (1978)
[e]Klotz et al. (1978)

(Table 7). These subregions occur in all regions of the study area. Hence, the estimate of the amount of coastline with eelgrass based upon the WDF data is low. However, WDF biologists and Phillips probably conducted their surveys in areas which had at least a moderate probability of harboring eelgrass (e.g., bays and shorelines with sandy or muddy substrata).

On the basis of the comprehensive Coastal Zone Atlas surveys, 25.1% (659 km) of the coastline within the study region contained eelgrass in 1977 (Table 8). Northern Puget Sound, Hood Canal and the Main Basin contained substantial amounts of eelgrass. South Puget Sound contained the least. The estimate for the Straits (which includes the San Juan Islands) may be low due to the fact that eelgrass is found predominately in the subtidal zone (T. Mumford, pers.

Table 6. Estuarine wetland areas (ha) for counties bordering Puget Sound. Modified from Boulé et al. (1983).

County	Beaches[1]	Emergent marsh	Scrub/ shrub	Forested wetland	Aquatic bed	Total
Clallum	870	193			827	1890
San Juan	1005	90	5		1593	2693
Island	3387	301	0.4	7	2620	6315
Skagit	2689	1681	0.4	2	516	4888
Jefferson	912	272			2677	3861
King	1483	4			883	1487
Kitsap	1596	115	2		3797	5510
Mason	1462	284	1	2	838	2587
Pierce	211	96	2		1320	1629
Snohomish	3003	1515		214	875	5607
Thurston	932	170			549	1651
Whatcom	1519	24			645	2188
Total	18586	4745	11	225	17140	42190

[1]Includes tidal flats, rocky shores, consolidated and other beach substrata categories.

comm.). Of note is the similarity in shoreline distribution for Hood Canal based upon WDF and Coastal Zone Atlas data. Hood Canal was the only region that WDF had completely surveyed.

Remote sensing studies of eelgrass area by Webber et al. (1987) has shown that Padilla Bay contains ~2,854 ha of eelgrass, March Point contains ~823 ha, Lummi/Bellingham Bay contains ~1052 ha, Skagit Bay contains ~790 ha and Port Susan contains ~406 ha. Perhaps more common are eelgrass meadows that are relatively narrow, but that occupy the relatively steep shorelines of much of Puget Sound. Thom et al. (1984) found that the meadow located between Alki Point and Duwamish Head in Elliott Bay was 3,556 m long, and had an average width of 31.0 m (range = 16.0 to 43.5 m; total surface area = 11.02 ha). Similarly, the meadow located in Seahurst bight between Point Pully and Brace Point was almost continuous for approximately 6 km, but was generally less than 50 m wide (Thom and Albright 1990).

Planimetry of eelgrass distribution in two urbanized bays where hydrographic charts showed definite, large patches of eelgrass indicated that considerable loss of eelgrass had occurred due primarily to filling and dredging for port development. In Bellingham Bay, a patch that measured 48.3 ha was noted on the delta of Whatcom Creek. When the present filled and dredged areas were superimposed on the old map, the area of the patch lost totaled 34.0 ha; a quantifiable loss of 30%. Other areas in Bellingham Bay appeared to have lost little area potentially inhabited by eelgrass. The eelgrass meadow indicated in 1886 along the shoreline immediately south of Preston's Point in Snohomish delta has been lost due to filling and dredging. This patch covered

Table 7. Eelgrass distributions by subregion. ND = not determined; blanks indicate no information.

Subregion ser. no.	Phillips sta. no.	Phillips (1962-1963) abbreviated station names	Phillips observations	Eelgrass distribution: CZ atlas shoreline length (m)	Eelgrass distribution: WDF shoreline length (m)
1				2000	3500
2				8000	13000
3				13500	12000
4				18500	15000
5				0	ND
6				0	ND
7				0	ND
8				3500	ND
9				0	6200
10				23500	34000
11				8000	15000
12				0	8500
13				19500	8500
14				27000	27000
15				3500	
16				6000	7500
17				0	
18				0	
19				11000	ND
20				2500	ND
21				800	ND
22				0	ND
23				0	ND
24				0	ND
25				0	ND
26				300	ND
27				3000	ND
28				2000	ND
29				5000	ND
30				14500	ND
31				15000	11000
32				500	2400
33				2000	ND
34				300	ND
35				800	1200
36				18000	8000
37				400	ND
38				4500	5500
39				0	ND
40				1500	ND
41				4500	3500
42				600	ND
43				600	ND
44				0	ND
45				0	ND
46	D-78	in Similk Bay, west shore	very sparse	8000	7000
47				0	
48				500	
49	D-77	SE tip of IKA Is.		none	0

Table 7—cont.

Subregion ser. no.	Phillips sta. no.	Phillips (1962-1963) abbreviated station names	Phillips observations	Eelgrass distribution: CZ atlas shoreline length (m)	Eelgrass distribution: WDF shoreline length (m)
50	D-95	Coronet Bay	dense	13000	17500
	D-79	just S. Pt. Hoypus, Whidbey Is.	common		
	D-75	just E. Polnell Pt., Whidbey Is.	none		
51	D-93	Partridge Pt., Whidbey Is.	none	500	ND
52				0	ND
53				8000	1500
54	D-47	just off Camano Head	none	20000	5250
	D-42	S. side Kayak Pt.	luxuriant		
55	D-70	Penn Cove	dense, subtidal	32500	12000
	D-71	North Bluff, E. side Whidbey Is.	present		ND
	D-72	S. side Dines Pt., Whidbey Is.	none		ND
	D-45	S. side East Pt., Whidbey Is.	present		ND
56	D-44	S. side Sandy Pt, Whidbey Is.	very sparse	7500	ND
	D-43	Betw. Columbia Bch and Clinton	none		ND
57	D-67	just N. Lagoon Pt., Admiralty Bay	patchy	26000	ND
	D-68	just S. Bush Pt	very dense		ND
	D-69	off Austin, Mutiny Bay	very abundant		ND
	BD-5	Useless Bay	very dense		ND
58	D-80	betw. Pt. Wilson and Pt. Hudson	dense, continuous	11500	2500
	D-82	N. side Kala Pt.		patchy, sparse	
59	D-83	upper Oak Bay, S. of Indian Is.	patchy	600	1350
	D-84	N. side Olele Pt.	dense		
60				6000	7500
61	D-81	Mystery Bay, N. side Kilisut Hbr.	dense	23000	8250
62	D-48	E. side Gedney Is.	common, not dense		0
63	BD-6	just S. Tala Pt.	dense	24500	8250
	D-89	just S. of South Pt., Hood Canal	patchy, but dense		
64	D-91	just N. of ?Tskutsko Pt. (Oak Head)	patchy	15500	23250
	D-92	Duckabush	dense		
65	D-4	betw. Potlatch and Hoodsport	very sparse		5000
	D-5	off Potlatch	very dense		
66				13500	34500
67	D-90	near (NE) Lone Rk, S. of Hazel Pt.	continuous but not dense	19000	9000
68	D-87	across from Port Gamble	continuous but not dense	26500	21000
	D-88	Salsbury Pt., at Hood C. bridge	dense, subtidal		
68	D-97	Kitsap Memorial St. Pk.	patchy		
	D-98	SW corner Foulweather Bluff	dense		
69	D-86	Skunk Bay	dense		15000
70	D-25	N. edge of sand bar, Miller Bay	dense	5500	12000
	D-26	Agate Pass, W. side, just N. bridge	sparse		
	D-27	Liberty Bay, N. side at Poulsbo	none		
	D-28	N. shore of inlet to Liberty bay	dense		
	D-29	in Port Orchard, just S. Brownsville	none		
71	D-35	Dyes Inlet, near Tracyton	dense		300
72	D-34	SW end Sinclair Inlet, near Gorst	none		0
73	D-30	Clam Bay, just N. of Middle Pt.	dense	7500	2625
	D-31	Yukon Hbr, at Colby	none		
	D-33	cove just N. Port Orchard	sparse		
74	D-16	Decatur Reef, off Restoration Pt.	none	20500	13875
	D-17	S. shore Blakely Hbr.	none		

Table 7—cont.

Subregion ser. no.	Phillips sta. no.	Phillips (1962-1963) abbreviated station names	Phillips observations	Eelgrass distribution: CZ atlas shoreline length (m)	Eelgrass distribution: WDF shoreline length (m)
74	D-19	Decatur reef, off Restoration pt.	very sparse		
	D-20	immed. S. Pt. Monroe, Bainbridge Is.	very patchy		
	D-22	just W. Skiff Pt.	none		
75	D-18	N. side Blake Is.	dense in patches	3500	3900
76	D-7	off Ellisport, Vashon Is.	dense	34500	7875
	D-32	Fern Cove, Vashon Is.	none		
	D-36	N. side Beals Pt., Vashon Is.	rare		
	D-37	N. of Neill Pt., Vashon Is.	sparse		
	D-38	Just N. Pt. Sandford, Vashon Is.	abundant but not dense		
77	D-41	Tulalip Bay, E. shore	sparse and patchy	4000	1125
78	BD-7	Carkeek Pk.	dense	19500	12000
	BD-8	just N. Edmonds ferry dock	dense		
	D-8	off 194th Pl., Richmond Bch.	patchy		
	D-13	adj. to N. side Edmonds ferry dock	dense		
	D-21	S. side of Elliott Pt.	present		
79	BD-1	just N. Alki Pt.	moderately dense	2000	ND
	D-23	immed. N. Alki Pt.	dense		
	D-24	Duwamish Head	dense, subtidal		
80	D-1	ca. .25mi. SE Alki Pt.	moderately dense	18500	ND
	D-2	off S. tip Lincoln Pk nr. ferry dk.	sparse		
	D-3	immed. E. Pulley Pt.	patchy, dense		
	D-6	Poverty Bay, near Zenith	patchy, dense		
	D-9	immed. E. of pier at Dash Pt.	dense		
	D-99	Seahurst Pk.	patchy, dense		
81	D-10	Owen Bch., Pt. Defiance, NE section	sparse, large plants	1000	
82	D-39	at Fragaria, on Peninsula, Colvos	abundant		14000
83	D-11	nr Day Is. Yacht Club	very dense		2700
	D-15	off ferry dock, Stielacoom	sparse but large plants		
	D-55	Nisqually Flats	none		
84	D-49	E. side Fox Is., across from Sylvan	none		3500
85	D-53	just N. Still Hbr., McNeil Is.	none		0
86	D-54	Oro Bay, nr Vega, Anderson Is.	none		0
87				1200	
88	D-14	off Dickerson Pt.	none	800	
	D-56	Taylor Bay, accr. from Hartstene Is.	none		
	D-58	Vaughn Bay, nr Vaughn	none		
	D-60	cove inside Graham Pt.	none		
	D-61	off Libby Pt., Hammersley Inlet	none		
	D-63	Totten Inlet	none		
	D-64	Eld Inlet	none		
	D-65	near Gull Hbr, Budd Inlet	none		
89	D-62	inside Potlatch Pt., Squaxin Is.	none		0
	D-66	E. side Squaxin Is.	none		
90				0	
91				0	
92				0	
93	D-57	S. of Dougall Pt., Hartstene Is.	none		0
	D-59	Gerald Cove, Hartstene Is.	none		
94	D-40	Gig Hbr.	none	17000	1000
	D-50	cove nr Arletta, W. end Hale Pass.	sparse		
	D-51	just S. of Raft Is.	none		
	D-52	cove inside South Head	patchy		

Table 8. Length of shoreline occupied by eelgrass based on surveys by Washington Department of Fisheries (D. Pentilla pers. communication) and by the Washington Department of Wildlife for the Coastal Zone Atlas (CZA). Total coastline lengths for each region are given in parentheses. The percent of coastline surveyed by WDF is shown in parentheses under eelgrass distribution.

Region	WDF (1975-1989)		CZA (1977)	
	Eelgrass distribution (km)	Coastline with eelgrass (%)	Eelgrass distribution (km)	Coastline with eelgrass (%)
Straits (1044 km)	206 (80%)	19.8	243	23.3
N. Sound (331 km)	38 (55%)	11.6	141	42.4
Hood Canal (295 km)	96 (~100%)	32.5	104	35.2
Main Basin (455 km)	53 (78%)	11.7	146	32.1
S. Sound (497 km)	~0 (~0%)	~0	25	5.1
Total (2,622 km)	393 (64%)	15.0	659	25.1

61.7 ha in 1886. Eelgrass was also indicated on the northern edge of the delta and due west of Preston's Point. These patches were still present in the 1988 infrared aerial photographs. In addition, the location of two narrow patches, each about 200- to 300-m long in the north channel just inside (east) of Priests Point in 1886, was indicated in the 1886 map. Jetty Island, constructed with dredged material, is located on the former site of small eelgrass patches. The presence of eelgrass in virtually the same location in the 1886 map and in the 1988 photographs indicates that the 1886 maps reliably document at least the major eelgrass patches in the delta. Driscoll (1978) estimated that 40% (465 ha) of the Snohomish delta was covered by eelgrass. In all, a minimum of about 15% of the eelgrass area probably has been lost in the delta over the past 100 years due to filling and dredging.

About 598 ha of eelgrass is indicated on the 1887 chart for Padilla Bay. Roughly 475 ha are located in the northern portion of the Bay (i.e., north of the southern tip of Hat Island), and 123 ha were located in the southern portion of the Bay. The 1986 estimate of eelgrass (*Z. marina* + *Z. japonica*) area in the Bay is approximately 2,854 ha based on the study of Webber et al. (1987). Hence, a 4.8-fold increase in *Zostera* is indicated. According to an 1989 estimate made using aerial photographs and groundtruthing by Douglas Bulthuis (Padilla Bay Research News vol. 2, no. 1, Padilla Bay Estuarine Research Reserve, Mount Vernon, WA), Padilla Bay contained 2300 ha of eelgrass. We estimate that about one third of the present stand of eelgrass in the Bay is comprised of the recent invader *Z. japonica*. The soundings and substrata notes on the 1887 chart are spatially very close together (i.e., within approximately 50-100 m), and cover the entire bay, suggesting that the surveys were very comprehensive. In addition, the season of the survey (August-October) corresponds with the peak biomass of eelgrass in the Bay (Thom 1990).

Anecdotal observations by Ronald Phillips (pers. comm., Seattle Pacific University, telephone, 27 February 1989) indicated that the meadow on the north side of Duwamish Head, in Elliott Bay, has been declining in size since the 1960s. Observations by a resident of Vashon Island (Scott Borkland, commercial fisherman, pers. comm., 22 January 1990) over the past ca. 40 years indicate that eelgrass has declined substantially, particularly in the beach areas located on the northwest shoreline of the Island. Black Brandt geese, which used to inhabit these meadows for extended periods during the winter and feed on the eelgrass, are no longer observed. In addition, young Dungeness crab which inhabited the eelgrass are no longer present in this area. In the area between Point Robinson and Dolphin Point along the eastern shoreline of Vashon Island, a brown scum dominates the leaves of eelgrass plants. The scum, which probably is comprised largely of filamentous and tube-dwelling diatoms, is dense enough in the fall to clog commercial fishing nets and prevent fishing in the area.

KELP FORESTS

The 1841 maps from the Wilkes survey showed only two locations with kelp patches: near Port Townsend and in the vicinity of Neah Bay. The maps are interesting but provide little detail with regard to kelp.

The shoreline lengths of kelp differed between the surveys of Rigg in 1911-12 and those of the WDW in 1978 (Table 9). Overall, there was 53% more shoreline with kelp in 1977 as compared to 1911-12. In 1911-12, 7.8% of the shoreline in the study area was bordered by kelp (Table 9). Whereas, 12.0% of the shoreline was bordered by kelp in 1978.

Both Rigg and WDW studies showed that the Straits region contained the greatest percentage of shoreline occupied by kelp. Hood Canal contained the least coverage of kelp in both surveys. All regions, except Hood Canal, showed increased coverage of kelp in 1978 as compared to 1911-12. The largest increases were recorded for the Main Basin and south Sound; areas which have undergone the most extensive human population increases and urbanization since the turn of the century.

Table 9. Length of shoreline occupied by kelp based on surveys by Rigg in 1911-12 and Washington Department of Wildlife (WDW) in 1978. Total coastline lengths for each region is given in parentheses.

	Shoreline with Kelp (km)			Percent of total shoreline with kelp	
Region	Rigg 1911-12	WDW 1978	Difference (%)	Rigg 1911-12	WDW 1978
Straits (1044 km)	169.8	180.6	+6.4	16.3	17.3
N. Sound (331 km)	15.9	36.3	+128.3	4.8	11.0
Hood Canal (295 km)	1.4	0.8	-42.9	0.5	0.3
Main Basin (455 km)	11.0	64.1	+482.7	2.4	14.1
S. Sound (497 km)	7.4	32.0	+332.4	1.5	6.4
Total (2622 km)	205.5	313.8	+52.7	7.8	12.0

The 1989 WCKR mapping showed kelp shoreline distributions for six subregions in the Straits as being generally intermediate in length between Rigg and WDW data (Table 10). The WDW and WCKR maps illustrated a change of +60.7% and +13.6% in total kelp distribution, respectively, as compared with Rigg for the six subregions.

The estimate of kelp distribution in the Straits made by WDW exceeded the estimate by WCKR by 42% (Table 10). The WDW estimate was greater in five of the six subregions in the region, with estimates for subregion 2 (Angeles Pt. to NW entrance of Sequim Bay) accounting for much of the difference. In contrast, the estimate of Rigg for subregion 2 is very similar to that of WCKR. The reason for the high value for subregion 2 in 1978 is unclear. The data in Table 10 suggest to us that (1) kelp distribution has been relatively stable in subregions 1, 6, and 8 this century; (2) substantial increases in kelp may have occurred in subregion 3 and 4 this century; (3) WDW data from subregion 2 may be anomalous; and (4) because of the relative remoteness and lack of development and riverine influence, Protection Island (subregion 6) may be the most accurate "barometer" of kelp variations over time. This latter point needs further study.

Table 10. Coastline lengths (in meters) occupied by kelp in six subregions in the Straits. Data are from Rigg (1911-12), Washington Department of Wildlife (WDW 1978) and the Washington Coastal Kelp Resources maps (WCKR 1989).

Subregion	Rigg (1911-12)	WDW (1978)	WCKR (1989)
1. Cape Flattery to Angeles Pt.	69,600	84,000	76,750
2. Angeles Pt. to NW entrance of Sequim Bay	5,200	32,500	6,500
3. NW entrance of Sequim Bay to Diamond Pt.	0	5,400	2,350
5. Cape George to McCurdy Pt.	150	2,625	1,050
6. Protection Island	2,100	3,000	4,750
8. McCurdy Pt. to Pt. Wilson	6,150	6,150	3,100
TOTAL	83,200	133,675	94,500

Kelp distribution differed considerably in several subregions between the surveys of Rigg and WDW (Figs. 8-12), and between WDW, Dugan (1982) and WCKR (1989) (Tables 9-11). The distribution of kelp in the 1988 photographs generally agreed with that shown by WDW in 1978 for the subregion (57) between Point Partridge and Possession Point (Table 11). The same was true for the subregion (63) between Tala Point and Oak Head, and for the subregion (80) between Alki Point and Brown's Point. The area just north of Steilacoom, a section of subregion 83 that hydrographic charts had indicated almost a continuous band of kelp, was largely devoid of kelp in the 1988 photos. Even with this apparent decrease, WDW data indicated a large increase in kelp coverage in the subregion since 1912. Incomplete photographic coverage of this subregion prevented the evaluation of the major differences between Rigg and WDW surveys. No kelp was evident in the photos of Ketron Island (subregion 87). Rigg had not indicated kelp on Ketron Island, whereas WDW showed kelp at the north and south points. The south point (Tucksel Point) of Squaxin Island (subregion 89) had kelp in early hydrographic records and in 1978 and 1988, but kelp was not indicated in 1912. Although no 1988 photos covered Toliva Shoal (subregion 111), kelp was not noted there in 1978. Thomas Mumford (pers. comm., March 1990) stated that no kelp has been noted on Toliva Shoals since 1983. Kelp had been reported from this Shoal by several hydrographic surveys as long ago as 1856, and Rigg noted a kelp forest here in 1912. Although older records showed a kelp forest distributed almost continuously around the apex of Point Defiance (subregion 122), a relatively thin band of kelp was noted by us only on either side of the Point and not at the apex. Brisco Point (subregion 125), Hartstene Island, was shown to have kelp on 19th century hydrographic charts, but no kelp was noted by Rigg in 1912, WDW in 1978 or on the 1988 aerial photos.

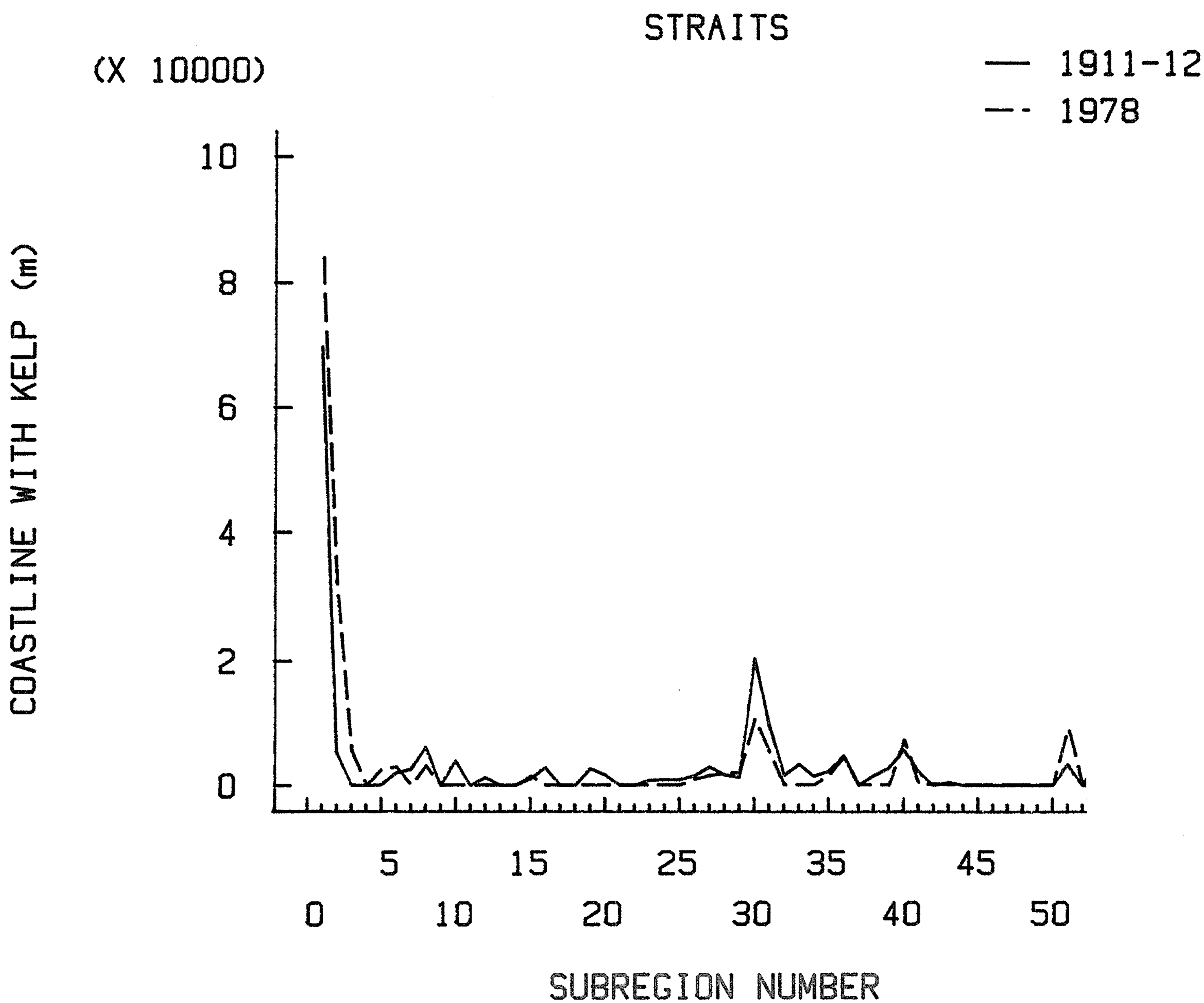

Figure 8. Length of coastline occupied by kelp forests in subregions within the Straits region for records made in 1911-12 and 1978.

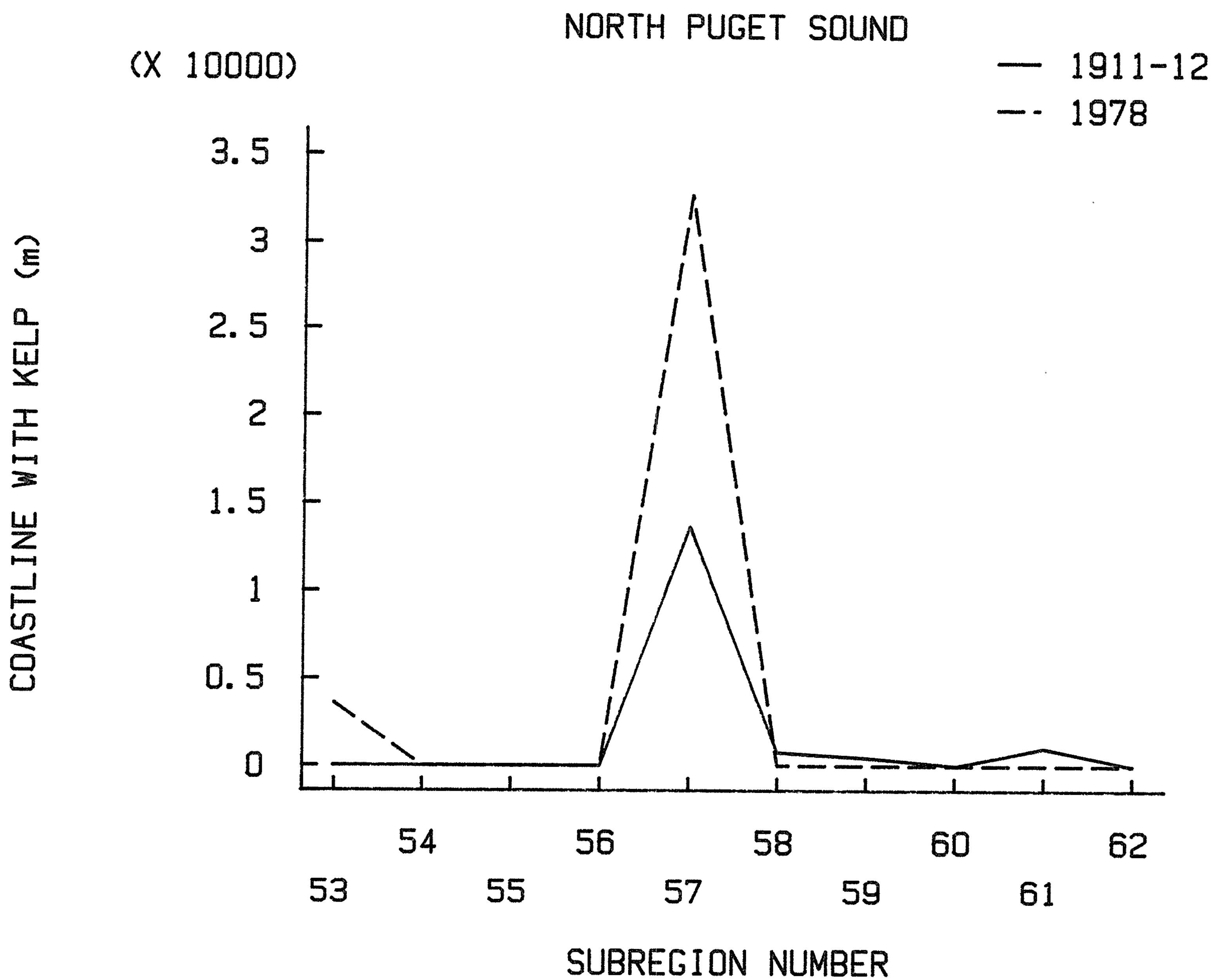

Figure 9. Length of coastline occupied by kelp forests in subregions within the North Puget Sound region for records made in 1911-12 and 1978.

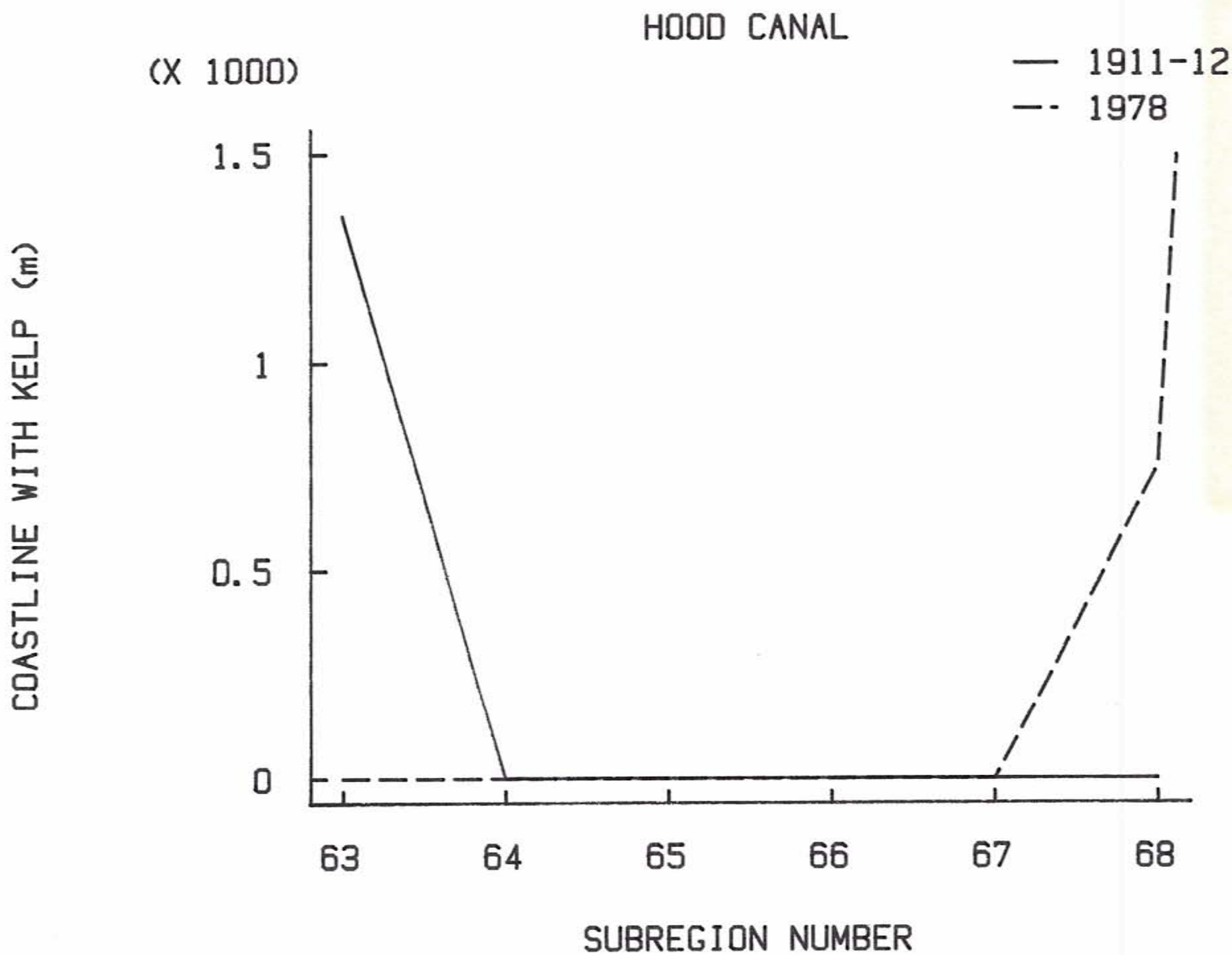

Figure 10. Length of coastline occupied by kelp forests in subregions within the Hood Canal region for records made in 1911-12 and 1978.

