

Habitat Mapping and Characterization in Port Susan Bay: Summary of 2004 and 2005 Monitoring

Danelle Heatwole, The Nature Conservancy of Washington, Seattle, WA May 2006



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Intent

The Nature Conservancy acquired the 1,600 ha Port Susan Bay (PSB) preserve in 2001. Three years later, we initiated mapping and characterization of estuarine habitats within and around the preserve. This effort was intended to inform TNC's conservation efforts, establish a baseline prior to restoration actions, and found a long-term estuary monitoring program. Protocols were designed to address the following objectives:

- Inventory existing estuarine habitats in the Stillaguamish estuary and map their spatial extents and distributions;
- Characterize physical and biological traits of the various habitats and evaluate differences in traits among habitats and across the landscape; and
- Quantify the density, extent, and distribution of invasive non-native plant species in the Stillaguamish estuary, particularly *Spartina anglica* (common cordgrass).

Methods

Study area

Port Susan Bay is located in northern Puget Sound, situated between the mainland and Camano Island (Fig. 1). The primary freshwater input is the Stillaguamish River, which drains an area of roughly 1,800 km² and discharges on average 3,700 cfs into PSB (USGS 2006). Some Stillaguamish water is also directed into south Skagit Bay through the old mainstem channel, but this flow is typically very low. It is estimated that PSB historically included 1,120 ha of estuarine emergent wetlands, 1,190 ha of scrub-shrub wetlands, and 2,010 ha of floodplain forests in the Stillaguamish delta (Collins 2000). However, more than 85% of emergent wetlands (Collins 1997), and nearly all of scrub-shrub and forested habitats (Collins 2000), were converted to agricultural uses by the mid-1900s. Thus, the remaining estuary includes the

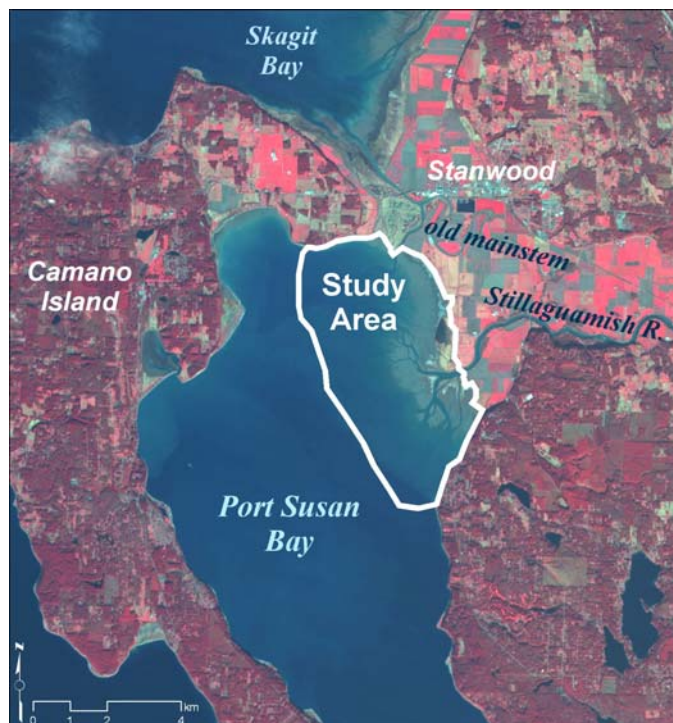


Figure 1. Location of Port Susan Bay in northern Puget Sound. The sampling area incorporated 2,160 ha of estuarine emergent wetlands and tideflats as well as 60 ha of diked wetlands and uplands.

most seaward fraction of historical emergent wetlands. The study area for this project included a majority of these wetlands and a portion of the intertidal flats.

Habitat mapping

We mapped intertidal habitats across 2,160 ha of the existing Stillaguamish estuary in PSB. Using georeferenced infrared aerial photographs from summer 2003, we used ArcGIS to manually digitize approximate boundaries for six estuarine habitats: backshore (BS), high and low elevation emergent wetlands (HE and LE), vegetated and unvegetated tideflats (VT and UT), and non-native eelgrass (EG; Table 1). In addition, we mapped diked wetlands (DW) and uplands (DU) within an adjacent 60-ha parcel owned by The Nature Conservancy.

Code	Habitat
EG	non-native eelgrass
UT	unvegetated tideflat
VT	vegetated tideflat
LE	low emergent wetland
HE	high emergent wetland
BS	backshore
DW	diked wetland
DU	diked upland

Table 1. Habitat abbreviations used in this document.

Habitats were defined by apparent differences in intertidal elevation as well as vegetation density and composition. BS was infrequently inundated by tides and positioned behind a wrack line of large woody debris (LWD). Emergent wetlands occurred seaward of the LWD wrack line and supported emergent vegetation at $\geq 25\%$ cover. HE was generally characterized by *Agrostis* spp. (bentgrass), *Juncus balticus* (Baltic rush), or *Carex lyngbyei* (Lyngby's sedge), and LE by *Scirpus americanus* (American bulrush) or *Scirpus maritimus* (maritime bulrush). Seaward of the wetlands were tideflats: VT supported emergent vegetation at $< 25\%$ cover, and UT contained no emergent vegetation. EG occurred within the otherwise unvegetated tideflats and was characterized by $\geq 25\%$ cover of *Zostera japonica* (Japanese eelgrass). Within the diked property, a wetland has recently developed in response to reduced pumping of rain and groundwater. We distinguished the wetland from upland by the presence of emergent estuarine species, ponded water, or decaying terrestrial grasses.

