Padilla Bay
National Estuarine Research Reserve

Technical Report No. 2

DISTRIBUTION OF HABITATS AND SUMMER STANDING CROP OF SEAGRASSES AND MACROALGAE IN PADILLA BAY, WASHINGTON

Douglas A. Bulthuis

May 1991

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

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Bibliographic citation: Bulthuis, Douglas A. 1991. Distribution of habitats and summer standing crop of seagrasses and macroalgae in Padilla Bay, Washington, 1989. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 2. , Mount Vernon, Washington. 35 pp.

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ABSTRACT

Bulthuis, D.A. 1990. Distribution of habitats and summer standing crop of seagrasses and macroalgae in Padilla Bay, Washington, 1989. Washington State Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 2, Mount Vernon, Washington. 35 pp.

The channels, seagrass and macroalgae beds and intertidal flats in Padilla Bay, Washington were mapped during summer, 1989, based on color aerial photography. At 14 selected sites within apparently homogeneous areas, the density and biomass of seagrasses and macroalgae and the particle size distribution of sediments were determined. Seagrasses, principally *Zostera marina* L., were the most important habitat, covering about 3200 hectares, 53% of Padilla Bay. *Zostera japonica* Aschers. & Graebn. was distributed higher in the intertidal than *Z. marina* and covered about 320 hectares, 6% of the bay. The seagrass, *Ruppia maritima*, reported from Padilla Bay for the first time, is widely distributed at a very sparse density over about 140 hectares 3% of the bay. Large accumulations of *Ulva* and *Enteromorpha* covered about 160 hectares (3% of the bay) in the southern part of Padilla Bay. Mean density of *Zostera marina* ranged from 61 to 441 shoots m^{-2} and for *Z. japonica* from 394 to 1095 shoots m^{-2}. Mean standing crop (above ground dry weight) of seagrasses ranged from 12 to 103 g dry weight m^{-2} at 9 seagrass covered sites. Macroalgal biomass at these same seagrass covered sites ranged from less than 1 to 190 g dry weight m^{-2}. Within one *Ulva* and *Enteromorpha* covered site, macroalgae standing crop averaged 526 g dry weight m^{-2}. The sediments in most of Padilla Bay are sandy; silt and clay are the dominant particle size only in the southeastern corner. The seagrass beds in Padilla Bay are one of the largest contiguous beds of seagrass in Washington State and along the Pacific Coast of North America.

INTRODUCTION

The extensive area of important estuarine habitats in Padilla Bay was a major reason for designation of the Padilla Bay National Estuarine Research Reserve (Sanctuary) in 1980. No comprehensive maps have been made of these habitats although a very generalized estimate of the distribution of habitats in the bay was made for the Padilla Bay Management Plan (Washington Dept. Ecology 1984).

Several studies have contributed to an understanding of individual habitats in Padilla Bay and their vegetative characteristics. Webber *et al.* (1987) estimated the area of seagrasses in Padilla Bay to be 3097 ha on the basis of satellite imagery. That study included a generalized map of seagrass distribution and significantly increased our knowledge of the location and distribution of seagrasses in Padilla Bay. The distribution of the introduced salt marsh plant, *Spartina alterniflora* Loisel., in Padilla Bay was mapped by Wiggins and Binney (1987). Granger and Burg (1986) identified the salt marsh communities at one site in Padilla Bay. Biomass estimates of seagrasses in Padilla Bay ranged from 47 to 119 g m^{-2} by Webber *et al.* (1987) and up to 285 g m^{-2} by Thom (1988, 1990). Density of seagrasses in Padilla Bay measured from May to August by Thom (1990) ranged from 0 to 3900 shoots m^{-2} for *Zostera japonica* and from 0 to 900 shoots m^{-2} for *Zostera marina.* The sand, silt and clay content of sediments was measured by Turner (1980) at 34 sample sites in Padilla Bay. Most of the soil was classified as sandy loams, loamy sands and fine sands.

While these and other studies (e.g. Cassidy and McKeen 1986, Dinnel *et al.* 1986, Wissmar 1986, Ruckelshaus 1988, Simenstad *et al.* 1988, Mayer 1989, and Mayer and Elkins 1990) have contributed to our understanding of various parts of the Padilla Bay ecosystem, there have been no detailed maps of overall vegetation cover or habitats developed for Padilla Bay. The objectives of the present study were to identify, delineate, describe and map the major habitat units in Padilla Bay and to determine the sediment and macrophyte characteristics of these habitat areas. The habitat areas were mapped from color aerial photographs and the vegetation and sediment characteristics measured at selected sites within different habitat areas.

MATERIALS AND METHODS

Mapping and aerial distribution

The channels, macrophyte dominated intertidal flats and intertidal flats without macrophytes in Padilla Bay were mapped at a scale of 1:12,000 based on color aerial photographs taken at a scale of 1:12,000 on 3 June 1989 near the time of low tide which was -1.00m (-3.2 feet) below mean lower low water. The apparent channel and vegetation boundaries were mapped from the color aerial photographs using a Bausch and Lomb Zoom Transfer Scope onto a 1:12,000 map of the shorelines and roads that had been traced from U.S. Geological Survey 7.5 minute series (topographic) maps and enlarged from 1:24,00 to 1:12,000. Apparent units of about 0.1 ha and larger were delineated based on units that appeared homogenous in the aerial photographs with respect to color and texture. Units smaller than 0.1 ha were not mapped and included in the surrounding apparent ecological unit. False-color infrared aerial photographs taken for the Washington Dept. of Natural Resources, Aquatic Lands Division on July 17, 1988 at a scale of 1:14,000 when low tide was -0.15m (-0.5 feet) below mean lower low water were consulted and compared to the color aerial photographs in determining the vegetation boundaries. (Copies of both sets of aerial photographs are kept at the Padilla Bay National Estuarine Research Reserve and are available for inspection.)

Ground truth data in the various vegetation units were obtained on 24 days in June, July and August, 1989 at over 100 different sites in the bay to aid the interpretation of the various vegetation units. Ground truth data consisted of walking over the vegetation unit during low tide, identifying the species of seagrass, visually estimating percent cover of seagrasses over the sediments to the nearest 10%, and closely examining the boundaries of the apparent units that had been delineated from the aerial photographs. Location in the bay was determined by reference to the aerial photographs and a microloran. The microloran has a stated accuracy of 100 feet in the Puget Sound area. In comparison to known geodetic survey markers in Padilla Bay, the microloran was accurate within 300 feet. In some parts of Padilla Bay, unknown sources of interference prevented use of the microloran. Reference was then made to shore features, channels and other markings on aerial photographs to determine location in Padilla Bay. Based on the ground truth data, the apparent mapping units that had been identified in the aerial photographs were merged into 12 habitat areas in. In places where transition zones were apparent between the habitat areas or the transition was ragged or unclear, a boundary line was delineated about midway through the apparent transition zone. In a few areas the transition zone between *Zostera marina* and *Z. japonica* was so extensive that the transition zone itself was delineated as a separate unit. The area of each category was measured with a planimeter on the 1:12,000 scale map.

Sediment and vegetation characteristics at representative sites.

Fourteen sites were selected within the various habitat areas for measurement of sediment and vegetation characteristics (Fig. 1). The sites were selected to represent different areas of Padilla Bay and were chosen from areas that appeared to be homogeneous with regard to vegetation cover in the aerial photographs. Each site was a 1 ha area in which six sample localities of $25m^2$ were randomly allocated. At each sample locality density, percent cover and leaf length of seagrasses and percent cover of macroalgae were measured in 3 quadrats. A sample for above ground biomass of seagrasses and macroalgae was taken in one quadrat. A sample also was taken of surface sediment for particle size analysis. All samples and quadrats were randomly allocated within the $25m^2$ of each sample locality.

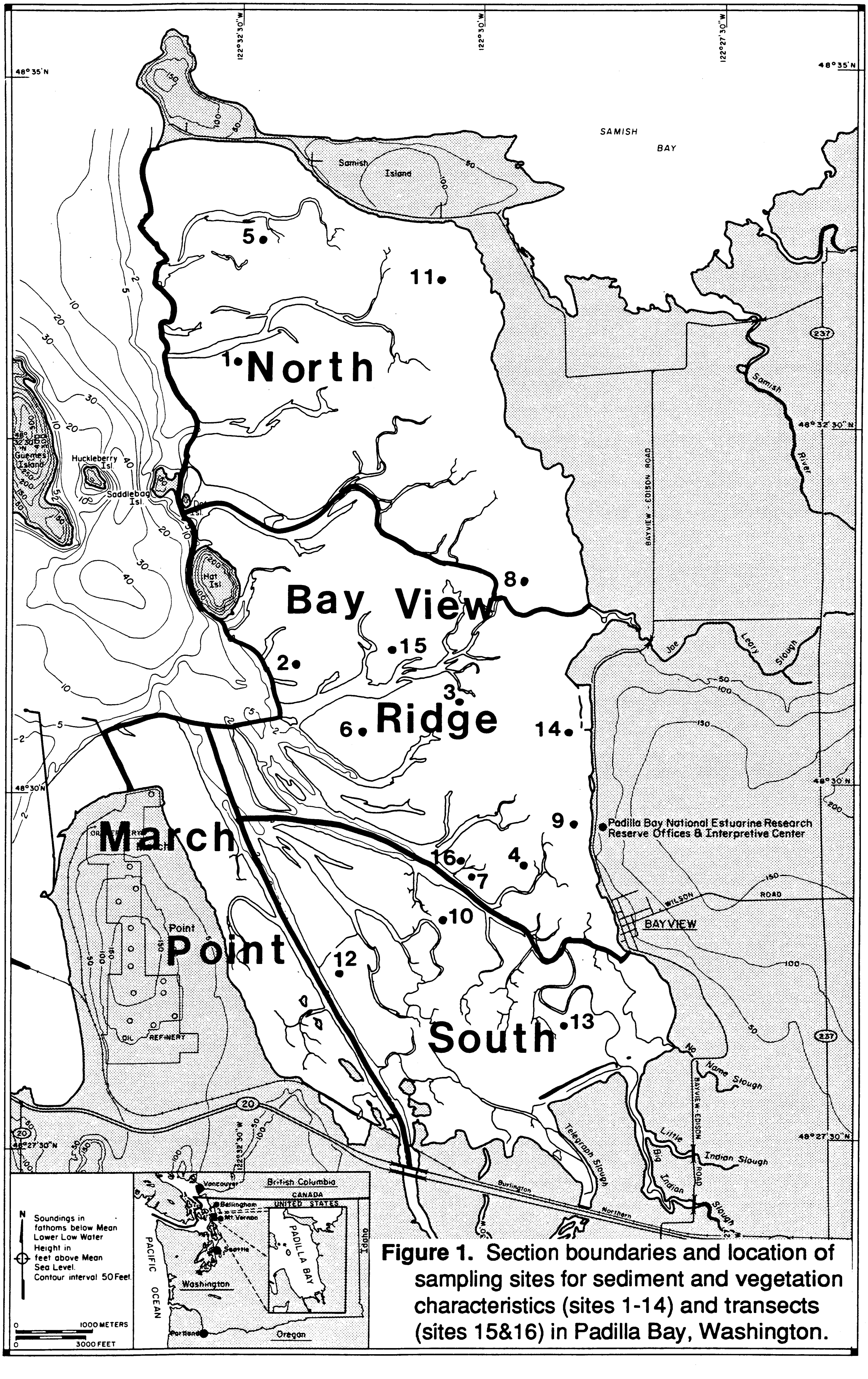

Figure 1. Section boundaries and location of sampling sites for sediment and vegetation characteristics (sites 1-14) and transects (sites 15&16) in Padilla Bay, Washington.