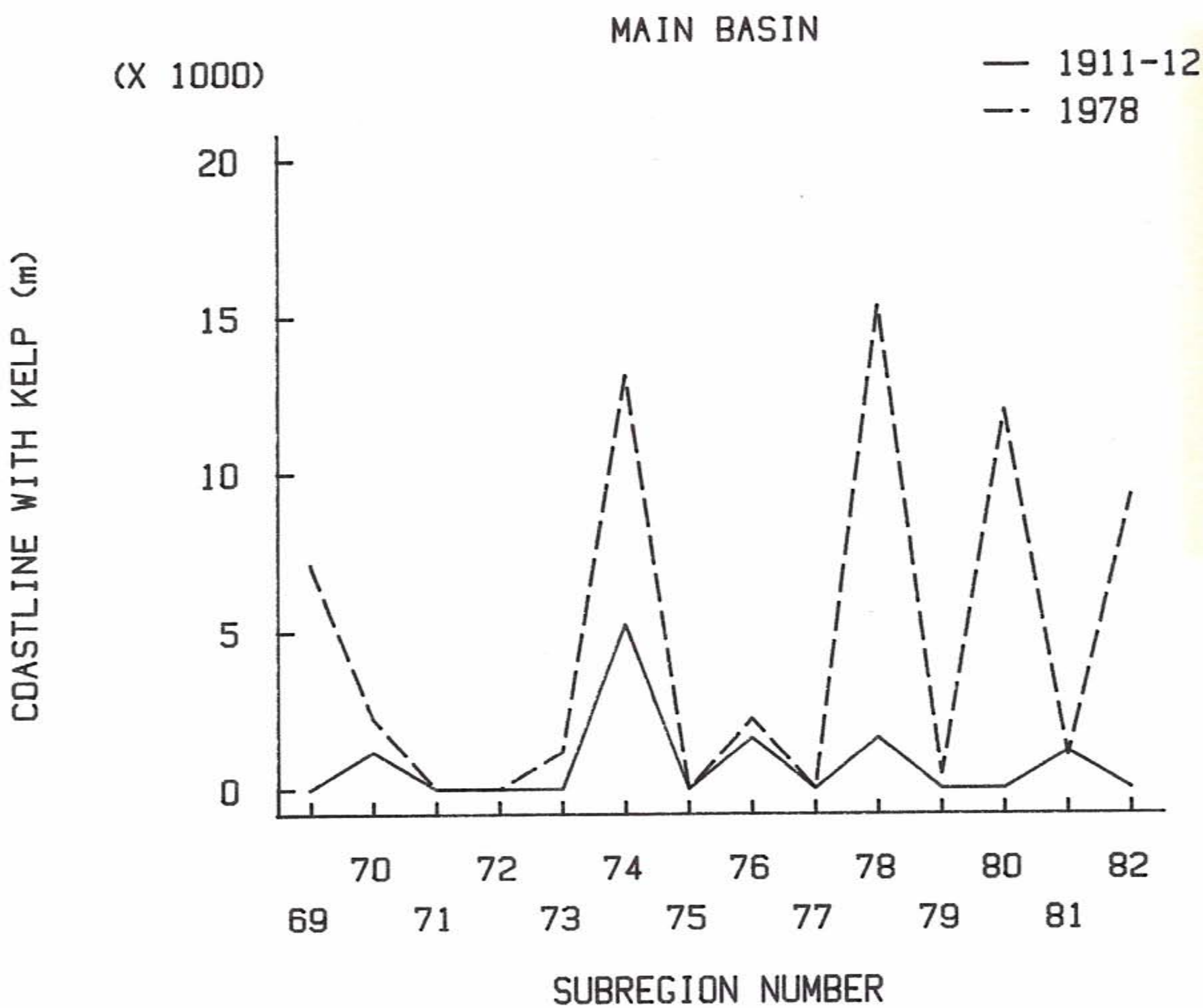

Figure 11. Length of coastline occupied by kelp forests in subregions within the Main Basin region for records made in 1911-12 and 1978.

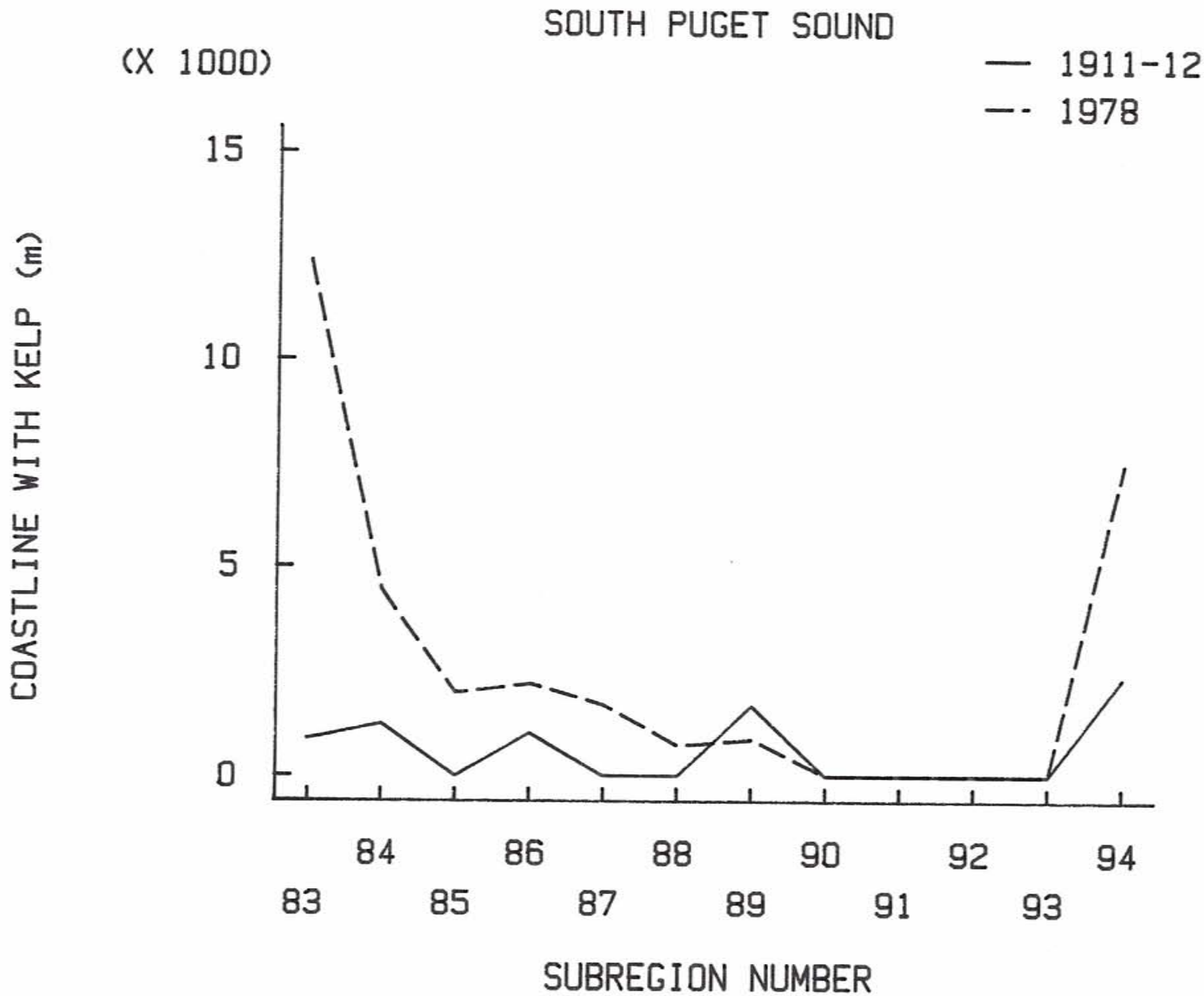

Figure 12. Length of coastline occupied by kelp forests in subregions within the South Puget Sound region for records made in 1911-12 and 1978.

Table 11. Kelp distributions by subregions in 1911-12, 1978, and notes and kelp distributions from 1982, 1988, and 1989 aerial photographs. Units = length (m) of coastline bordered by kelp; blanks indicate no information; yes = kelp present.

Subregion ser. no.	Rigg 1911-12	WDW 1978	WDW - Rigg	Percent change	Duggan 1982	WCKR 1989	1988 aerial photographs (frame no.; flight line)
1	69600	84000	14400	21		76750	
2	5200	32500	27300	525	15600	6500	
3	0	5400	5400	5400		2350	
4	0	0	0	0			
5	150	2625	2475	1650	2900	1050	
6	2100	3000	900	43		4750	
7	2625	0	-2625	-100			
8	6150	6150	0	0		3100	
9	0	0	0	0			
10	4000	0	-4000	-100			
11	0	0	0	0			
12	1300	0	-1300	-100			
13	0	0	0	0			
14	0	0	0	0			
15	1100	1500	400	36			
16	2900	0	-2900	-100			
17	0	0	0	0			
18	0	0	0	0			
19	2700	0	-2700	-100			
20	1700	0	-1700	-100			
21	0	0	0	0			
22	0	0	0	0			
23	900	0	-900	-100			
24	1000	0	-1000	-100			
25	1000	0	-1000	-100			
26	1600	1000	-600	-38			
27	3000	1600	-1400	-47			
28	1700	2000	300	18			
29	1300	2100	800	62			
30	20400	10700	-9700	-48			
31	9600	5100	-4500	-47			
32	1600	0	-1600	-100			
33	3400	0	-3400	-100			
34	1500	0	-1500	-100			
35	2300	1700	-600	-26			
36	4800	4500	-300	-6			
37	0	0	0	0			
38	1600	0	-1600	-100			
39	2800	0	-2800	-100			
40	5700	7300	1600	28			
41	2200	0	-2200	-100			
42	0	200	200				
43	500	0	-500	-100			
44	0	0	0	0			
45	0	0	0	0			
46	0	0	0	0			

Table 11—cont.

Subregion ser. no.	Rigg 1911-12	WDW 1978	WDW - Rigg	Percent change	Duggan 1982	WCKR 1989	1988 aerial photographs (frame no.; flight line)
47	0	0	0	0			
48	0	0	0	0			
49	0	0	0	0			
50	0	0	0	0			
51	3400	9200	5800	171			
52	0	0	0	0			
53	0	3600	3600				
54	0	0	0	0			
55	0	0	0	0			
56	0	0	0	0			
57	13650	32700	19050	140			(1084; 1078) kelp in Admiralty Bay; Admiral. Head-Pt. Partridge
58	750	0	-750	-100	0		
59	450	0	-450	-100	0		
60	0	0	0	0			
61	1050	0	-1050	-100	0		
62	0	0	0	0			
63	1350	0	-1350	-100	0		(1396-1409; 1418) very little kelp indicated
64	0	0	0	0			
65	0	0	0	0			
66	0	0	0	0			
67	0	0	0	0			
68	0	750	750				
69	0	7125	7125				
70	1200	2250	1050	88			
71	0	0	0	0			
72	0	0	0	0			
73	0	1200	1200				
74	5250	13125	7875	150			
75	0	0	0	0			
76	1650	2250	600	36			
77	0	0	0	0			
78	1650	15375	13725	832			
79	0	450	450				
80	0	12000	12000				(Flt. Line 51) kelp as in 1978; (1173) none at Brown's Pt.
81	1200	1050	-150	-13			
82	0	9300	9300				
83	900	12375	11475	1275	0		(Flt Line 91 & 86) only one small patch at north Steilacoom
84	1275	4425	3150	247	0		
85	0	2025	2025	0			
86	1050	2250	1200	114	0		
87	0	1725	1725		0		(1742-1743) no kelp on N. or S. end of Island
88	0	750	750	0			
89	1725	900	-825	-48			(1642) kelp present

Table 11—cont.

Subregion ser. no.	Rigg 1911-12	WDW 1978	WDW - Rigg	Percent change	Duggan 1982	WCKR 1989	1988 aerial photographs (frame no.; flight line)
90	0	0	0	0			
91	0	0	0	0			
92	0	0	0	0			
93	0	0	0	0			
94	2400	7500	5100	213	0		
95	2500	No record					
96	No record	No record					
97	1200	No record					
98	600	No record					
99	No record	No record					
100	1000	No record					
101	800	No record					
102	No record	No record					
103	500	No record					
104	No record	No record					
105	No record	No record					
106	No record	No record					
107	No record	No record					
108	500	No record					
109	300	No record					
110	No record	No record					
111	750	0			0		
112	Yes	Yes					
113	No	Yes					
114	Yes	Yes					
115	Yes	Yes					
116	Yes	Yes					
117	Yes	Yes					
118	Yes	Yes					
119	No	Yes					
120	Yes	Yes					
121	Yes	Yes					
122	Yes	Yes					(1193) narrow band on either side of point
123	Yes	Yes					
124	Yes	Yes					
125	No record	No record					(1664) no kelp at point
126	No record	Yes					
127	Yes	Yes					
128	1917PUBL.	Yes					

The patches of kelp along Magnolia Bluff (subregion 78), Elliott Bay, were estimated to cover a total of 13.1 ha by Thom et al. (1984). These beds were noted by WDW but were not shown on the 1912 Rigg map.

The kelp forest at Lincoln Park Beach (Fauntleroy Cove, subregion 128) was studied by Rigg (1917) between October 1914 and February 1917. He made notes on the length of the forest, located immediately to the south of Point Williams, and other aspects of the plants on 15 visits. Most of the visits were made in spring-summer. Rigg stated that the forest at best development reached a length exceeding approximately 213 m (700 ft). Of note is the fact that Rigg did not include this patch in his 1911-12 maps. Observations made almost annually between 1974-1989 (Thom 1978, Thom and Hampel 1985, and Thom unpublished data) indicate that this patch is on the order of 640 m (2,100 ft) long. This patch was noted on 19th century hydrographic charts.

Anecdotal information indicates that the kelp patches around Fox Island have become less dense over the past approximately 10 years (Thomas Mumford, pers. comm., 16 July 1984). Long-time residents of Fauntleroy Cove indicate that kelp has been increasing in its distribution over the past approximately 40 years. At Fourmile Rock located along the northeast shoreline of Elliott Bay, kelp appears to have been sparse in 1972, increased in 1980 and showed a decline in 1984 (Bonny Orme, pers. comm., 11 March 1985). Observations made on Vashon Island (Scott Borkland, pers. comm., 22 January 1990) over the past 40 years have noted a decline in the distribution of kelp there. Aerial photographs from 1988 of the Vashon Island shoreline were not available. Lyon McCandless (pers. comm., conversation, 24 February 1990) has observed widespread a general reduction in kelp distribution along the eastern shoreline of Bainbridge Island over the past 35 years. McCandless, a long-time member of the Marine Science Society of the Pacific Northwest (Poulsbo, WA), made these observations primarily by snorkel and SCUBA diving. He stated that the Wing Point forest, and forests in the Ferncliff and Rockaway Beach areas, are either much reduced or gone. The change has been gradual over the time period of McCandless' observations.

INTRODUCED SPECIES

Spartina spp.

Historical evidence suggests that *Spartina* was planted for either cattle grazing, dike stabilization or waterfowl habitat in each of these areas. *Spartina alterniflora* is presently known from southern Padilla Bay, Thorndyke Bay, Gibson spit and Kala Point. *Spartina patens* is presently found at the mouth of the Dosewallips River. *S. townsendii/anglica* has invaded the *Scirpus* marsh in Port Susan. *S. alterniflora* and *S. patens* appear to be spreading very slowly in Puget Sound (B. Aberle, letter dated October 23, 1990 to M. Rylko). In contrast, *S. townsendii/anglica* may be spreading rapidly. This species, normally found in low intertidal mudflats and saltmarshes, has recently been observed on sandy and gravel beaches (B. Aberle, ibid.).

Zostera japonica

There is very little information on the present distribution of this species in Puget Sound. It occurs in dense stands in Boundary Bay (Harrison 1979), Drayton Harbor (Thom et al. 1989), Lummi Bay (Thom, personal observation, 1989) and Padilla Bay (Thom 1990), and has been seen in small patches in the flats to the west of Jetty island on the Snohomish River delta (Thom, pers. observation, 1989). Phillips did not note the presence of *Z. japonica* during his surveys in 1962-63. The effect of the invasion of this species on the native eelgrass has yet to be fully evaluated. *Z. japonica* now occupies formerly unvegetated mud and sandflats.

Sargassum muticum

This species was present throughout the study area by the early 1960s. Phillips noted *Sargassum* at Oak Head (subregion 64), near Hoodsport (subregion 65), on Fox Island (subregion 84), and at Dickerson Point (subregion 88) during his eelgrass surveys of 1962-63. During surveys made in 1966-68, Phillips and Fleenor (1970) collected *Sargassum* at sites located at the Hood Canal Bridge (subregion 64), Beacon Point (subregion 65) and just north of Hoodsport (subregion 65) in Hood Canal. Harlin (1969) recorded *Sargassum* at Steamboat Island (subregion 88) in South Puget Sound during surveys made approximately monthly from June 1967 through August 1968.

Quantitative data taken at a site in the lower intertidal zone on the south side of Alki Point indicate substantial changes in the percentage cover of *Sargassum* and *Nereocystis* since 1979 (Fig. 13; Thom, unpublished data). *Nereocystis* showed wide fluctuations at this site, which is at the extreme upper depth limit of its distribution. Between 1984 and 1985, there was a dramatic decline in *Nereocystis* and a dramatic increase in cover of *Sargassum* at this site. *Sargassum* cover has remained high since 1985, and *Nereocystis* cover has remained near zero during this period. Of note is the fact that heavy harvesting of *Nereocystis* at this site (Region X, U.S. EPA) was noted by Thom (unpublished data). Heavy harvesting of kelp was noted by J. Armstrong in the late 1970s at this beach (pers. comm., January 1991). Harvesting involved removing the blades, which produce reproductive sori in summer, at the level of the float. The extant plants in the area indicated that the population was not reproductively mature prior to the harvesting in spring.

DISCUSSION

Changes in the area covered by tidal marshes, eelgrass meadows and kelp forests have taken place since the mid-1800s in Puget Sound. Declines in tidal marshes are the most well quantified

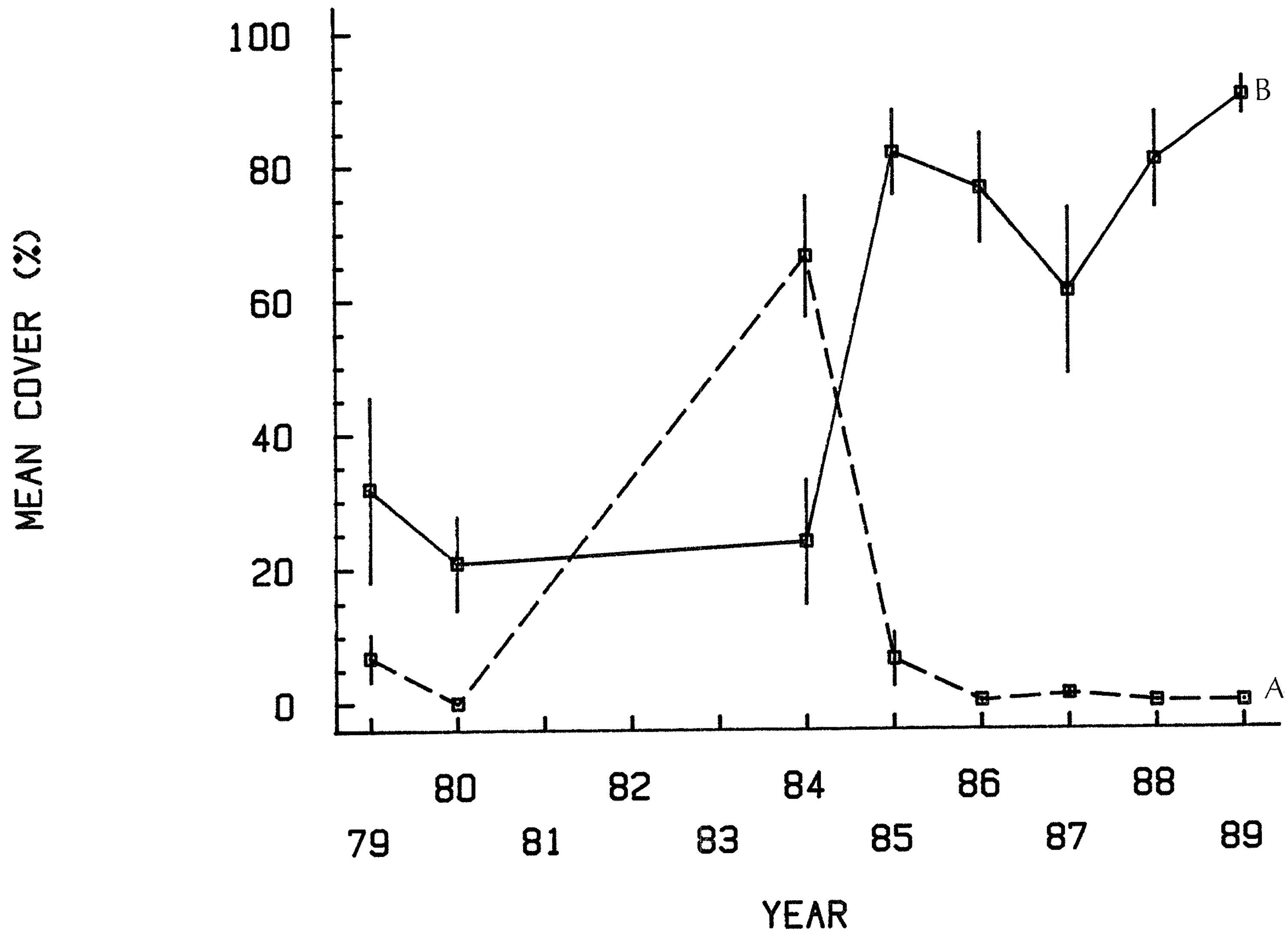

Figure 13. Changes in mean percent cover (±1 SE) of (A) *Nereocystis luetkeana* and (B) *Sargassum muticum* in the low intertidal zone at Alki Beach between 1979 and 1989.

and have been substantial (73%). The losses are largely due to diking, filling and dredging for agriculture and port development. Eelgrass meadows have also been lost due to diking, filling and dredging, but overall changes in Puget Sound could not be assessed due to a lack of comprehensive early records. On the basis of two Sound-wide data sets taken 66 years apart, kelp forests may have increased their distribution this century. Several introduced plant species may have affected, and will probably continue to affect, the distribution of native salt marshes, eelgrass meadows and kelp forests.

Tidal marshlands occur primarily at the mouths of rivers and streams that are tributary to Puget Sound. These areas were considered prime candidates for agriculture which could be accomplished through diking (Nesbit 1885). The majority of losses of tidal marshlands in Puget Sound have occurred at the mouths of the largest rivers. Agricultural diking has reduced marsh area in the Lummi, Samish, Skagit, Nisqually, Skokomish and Snohomish River deltas 25%-95%. Filling and dredging for port development are primarily responsible for losses of wetlands in the urbanized estuaries of the Duwamish and Puyallup Rivers; wetland losses in these latter systems are 99% and 100%, respectively. The Nooksack, Stillaguamish and Dungeness River estuaries, which have remained relatively undisturbed, have either remained the same since the 1800s or have increased in size (i.e., prograded).

The rate of estuarine wetland loss was greatest in the most urbanized estuaries from about 1900 through about 1950. This was a period when construction of port facilities was most rapid (Boule' et al. 1983). The rate has slowed either due to decline in economic justification for further port expansion (i.e., Snohomish) or the fact that very few wetlands remain in the estuary (i.e., Duwamish and Puyallup). The passage of the Clean Water Act in the early 1970s has probably slowed wetland loss in other estuaries (Puget Sound Water Quality Authority 1986, Stevens and Canning 1989).

Some systems have been subject to extensive diking along the mainstem of the river (e.g., Puyallup River). This probably has caused major shifts in the dynamics and spatial patterns of sediment deposition in the estuaries. The effect of changes in sedimentation could not be assessed based upon the available data. According to Nesbit (1885) sedimentation was heavy during periods of heavy runoff in several major river deltas in Puget Sound. Diking and increased sediment loads due to logging activities in the watersheds of these rivers may have affected the spatial development of marshes in the estuary. This aspect of habitat changes in Puget Sound has not been studied.

Marshland changes associated with disease, variations in water temperature, storm events and decreased water quality (e.g., elevated nutrients, pesticides) were not a part of this study. However, these factors have probably be concomitant with other factors that have resulted in the loss of wetland area and functional quality in Puget Sound (Puget Sound Water Quality Authority 1986).

Functional quality can be measured in terms of primary productivity, numbers of plant and animal species in a system, contamination of the soils and food web in the system, hydrological aspects, and sediment trapping. Functional degradation of estuarine wetlands needs further study in Puget Sound.

Although the changes in marsh dominated wetlands in Puget Sound have been quantified to a large degree, the accuracy of the estimates of change in area appears to depend upon the methodology used. Estuarine marsh area was estimated by hydrographic charts (Bortleson et al. 1980) and intensive transect studies in the field (Brewer 1980) in the Skagit and Stillaguamish deltas. In both deltas, the field studies estimated a greater marsh area than did the chart studies. For the Stillaguamish, the field-based estimate in 1974 was approximately twice the chart-based estimate for the same year. Although the difference in estimates between the two techniques for the Skagit was less, the field-based method showed progradation since the late 1940s, whereas the chart-based method indicated a steady decline since the late 1800s. It is our opinion that the field-based method produced the most accurate estimate. The substantial differences between the two methods strongly supports the effort of the WDNR to develop accurate methodology for assessing and monitoring the aerial coverage of nearshore habitats in Puget Sound (Mumford et al. 1990).

At least 25% (659 km) of the shoreline in the study area has documented eelgrass meadows. Although some bays (e.g., Padilla, Lummi) contain extensive stands of eelgrass, much of the eelgrass occurs within a narrow band along relatively steeply sloping shores (e.g., Phillips' notes, Thom and Albright 1990). The availability of early maps depicting the location of eelgrass allowed us to quantify losses in Bellingham Bay and the Snohomish River delta. In contrast, there may have been a substantial increase in eelgrass cover in Padilla Bay. A substantial proportion of this increase is attributable to the invasion of *Z. japonica*, but may also be due to the spread of the native *Z. marina*. Virtually complete diking of the Skagit River delta at the south end of Padilla Bay, and the restriction of freshwater flow from the Skagit to the Swinomish Channel, may have reduced the amount of freshwater flowing into the southern end of the Bay. This reduction may have allowed higher salinities to prevail in the southern end, which would favor the invasion of *Zostera* onto previously unvegetated flats. This hypothesis needs further study.

Other changes are very difficult to assess. Anecdotal accounts indicate widespread declines in eelgrass in certain areas over the last 30-40 years. In these cases, changes in water quality may be the reason owing to the noted increase in brown scum on eelgrass leaves. Increase in epiphytic algae is known to significantly reduce the growth of eelgrass. Reduced growth rate is due to competition between eelgrass and its epiphytic flora for light energy and nutrients. High epiphyte loads coupled with reduced seagrass growth rates is indicative of eutrophication in estuarine systems (Zimmerman and Livingston 1976). Orth and Moore (1984) relied in large part on observations made by fishermen, bird watchers and other careful observers to document the long-term changes in the SAV of Chesapeake Bay. Similarly, our anecdotal information came in part from professional aquatic ecologists and a professional fisherman, and these observations are at present our best general indicator of possible degradation of eelgrass meadows in Puget Sound. Further study is needed on this subject in Puget Sound.

All regions, except Hood Canal, showed an increase in kelp between 1912 and 1978. The largest relative increases were recorded in the Main Basin and southern Puget Sound, the regions that have seen the greatest increase in population and urbanization. Several factors may explain the differences between the two records. First, methods differed: In 1912, all observations were from a boat; in contrast, all data in 1978 were taken from an airplane. Although not proven, it would seem that a better indication of kelp location would be gotten from the closest vantage point, and hence the estimates in 1912 would be most accurate. If this is true, then the increase by 1978 can be viewed as being a minimal estimate of change. Second, the definition of a patch of kelp may have differed between the observers. Rigg was interested in patches that were of commercial value as a source of potash, and hence would have concentrated on relatively large and dense patches when developing the maps. In contrast, the 1978 observers were interested in indicating where kelp occurred, and may have noted patches that were smaller or less dense than some lower limit Rigg set. The fact that Rigg did not map the 213 m long forest at Lincoln Park beach, but that he was well aware of the size and location of the forest, may indicate that this latter explanation is true. Furthermore, all but one patch on Rigg's maps was greater than 450-m long. Finally, kelp distribution varies annually. Several early notes (e.g., Rigg 1917, Coast Pilot) show that this variation was acknowledged. Crandal (1915) noted that 1912 appeared to be a "bad" year for kelp in that not as much was visible in the summer of 1912 as had been previously seen in some locations. In comparison, 1978 may have been a "good" year. Whether this explains the differences between the two records is questionable because, although kelp density varied significantly, Foreman (1984) found that semiannual variation in forest patch area was insignificant between 1974 and 1980 in British Columbia.

The kelp resources maps produced in 1989 (WCKR) from the Straits illustrated kelp distributions quite similar to those illustrated by Rigg in 1911-12. The difference (i.e., 13.6%) between the two records generally verifies that kelp has probably changed little in that region. Our measurements of kelp distribution on the 1989 WCKR maps included the smallest specks indicating kelp. These specks could indicate the location of one kelp plant. The fact that 1977-78 WDW data and the 1989 WCKR data differ substantially (i.e., 42%) from each other suggests that changes had occurred between the two records.

Perhaps the two best examples of changes in kelp that we found were from Lincoln Park beach where Rigg (1917) had documented the length and width of the forest for ca. 3 years, and from Toliva Shoal. The kelp forest of Toliva Shoal was long used as a navigation aid, and its loss can only be attributed to some change in the aquatic system in South Puget Sound. At Lincoln Park, the length of the kelp patch has tripled since 1917. This change is probably the best quantified change available for a kelp patch in Puget Sound. An explanation for this change may be related to changes in available substrata in the bay. A seawall was built in the mid-1930s to prevent erosion of the bluff in the northern portion of the bay. This bluff probably supplied sediment to the beach and adjacent subtidal zone. With the reduction of sediment to the bay, and sediment removal through shoreline waves and currents, additional stable rocky habitat may have become exposed in the bay which was colonized by *Nereocystis*. Erosion at the base of the seawall has been extensive, and caused failure of the seawall in the early 1950s (Corps of Engineers, 1986). Continued erosion prompted the City of Seattle to place fill along the seaward side of the old seawall in 1989 to prevent the wall from collapsing and affecting the adjacent Park lands. Erosion had exposed large cobble and boulders on the beach, and hardpan comprised much of the surface area of substrata near the base of the seawall by 1974 (Thom, personal observation, Thom and Hampel 1985).

Water quality changes may also explain an increase in kelp, particularly in the Main Basin and southern Puget Sound. A recent analysis of nutrients and phytoplankton in Puget Sound showed that nitrate and phosphate input to Puget Sound have changed this century and that phytoplankton blooms may explain recently observed declines in nitrates (TetraTech, Inc. 1988). *Nereocystis* is an annual kelp with a very high growth rate. Owing to its large size and short growing season, kelp forests probably require large quantities of inorganic nutrients. Recent evidence suggests that streams entering Puget Sound carry large concentrations of nutrients, and that the stream entering in the vicinity of the Lincoln Park forest has extremely high nitrate concentrations (Thom et al. 1988). In addition, nutrient limitation of algal growth is indicated for embayments in Puget Sound (Thom and Albright 1990). Hence, kelp growth may be nutrient limited and increased nutrient supplies could stimulate the growth and spread of kelp. *Nereocystis* also appears to be somewhat tolerant of contamination. Kelp grows in relatively dense patches near a large combined sewage overflow in Elliott Bay (Tomlinson et al. 1980). Finally, this species has been shown experimentally to dominate, by shading, the assemblage of understory algal species in the forest. Removal of *Nereocystis* results in a rapid change in the cover of other algal species in the forest (Thom 1978). Hence, it is a species with a high growth rate, relatively tolerant of pollution, and tends to dominate by size and growth rate the subtidal assemblages where it occurs. Obviously, study of the nutrient requirements and ecology of this species is needed in Puget Sound to fully explain any long term changes.

Ebbesmeyer et al. (1988) detected a pattern in oceanographic conditions in the North Pacific that occurs with a period of about a decade. Rensel (1990) suggested that these shifts could have profound effects on phytoplankton and nutrient dynamics in Puget Sound. Thom and Albright

(1990) indicated that the strong El Niño of 1983-1984 had a significant effect on the biomass and species composition of benthic algae at a site in the East Passage of Puget Sound. It is reasonable to assume that kelp and other nearshore vegetation could be influenced by the periodic changes discovered by Ebbesmeyer et al.

If the data from the Straits, the region with the least anthropogenic environmental impacts, are used as a control for natural changes in kelp and methodological differences, then these factors explain a 1.0% relative increase in the amount of shoreline occupied by kelp over the 66-year period between Rigg's and WDW's surveys. In comparison, northern Puget Sound, the Main Basin and Southern Puget Sound have substantially greater relative changes than is explained by normal variation and methodological differences. Again, however, the fact that kelp beds are larger and perhaps denser in the Straits as compared to the other regions, may have reduced the effect of observer differences in that region as compared to the other regions.

The effect of introduced macrophytes to the habitats we studied appears to be significant. Although *Spartina alterniflora* has not spread rapidly in Puget Sound, it does appear that *S. townsendii/anglica* is spreading rapidly within natural stands of *Scirpus* and other marsh species, and now occupies formerly unvegetated mudflats. These latter habitats are of known importance to waterfowl and fisheries resources. The continued slow invasion should be of concern. In particular, the spread of *S. alterniflora* would be a significant threat if flowering and the production of viable seed were to occur (B. Aberle, letter dated October 23, 1990, to M. Rylko). Viable seed production is now common in Willapa Bay, where this species is now spreading exponentially. The invasion of *Z. japonica* has probably affected the native *Zostera* at the upper limits of its distribution. These species co-occur at the +0.3 to 1.0 m MLLW elevation on flats, and competition for space is demonstrated (Harrison 1976). In addition, *Z. japonica* can invade newly created bare patches within native *Zostera* meadows, and hold this space for a considerable amount of time (Michele Nielsen, University of British Columbia, conversation, 5 May 1990). *Z. japonica* also now occupies formerly unvegetated flats. The ecological role of these latter areas has probably been altered substantially. However, the full impact of this alteration has not been documented. In a fashion similar to the eelgrass interaction, the highly invasive seaweed *Sargassum muticum* appears to be able to hold and dominate space in the low intertidal zone; the zone at the upper depth limit of *Nereocystis*. Documented dominance of this zone by *Sargassum* at Alki beach appears to be in response to loss of kelp due to harvesting. At this particular beach, harvesting has been intense enough to reduce the size of the kelp forest significantly over the past 10 years (Thom, unpublished data). The widespread occurrence of *Sargassum* in Puget Sound suggests that our productive low intertidal seaweed dominated systems have been altered significantly.

CONCLUSIONS AND RECOMMENDATIONS

Substantial changes have taken place in estuarine habitats in Puget Sound. The easiest to document are those due to physical disturbances such as the filling and dredging of tidal marshes. The effects of reductions in water quality, and invasion by non-native macrophytes, on nearshore vegetated habitats are more difficult to assess. The widespread declines in submerged aquatic vegetation in Chesapeake Bay is attributed to eutrophication due to increased anthropogenic introductions of nutrients. Recently, Biggs et al. (1989) showed that Chesapeake Bay, due to physical morphology and hydrological factors, is much more susceptible to eutrophication than is Puget Sound. Although eutrophication may not be a general concern in Puget Sound, nearshore bays and river deltas, where eelgrass and other macrophytic assemblages predominate, may be more vulnerable (Thom et al. 1988, Thom and Albright 1990). The general lack of comprehensive and quantitative historical data sets on macrophytes hinder the analysis of historical changes. The monitoring program presently under development by the WDNR (Mumford et al. 1990), along with other measurements proposed for the comprehensive Puget Sound Ambient Monitoring Program (PSWQA 1988), is critical in documenting accurately the spatial and temporal patterns of changes in nearshore habitats in Puget Sound.

The following recommendations can be made based upon our analysis of historical changes in nearshore habitats:

1. The accuracy of the historical records for all habitat types is questionable. Although the direction and magnitude of changes are probably valid, the quantification of changes are subject to considerable error. Hence, it is recommended that changes in habitat be based on studies developing new records that target specific habitats and are designed for the purpose of detecting changes.
2. Although large declines in the area covered by marshes and eelgrass can be explained by physical disturbances such as diking and dredging, we have little information to explain changes in kelp distribution. It is recommended that changes in kelp distribution be explored further in terms of possible causal factors. Kelp forests may form the most noticeable and easily monitored habitat in Puget Sound, and it may be highly sensitive to changes in water quality.
3. The subtidal distribution of eelgrass is essentially unknown. These meadows may be extensive and highly important, and could be impacted by increased turbidity linked to increased phytoplankton blooms or river-borne sediments. It is recommended that the factors affecting eelgrass distribution be investigated and that the habitat monitoring program develop methodologies for mapping subtidal meadows.

4. New, quantitative records of habitat distribution should be incorporated into a Geographic Information System (GIS) that can be used to compare records taken over time. This would greatly facilitate our ability to detect changes and generate hypotheses regarding the possible reasons for the changes. The GIS should include information on water quality and physical alterations.

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APPENDIX 1

MAPS OF DISTRIBUTION RECORDS OF EELGRASS

SYMBOLS USED FOR EELGRASS RECORDS

• Phillips 1962-63

Jamison 1970s

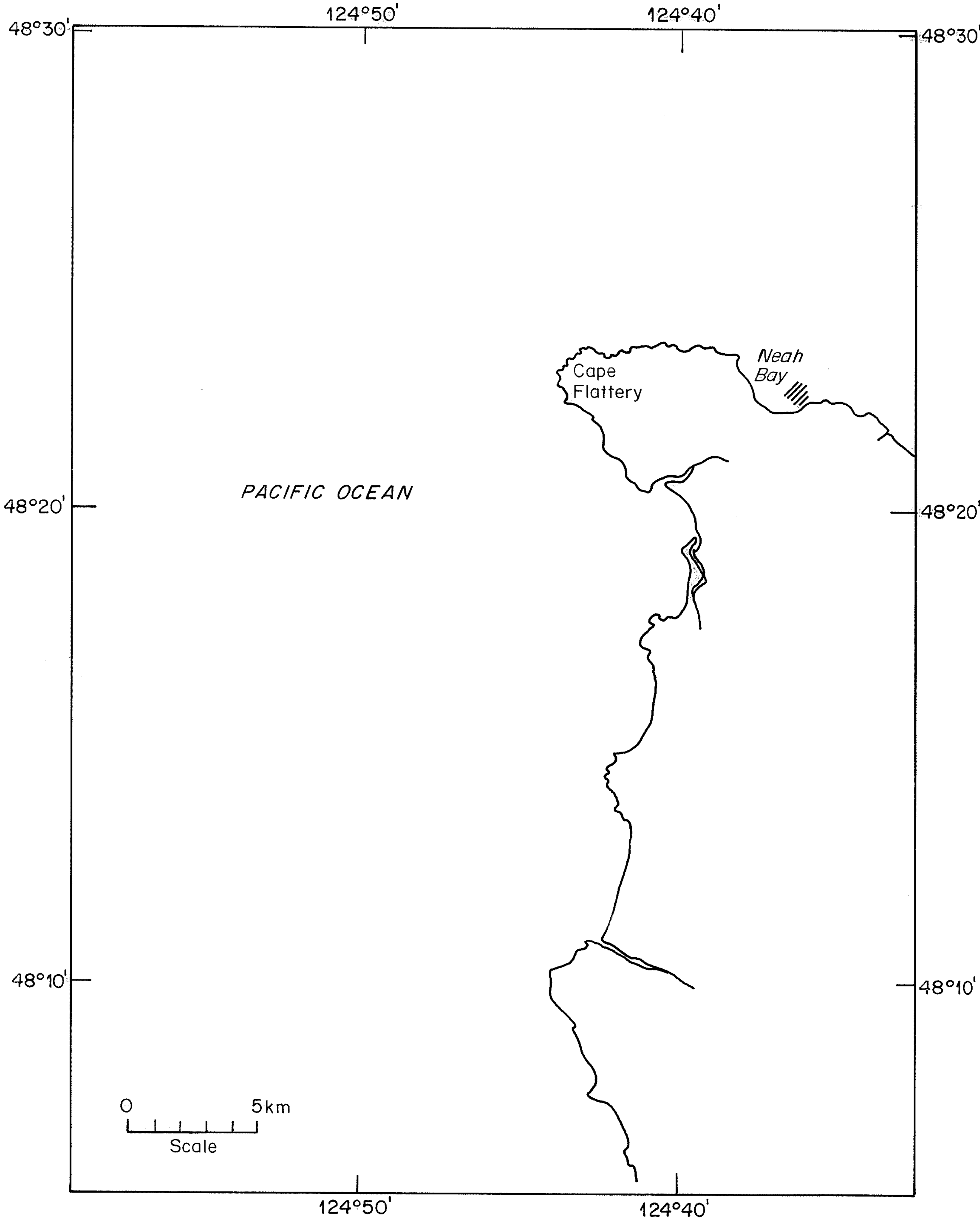
xxxxxx U.S. Geological Survey 1886

□□□□□ Coastal Zone Atlas (including supplement from field maps)

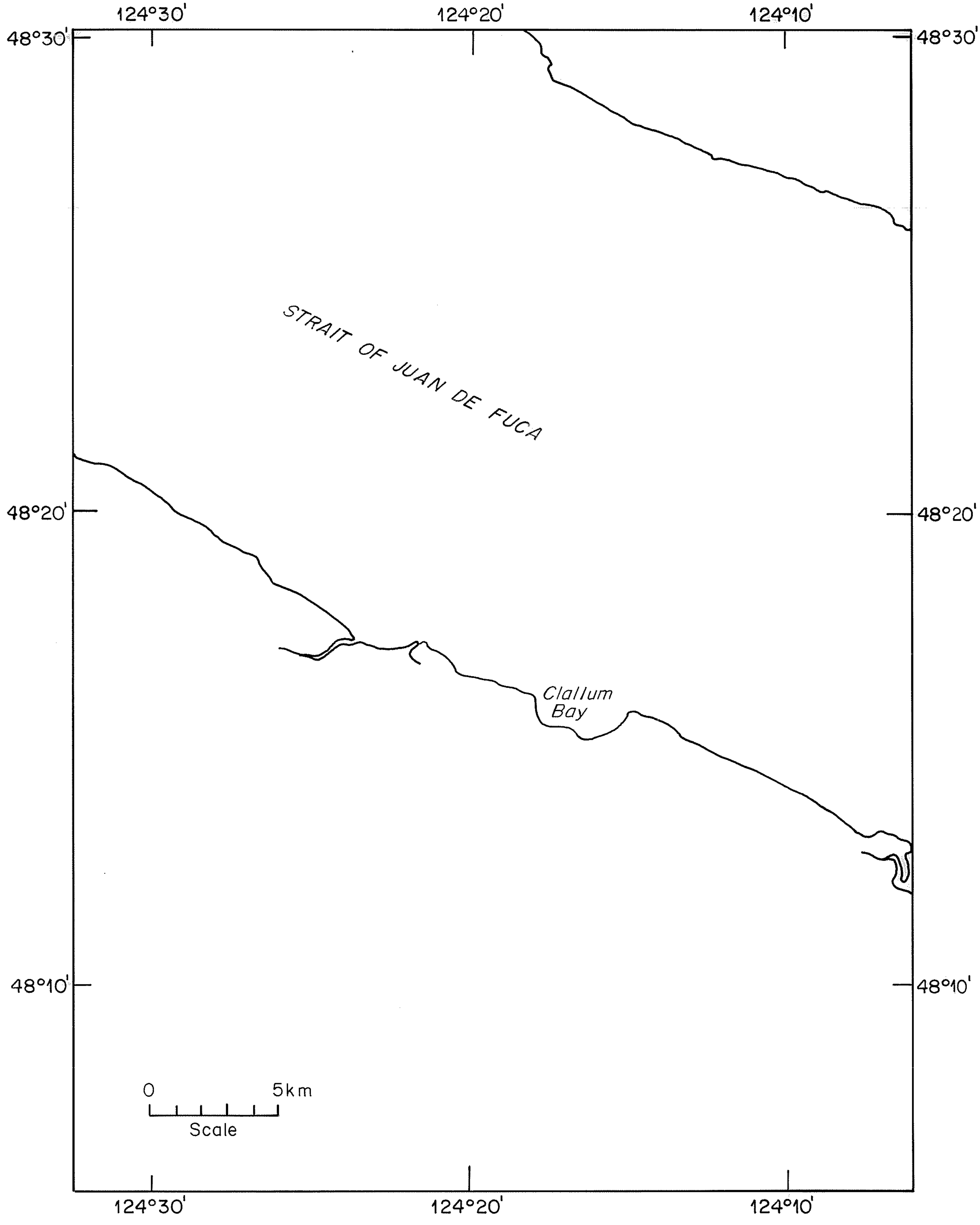
△△△△△ Washington Department of Fisheries 1975-1989

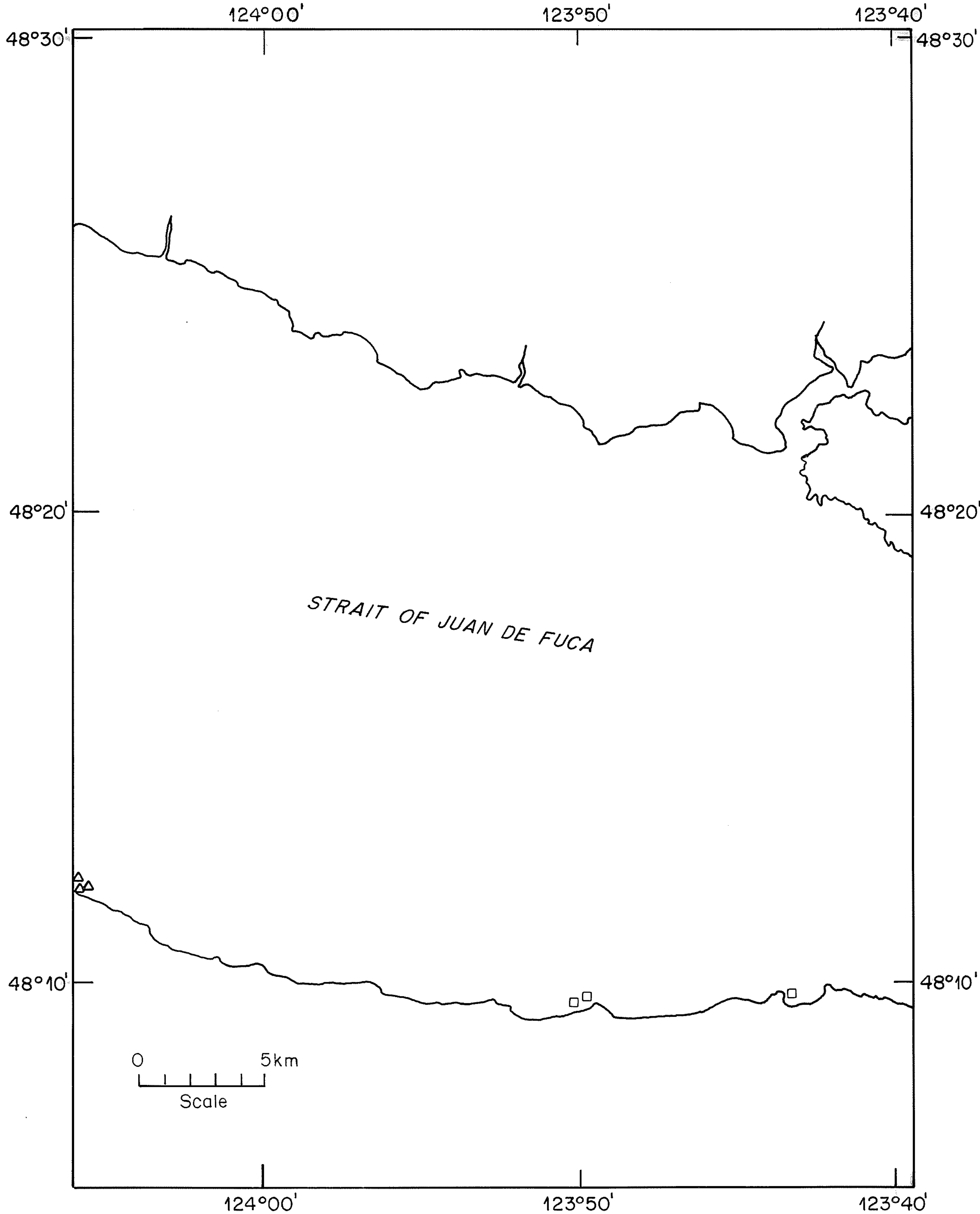
oooooo Hydrographic Surveys 1852-1899

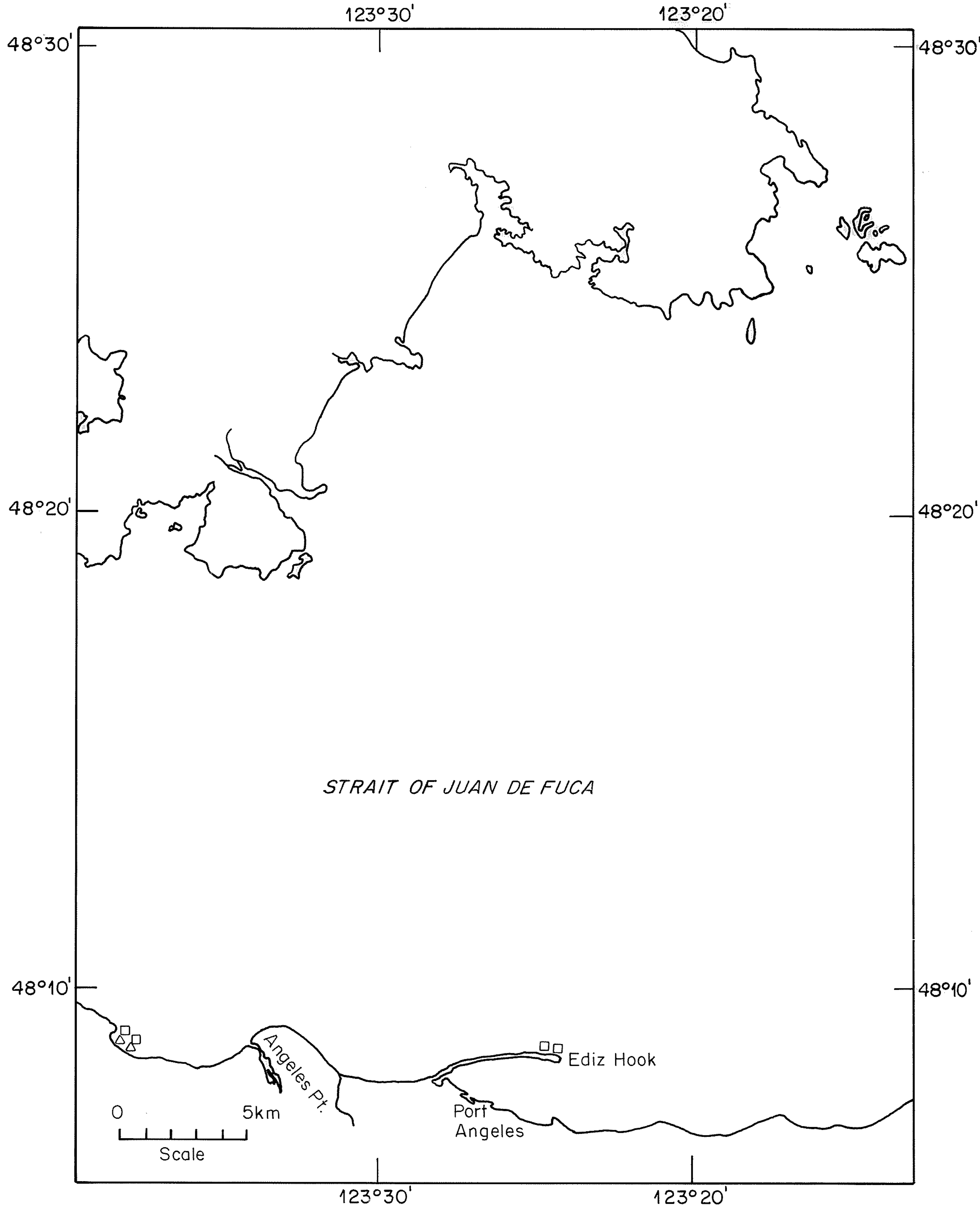
/////// Thom 1974-1989

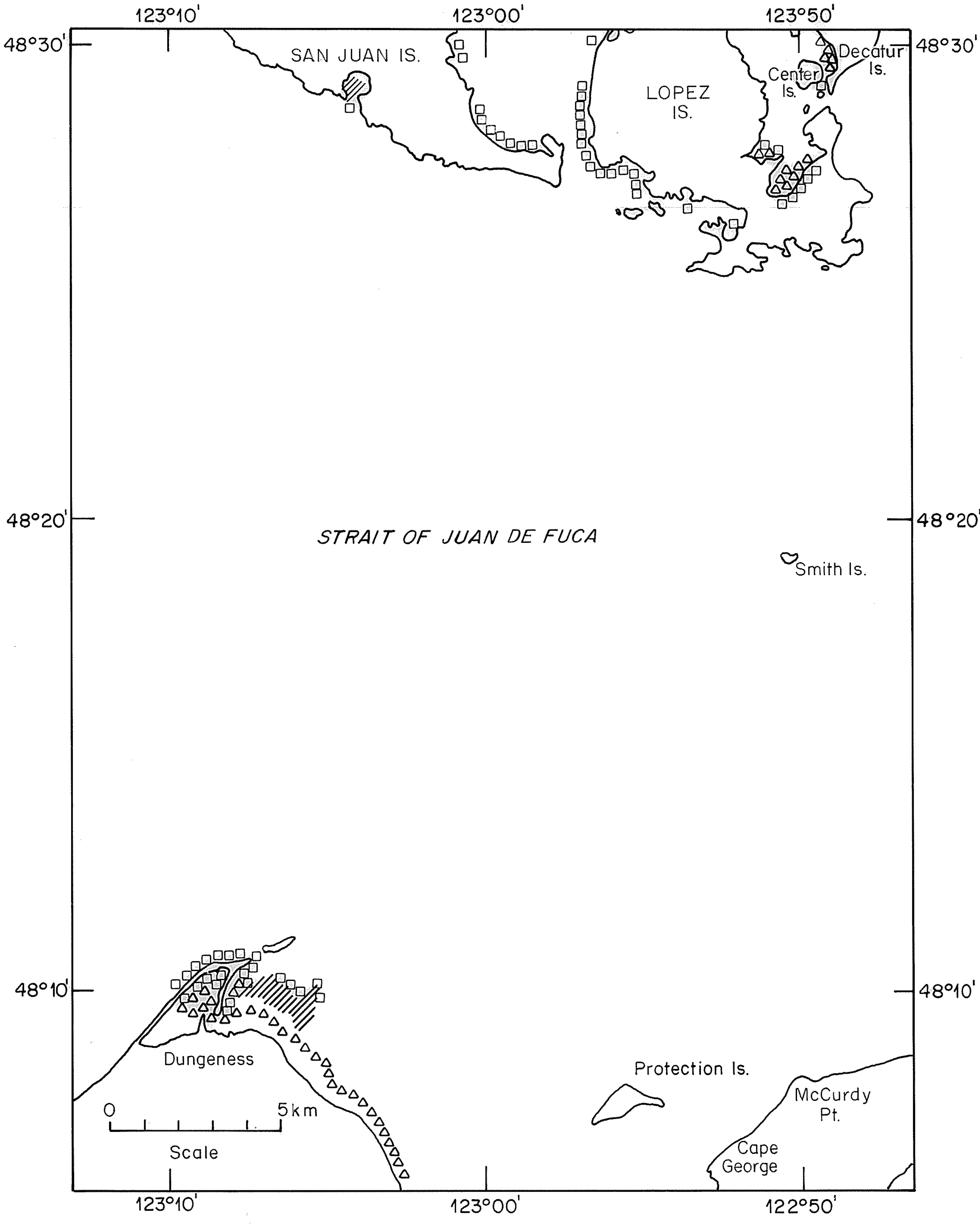

124°50'
124°40'
48°30'
48°30'
Neah
Bay
Cape
Flattery
PACIFIC OCEAN
48°20'
48°20'
48°10'
48°10'
0
5km
Scale
124°50'
124°40'

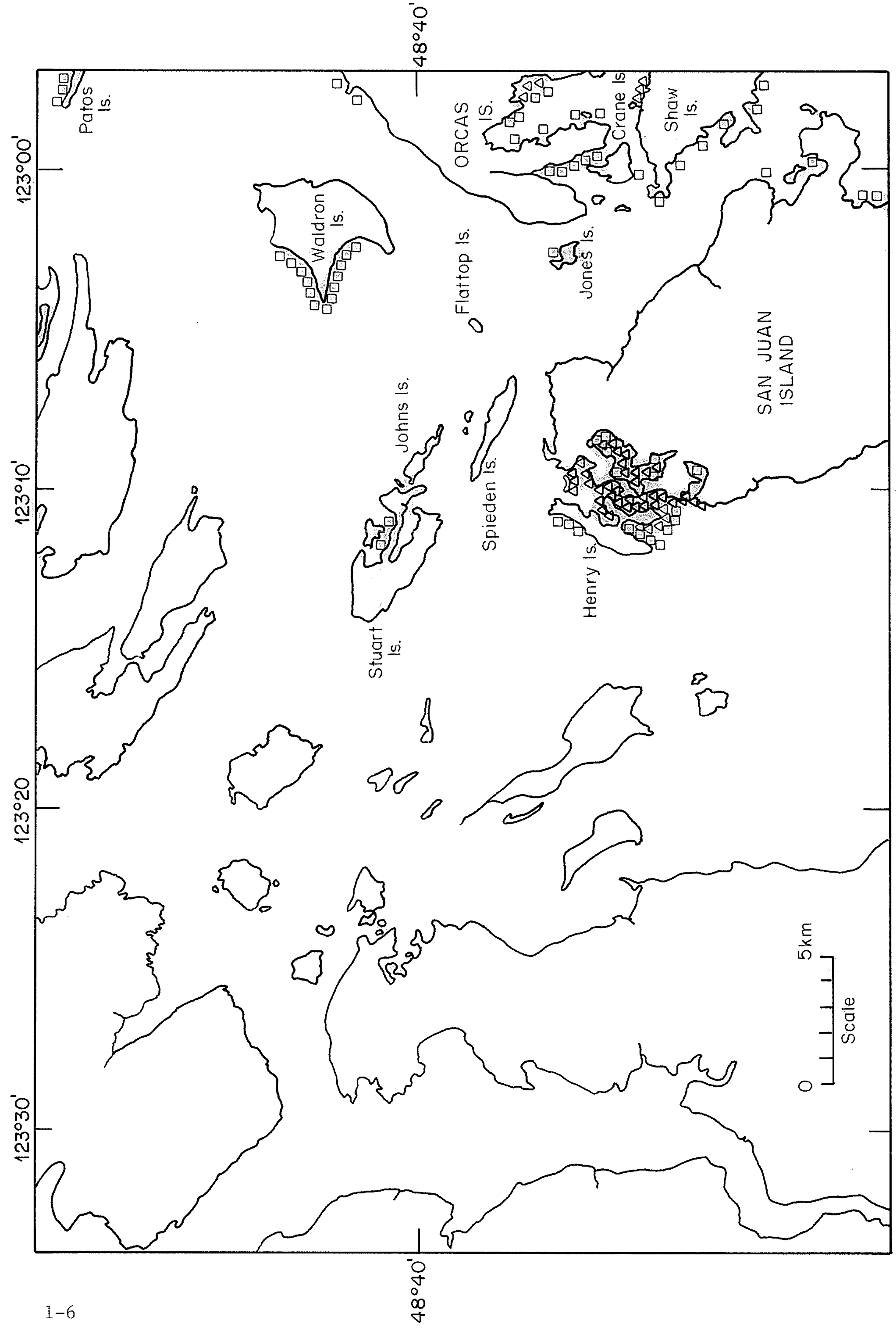
1-1


124°30'
124°20'
124°10'
48°30'
48°30'
STRAIT OF JUAN DE FUCA
48°20'
48°20'
Clallum Bay
48°10'
48°10'
0
5km
Scale
124°30'
124°20'
124°10'

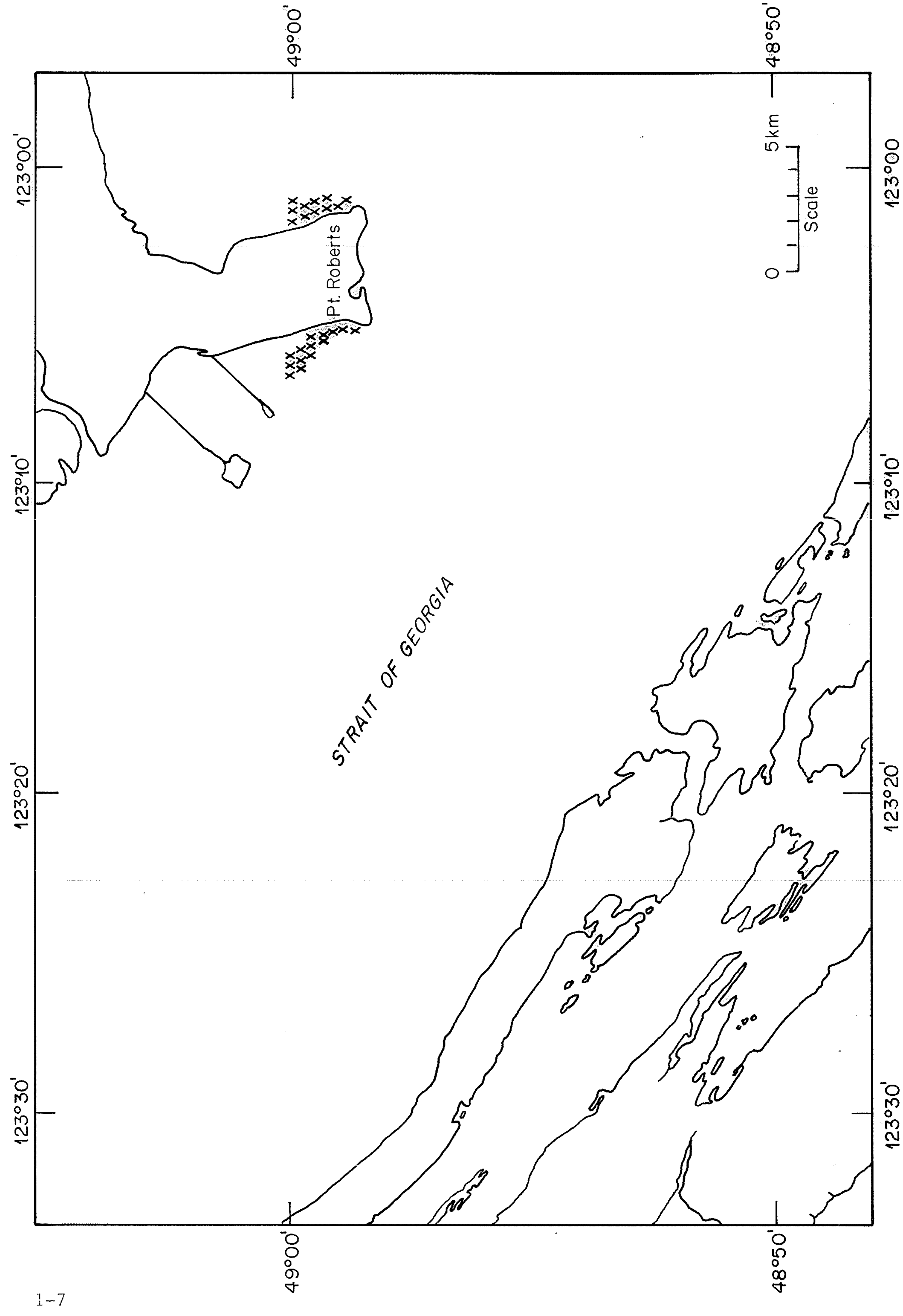

124°00'
123°50'
123°40'
48°30'
48°30'
48°20'
48°20'
STRAIT OF JUAN DE FUCA
48°10'
48°10'
0
5km
Scale
124°00'
123°50'
123°40'


123°30'
123°20'
48°30'
48°30'
48°20'
48°20'
48°10'
48°10'
STRAIT OF JUAN DE FUCA
Angeles Pt.
Ediz Hook
Port Angeles
0
5km
Scale
123°30'
123°20'


123°10'
123°00'
123°50'
48°30'
48°30'
SAN JUAN IS.
LOPEZ IS.
Center Is.
Decatur Is.
48°20'
48°20'
STRAIT OF JUAN DE FUCA
Smith Is.
48°10'
48°10'
Dungeness
Protection Is.
McCurdy Pt.
Cape George
0
5km
Scale
123°10'
123°00'
122°50'


48°40'
123°00'
123°10'
123°20'
123°30'
Patos Is.
ORCAS IS.
Crane Is
Shaw Is.
Waldron Is.
Flattop Is.
Jones Is.
SAN JUAN ISLAND
Johns Is.
Spieden Is.
Henry Is.
Stuart Is.
0
Scale
5km