Surface sediments (0-5cm depth) were sampled with a 5cm diameter hand corer (except for Site 14 [gravel patch] where a 14.5cm corer was used), and treated and tested in the following way: stored cool (5°C) until analysis, subsampled for particle size analysis, wet sieved to split the sand fraction (particles >62 um) from the silt-clay fraction (particles < 62 um), oven dried to constant weight at 80°C, dry sieved to split the sand fraction into size categories based on the Wentworth scale and weighed to the nearest 0.01 g (Buchanan 1984; Puget Sound Estuary Program 1990). A subsample for total volatile solids was dried to constant weight at 105°C, ignited at 550°C and weighed to the nearest 0.01 g (Puget Sound Estuary Program 1990).

Density, percent cover, leaf length and biomass of seagrasses and percent cover and biomass of macroalgae were determined in 0.25 X 0.25 m quadrats by the following methods: density of seagrasses by counting all shoots; percent cover by visually estimating percent of sediment surface covered by seagrasses or macroalgae to the nearest 10%; leaf length by measuring the longest leaf of 5 haphazardly selected shoots in each quadrat; biomass by clipping at the sediment surface all seagrasses and macroalgae and keeping samples cool (<5°C). Seagrasses and macroalgae were sorted in the laboratory, rinsed free of mud and large epiphytes and dried at 80°C to constant weight.

At Sites 15 and 16 samples were taken along a transect line from an area of high percent cover of *Zostera marina* across a boundary zone and into an area of a raised sand hummock. Two 0.25 X 0.25m quadrats were sampled and processed as described above at previously determined locations along the transect. At Site 15, a sediment core 3.5cm diameter and 80 cm deep was sampled, divided into 10cm depth increments and particle size and volatile solids measured as previously described.

RESULTS

Habitat area and distribution

Habitats characterized as intertidal flats dominated by seagrasses were widely distributed throughout Padilla Bay (Fig. 2) and covered a total of 3209 hectares or 58% of the intertidal area (to extreme spring lows) (Table 1). Within the seagrass dominated habitats, the following five categories of cover, exposure and species were distinguishable both on aerial photographs and by ground truth: *Zostera marina* L. with high percent cover (intertidal flats where 50-100% of the bottom area was covered by seagrass leaves during low tide); *Z. marina* with medium percent cover (intertidal flats with 20-50% cover); *Z. marina* with low percent cover (intertidal flats with 5-20% cover); subtidal *Z. marina* (subtidal areas of *Z. marina* cover, usually very dense and located in channel bottoms or along the edge of larger channels); *Zostera japonica* Aschers. and Graebn. (flats primarily with *Z. japonica* cover but with some *Z. marina* also present). Most seagrass habitats also had a large amount of macroalgae that was attached to leaves or shells or was loosely floating beneath the leaves. South of the Bay View channel, large macroalgal mats covered more than 100 hectares (Table 1). Intertidal flats with *Ulva* sp. and/or *Enteromorpha* sp. were divided into two categories: High percent cover (intertidal flats with 50 -100% cover), and medium percent cover (intertidal flats with 20-50% cover). The areas characterized as habitats without macrovegetation sometimes had scattered seagrass plants or clumps of macroalgae in some areas, but cover was considered less than 5% when areas the size of 1 hectare were considered. In the southwestern intertidal sands where the euryhaline seagrass, *Ruppia maritima* L., was widely distributed but cover did not exceed 10% of the surface area and general habitat characteristics were similar to the areas labelled sparse or unvegetated intertidal flats.

Table 1. Area in hectares of different habitats in Padilla Bay, Washington in June 1989. Sections of Padilla Bay are outlined in Fig. 1.; vegetation boundaries in Fig. 2.

	Fig. 2 I.D. No.	North	Bay View Ridge	South	Total in PBNERR[2]	March Point	Total in Padilla Bay
Zostera marina subtidal	12	64	163	12	239	13	252
Zostera marina high % cover	11	702	570	54	1326	125	1451
Zostera marina medium % cover	10	386	413	40	839	31	870
Zostera marina low % cover	9	43	206	48	297	14	311
Zostera japonica	7	153	83	<1	236	<1	236
Zostera japonica with *Z. marina*	8	64	<1	17	81	7	88
Seagrass subtotal		1412	1435	171	3018	190	3208
Ulva and *Enteromorpha* high % cover	6	<1	<1	52	52	<1	52
Ulva and *Enteromorpha* medium % cover	5	54	4	51	109	59	168
Ruppia maritima	4	<1	2	135	137	<1	137
bare	3	573	225	718	1561	212	1728
native salt marsh	1	5	10	35	50	12	62
Spartina alterniflora	2	0	0	8	8	0	8
Total intertidal[1]		1980	1513	1158	4651	460	5111
Channels		111	322	210	599	95	694

1 Total excludes subtidal *Zostera marina*.

2 Total in area east of Swinomish Channel and Guemes Channel which is the approximate areaof the proposed boundaries for Padilla Bay National Estuarine Research Reserve.

Sediments

The sediments at 12 of the 14 sites were composed of 70% or more sand (Figs. 3-5). The silt-clay fraction was less than 20% in the northern and western parts of the bay and only in the most southeastern site was the silt-clay fraction greater than 50% (Fig 6). Both sites 3 and 4 had a 50-100% cover of *Zostera marina* but the sediment texture was quite different (Fig. 3) indicating a wide sediment particle size tolerance of *Z. marina*.

The content of volatile organics in the sediment ranged from 1.30% to 2.81% at the fourteen sites (Fig. 6) and was distributed in Padilla Bay in a pattern similar to the silt-clay content of the sediments (cf Fig. 6 and Fig. 7). The sites with a higher percentage of silt and clay also had a higher content of volatile organics (Table 2).

Vegetation characteristics

At nine of the ten sites that were characterized as macrophyte dominated habitat areas, the seagrasses *Zostera marina* or *Z. japonica* were the characteristic and structuring plant. However, macroalgae also were abundant at most sites and biomass of macroalgae was greater than that of seagrasses at all seven *Z. marina* dominated sites (Table 3, Fig. 8). Cover by seagrasses and macroalgae was measured as a percent of bottom area covered; therefore, at several sites, the sum of seagrass and macroalgae cover was greater than 100% (Table 3 - Sites 2-5). Density of *Z. marina* ranged from 61 to 441 shoots per square meter and *Z. japonica* from 394 to 1095 (Table 3). Site 9 had a dense monospecific cover of *Z. japonica* throughout the site with very little macroalgae. In contrast Site 8 had a mixture of *Z. japonica* and a short *Z. marina* with a small amount of macroalgae.

Most of the macroalgae biomass was made up of *Ulva* sp. and *Enteromorpha* sp. at all sites but other common genera included *Laminaria*, *Ceramium*, *Gracilaria* and *Fucus*.