1-6


49°00'
48°50'
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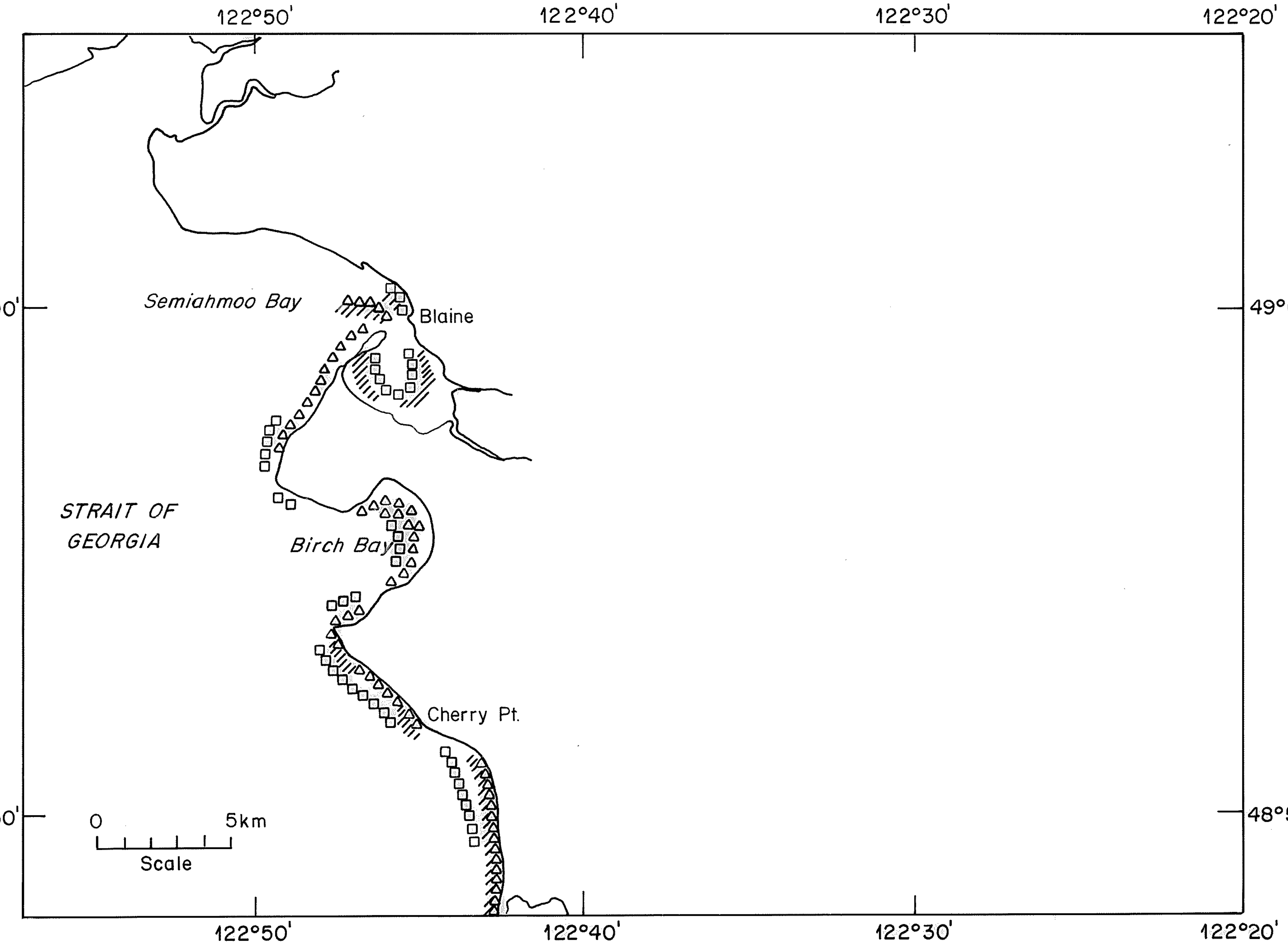
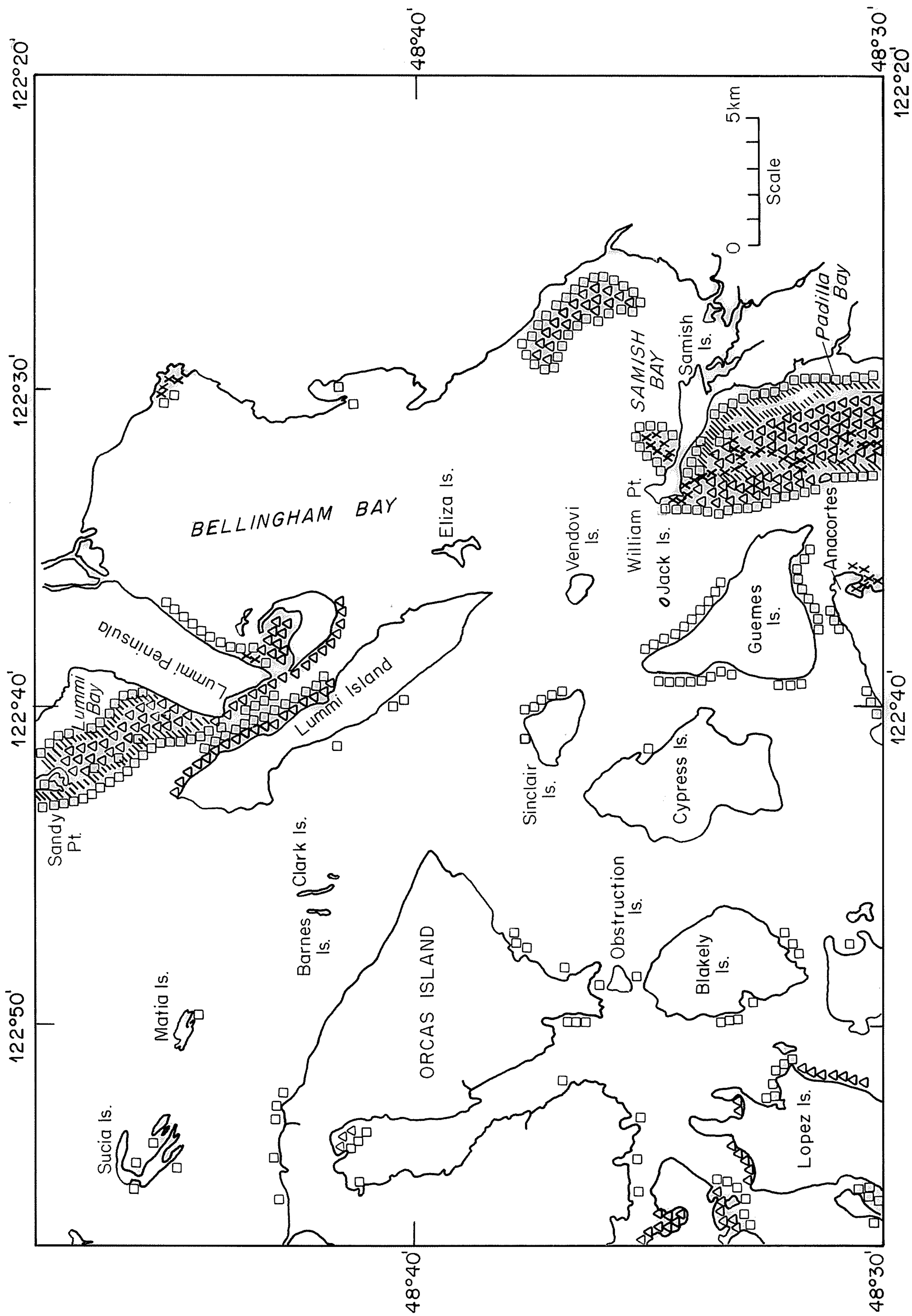
123°10'
123°20'
123°30'
Pt. Roberts
STRAIT OF GEORGIA
Scale
0
5 km

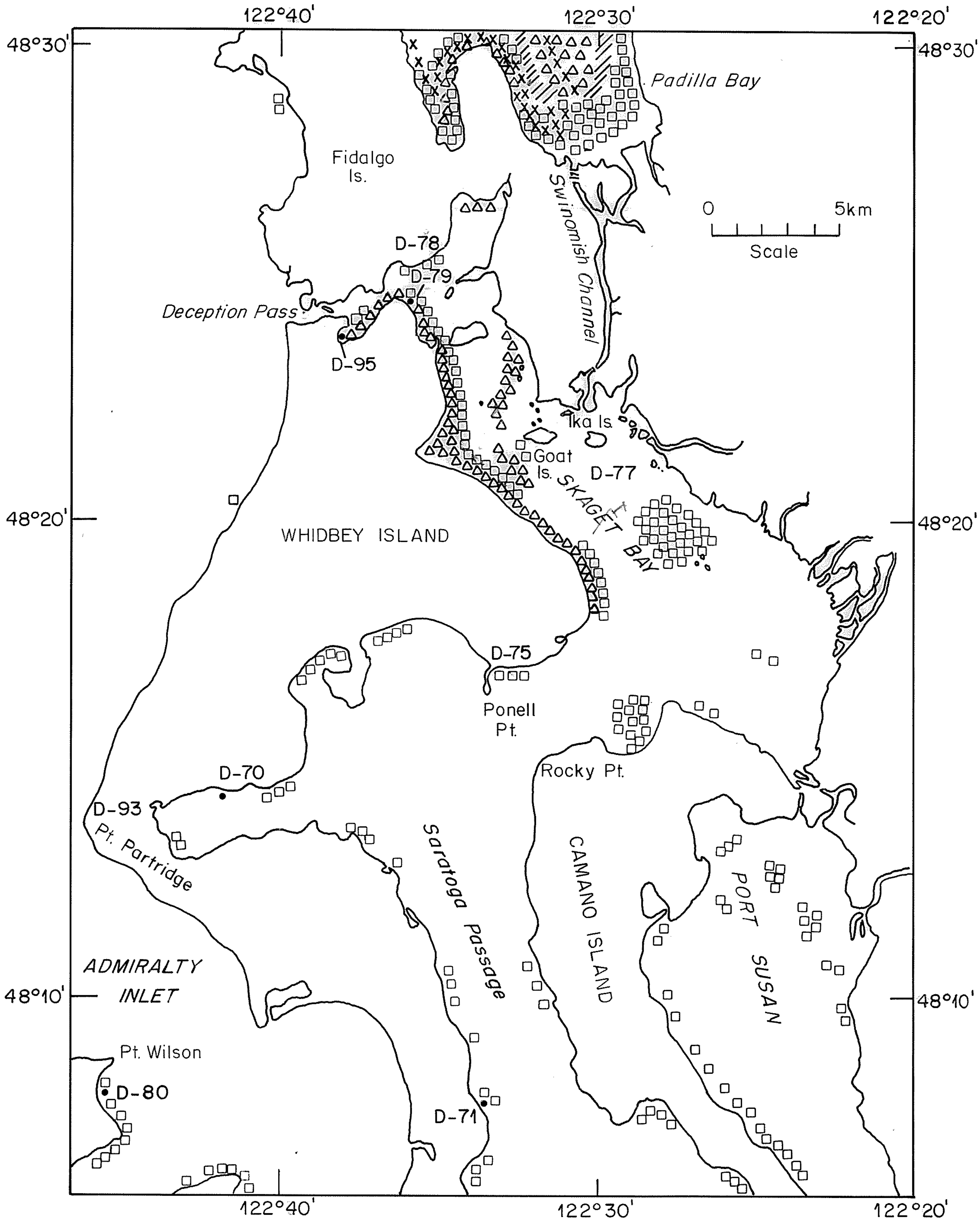
1-7

1-8

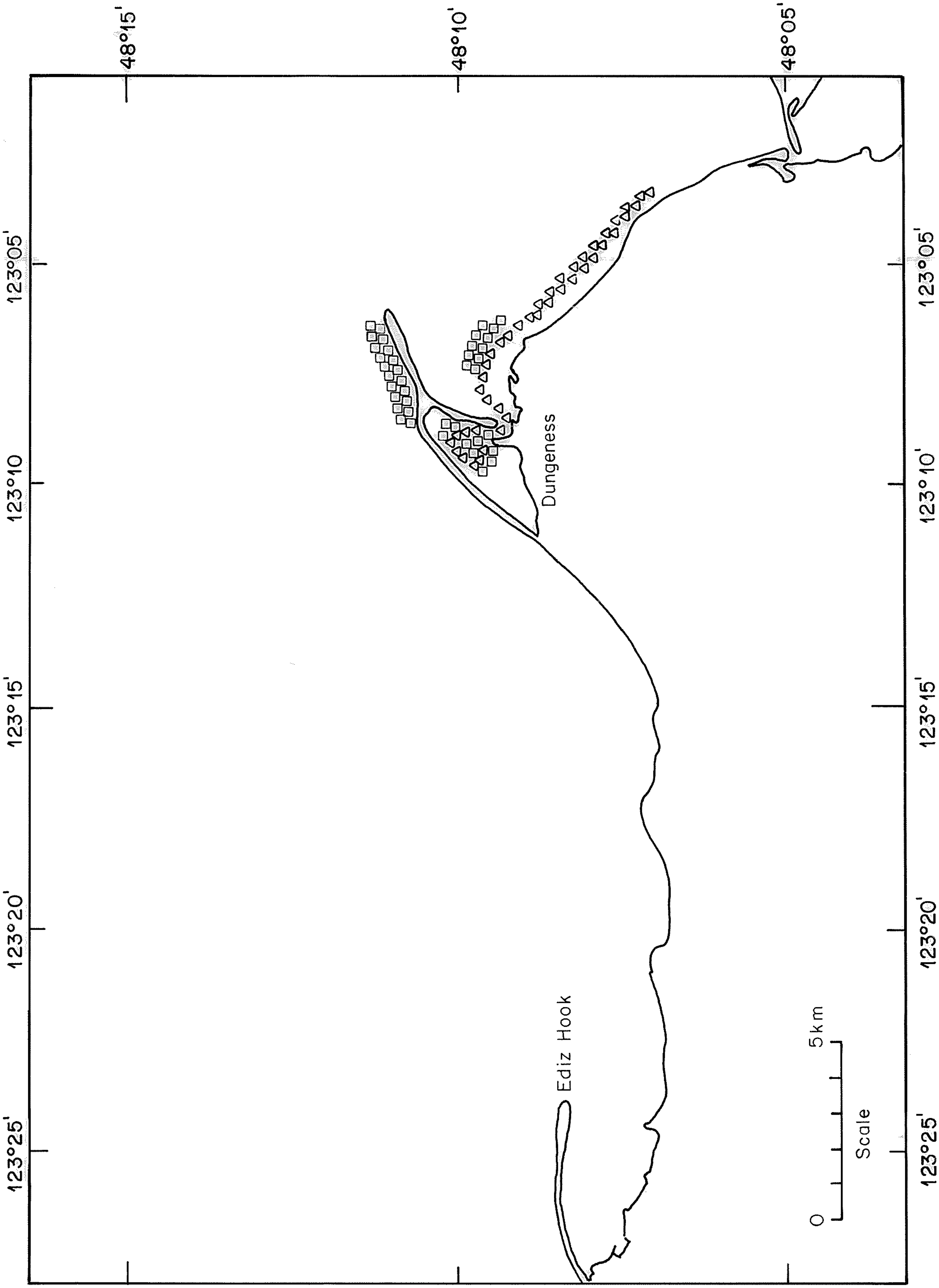

122°50'
122°40'
122°30'
122°20'
49°00'
48°50'
Semiahmoo Bay
Blaine
STRAIT OF GEORGIA
Birch Bay
Cherry Pt.
0
5km
Scale


122°20'
48°40'
48°30'
122°30'
122°40'
122°50'
5km
0
Scale
BELLINGHAM BAY
SAMISH BAY
Samish Is.
Padilla Bay
William Pt.
Eliza Is.
Vendovi Is.
Jack Is.
Anacortes
Guemes Is.
Lummi Peninsula
Lummi Bay
Lummi Island
Sandy Pt.
Sinclair Is.
Cypress Is.
Clark Is.
Barnes Is.
Obstruction Is.
ORCAS ISLAND
Blakely Is.
Matia Is.
Sucia Is.
Lopez Is.

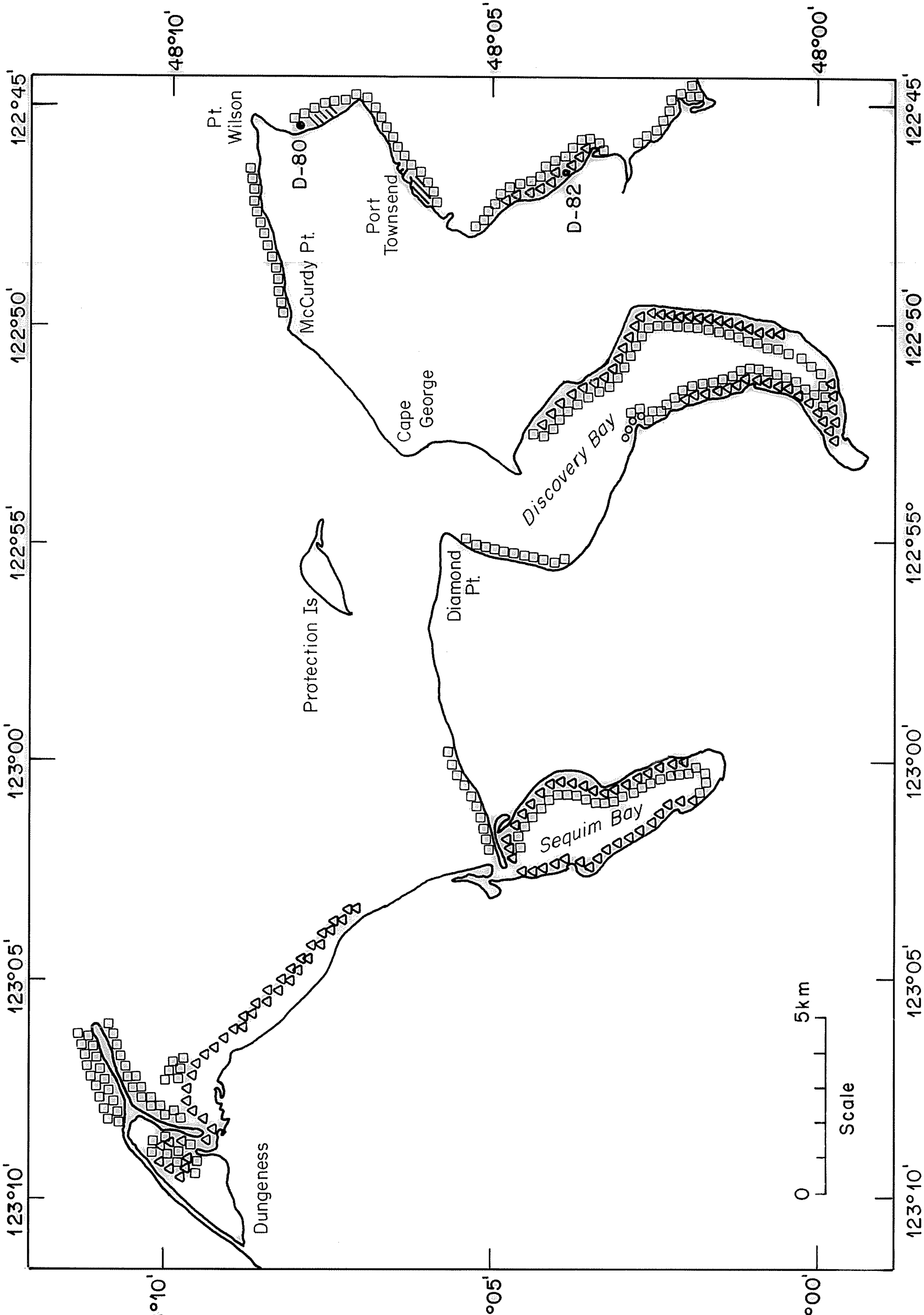
1-9

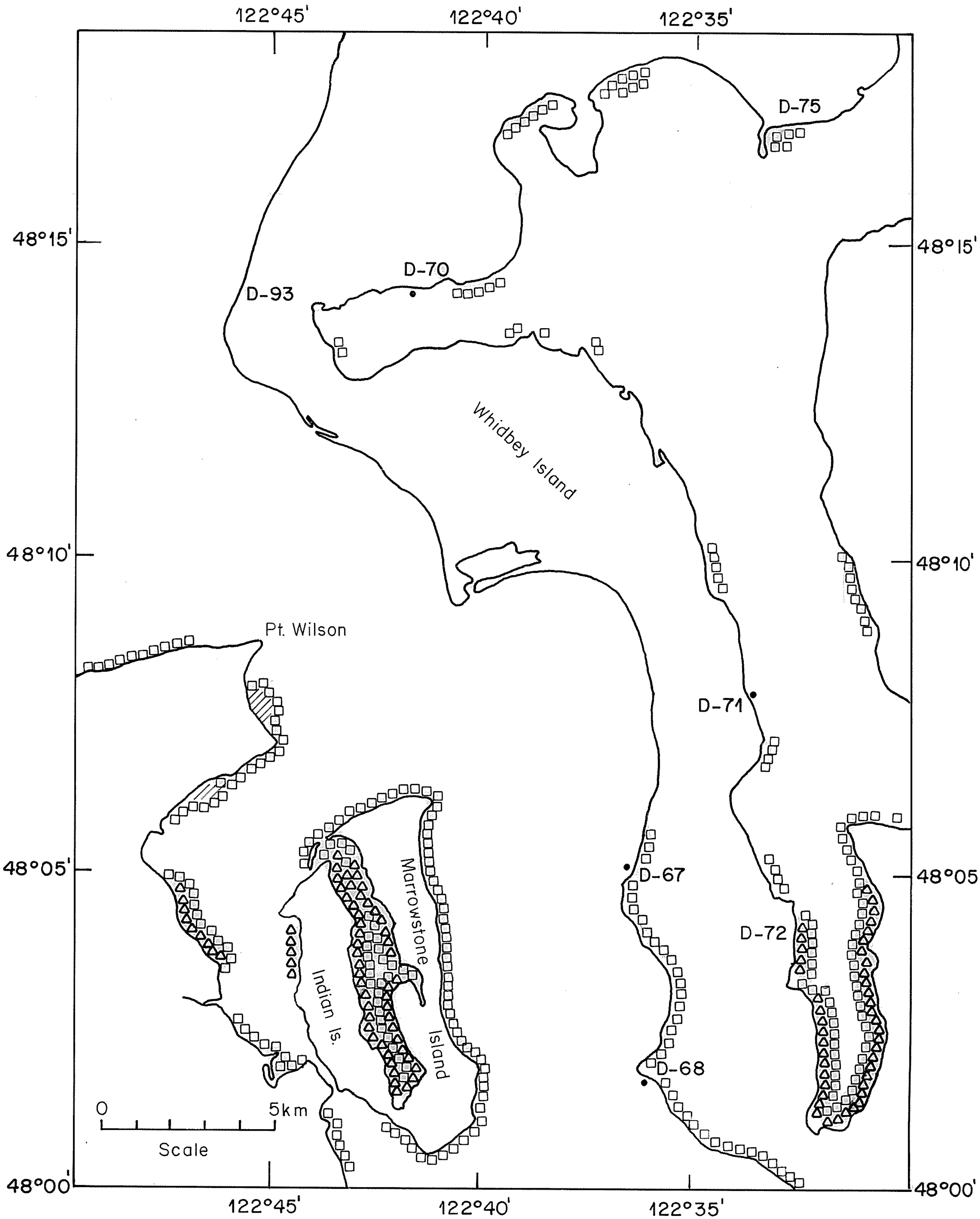

122°40'
122°30'
122°20'
48°30'
48°20'
48°10'
Padilla Bay
Fidalgo Is.
Swinomish Channel
0
5km
Scale
D-78
D-79
Deception Pass
D-95
Ika Is.
Goat Is.
D-77
SKAGET BAY
WHIDBEY ISLAND
D-75
Ponell Pt.
Rocky Pt.
D-70
D-93
Pt. Partridge
Saratoga Passage
CAMANO ISLAND
PORT SUSAN
ADMIRALTY INLET
Pt. Wilson
D-80
D-71

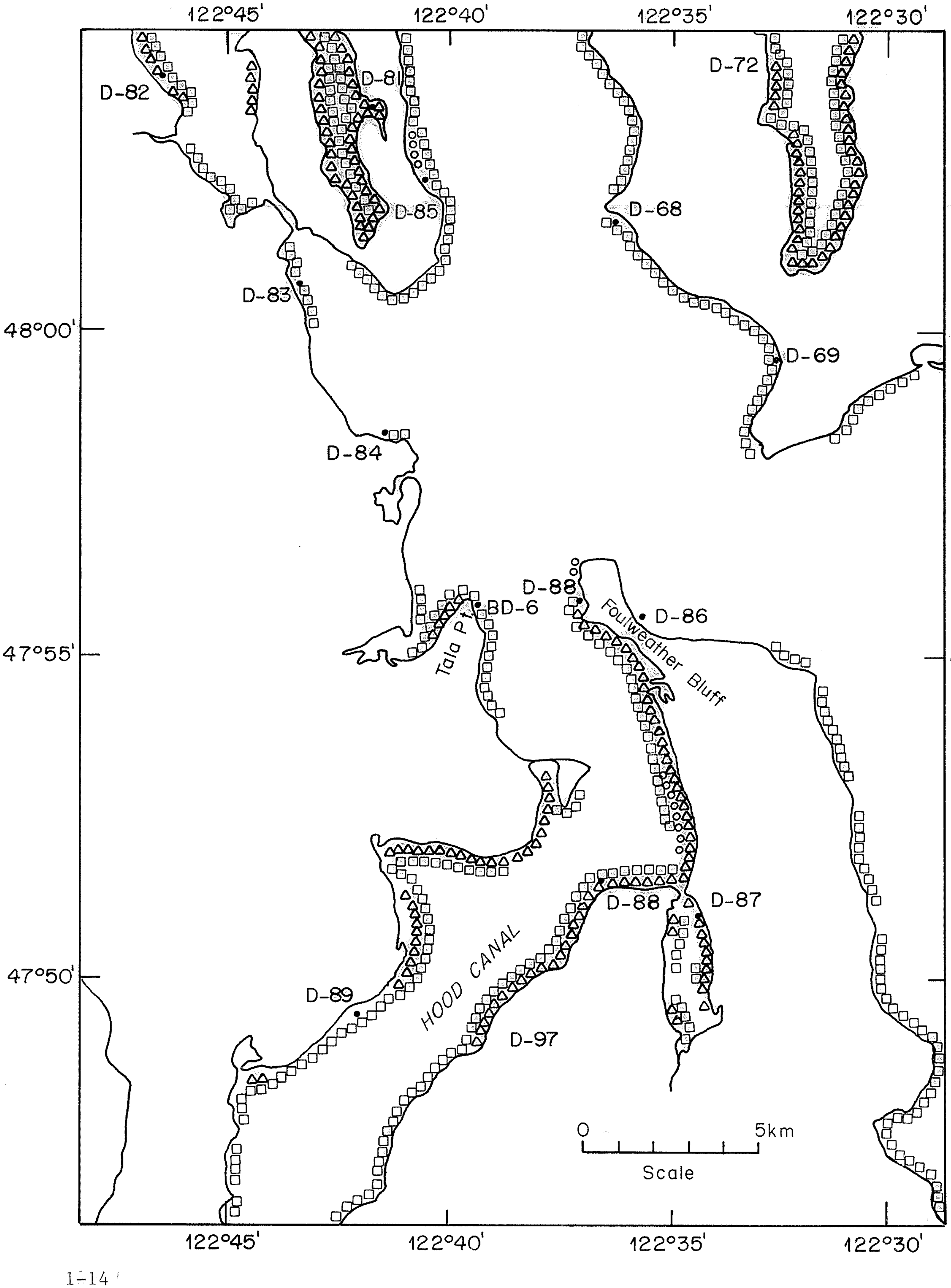
1-10


48°15'
48°10'
48°05'
123°05'
123°10'
123°15'
123°20'
123°25'
Dungeness
Ediz Hook
0
5km
Scale

1-11


48°10'
48°05'
48°00'
122°45'
122°50'
122°55'
123°00'
123°05'
123°10'
Pt. Wilson
D-80
McCurdy Pt.
Port Townsend
D-82
Cape George
Discovery Bay
Protection Is
Diamond Pt.
Sequim Bay
Dungeness
Scale
0
5 km