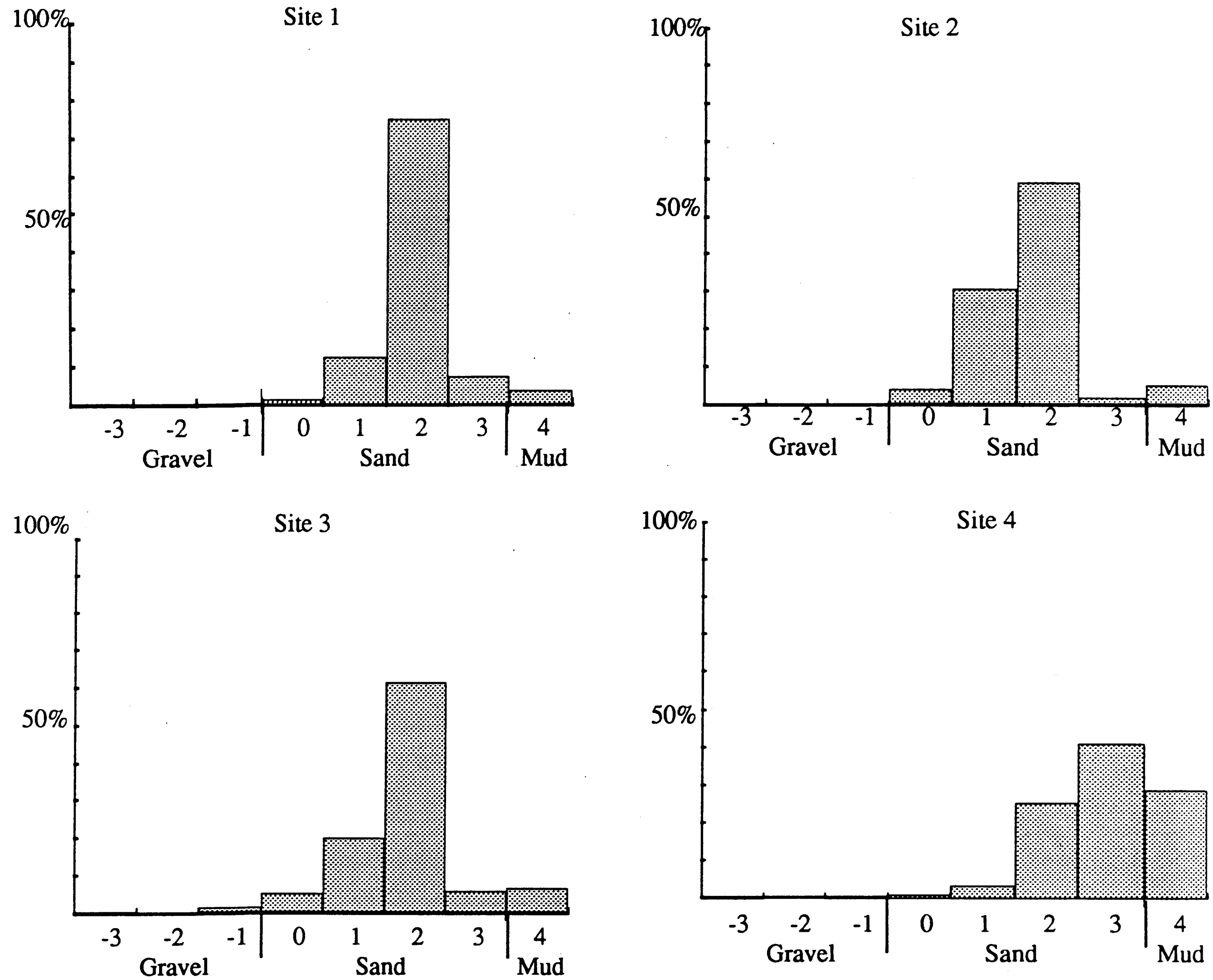

Figure 3. Particle size of sediments at 4 sites in habitat characterized by high percent cover of Zostera marina. Mean of six samples at each site with particle size diameter based on the Wentworth scale (phi notation: $\phi = -\log_2$ of the particle diameter).

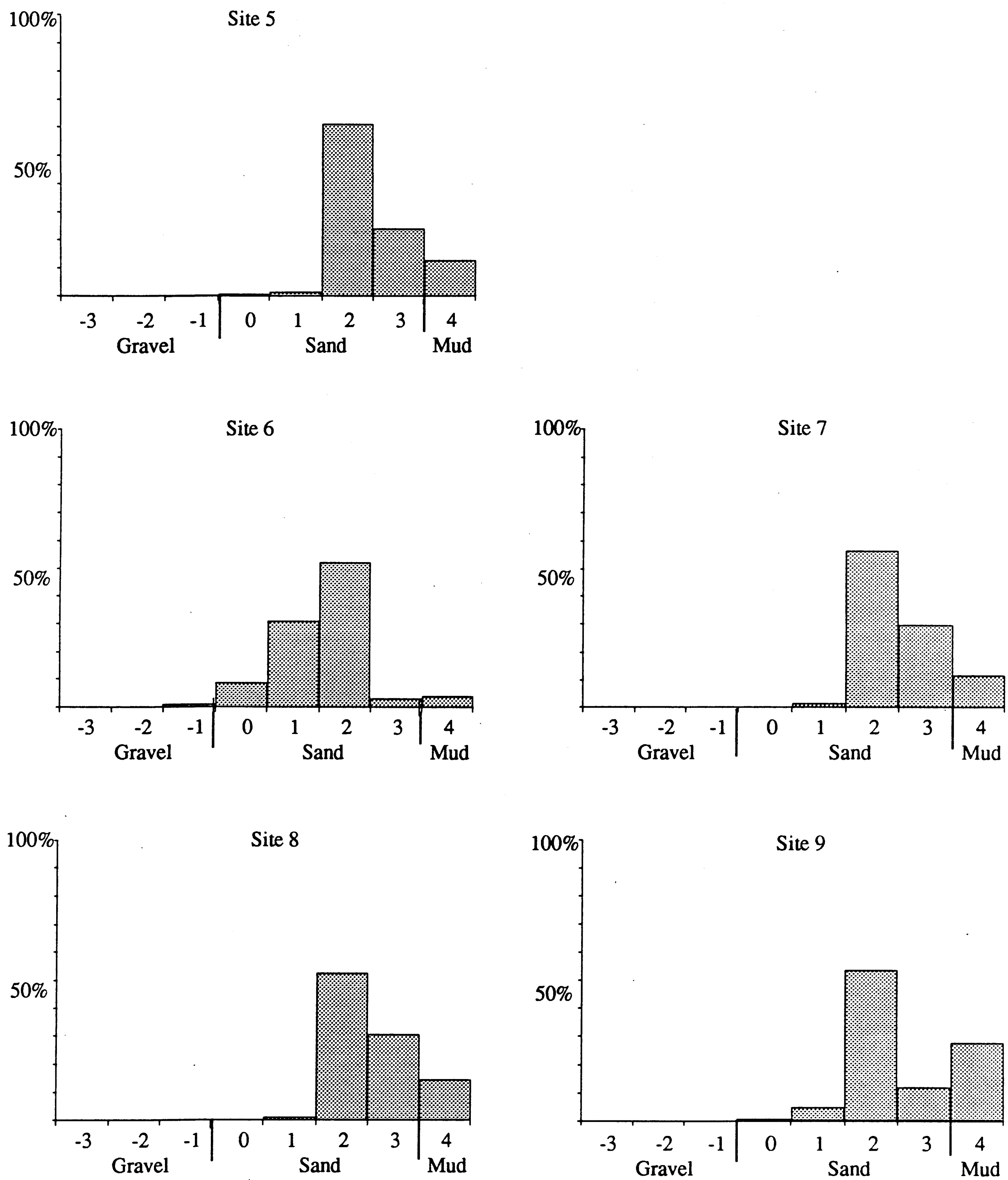

Figure 4. Particle size of sediments at 5 sites in habitat characterized by medium percent cover of Zostera marina (site 5), low percent cover of Zostera marina (sites 6 and 7) and covered by Zostera japonica (sites 8 and 9). Mean of six samples at each site with particle size diameter based on the Wentworth scale (phi notation: $ø=-\log_2$ of the particle diameter).

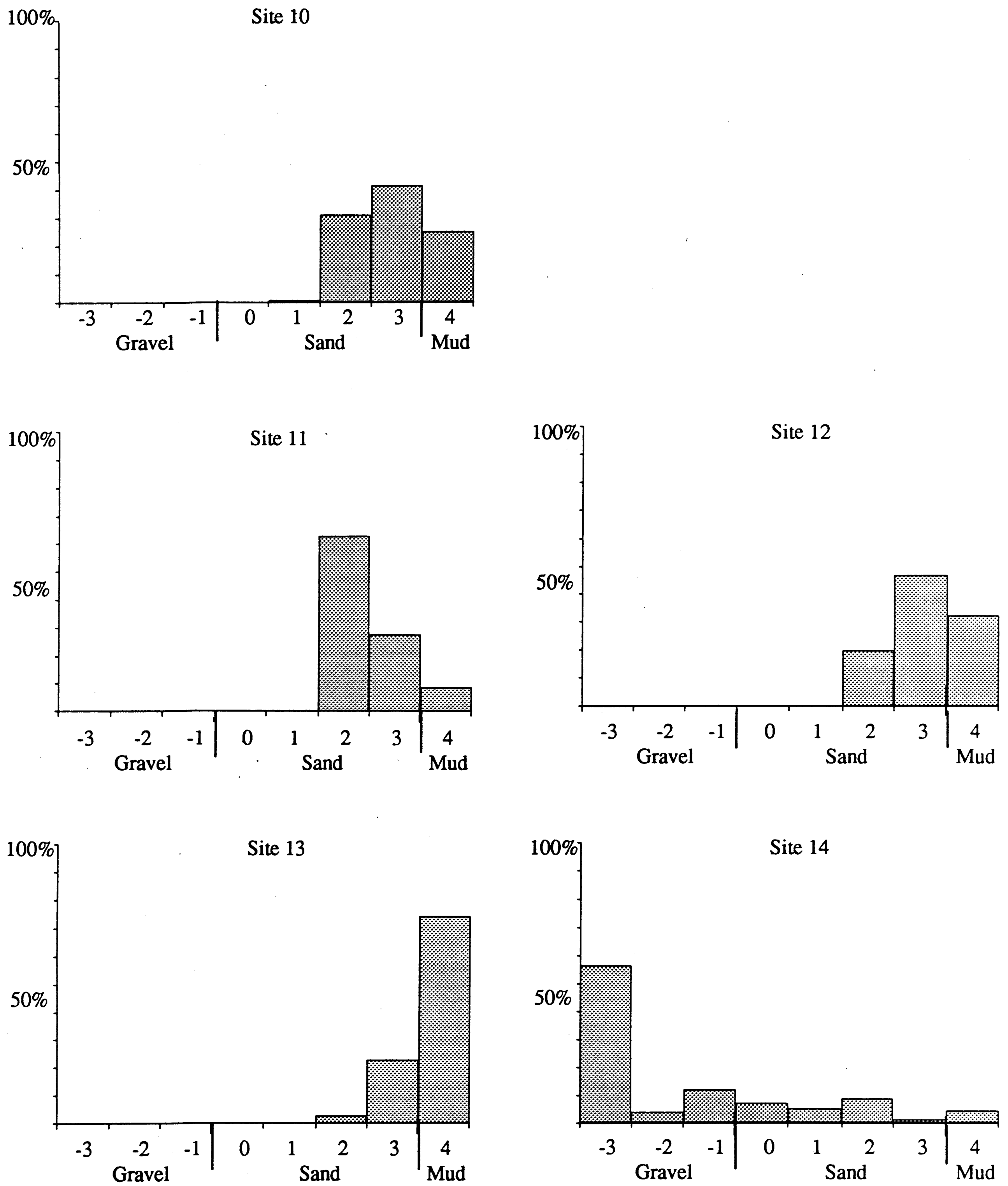

Figure 5. Particle size of sediments at 5 sites in habitat covered by Ulva (Site 10), habitats without macrovegetation (sites 11 to 14). Mean of six samples at each site with particle size diameter based on the Wentworth scale (phi notation: $\phi = -\log_2$ of the particle diameter).