122°45'
122°40'
122°35'
48°15'
48°10'
48°05'
48°00'
D-75
D-70
D-93
Whidbey Island
Pt. Wilson
D-71
D-67
D-72
Marrowstone
Island
Indian Is.
D-68
0
5km
Scale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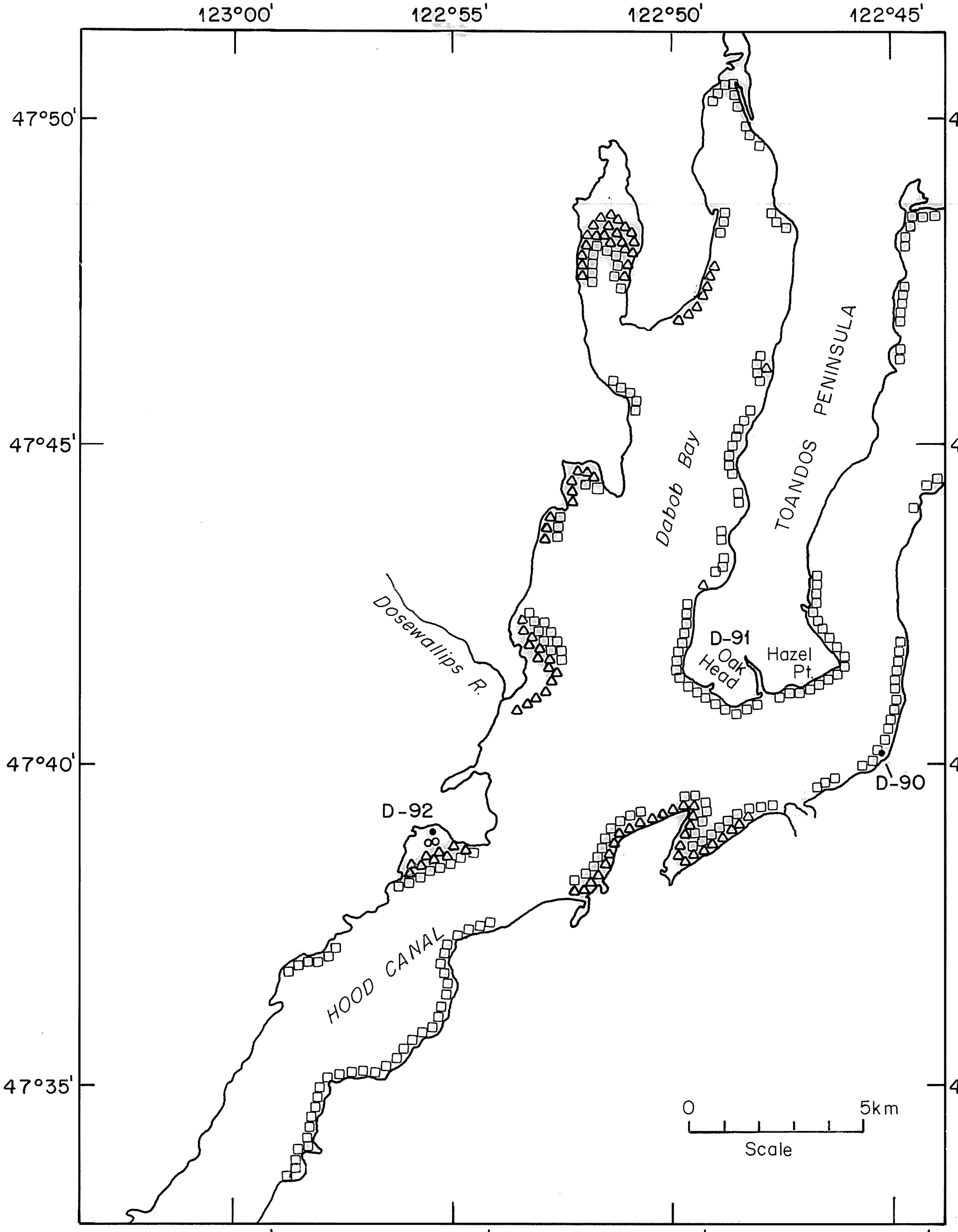
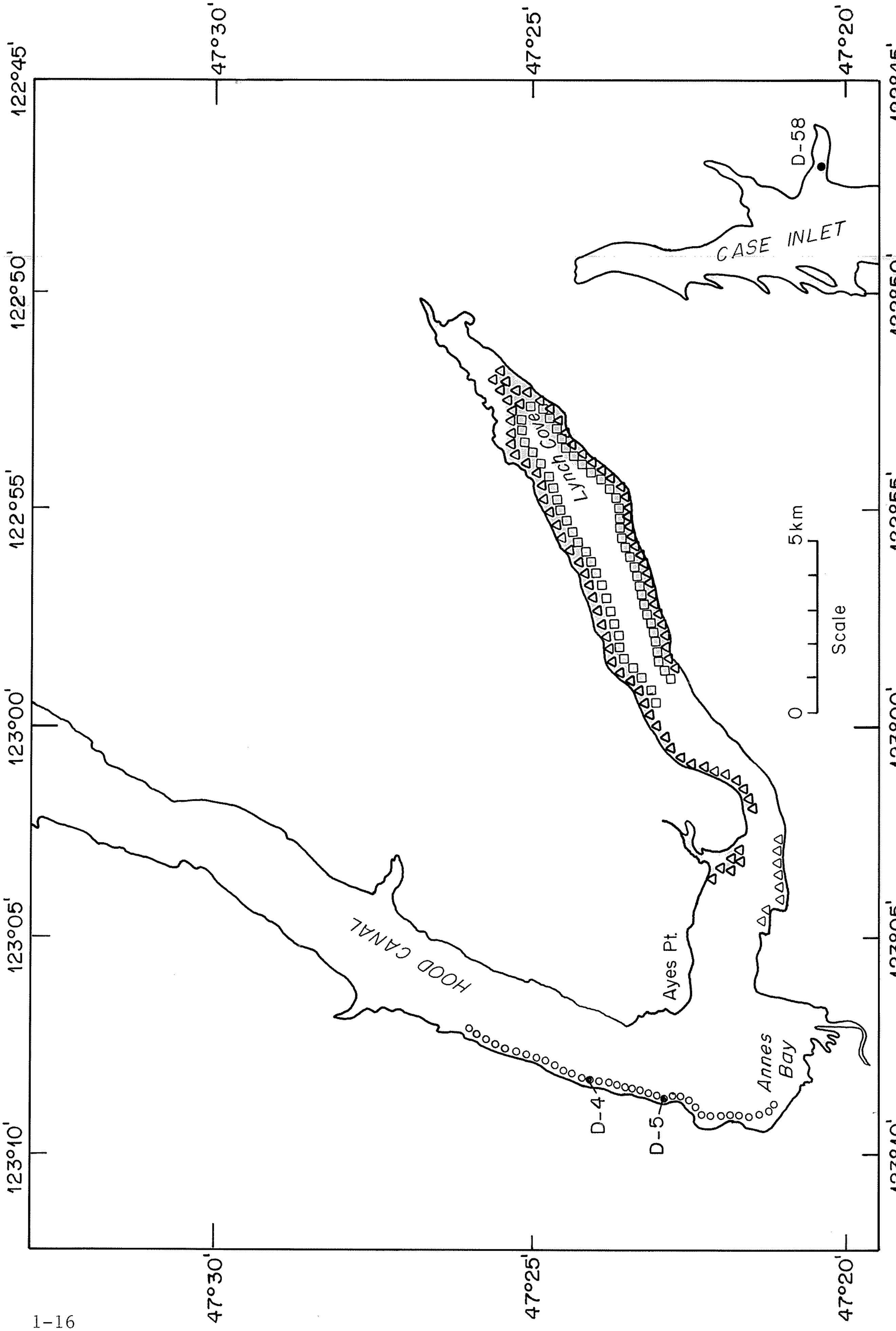
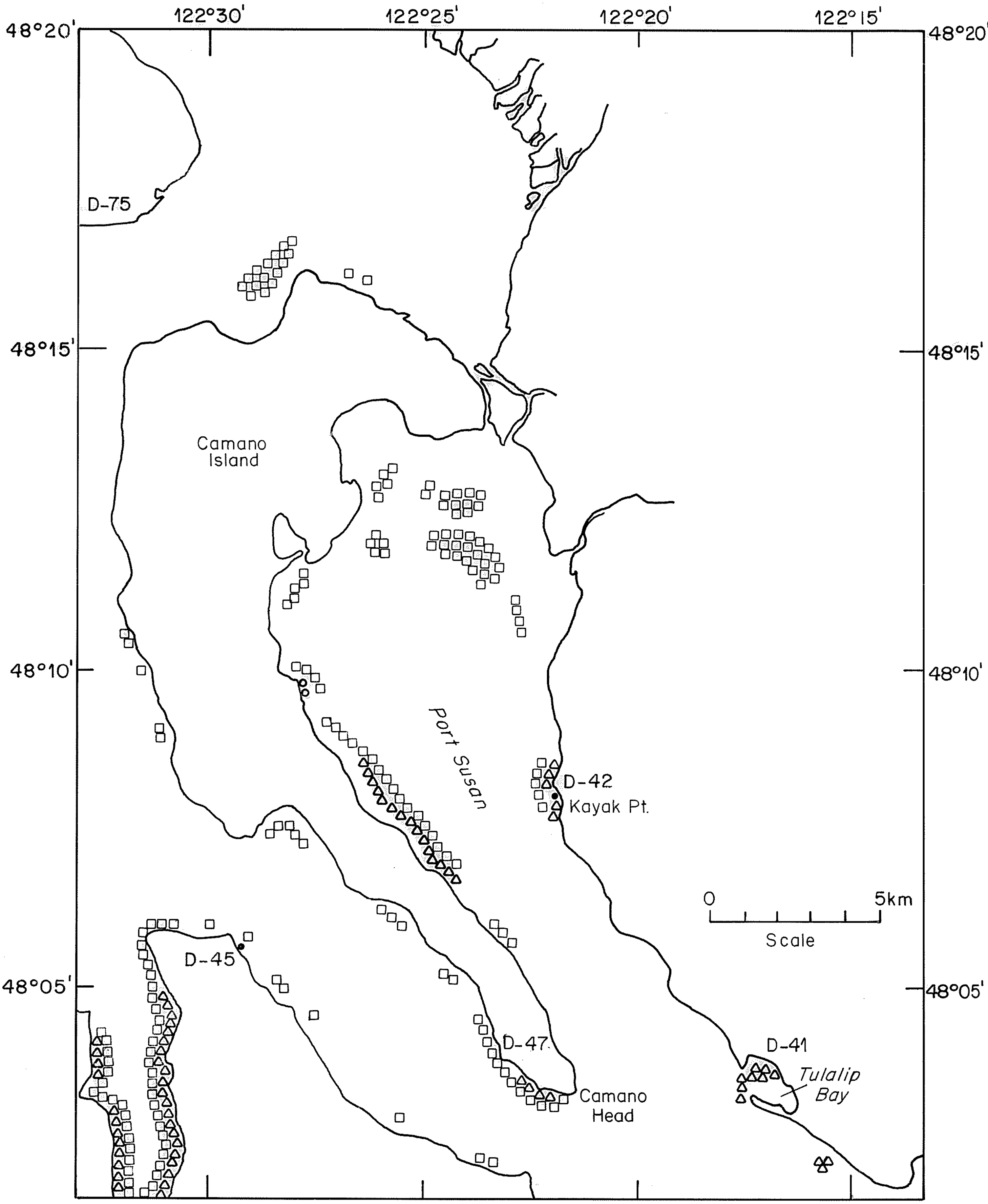
122°40'
122°35'
122°30'
48°00'
47°55'
47°50'
D-82
D-81
D-85
D-83
D-84
D-72
D-68
D-69
D-88
BD-6
D-86
Tala Pt.
Foulweather Bluff
D-87
D-88
D-89
HOOD CANAL
D-97
0
5km
Scale


123°00'
122°55'
122°50'
122°45'
47°50'
47°45'
47°40'
47°35'
Dabob Bay
TOANDOS PENINSULA
Dosewallips R.
D-91
Oak Head
Hazel Pt.
D-90
D-92
HOOD CANAL
0
5km
Scale



47°30'
47°25'
47°20'
122°45'
122°50'
122°55'
123°00'
123°05'
123°10'
CASE INLET
D-58
Lynch Cove
5km
0
Scale
HOOD CANAL
Ayes Pt.
Annes Bay
D-4
D-5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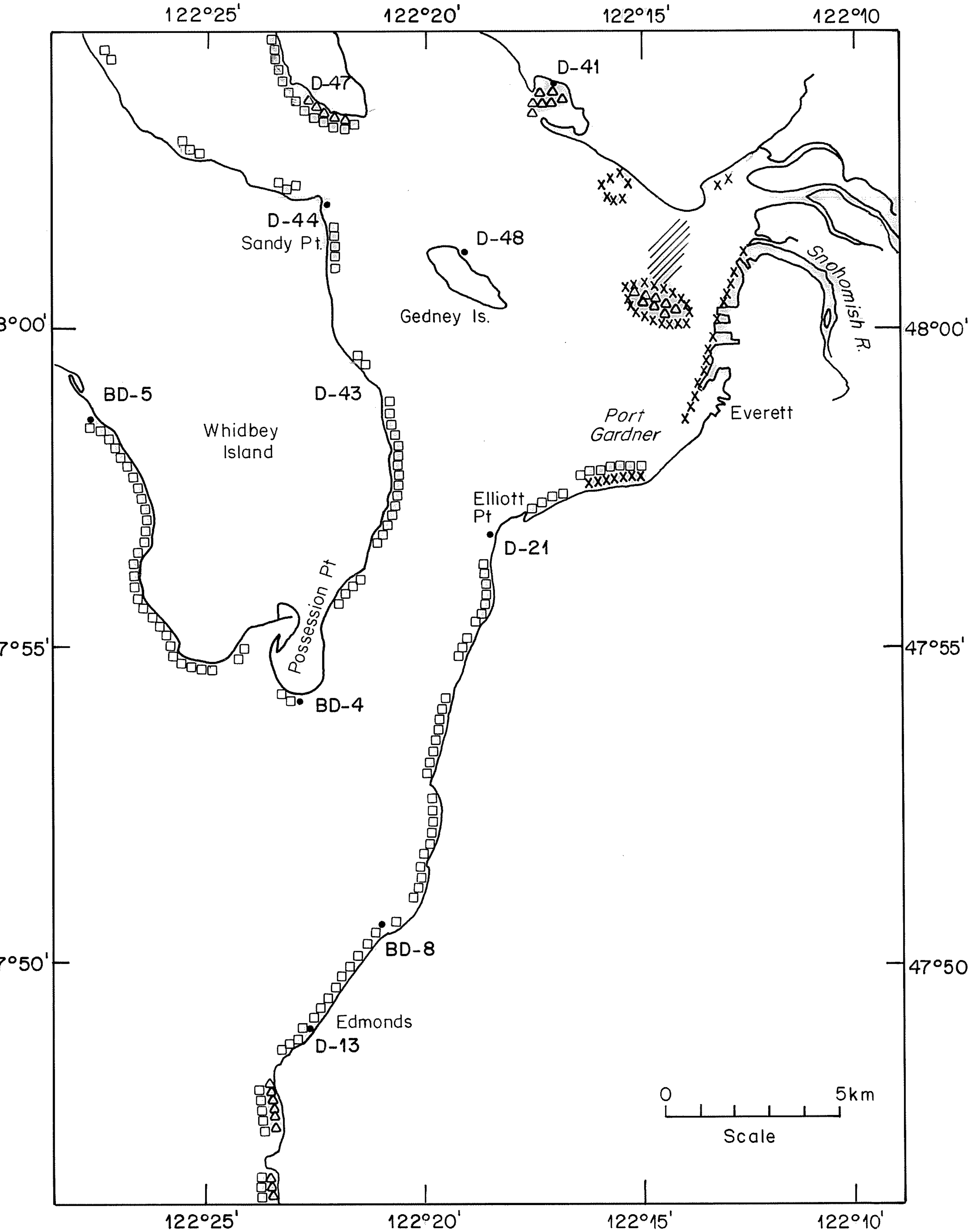
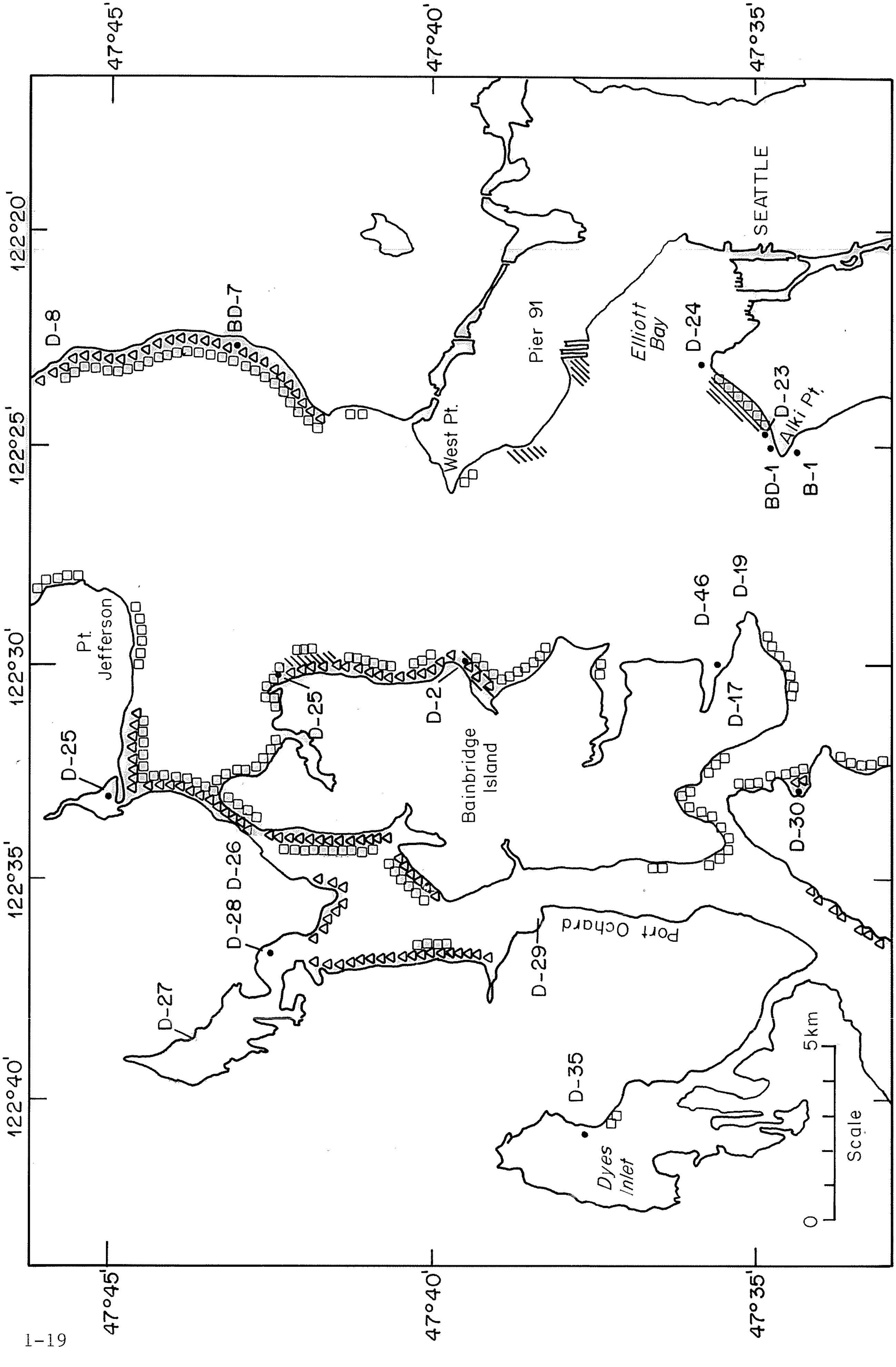
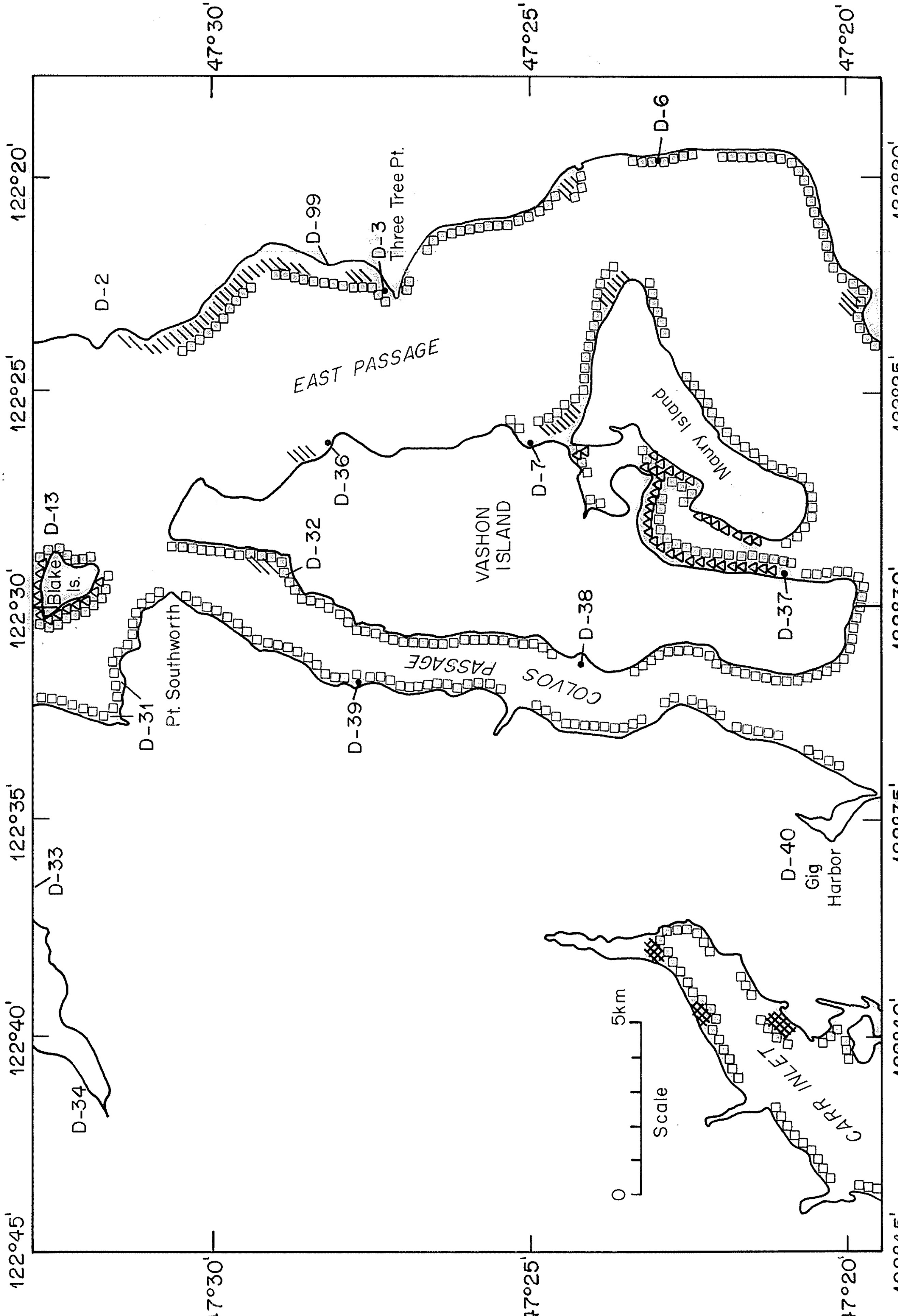
122°25'
122°20'
122°15'
48°20'
48°15'
48°10'
48°05'
D-75
Camano Island
Port Susan
D-42
Kayak Pt.
0
5km
Scale
D-45
D-47
Camano Head
D-41
Tulalip Bay


122°25'
122°20'
122°15'
122°10'
48°00'
47°55'
47°50'
D-47
D-41
D-44
Sandy Pt.
D-48
Gedney Is.
Snohomish R.
BD-5
D-43
Whidbey
Island
Port
Gardner
Everett
Elliott
Pt
D-21
Possession Pt
BD-4
BD-8
Edmonds
D-13
0
5km
Scale



47°45'
47°40'
47°35'
122°20'
122°25'
122°30'
122°35'
122°40'
D-8
BD-7
Pier 91
Elliott Bay
D-24
D-23
Alki Pt.
West Pt.
BD-1
B-1
SEATTLE
Pt. Jefferson
D-25
D-2
D-46
D-19
D-17
Bainbridge Island
D-30
D-26
D-28
D-27
D-29
Port Orchard
D-35
Dyes Inlet
0
5km
Scale

1-19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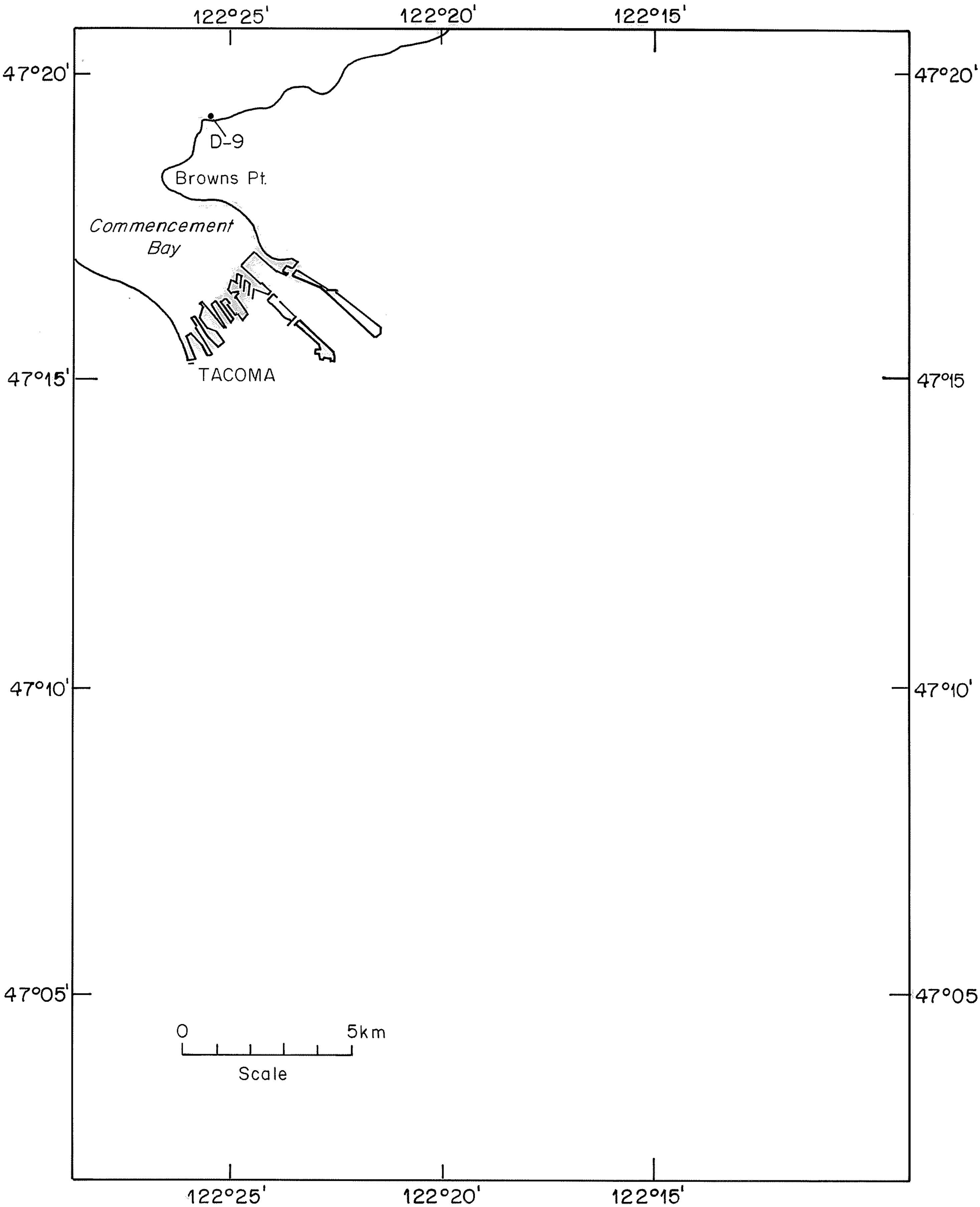
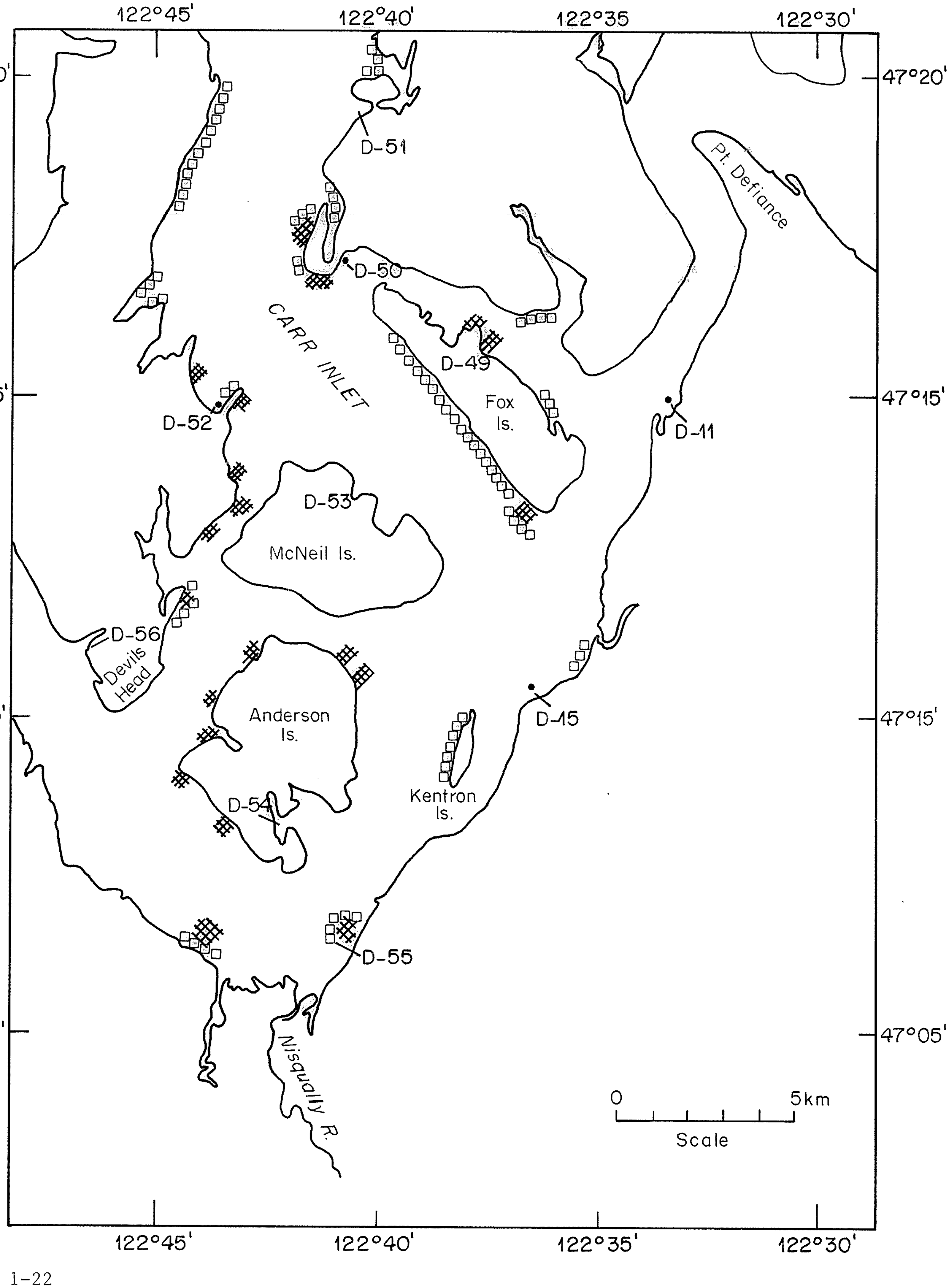
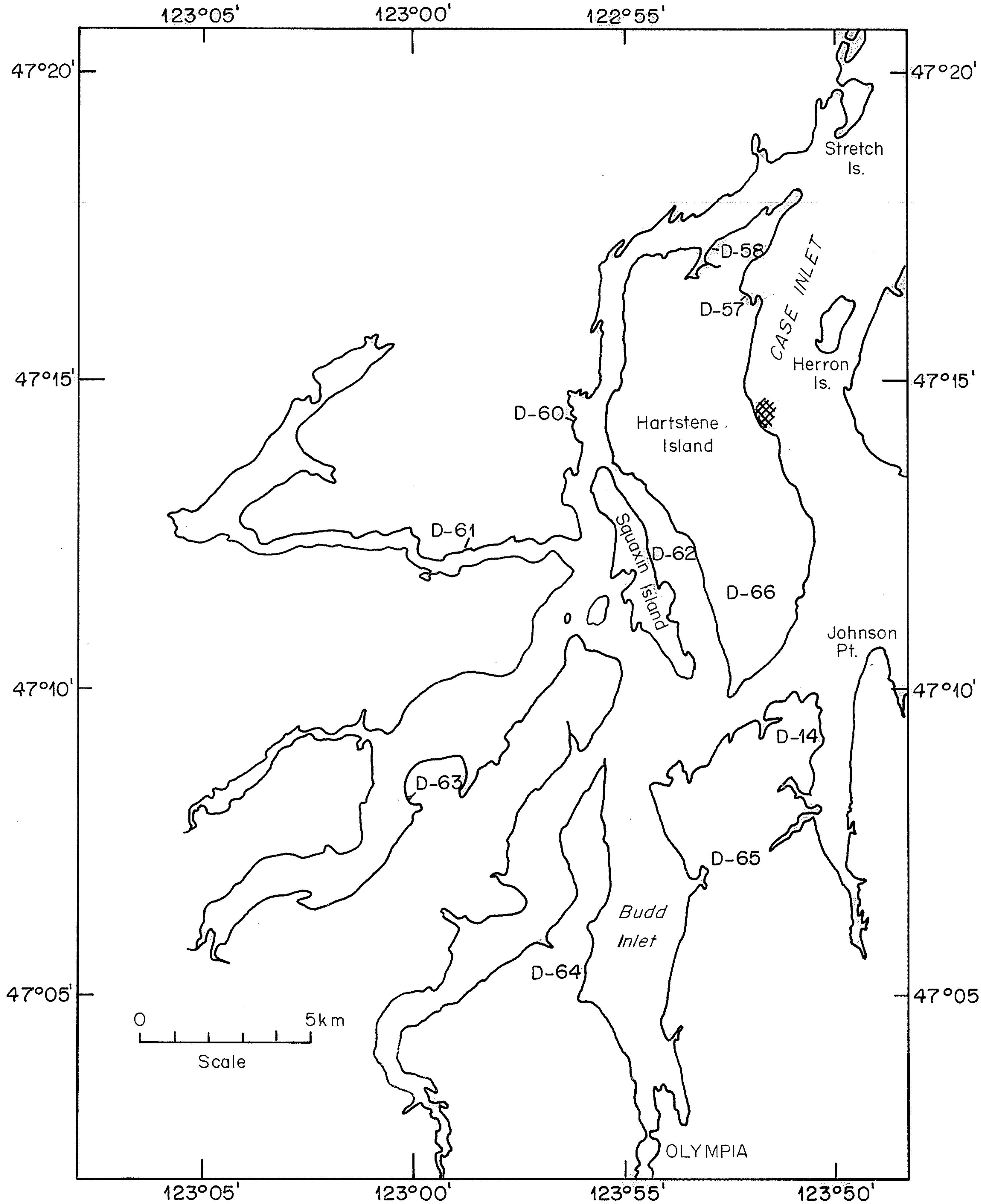
47°25'
47°20'
122°20'
122°25'
122°30'
122°35'
122°40'
122°45'
D-2
D-99
D-3
Three Tree Pt.
D-6
EAST PASSAGE
Maury Island
D-7
D-36
VASHON
ISLAND
D-13
Blake
Is.
D-32
D-38
D-37
Pt. Southworth
D-31
D-39
COLVOS
PASSAGE
D-33
D-40
Gig
Harbor
D-34
CARR INLET
Scale
0
5km

1-20



122°25'
122°20'
122°15'
47°20'
47°20'
D-9
Browns Pt.
Commencement Bay
TACOMA
47°15'
47°15
47°10'
47°10'
47°05'
47°05'
0
5km
Scale
122°25'
122°20'
122°15'


122°45'
122°40'
122°35
122°30'
47°20'
47°15'
47°10'
47°05'
D-51
D-50
Pt. Defiance
CARR INLET
D-49
D-52
Fox Is.
D-11
D-53
McNeil Is.
D-56
Devils Head
Anderson Is.
D-15
D-54
Kentron Is.
D-55
Nisqually R.
0
5km
Scale

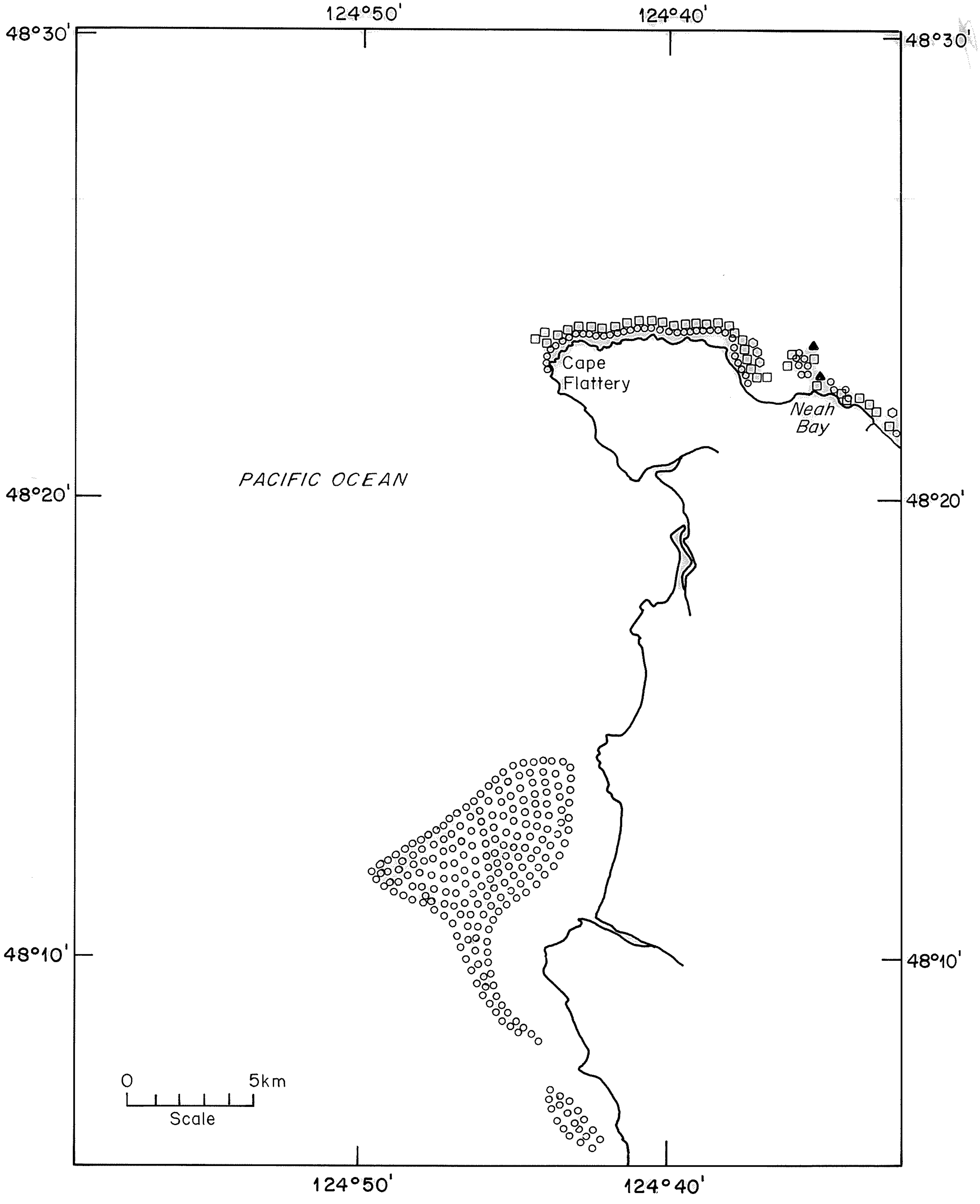

123°05'
123°00'
122°55'
47°20'
47°15'
47°10'
47°05'
Stretch Is.
D-58
CASE INLET
D-57
Herron Is.
D-60
Hartstene Island
D-61
Squaxin Island
D-62
D-66
Johnson Pt.
D-14
D-63
D-65
Budd Inlet
D-64
0
5km
Scale
OLYMPIA
123°05'
123°00'
123°55'
123°50'

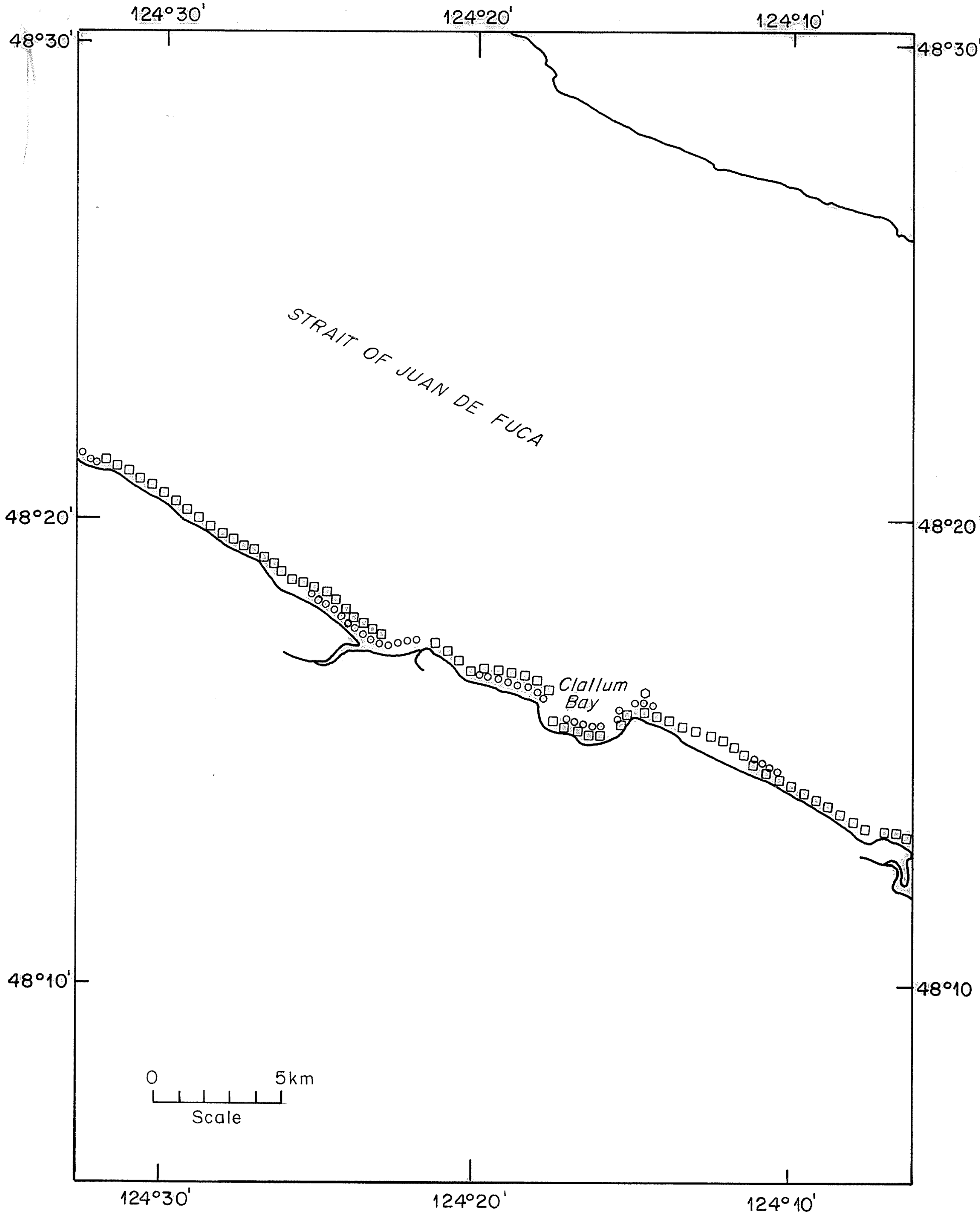
APPENDIX 2

MAPS OF DISTRIBUTION RECORDS OF KELP

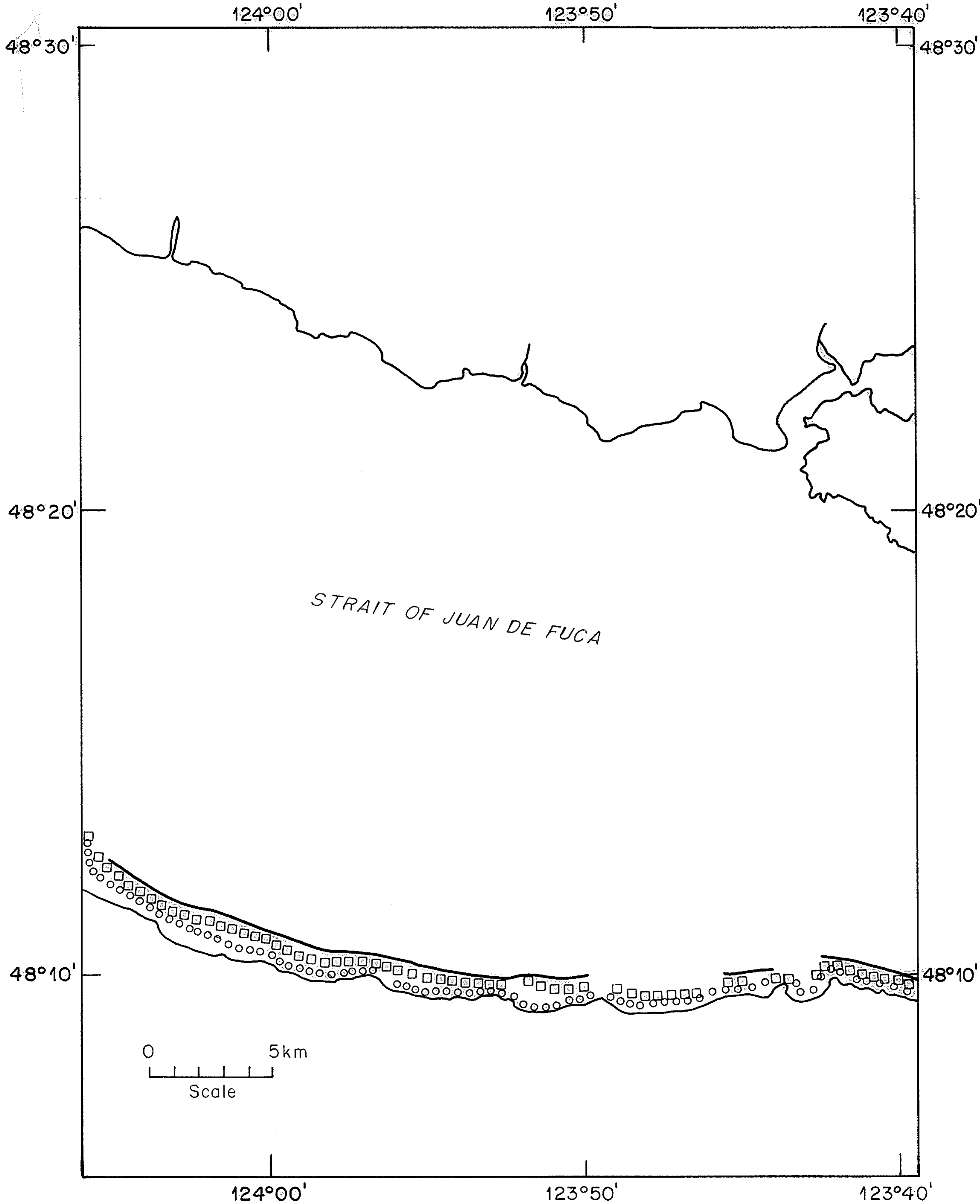
SYMBOLS USED FOR KELP RECORDS

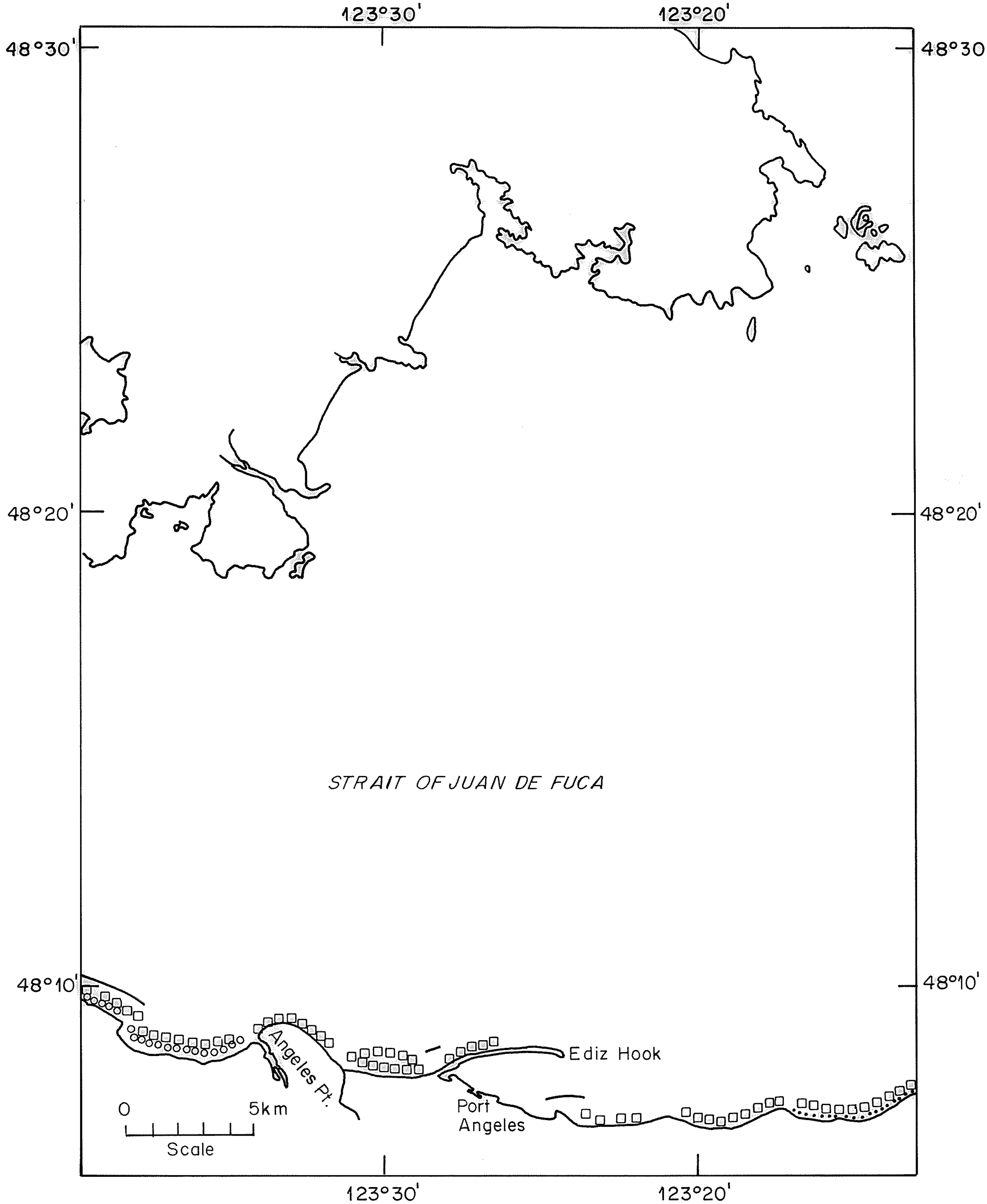
oooooo	Rigg 1911-12
ΔΔΔΔΔ	Washington Department of Fisheries 1975-89
□□□□□	Washington Department of Wildlife 1977-78
....	U.S. Geological Survey 1886
+++++	U.S. Geological Survey 1875
//////	Washington State University 1954
xxxxxx	U.S. Coast Survey 1856
*****	U.S. Geological Survey 1854
■■■■■	Coast Pilot 1889
▲▲▲▲	Coast Pilot 1926
OOOO	Coast Pilot 1951
———	Hydrographic Surveys 1852-1889
•	Phillips 1962-63


124°50'
124°40'
48°30'
48°30'
48°20'
48°20'
48°10'
48°10'
Cape
Flattery
Neah
Bay
PACIFIC OCEAN
0
5km
Scale
124°50'
124°40'


124°30'
124°20'
124°10'
48°30'
48°30'
STRAIT OF JUAN DE FUCA
48°20'
48°20'
Clallum Bay
48°10'
48°10
0
5km
Scale
124°30'
124°20'
124°10'

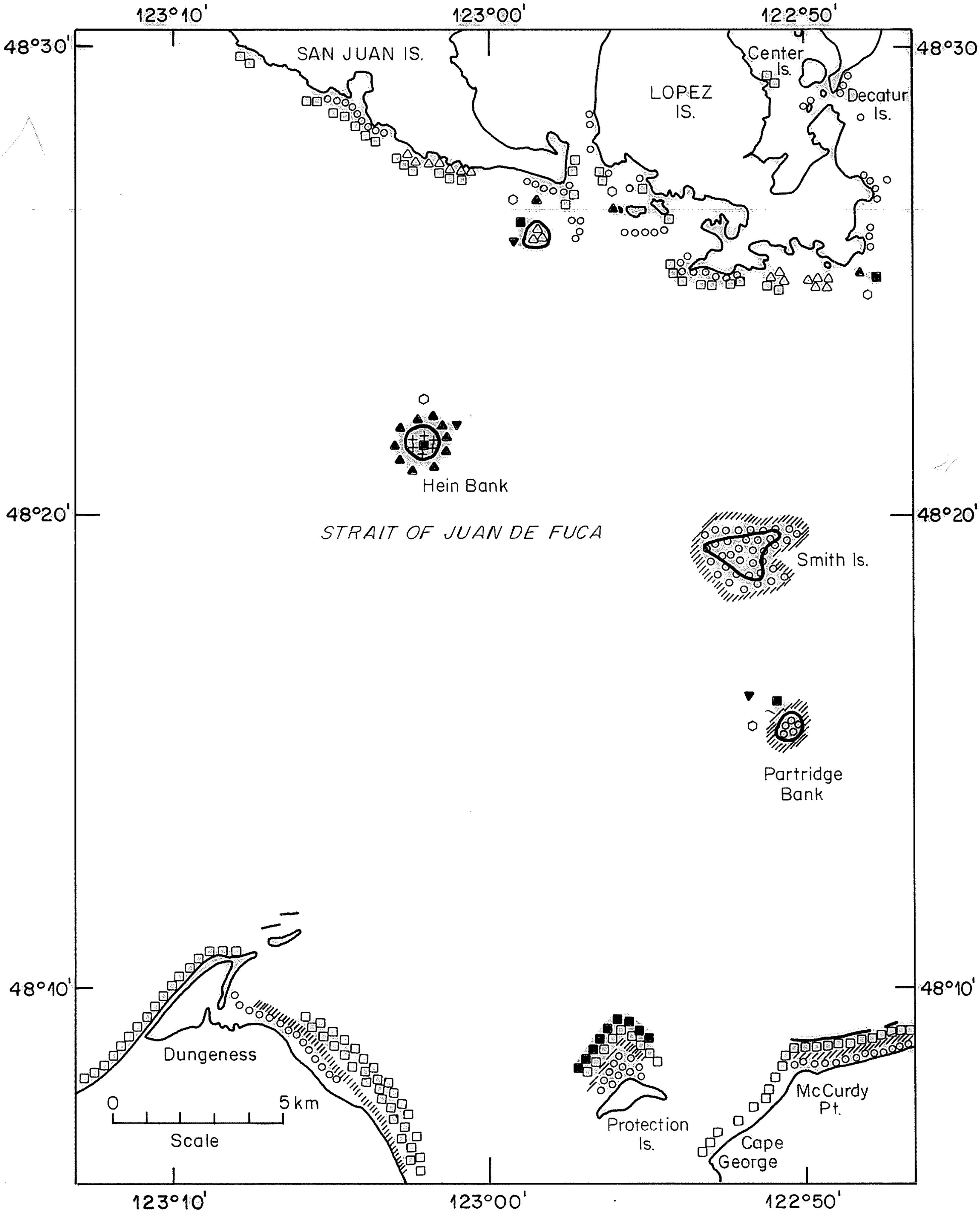
2-2

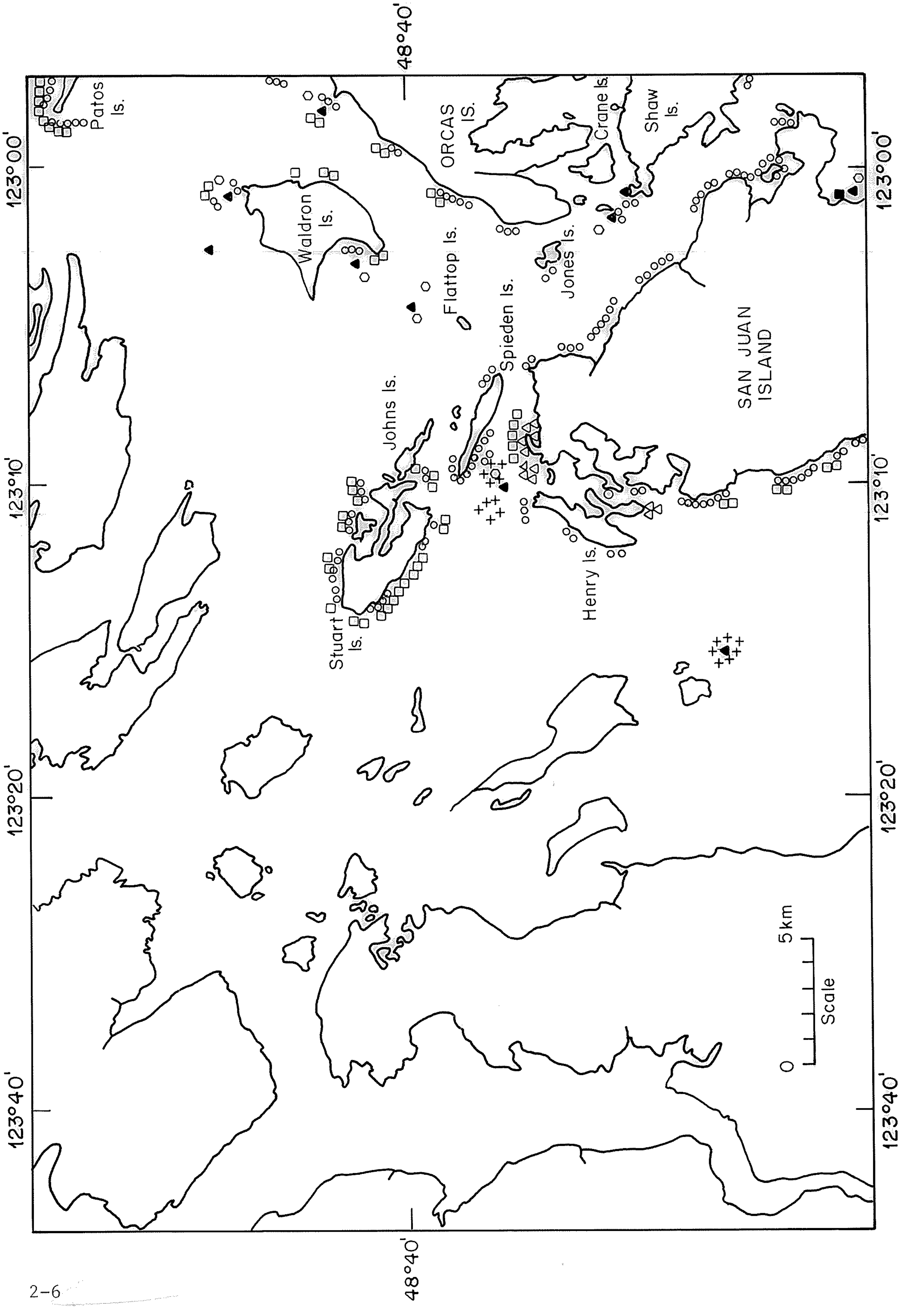

124°00'
123°50'
123°40'
48°30'
48°30'
48°20'
48°20'
STRAIT OF JUAN DE FUCA
48°10'
48°10'
0
5km
Scale
124°00'
123°50'
123°40'



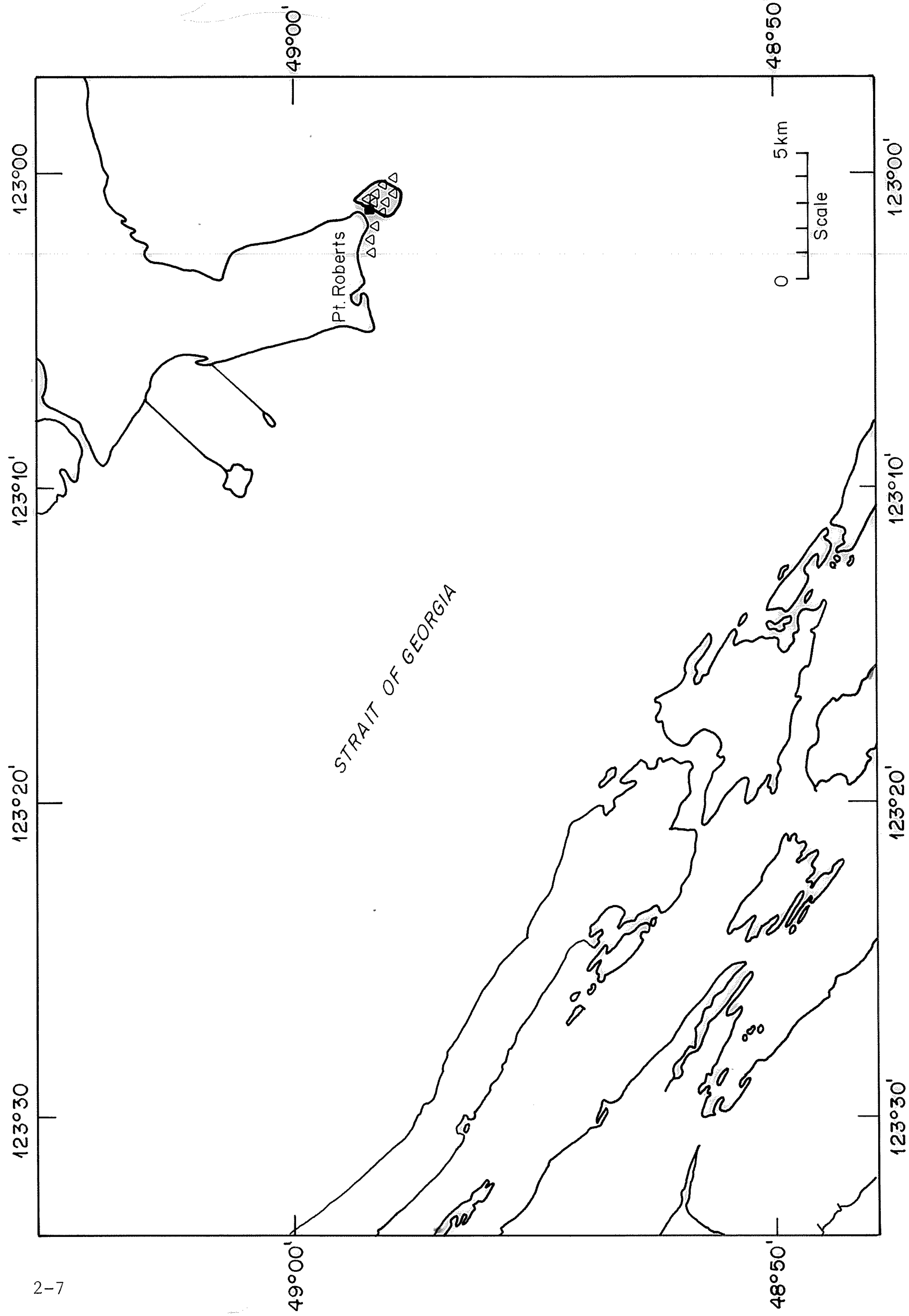
123°30'
123°20'
48°30'
48°30'
48°20'
48°20'
STRAIT OF JUAN DE FUCA
48°10'
48°10'
Angeles Pt.
Ediz Hook
Port Angeles
0
5km
Scale
123°30'
123°20'

2-4

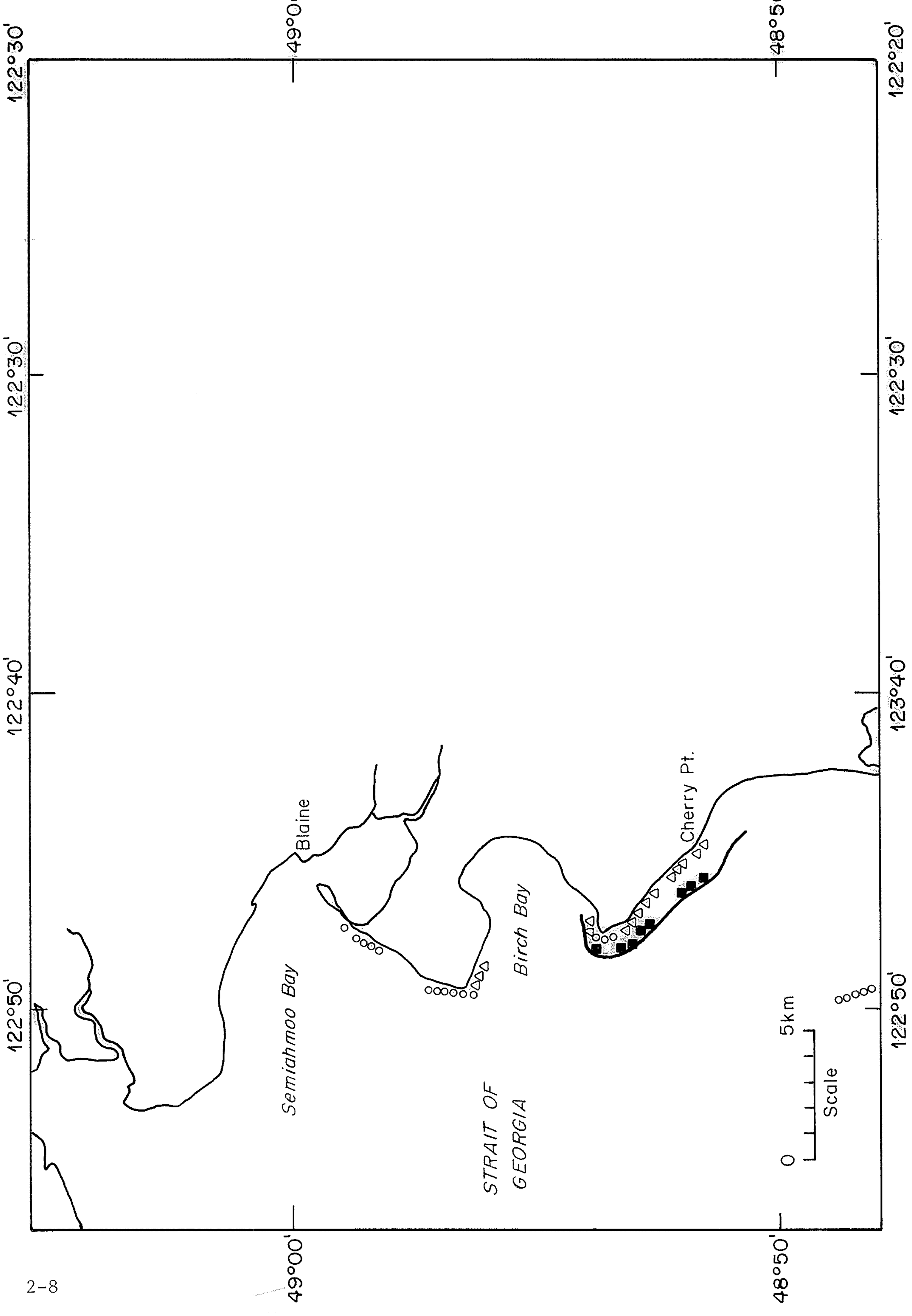

123°10'
123°00'
122°50'
48°30'
48°20'
48°10'
SAN JUAN IS.
LOPEZ IS.
Center Is.
Decatur Is.
Hein Bank
STRAIT OF JUAN DE FUCA
Smith Is.
Partridge Bank
Dungeness
0
5 km
Scale
Protection Is.
McCurdy Pt.
Cape George