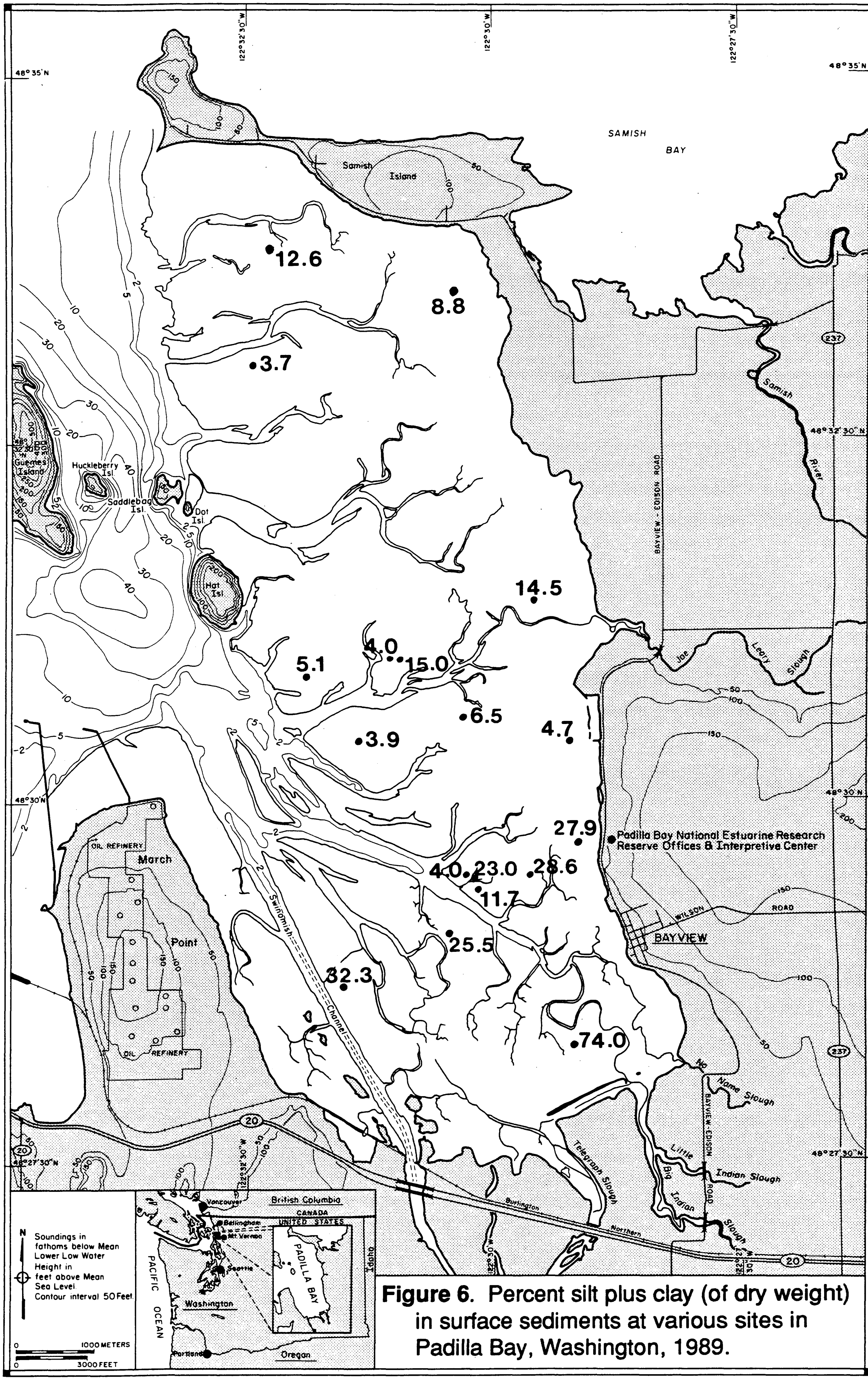

Figure 6. Percent silt plus clay (of dry weight) in surface sediments at various sites in Padilla Bay, Washington, 1989.

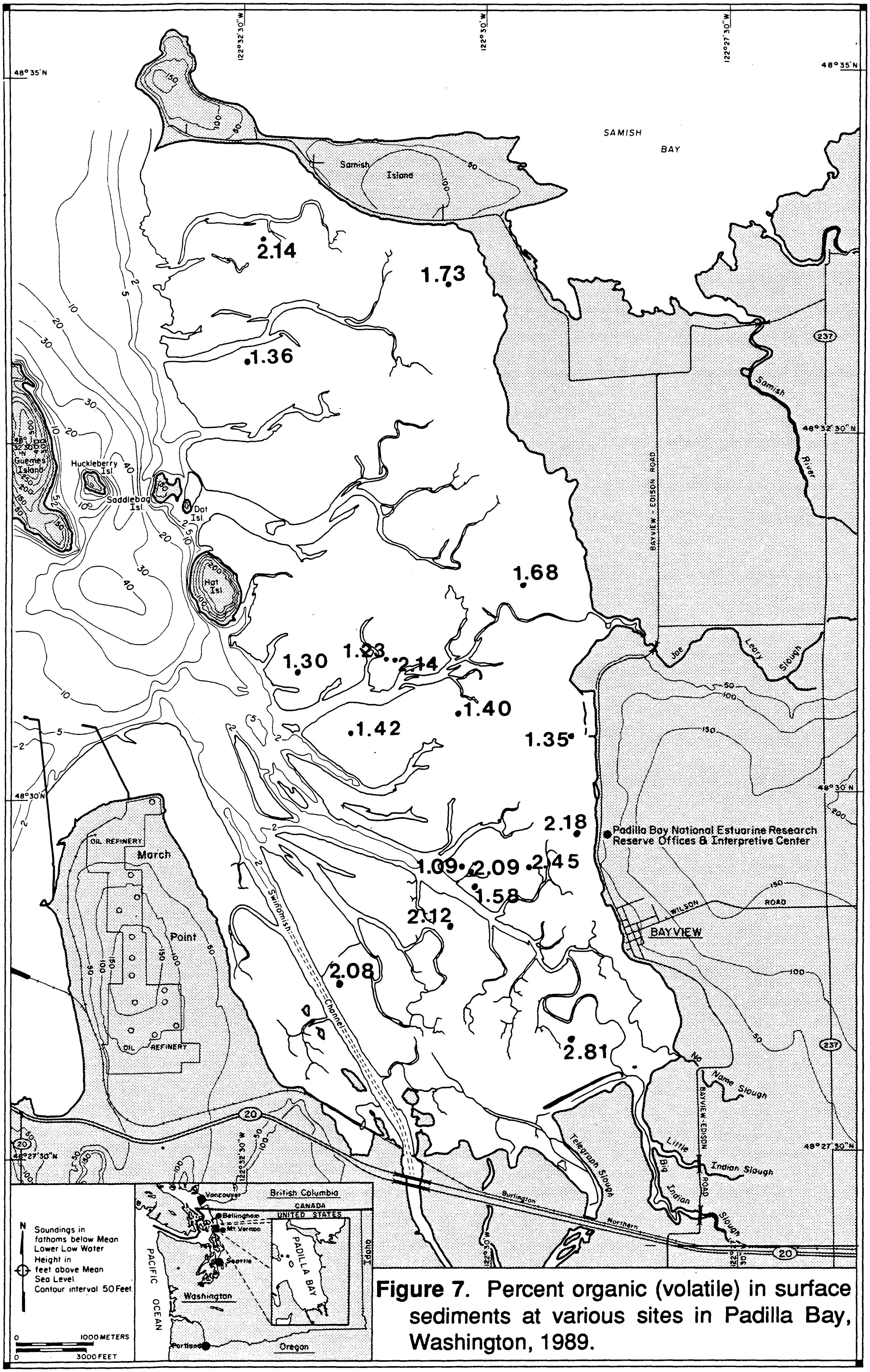

Figure 7. Percent organic (volatile) in surface sediments at various sites in Padilla Bay, Washington, 1989.

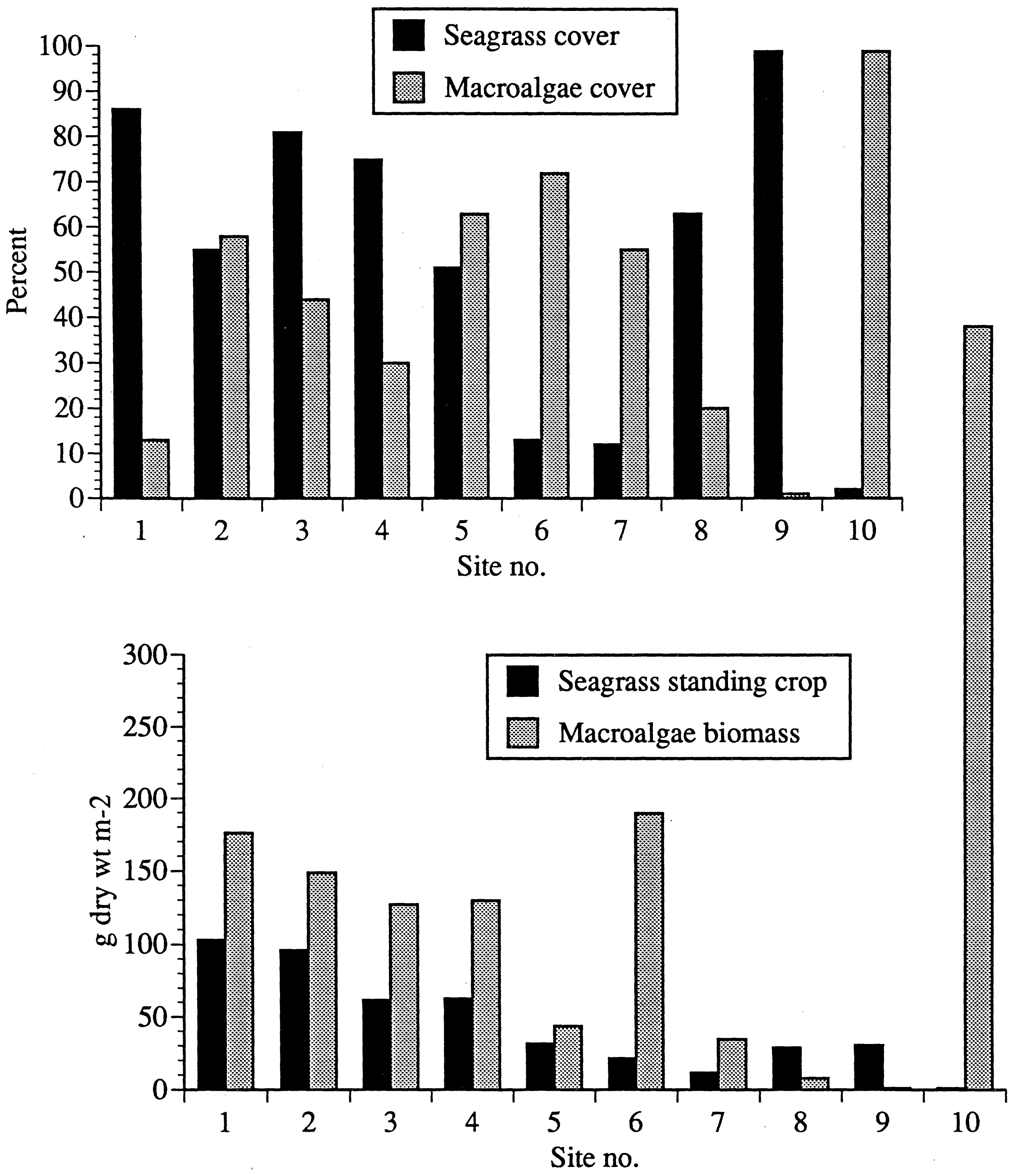

Figure 8. Percent cover of seagrasses and macroalgae and seagrass standing crop and macroalgal biomass at ten sites with macrovegetation in Padilla Bay, Washington in 1989. See Table 3 for habitat types and standard errors.