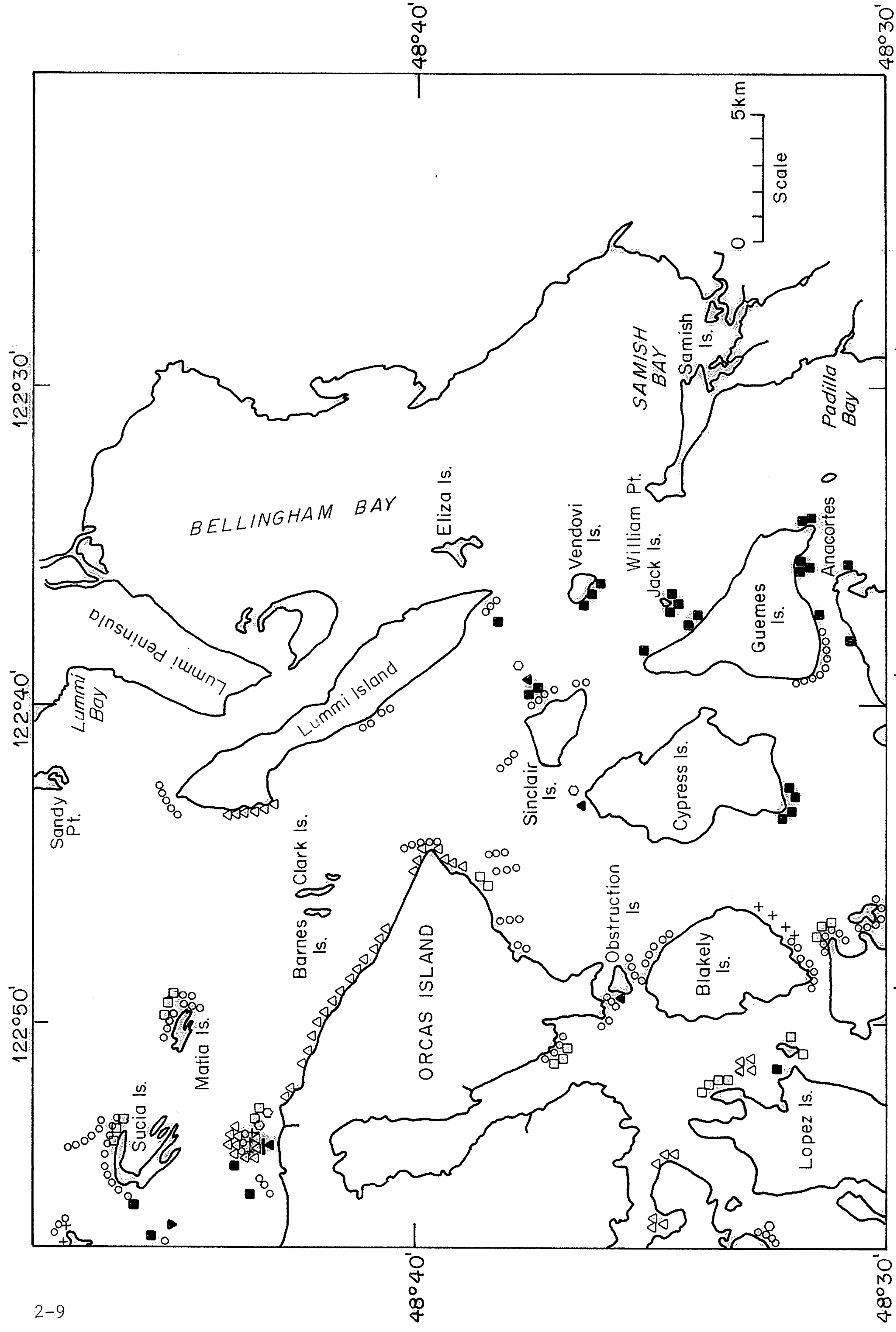

48°40'
123°00'
Patos Is.
ORCAS IS.
Crane Is.
Shaw Is.
Waldron Is.
Flattop Is.
Spieden Is.
Jones Is.
SAN JUAN ISLAND
Johns Is.
123°10'
Stuart Is.
Henry Is.
123°20'
5 km
Scale
0
123°40'
48°40'

2-6

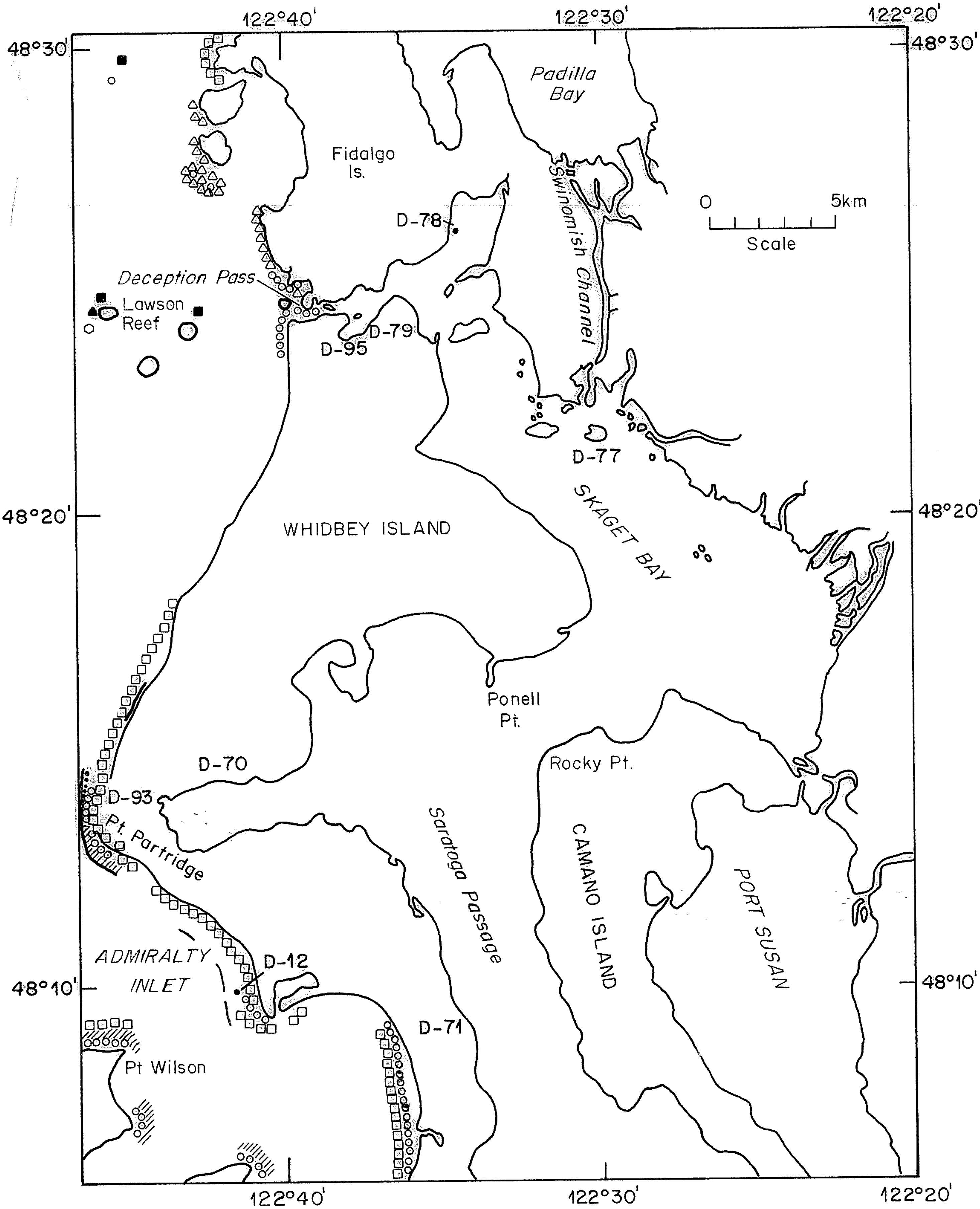

49°00'
48°50'
123°00'
123°10'
123°20'
123°30'
Pt. Roberts
STRAIT OF GEORGIA
Scale
0
5km

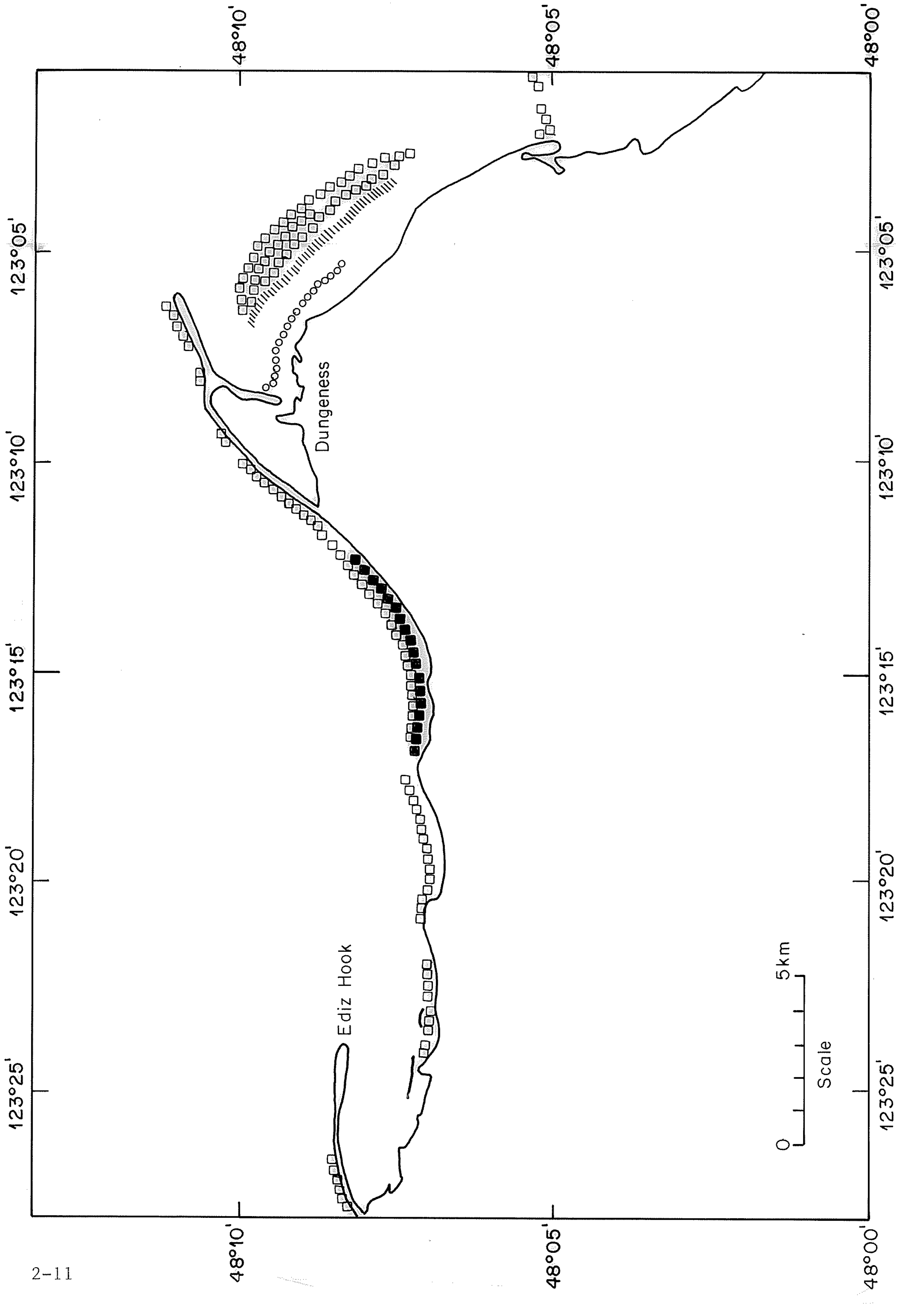
2-7


49°00'
48°50'
122°30'
122°20'
122°30'
122°30'
122°40'
123°40'
122°50'
122°50'
49°00'
48°50'
Blaine
Semiahmoo Bay
Birch Bay
Cherry Pt.
STRAIT OF GEORGIA
Scale
0
5km

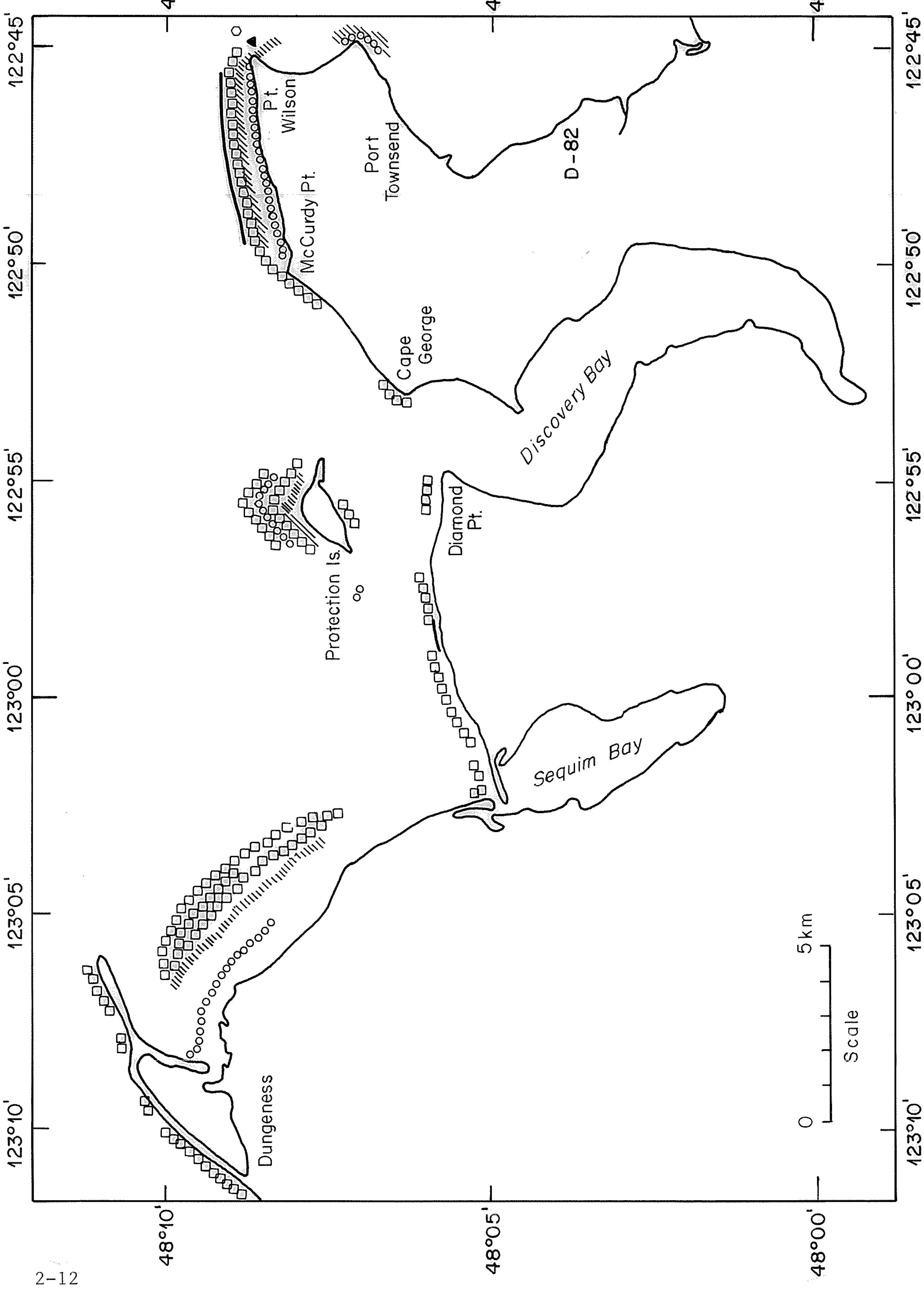


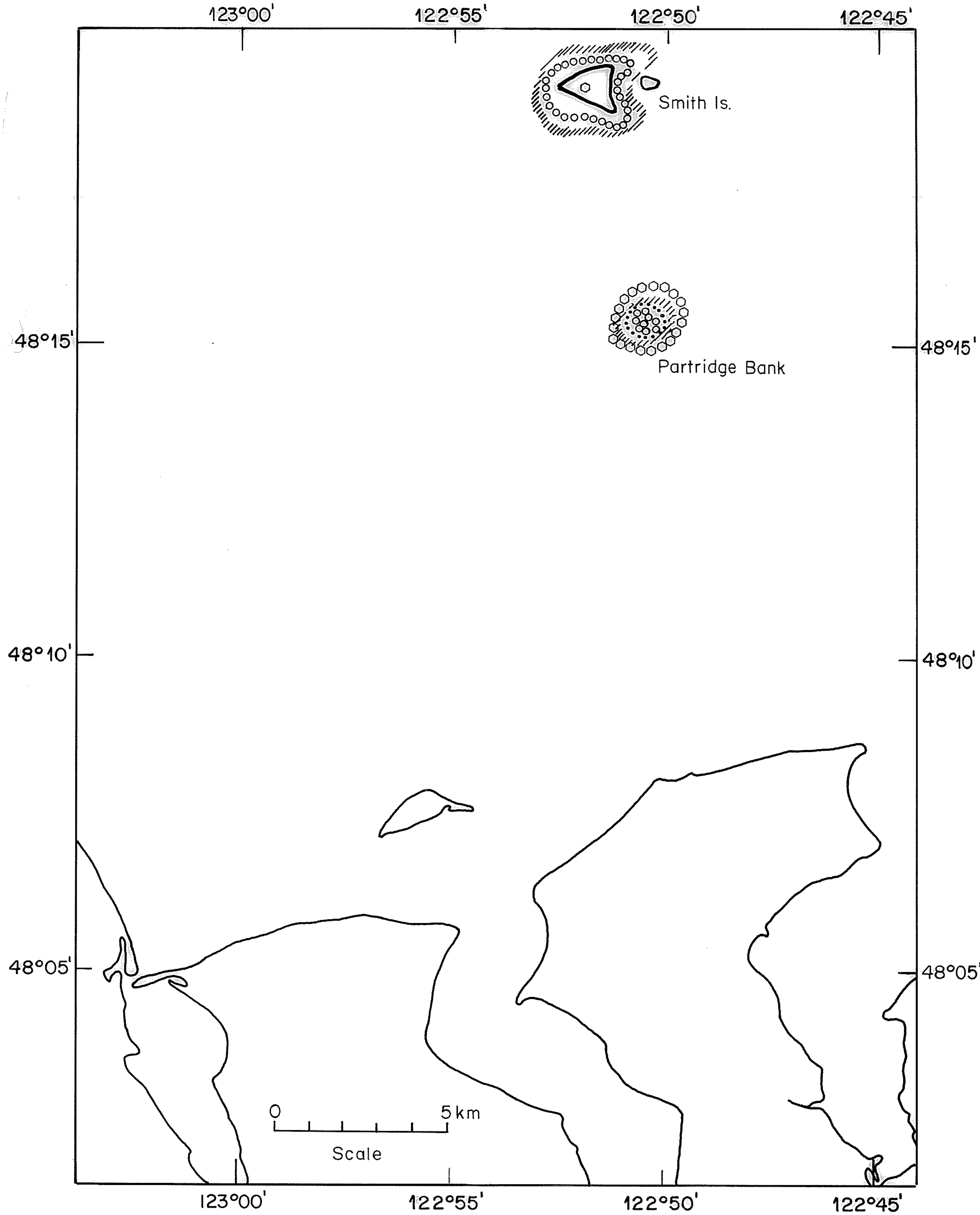
48°40'
48°30'
122°30'
122°40'
122°50'
5km
0
Scale
BELLINGHAM BAY
SAMISH BAY
Samish Is.
Padilla Bay
Eliza Is.
William Pt.
Vendovi Is.
Jack Is.
Anacortes
Guemes Is.
Lummi Peninsula
Lummi Bay
Lummi Island
Sandy Pt.
Sinclair Is.
Cypress Is.
Clark Is.
Barnes Is.
ORCAS ISLAND
Obstruction Is
Blakely Is.
Matia Is.
Sucia Is.
Lopez Is.

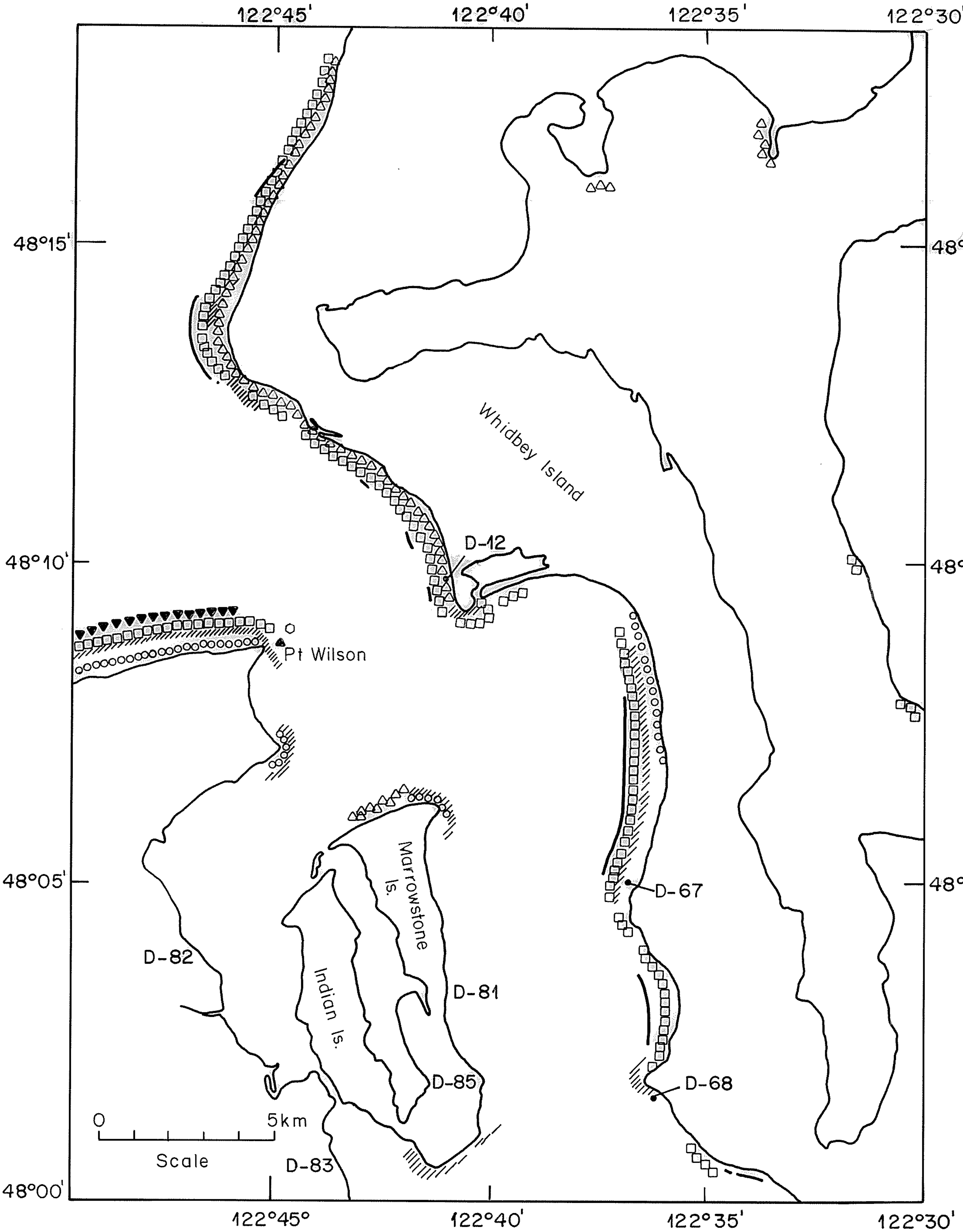

122°40'
122°30'
122°20'
48°30'
48°20'
48°10'
Padilla Bay
Fidalgo Is.
Swinomish Channel
0
5km
Scale
D-78
Deception Pass
Lawson Reef
D-79
D-95
D-77
SKAGET BAY
WHIDBEY ISLAND
Ponell Pt.
Rocky Pt.
D-70
D-93
Pt. Partridge
Saratoga Passage
CAMANO ISLAND
PORT SUSAN
ADMIRALTY INLET
D-12
D-71
Pt Wilson

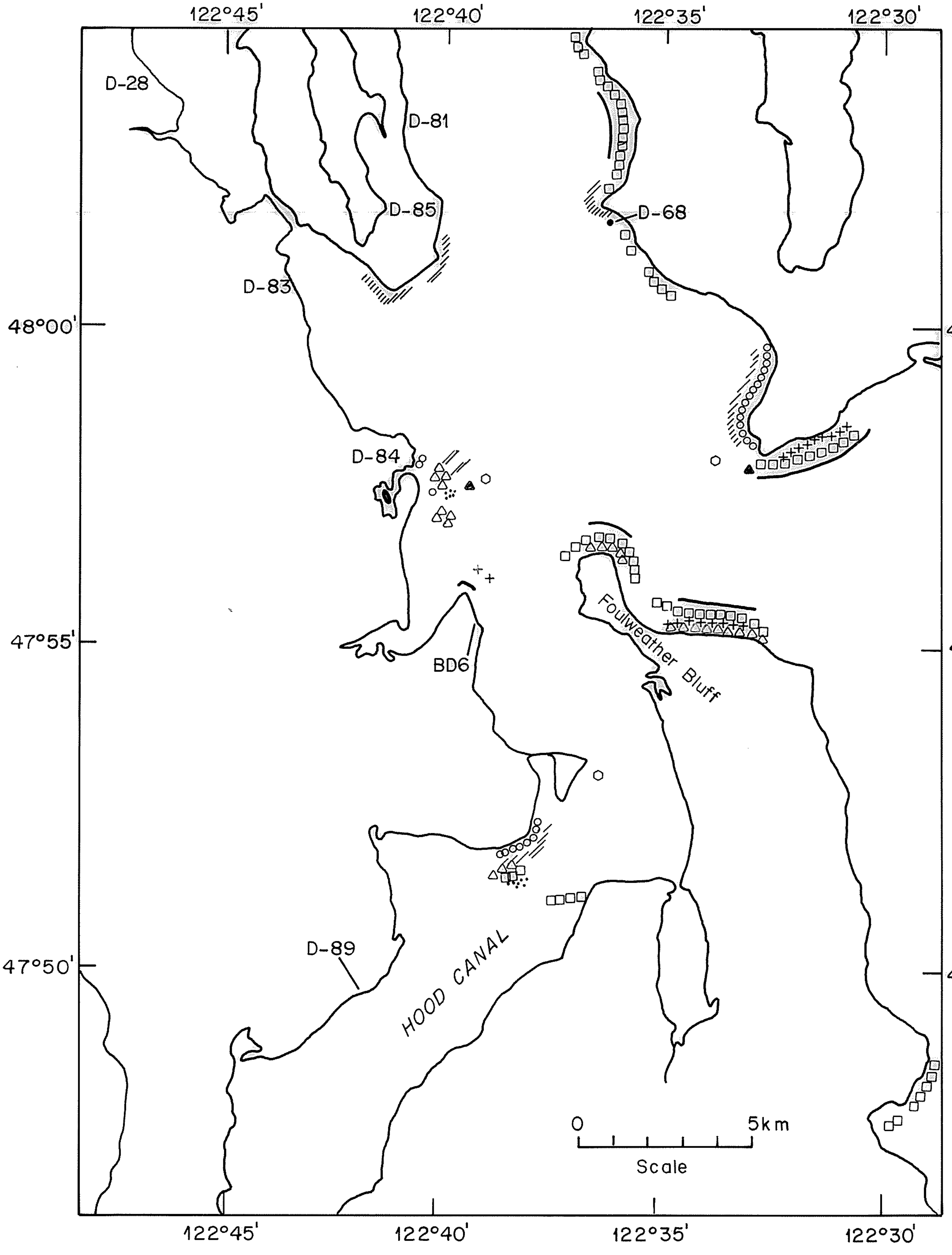

48°10'
48°05'
48°00'
123°05'
123°10'
123°15'
123°20'
123°25'
Dungeness
Ediz Hook
Scale
0
5km

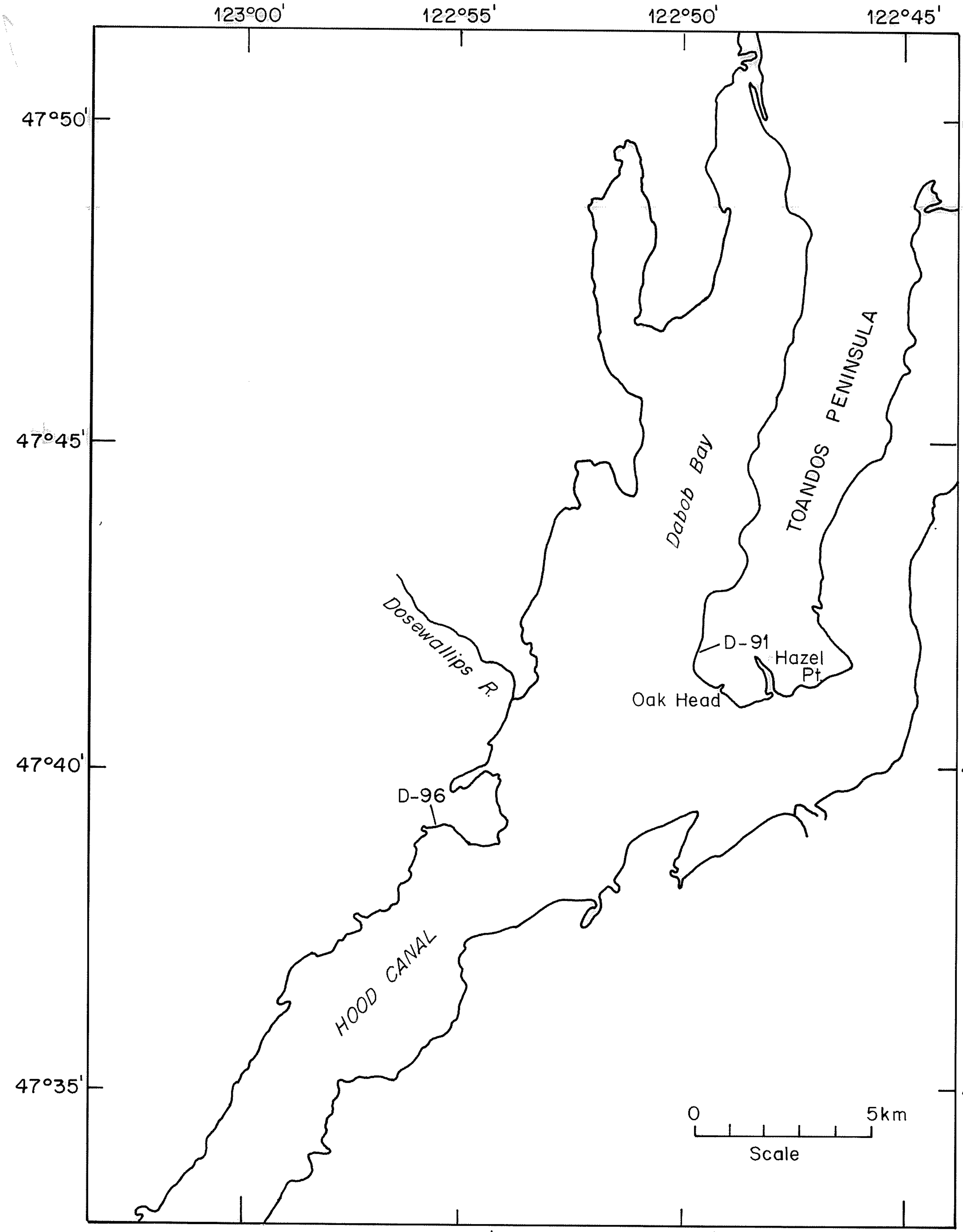
2-11

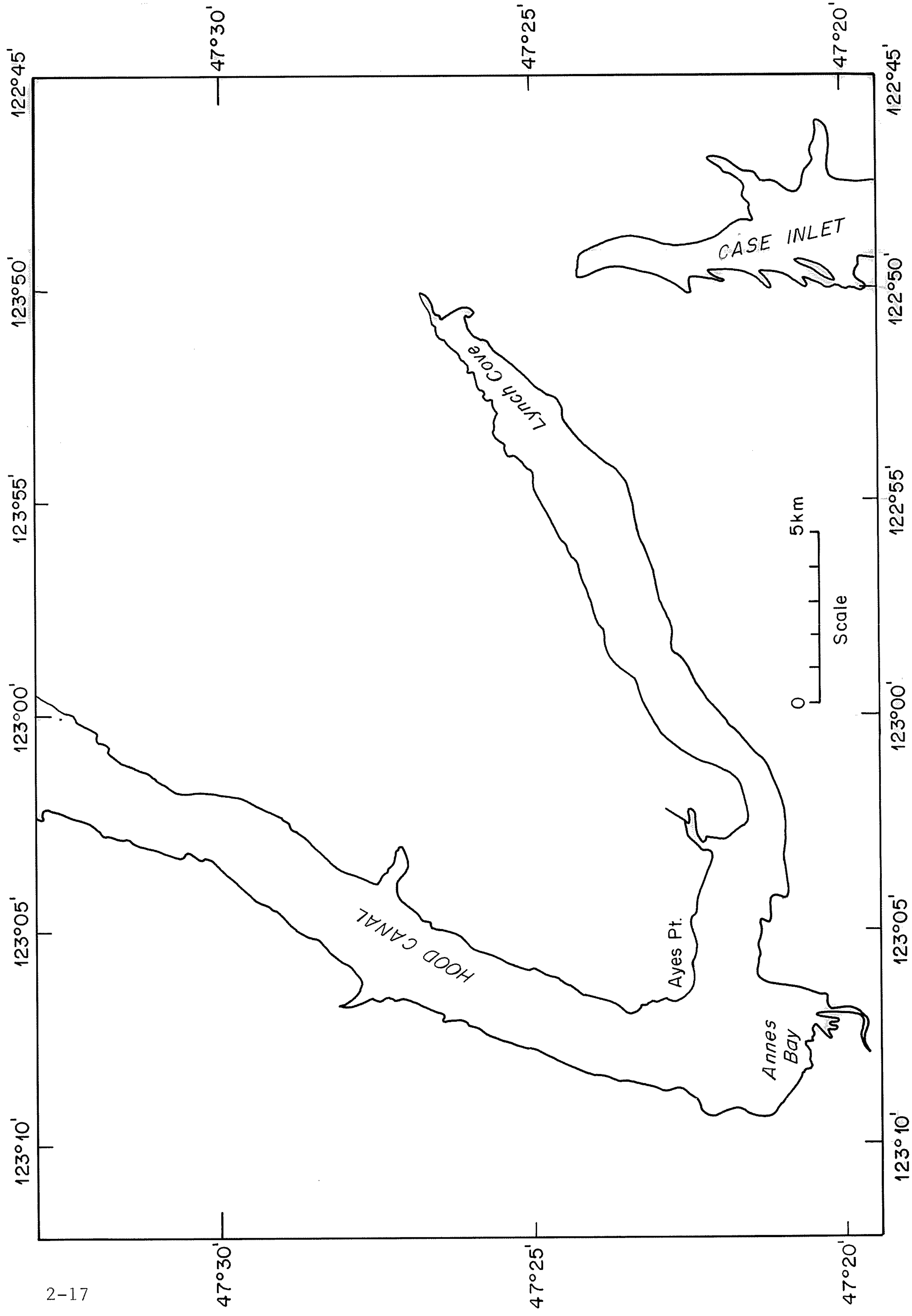

48°10'
48°05'
48°00'
122°45'
122°50'
122°55'
123°00'
123°05'
123°10'
Pt. Wilson
McCurdy Pt.
Port Townsend
D-82
Cape George
Discovery Bay
Protection Is.
Diamond Pt.
Sequim Bay
Dungeness
0
5 km
Scale