Table 2. Volatile solids and silt and clay content of sediments at fourteen sites in Padilla Bay, Washington in 1989. See Fig. 1. for location of sites.

	Site No.	Volatile %	Silt & Clay %
Zostera marina high % cover	1	1.36	3.7
" "	2	1.30	5.1
" "	3	1.40	6.5
" "	4	2.45	28.6
Zostera marina medium % cover	5	2.14	12.6
Zostera marina low % cover	6	1.42	3.9
" "	7	1.58	11.7
Zostera japonica with *Zostera marina*	8	1.68	14.5
" "	9	2.18	27.9
Ulva and *Enteromorpha*	10	2.12	25.5
Intertidal flats without vegetation	11	1.73	8.8
" "	12	2.08	32.3
" "	13	2.81	74.0
Gravel patch	14	1.35	4.7

Table 3. Percent cover, density, leaf length and standing crop of seagrasses and macroalgae at ten sites in habitats with macrovegetation in Padilla Bay, Washington in 1989. Mean (± standard error) n=6. See Fig. 1. for location of sites.

Habitat type	Site No.	Seagrass Cover (percent)	Macroalgae Cover (percent)	Seagrass Density (shoots m^{-2})	Seagrass Leaf Length (cm)	Seagrass Standing Crop (g dry wt m^{-2})	Macroalgae Biomass (g dry wt m^{-2})
Zostera marina high % cover	1	86 (±6.9)	13 (±5.9)	254 (±32)	90 (±3.0)	103 (±12)	176 (±34)
"	2	55 (±5.9)	58 (±3.5)	227 (±32)	103 (±2.5)	96 (±26)	149 (±39)
"	3	81 (±6.5)	44 (±4.6)	441 (±45)	53 (±3.5)	62 (±19)	127 (±24)
"	4	75 (±4.1)	30 (±3.7)	162 (±13)	94 (±2.7)	63 (±14)	130 (±28)
Zostera marina medium % cover	5	51 (±13.7)	63 (±17.3)	182 (±28)	48 (±8.3)	32 (±9.2)	44 (±12)
Zostera marina low % cover	6	13 (±6.5)	72 (±13.3)	61 (±21)	37 (±9.9)	22 (±10)	190 (±54)
"	7	12 (±9.8)	55 (±6.0)	158 (±47)	21 (±2.1)	12 (±7.5)	35 (±13)
Zostera japonica with	8	63 (±5.4)	20 (±7.3)	394 (±55)	38 (±1.9)	29 (±5.5)	8.3 (±3.0)
Zostera marina	9	99 (±0.4)	<1	1095 (±44)	27 (±2.8)	31 (±4.4)	<1
Ulva and *Enteromorpha*	10	2 (±0.9)	99 (±1.1)	6.2 (±4.4)	4 (±2.8)	<1	526 (±111)

At the four sites without conspicuous macrovegetation (Sites 11 to 14) both seagrasses and macroalgae were present but at very low levels of cover and biomass (Table 4). At Site 12 the seagrass *Ruppia maritima* was widespread and abundant but the plants were very short (<5cm), flowering and covered less than 10% of the surface area.

Transects

At two sites in the bay transects were set up that crossed the boundary from areas of high percent cover of *Z. marina* to sand hummocks that either had very little macrovegetation or only had loosely attached macroalgae. At Site 15 (Fig. 9) the change in percent cover and biomass of seagrasses and macroalgae occurred within a few meters (Fig. 10). A sediment core taken near the transition zone showed sandy sediments overlying sediments with a higher silt-clay fraction and higher volatile solids (Table 5). The lower sediments were similar to surface sediments in the *Z. marina* zone while the upper sediments were similar to surface sediments in the sand hummock zone (cf Table 5 and Fig. 10). At Site 16 (Fig. 9) there was an abrupt change in cover and biomass of seagrasses but macroalgae were present in both dense *Z. marina* and on the sand hummock (Fig. 11)

DISCUSSION

The map of seagrasses, macroalgae and intertidal flats in Padilla Bay is the first detailed map of the distribution and area of these communities in Padilla Bay. On a broad scale this information is consistent with earlier studies (Washington Dept. Ecology 1984, Webber *et al.* 1987) that indicated large areas of seagrass meadows in the mid and lower intertidal regions of Padilla Bay and extensive intertidal flats without macrophytes in the southern part of the bay and in the northeast corner. The presence of *Ruppia maritima* has not been reported from Padilla Bay in previous studies but was found in the present study at a very sparse density

Table 4. Percent cover, density, leaf length and biomass of seagrasses and macro-algae at four sites in habitats characterized as less than 5% cover of macro-vegetation in Padilla Bay, Washington in 1989. Mean (± standard error) n=6. See Fig. 1. for location of sites.

Habitat type	Site No.	Seagrass Cover (percent)	Macroalgae Cover (percent)	Seagrass Density (shoots m^{-2})	Seagrass length (cm)	Seagrass Biomass (g dry wt m^{-2})	Macroalgae Biomass (g dry wt m^{-2})
Unvegetated northeast	11	<1	5.4 (±3.6)	2.7 (±2.7)	--	0	3.0 (±2.6)
Unvegetated southwest	12	5.7 (±2.6)	24 (±9.3)	277 (±77)	4 (±0.5)	1.7 (±0.7)	2.9 (±1.2)
Unvegetated southeast	13	<1	3.6 (±2.0)	0	--	0	6.7 (±6.4)
Gravel patch	14	<1	<1	26 (±14.5)	3.5	<1	<1

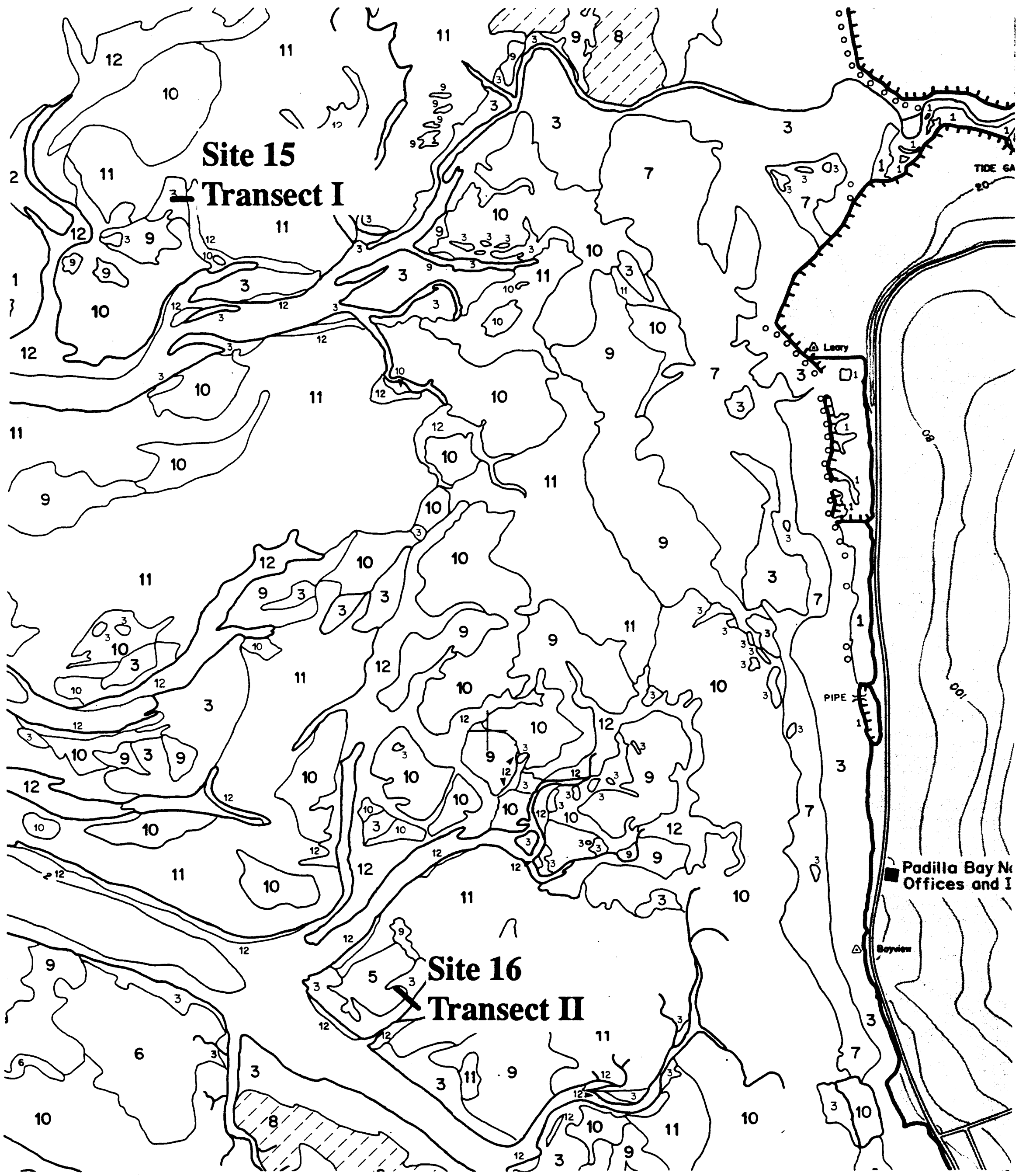

Figure 9. Location of transects I and II which originate on intertidal flats with high cover of *Zostera marina* (11 and 12) and cross vegetation boundaries to intertidal flats bare of macrovegetation (3). Scale 1:24,000. Cf. Fig. 2 for orientation within Padilla Bay.

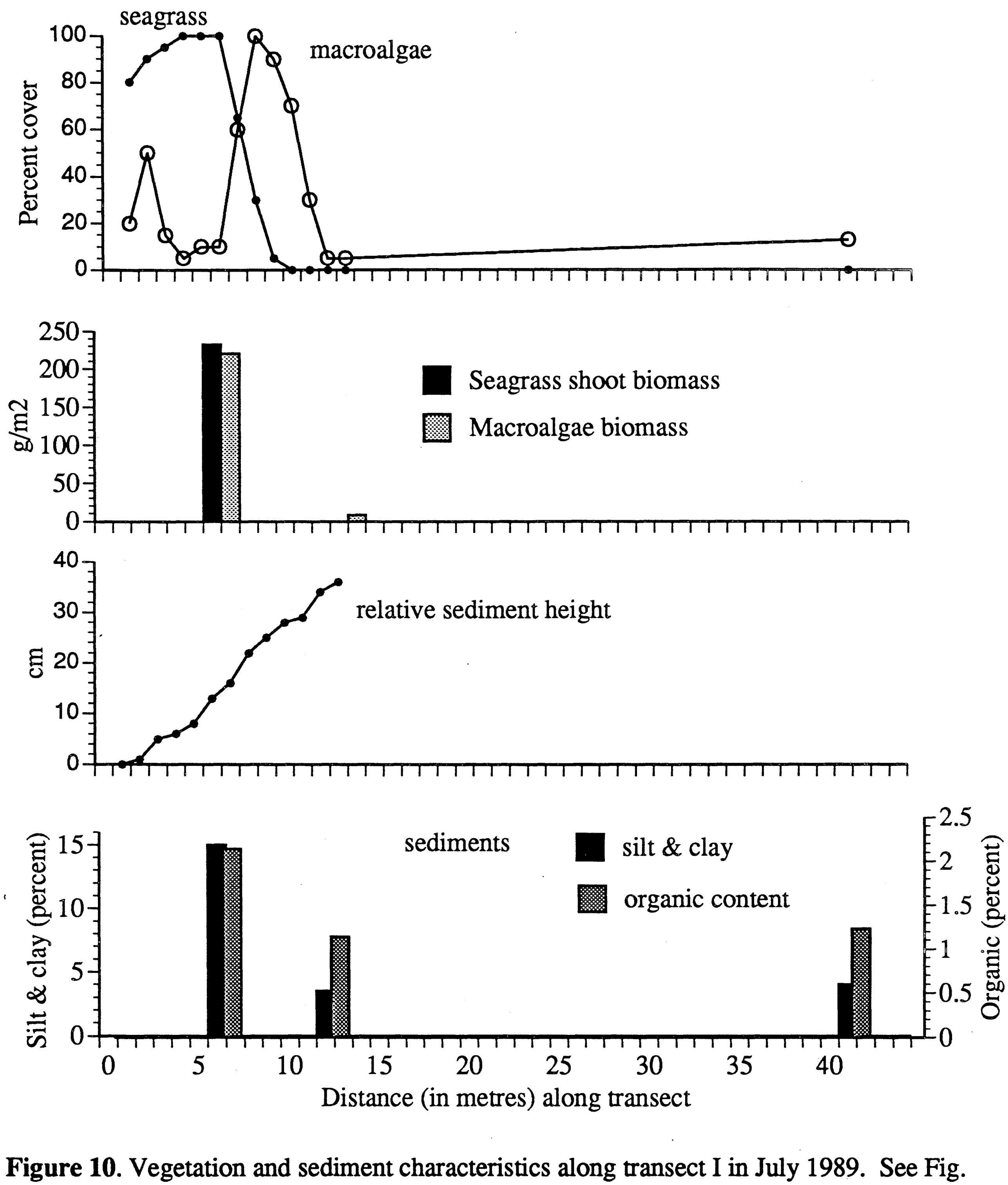

Figure 10. Vegetation and sediment characteristics along transect I in July 1989. See Fig. 9 for location of transect.

Table 5. Particle size distribution and percent organic weight in sediment core at Station b of Transect I. See Fig. 8. for location of site.

Depth	Particle Size						
	<4.00 to >2.00 mm	<2.00 to>1.00 mm	<1.00mm to >500um	500 to>125 um	<125 to>63 um	<63um	Organic Weight %
0-10cm	0%	5%	32%	55%	2%	4%	1.13
10-20cm	0%	3%	27%	66%	1%	2%	0.99
20-30cm	0%	3%	15%	70%	5%	8%	1.22
30-40cm	1%	2%	13%	69%	7%	9%	1.07
40-50cm	1%	3%	11%	63%	8%	13%	1.44
50-60cm	0%	3%	11%	63%	9%	14%	1.40
60-70cm	1%	3%	12%	60%	9%	15%	1.51
70-79cm	1%	4%	12%	55%	11%	16%	1.55

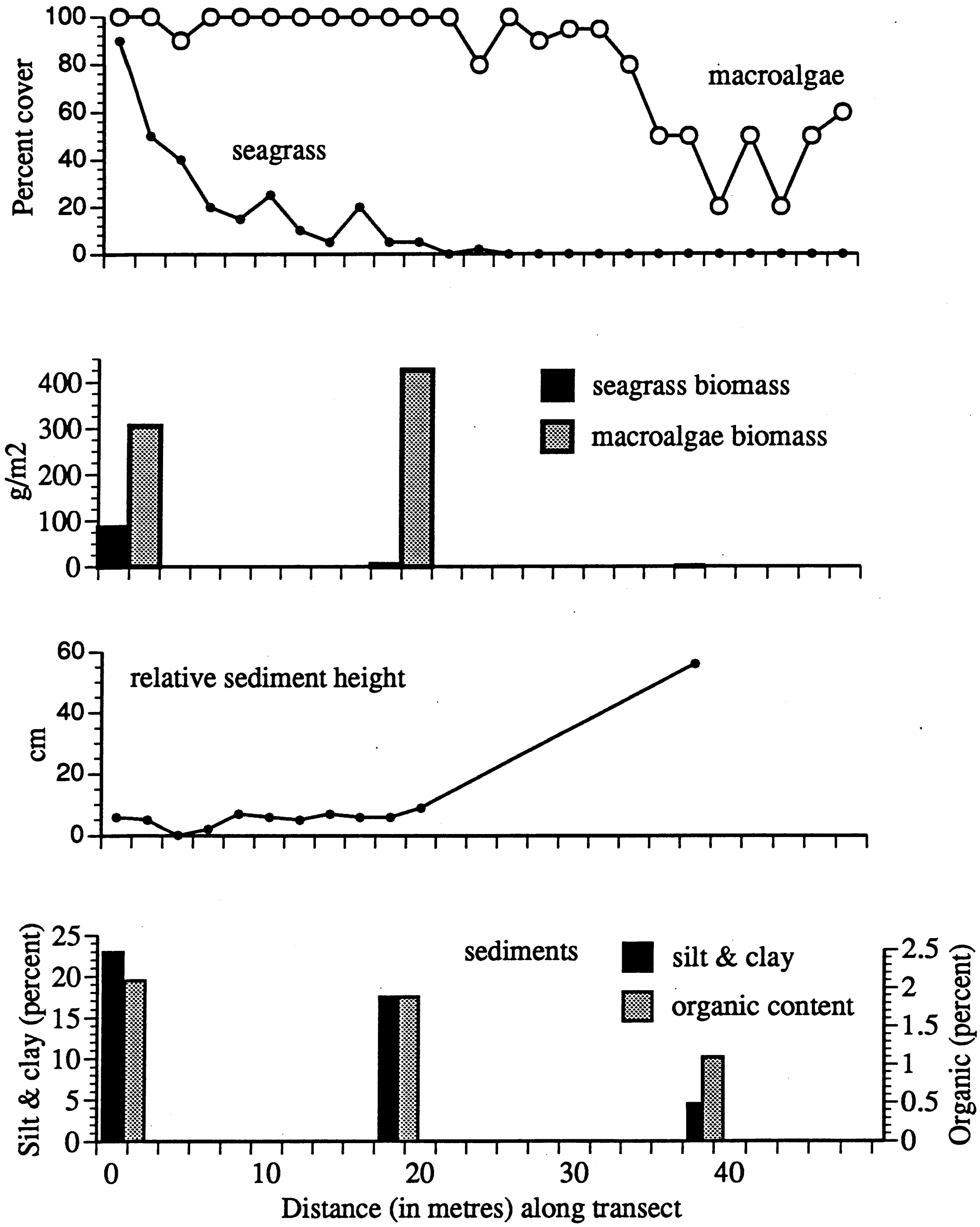

Figure 11. Vegetation and sediment characteristics along Transect II in July, 1989. See Fig. 9 for location of transect.

covering more than 100 hectares in the southern part of Padilla Bay. However, it is not certain whether *R. maritima* has recently become established in Padilla Bay or whether its presence had not been noticed in earlier studies. The seasonal pattern of shoot demography and morphology of *R. maritima* at Roberts Bank, British Columbia, about 70km north of Padilla Bay, has been described by Bigley and Harrison (1986). The Padilla Bay population, which was sampled in late June, had slightly shorter leaves but similar shoot densities to the Roberts Bank population. The presence of *R. maritima* in the southern part of Padilla Bay but not in the central and northern sections may occur because of the lower salinities in the southern part of Padilla Bay (Cassidy and McKeen 1986).

Ulva and *Enteromorpha* have been reported from Padilla Bay in previous studies as occurring in the seagrass beds or as a sparse cover on otherwise bare intertidal flats (Webber *et al.* 1987, Thom 1988, 1990). In the present study large areas totaling about 100 ha (Table 1) of high and medium cover of these algae were found on the southern intertidal flats. These beds of macroalgae had over 500 g dry wt m^{-2} (Table 3) in some areas and the sediment surface beneath the macroalgae was anaerobic at some sites. Because of the lack of any previous comprehensive survey similar to the present study it is unclear whether these large accumulations of macroalgae have only recently occurred in Padilla Bay or whether they were overlooked in previous studies. If these accumulations are new to Padilla Bay, they may indicate some of the initial deleterious effects of increased nutrient inputs to Padilla Bay. Nutrient enrichment in experimental and natural systems has increased growth of *Ulva* sp. and *Enteromorpha* sp. that, in turn have, caused decreases in seagrass populations (Harlin and Thorne-Miller 1981; Verhoeven and Van Vierssen 1978). The macroalgal accumulations in Padilla Bay should be monitored and their effects on eelgrass growth and distribution in the bay investigated.