123°00'
122°55'
122°50'
122°45'
Smith Is.
Partridge Bank
48°15'
48°10'
48°05'
0
5 km
Scale

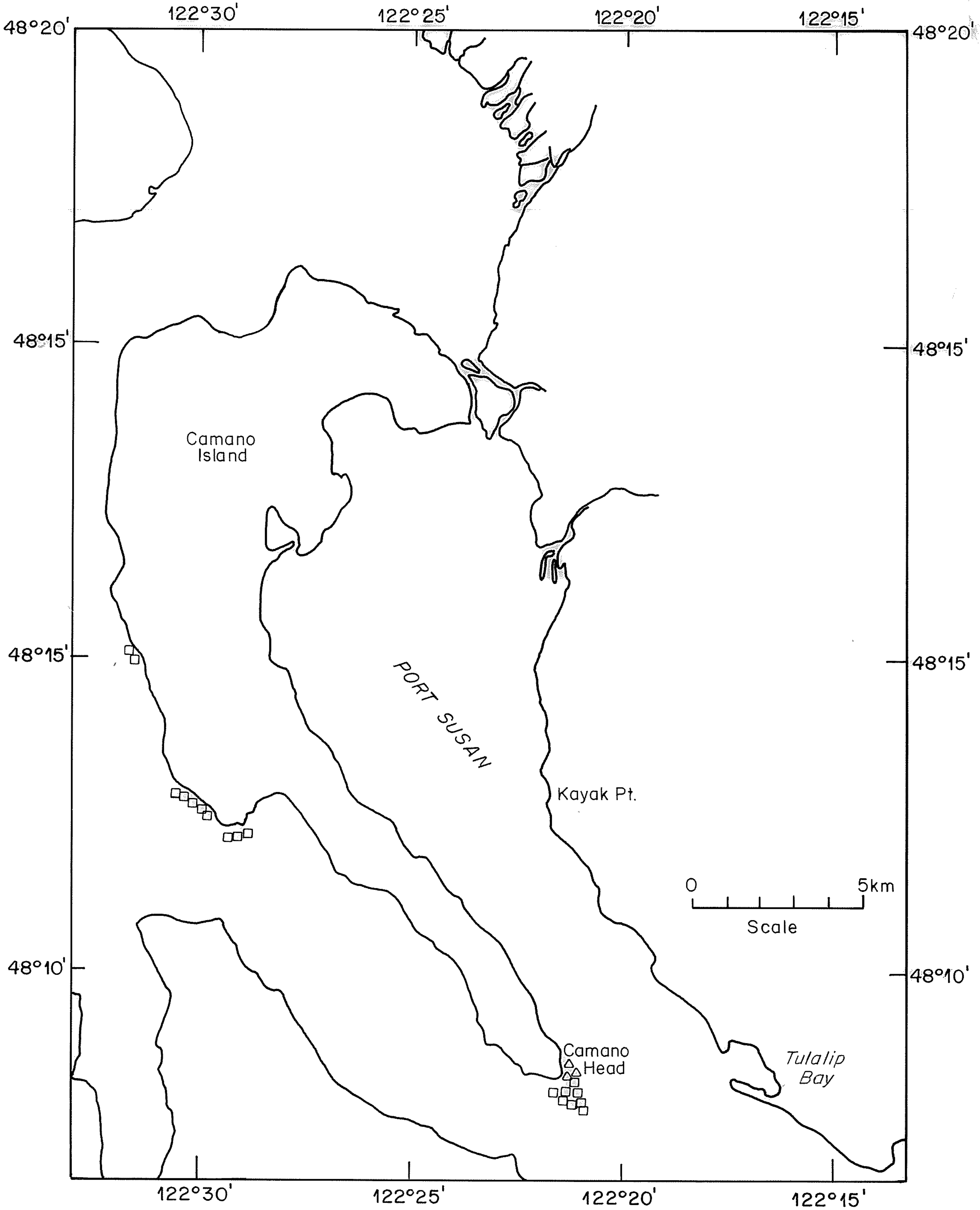

122°45'
122°40'
122°35'
122°30'
48°15'
48°10'
48°05'
48°00'
Whidbey Island
D-12
Pt Wilson
Marrowstone Is.
Indian Is.
D-67
D-68
D-81
D-82
D-83
D-85
0
5km
Scale

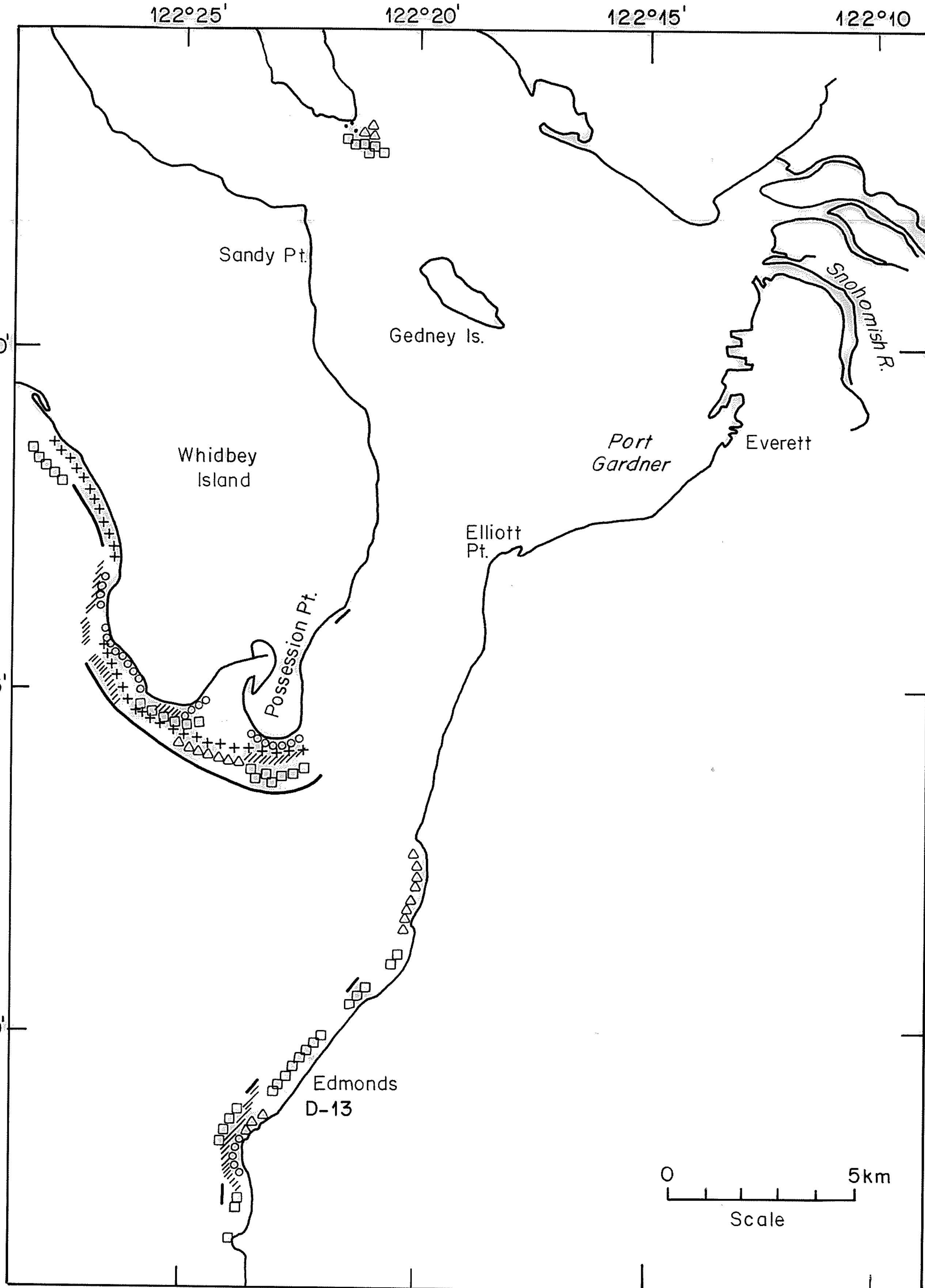

122°45'
122°40'
122°35'
122°30'
D-28
D-81
D-85
D-68
D-83
48°00'
48°00'
D-84
47°55'
47°55'
BD6
Foulweather Bluff
47°50'
47°50'
D-89
HOOD CANAL
0
5km
Scale
122°45'
122°40'
122°35'
122°30'

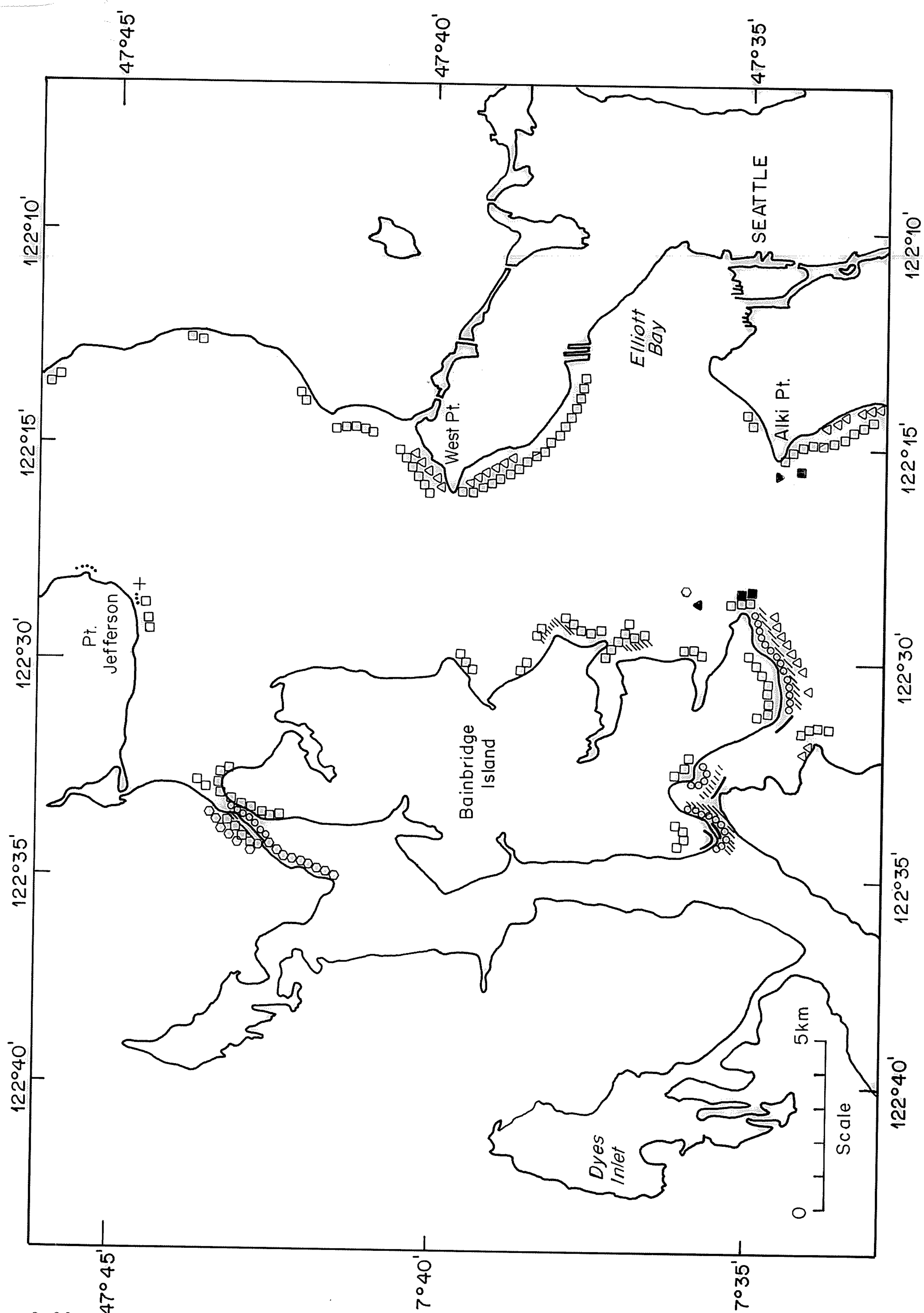

123°00'
122°55'
122°50'
122°45'
47°50'
47°45'
47°40'
47°35'
Dabob Bay
TOANDOS PENINSULA
Dosewallips R.
D-91
Hazel Pt
Oak Head
D-96
HOOD CANAL
0
5km
Scale
123°00
122°55'
122°50'
122°45'


47°30'
47°25'
47°20'
122°45'
123°50'
122°50'
123°55'
122°55'
123°00'
123°05'
123°10'
CASE INLET
Lynch Cove
5km
Scale
0
HOOD CANAL
Ayes Pt.
Annes Bay

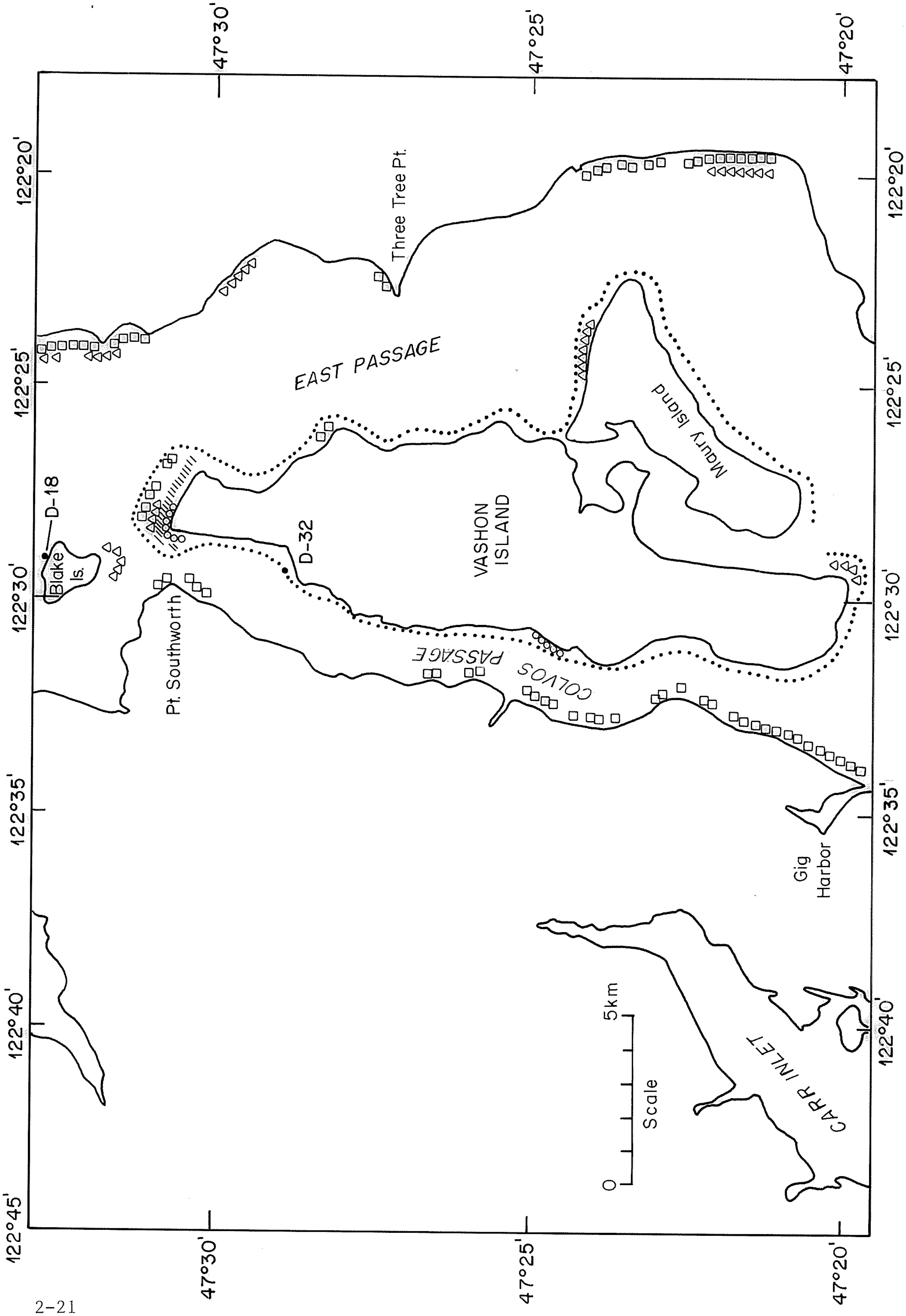
2-17

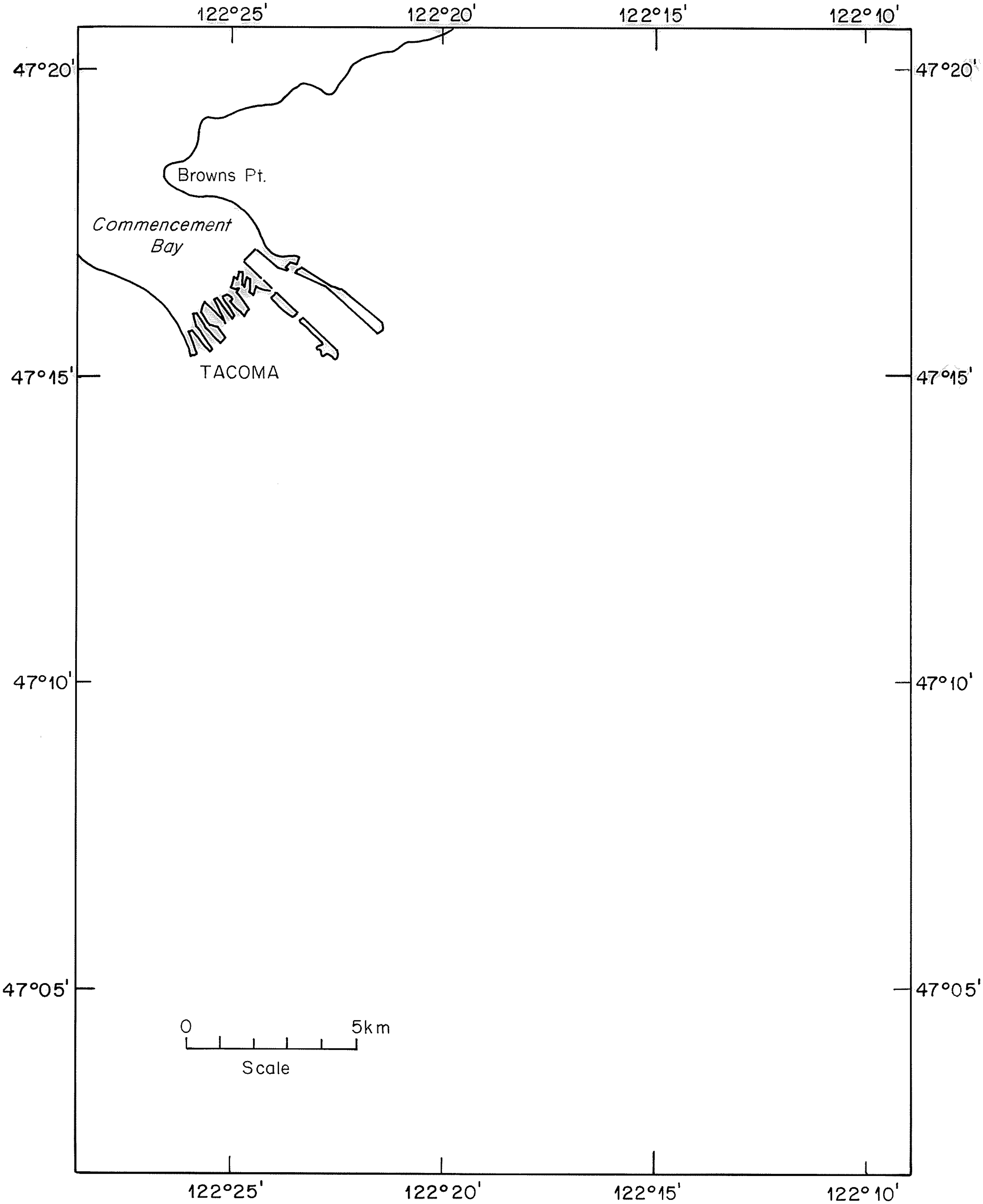

122°30'
122°25'
122°20'
122°15'
48°20'
48°15'
48°15'
48°10'
Camano Island
PORT SUSAN
Kayak Pt.
0
5km
Scale
Camano Head
Tulalip Bay


122°25'
122°20'
122°15'
122°10
48°00'
47°55'
47°50'
Sandy Pt.
Gedney Is.
Whidbey
Island
Possession Pt.
Port
Gardner
Everett
Snohomish R.
Elliott
Pt.
Edmonds
D-13
0
5km
Scale

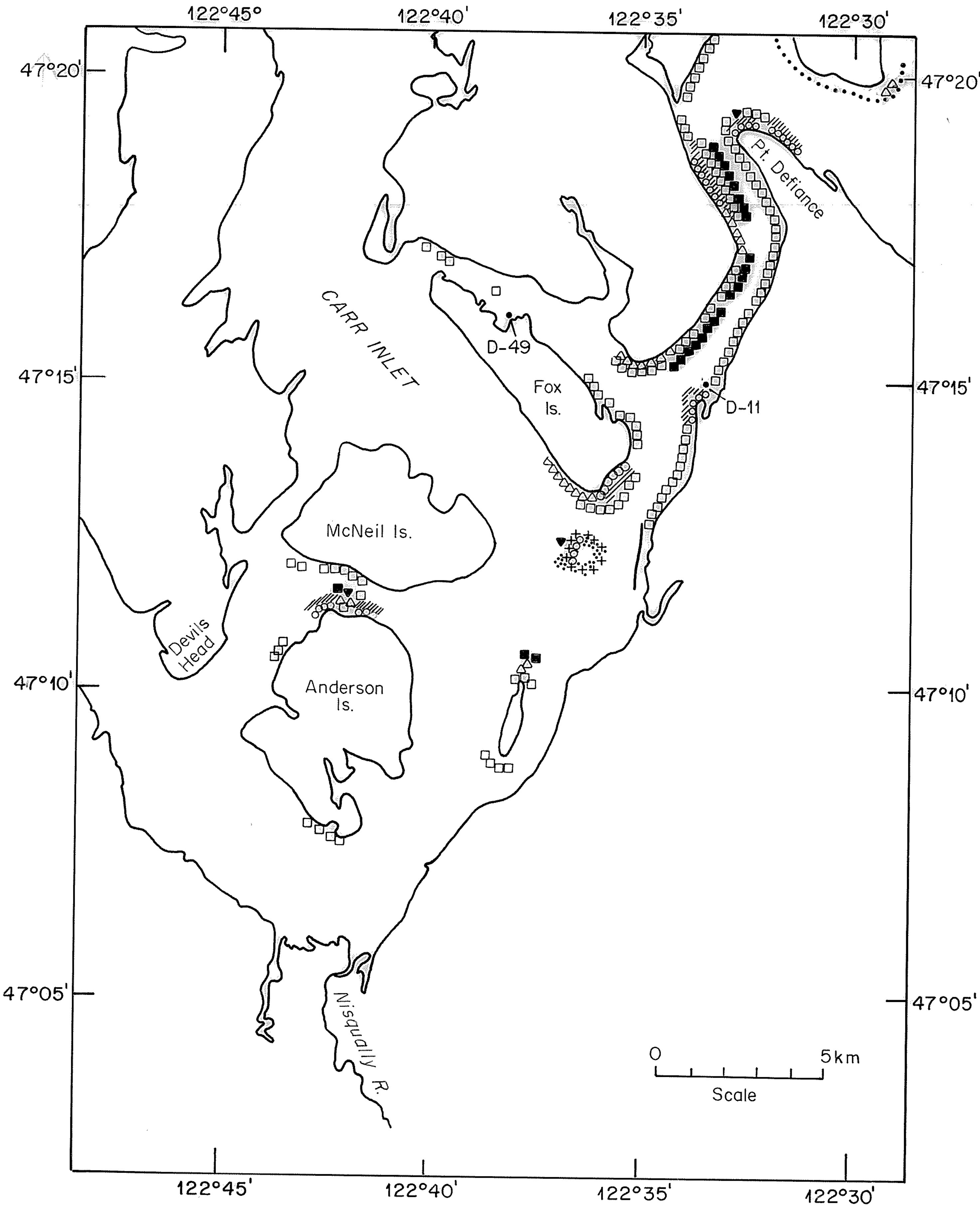

47°45'
47°40'
47°35'
122°10'
122°15'
122°30'
122°35'
122°40'
Pt. Jefferson
West Pt.
Elliott Bay
SEATTLE
Alki Pt.
Bainbridge Island
Dyes Inlet
Scale
0
5km

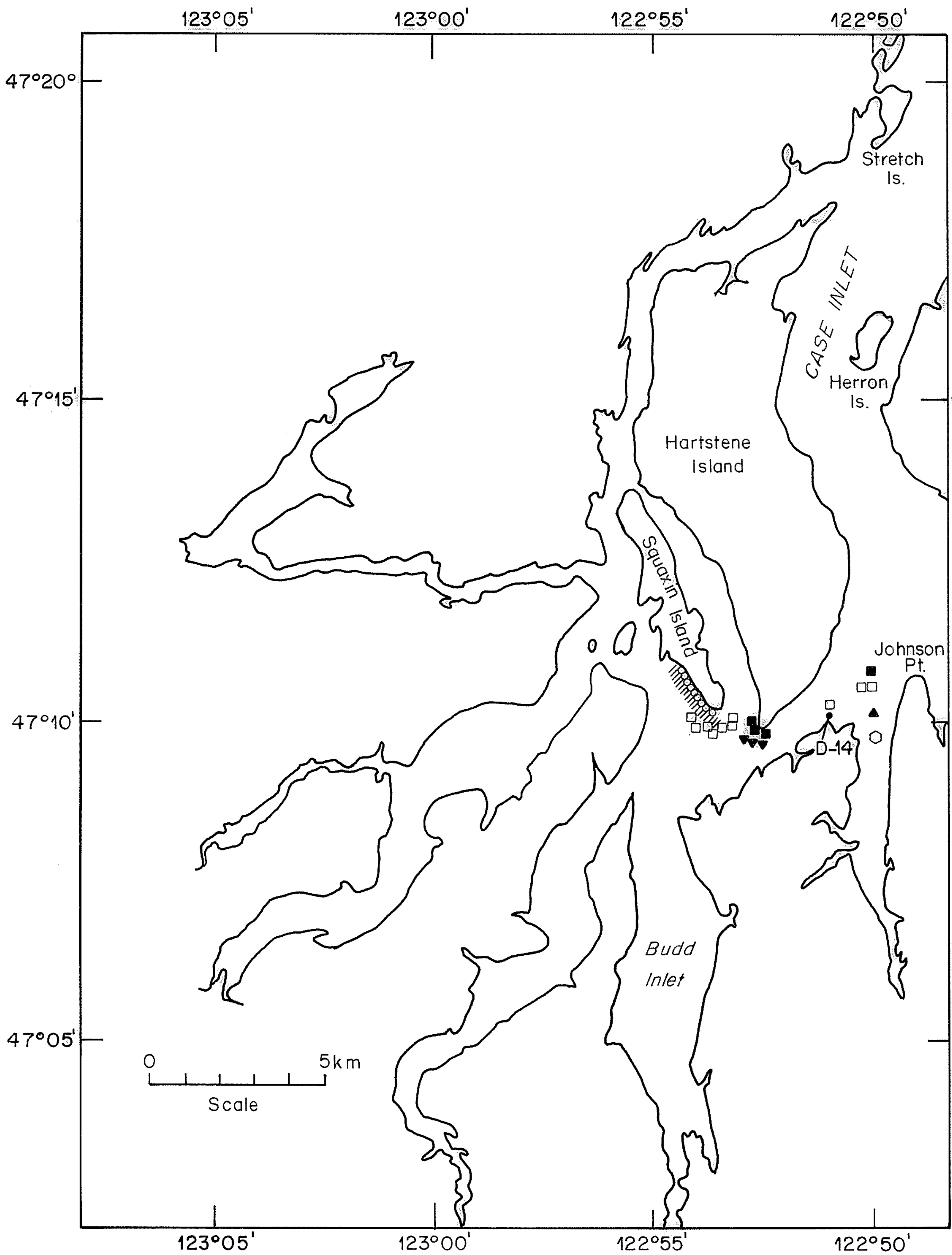
2-20


47°30'
47°25'
47°20'
122°20'
122°25'
122°30'
122°35'
122°40'
122°45'
Three Tree Pt.
EAST PASSAGE
Maury Island
VASHON
ISLAND
D-18
D-32
Blake
Is.
Pt. Southworth
COLVOS
PASSAGE
Gig
Harbor
CARR INLET
Scale
0
5km


122°25'
122°20'
122°15'
122°10'
47°20'
47°15'
47°10'
47°05'
Browns Pt.
Commencement Bay
TACOMA
0
5km
Scale

2-22


122°45°
122°40'
122°35'
122°30'
47°20'
47°15'
47°10'
47°05'
CARR INLET
Pt. Defiance
D-49
Fox Is.
D-11
McNeil Is.
Devils Head
Anderson Is.
Nisqually R.
0
5km
Scale
122°45'
122°40'
122°35'
122°30'


123°05'
123°00'
122°55'
122°50'
47°20'
47°15'
47°10'
47°05'
Stretch Is.
CASE INLET
Herron Is.
Hartstene Island
Squaxin Island
Johnson Pt.
D-14
Budd Inlet
0
5km
Scale