The total estimated area of seagrass cover in Padilla Bay east of the Swinomish and Guemes Channels (the approximate proposed boundaries of the Padilla Bay National Estuarine Research Reserve) was about 3020 hectares in the present study and the subtidal seagrasses were not included by Webber *et al.* (1987). This estimate is similar to the 3100 reported by Webber *et al.* (1987: Table 9) and somewhat less than the 3500 estimated in the Padilla Bay Management Plan (Washington Dept. Ecology 1984). The close similarity of the estimates in the present study with those of Webber *et al.* (1987) is surprising in view of the different methods used. Some differences with Webber *et al.*, may have been expected because the areas of channel within Padilla Bay that were generally included in the seagrass area by Webber *et al.* (1987) were excluded from the area of seagrass cover in the present study and the subtidal seagrasses were not included by Webber *et al.* (1987). Other differences between these two studies include intertidal flats in the northeast part of Padilla Bay and in the south that are mapped as seagrass areas by Washington Dept. of Ecology (1984) and Webber *et al.* (1987) but were bare of macrophytes in the present study; area south of Bay View channel that was found to be covered with *Ulva* and *Enteromorpha* in the present study but was mapped as seagrass cover by Webber *et al.* (1987). Such areas might have spectral characteristics similar to seagrasses that were not distinguished in the satellite imagery. Interannual variation also would be expected to cause different estimates between the studies. The winter of 1988/89 was more severe than usual with accumulations of ice in the upper intertidal. Such ice sheets scour seagrass beds in colder climates (Robertson and Mann 1984) and may have done so in Padilla Bay during the 1988-89 winter. Some researchers and staff who had worked on Padilla Bay for several years commented on the lack of seagrasses during the spring of 1989 (R. Thom, personal communication; P. Dinnel, personal communication; J. Friesem, personal communication).

Padilla Bay, with 3200 hectares of seagrasses, contains one of the largest stands of seagrasses in the Pacific Northwest. Few seagrass beds in the Pacific Northwest have been mapped with the resolution that was used in the present study (Thom and Halum 1990). However, the very general estimates that have been made indicate that Willapa Bay and Gray's Harbor along the Washington outer coast and Boundary Bay and Lummi and Bellingham Bays along the Strait of Georgia contain extensive seagrass beds covering a similar order of magnitude of area as Padilla Bay (Table 6). It is possible that estimated coverage in other bays would be somewhat lower if the methods used in the present study were employed in these other bays.

The biomass of all macroalgae within the *Zostera marina* beds was greater than the *Z. marina* shoot biomass at all *Z. marina* sites in Padilla Bay in this study (Fig. 8). Site averages ranged from 1.4 times up to 8.6 times as much macroalgae as seagrass shoot biomass (Table 3). Thom (1990) recorded epiphyte biomass up to 260 g m^{-2} on *Z. marina* in Padilla Bay but at most times and stations the biomass was less than 100 g m^{-2}.

Webber *et al.* (1987) reported much less macroalgae than seagrass (0-92 g m^{-2} macroalgae vs 23-147 g m^{-2} eelgrass shoot biomass) in Padilla Bay as did Smith and Webber (1978) (16-40 g wet weight m^{-2} macroalgae vs 530-1250 g wet weight m^{-2} eelgrass). The higher amounts of macroalgae found in the present study may be due to different collection methods or may reflect the interannual and seasonal variation in macroalgal growth.

When subtidal is defined as the depth below extreme low tide (Dethier 1990), then there is relatively little subtidal eelgrass in Padilla Bay. Most of the areas of subtidal seagrasses are in linear beds either along the edges of the deeper channels or covering the bottoms of the shallower channels (Fig. 2).

The high (50-100%), medium (20-50%) and low (5-20%) percent cover categories of *Z. marina* were designated from the aerial photographs. The percent cover estimated

Table 6. Estimated area of major seagrass beds in Pacific Northwest bays and estuaries.

Bay	Area (hectares)	Source
Roberts Bank, B.C.	430	Harrison 1987 quoting Moody personal communication 1984
Boundary Bay, B.C.	2500	Harrison 1979 (about 1/2 of 5,000 ha flats)
Lummi Bay/Bellingham Bay, WA	1000	Webber *et al.* 1987
Padilla Bay, WA	3300	Present study
Skagit Bay, WA	790	Webber *et al.* 1987
Port Susan, WA	400	Webber *et al.* 1987
Grays Harbor, WA	4500	Thom 1984
Willapa Bay, WA	6200	Phillips 1984, quoting Smith 1976
Netarts Bay, OR	340	Kentula and McIntire 1986, quoting Stout 1976
Humbolt Bay, CA	1200	Harding and Butler 1979

in 1/16 m^{-2} quadrats at the seven *Z. marina* sites (Table 3 Sites 1-7) confirmed that these photointerpreted designations were relatively accurate. However, percent cover changed in some areas during the period of sampling (June to August) and percent cover could be expected to be quite variable from year to year.

The standing crop (shoot biomass) of *Z. marina* at the seven sites was highest in the high percent cover category (62-103 g m^{-2}) and lowest in the low percent cover category (12-22 g m^{-2}), as expected. These weights are within the range reported for *Z. marina*
populations in other parts of the world in the reviews by McRoy and McMillan (1977) and Zieman and Wetzel (1980) and similar to seasonal maxima reported for *Z. marina* in Puget Sound [(18-400 g m^{-2}, Phillips 1972) (85 g m^{-2}, Thom and Albright 1990)] and for Padilla Bay [(530-1250 g wet weight m^{-2} total seagrass biomass, Smith and Webber 1978) (150 g m^{-2}, Webber *et al.* 1987) (40-285 g m^{-2} total seagrass biomass, Thom 1990)].

The density of *Z. marina* at the seven sites did not correspond well with percent cover or with standing crop (Table 3, Fig. 12). The differences were caused by a greater density of short plants at some sites and fewer large plants at other sites. For example, Sites 3 and 4 had similar percent cover (81% and 75%) and similar shoot biomass (62 and 63 g m^{-2}). However, this was a result of many shorter plants at Site 3 (441 shoots m^{-2}, 53cm leaves) and of fewer tall plants at Site 4 (162 shoots m^{-2}, 94cm leaves). The density of *Z. marina* reported in the present study (60-440 shoots m^{-2}) is similar to the seasonal maxima reported by Phillips (1972) for 4 sites in Puget Sound (160-610 shoots m^{-2}) and to seasonal maxima reported by Thom (1990) in Padilla Bay (300-850 shoots m^{-2}) and to the densities reported by Webber *et al.* (1987) for ground truth data collected in Padilla Bay in June (43-770 shoots m^{-2}). The present study was conducted over three months during summer and the biomass and density estimates would be expected to be near the annual maxima.

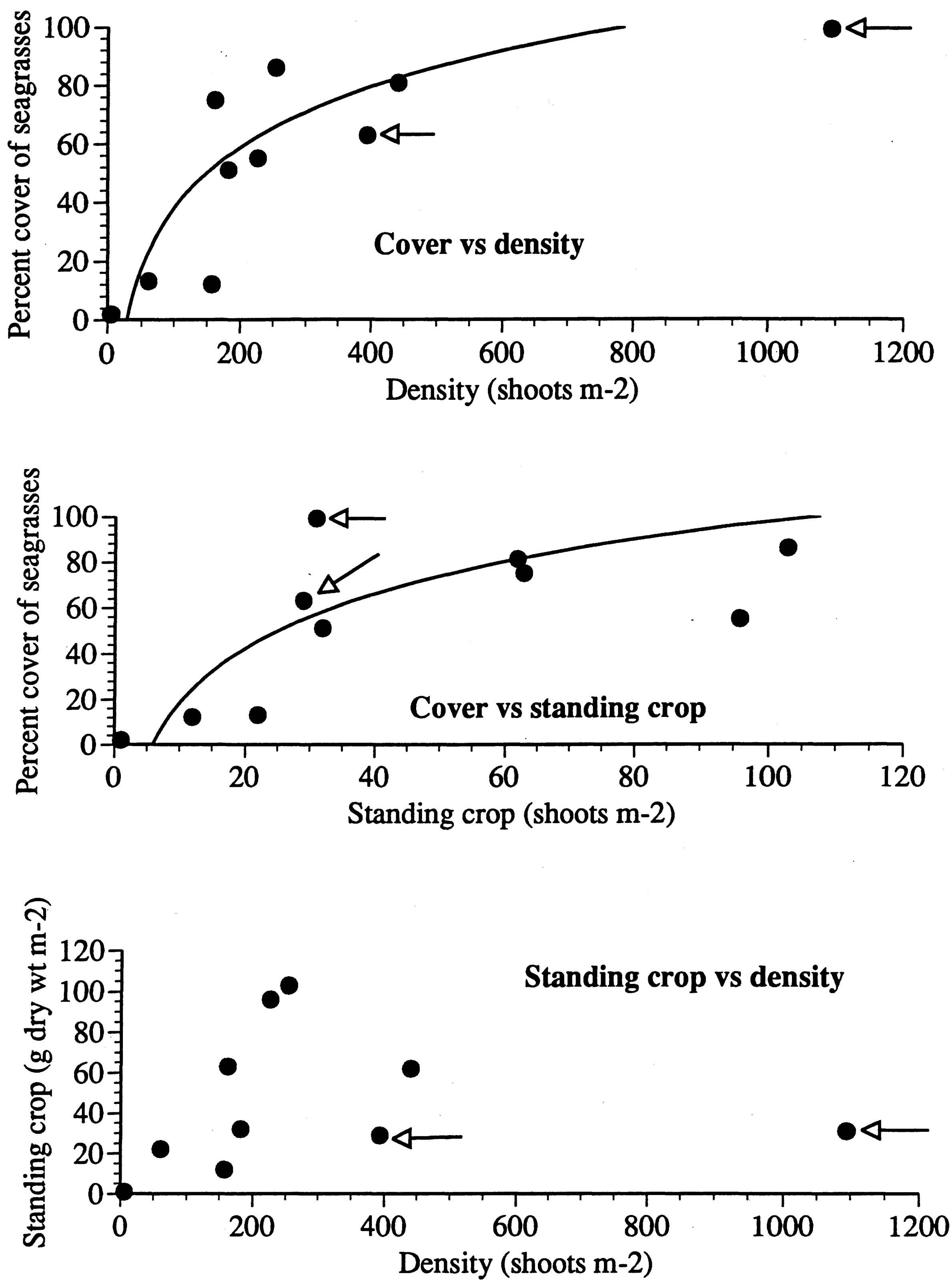

Figure 12. Scatter figures showing the relationship among seagrass density, standing crop and cover (percent of bottom area) at 10 sites with macrovegetation in Padilla Bay, Washington in 1989. Arrowed values are from *Zostera japonica* sites. Exponential curves are shown for the first two comparisons.

Zostera japonica is an introduced species to the west coast of North America, probably arriving from Japan along with the introduction of Japanese oysters (Harrison 1976; Phillips and Shaw 1976; Harrison and Bigley 1982). Samish Bay, directly north of Padilla Bay, was the site of the first large-scale introductions of Japanese oysters as seed, beginning in 1902. Thus, Padilla Bay may be among the oldest established *Z. japonica* populations on the west coast. The density and shoot biomass of *Z. japonica* reported in this study (390-1100 shoots m^{-2} and 30 g dry weight m^{-2}) is similar to previous reports for *Z. japonica* in the Pacific Northwest (Harrison 1982; Webber *et al.* 1987; Thom 1990).

The mapping and ground truth investigation showed the presence of many raised "sand hummocks" scattered throughout the bay, particularly in the western and northern parts of the bay (Fig. 2). Some of these hummocks were bare of macro-vegetation while others had some macroalgae or seagrasses present. Some of the sand hummocks appeared to have a "leading" edge where the height of the hummock above the surrounding mudflat was greatest and at which macrovegetation was sparse or non-existent. The "trailing" edge of the hummocks generally had a greater density and biomass of seagrasses and macroalgae. The data from the two transects (Figs. 9-11; Table 5) across the interface between the surrounding mudflat and the sand hummock are consistent with a model of sand hummocks moving across the eelgrass covered flats, covering the seagrass community with coarser sand and reestablishment of seagrasses on the "trailing" edge. Further studies are required to adequately test this hypothesis.

The present study has mapped the channels, seagrass and macroalgal beds and intertidal flats in Padilla Bay. The seagrass, *Ruppia maritima*, is reported from Padilla Bay for the first time. Large accumulations of *Ulva* and *Enteromorpha* have been reported for the first time and mapped. The area of seagrass cover is about 3200 ha in Padilla Bay of which about 3000 ha are east of the Swinomish Channel in the proposed boundaries of the National Estuarine Research Reserve. The seagrass beds in Padilla Bay are one of the largest contiguous beds of seagrass in Washington State and along the Pacific Coast of North America.

ACKNOWLEDGEMENTS

Sincere thanks are due to T. Stevens for support and encouragement to conduct this study, to S. Riggs, B. Pfaff, M. Olson and S. Moon for assistance in the field and laboratory, to J. Walker, Washington Department of Transportation, for arranging the aerial photographs, to Dr. T. Mumford, Washington Department of Natural Resources and M. Rylco, U.S. Environmental Protection Agency for providing a set of color infrared aerial photos of Padilla Bay taken in 1988, to Dr. F. Westerlund, University Washington Remote Sensing Laboratory for use of a Zoom Transfer Scope, to B. Lindquist and J. Greninger of Bellingham, Washington for drafting the maps, to S. Riggs and D. Fiscus for the tedious planimeter measurements and to L. Smith for typing and retyping the manuscript. Thanks also are due to E. Long, T. Mumford, R. Phillips, H. Webber, S. Riggs and T. Stevens who provided helpful comments on the manuscript. This study was financially aided through a grant to the Washington State Department of Ecology with funds obtained from NOAA/Office of Ocean and Coastal Resource Management/Sanctuaries and Reserves Division, and appropriated for Section 315 of the Coastal Zone Management Act of 1972, as amended.

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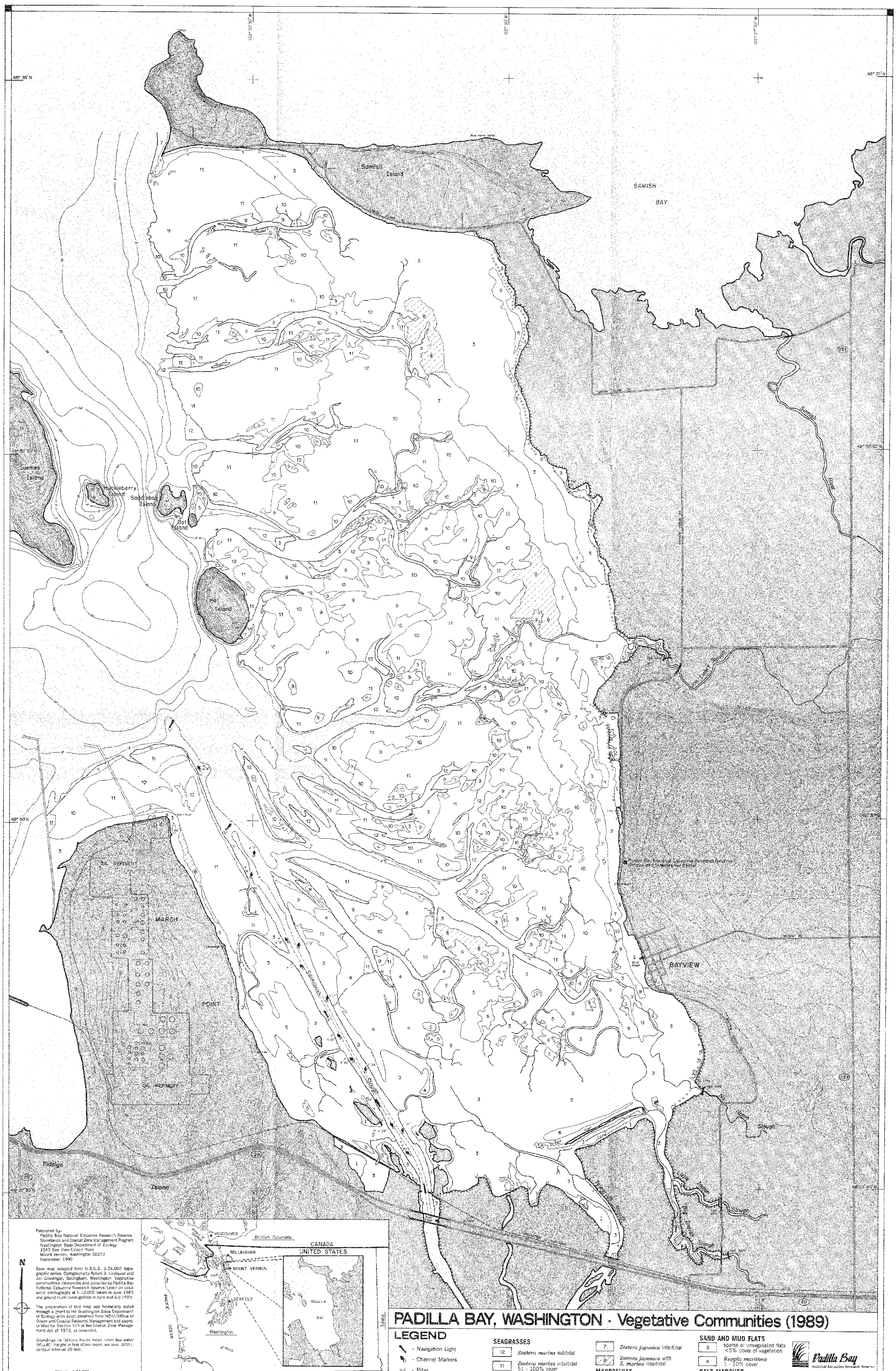

PADILLA BAY, WASHINGTON - Vegetative Communities (1989)
Samish Island
SAMISH BAY
Guemes Island
Huckleberry Island
Saddlebag Island
Dot Island
Hat Island
MARCH
POINT
OIL REFINERY
BAYVIEW
Fidalgo
Island
Swinomish
Slough
Published by:
Padilla Bay National Estuarine Research Reserve
Shorelands and Coastal Zone Management Program
Washington State Department of Ecology
1043 Bay View-Edison Road
Mount Vernon, Washington 98273
September 1990
Base map adapted from U.S.G.S. 1:24,000 topographic series. Cartography by Robert B. Lindquist and Jon Greninger, Bellingham, Washington. Vegetative communities interpreted and compiled by Padilla Bay National Estuarine Research Reserve based on color aerial photography at 1:12,000 taken in June 1989 and ground truth investigations in June and July 1989.
The preparation of this map was financially aided through a grant to the Washington State Department of Ecology with funds obtained from NOAA/Office of Ocean and Coastal Resource Management and appropriated for Section 315 of the Coastal Zone Management Act of 1972, as amended.
Soundings in fathoms below mean lower low water (MLLW). Height in feet above mean sea level (MSL), contour interval 20 feet.
N
SCALE 1:24,000
METERS
FEET
VANCOUVER
British Columbia
CANADA
UNITED STATES
BELLINGHAM
MOUNT VERNON
SEATTLE
PACIFIC OCEAN
Washington
PORTLAND
Oregon
Idaho
PADILLA BAY
LEGEND
- Navigation Light
- Channel Markers
- Piles
- Dike
- Horizontal Control Markers
SEAGRASSES
12 Zostera marina subtidal
11 Zostera marina intertidal 51 - 100% cover
10 Zostera marina intertidal 21 - 50% cover
9 Zostera marina intertidal 5 - 20% cover
7 Zostera japonica intertidal
8 Zostera japonica with Z. marina intertidal
MACROALGAE
6 Ulva and Enteromorpha 51 - 100% cover
5 Ulva and Enteromorpha 21 - 50% cover
SAND AND MUD FLATS
3 sparse or unvegetated flats <5% cover of vegetation
4 Ruppia maritima 1 - 10% cover
SALT MARSHES
1 Salicornia/ Distichlis/Triglochin
2 Spartina alterniflora
Padilla Bay National Estuarine Research Reserve
ECOLOGY