Habitats were groundtruthed at 223 stratified random locations throughout the estuary during 27 July–4 August 2004. The allocation of points among habitats was determined by conducting a sample size power analysis on vegetation species densities from 79 pilot points. For each habitat, we calculated the number of additional sampling points necessary to detect a 50% difference in densities of common plant species with 80% power and 10% Type I error rate. This number was then modified slightly for some habitats, based on feasibility and budgetary constraints. For the 223 groundtruthed points, 11 were allocated to BS, 44 to HE, 47 to LE, 29 to VT, 35 to UT, 22 to EG, 17 to DW, and 18 to DU. Sampling point coordinates were generated using Hawth's Analysis Tools for ArcGIS. We used a Trimble Pathfinder Pro XR global positioning system (GPS) to initially locate sampling points in the field. We marked sampling points with PVC pipe and recorded the observed habitat at each location.

In July 2005, we revisited 98 of the original 224 sampling points and added 10 new points to areas needing further map refinement. Overall, 23 points were assigned to HE, 24 to LE, 21 to VT, 12 to UT, 13 to EG, 10 to DW, and 5 to DU.

Habitat Characterization

Physical and biological characteristics of PSB's estuarine habitats were documented in two phases at the stratified random sampling points (Table 2). Porewater salinity and substrate class were recorded during 27 July–4 August 2004 and 11–17 July 2005.¹ We also measured surface elevations and collected benthic invertebrate samples during this period in 2005. Vegetation, tidal channels, and LWD were characterized at each point during 22 June–8 September 2004 and 28 June–18 August 2005. The standard plot design for 2004 differed slightly from 2005 (Fig. 2), including a square (vs. circular) vegetation plot, five (vs. four) 500-cm² vegetation subsamples, and four (vs. three) 50-m transects for tidal channels, LWD, and non-native plant species.

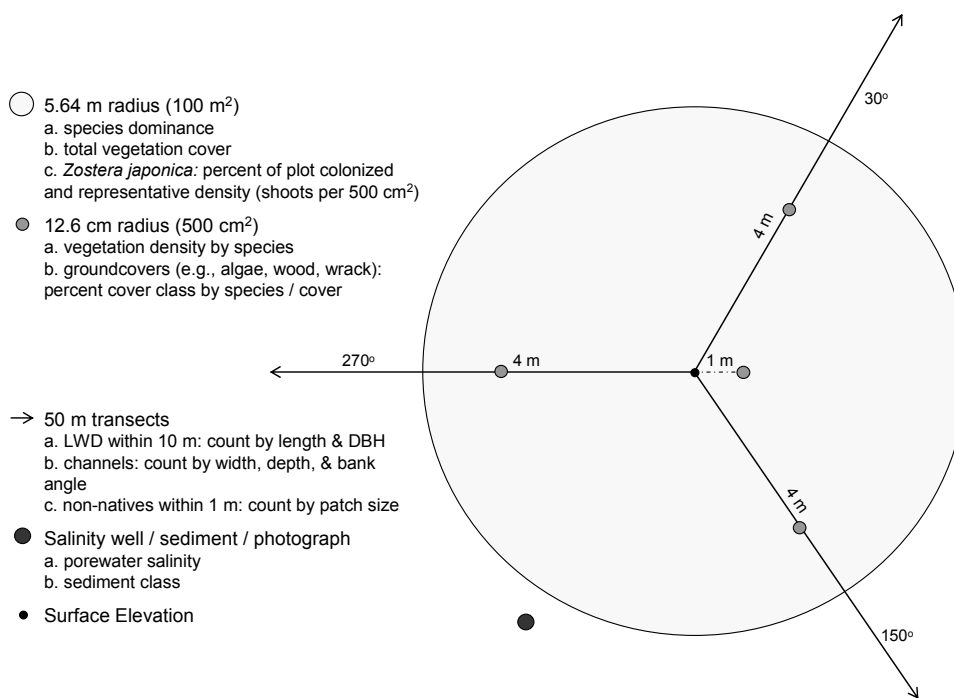


Figure 2. Plot design for 2005 habitat characterization at PSB. Plots were established at each stratified random sampling point.

Physical attributes were measured at each point to characterize effects of riverine and marine processes throughout the estuary, in terms of topography, salinity, substrate type, and LWD distribution. We used a Leica GPS1200 surveying system to record horizontal coordinates and surface elevations at the 2005 sampling points. A base station was established each day over one of two existing elevation monuments, located within 4 km of points to be visited that day. Porewater was accessed in temporary wells (dug with a hand auger), and salinity was gauged

¹ July 2005 porewater salinity and substrate data were lost for most VT, LE, and HE points in North region, and recollected on 9 August. Due to time constraints, these data were not collected for EG points in North and Central regions until 18 August.

using a digital salinity-conductivity-temperature instrument. We qualitatively classified surface substrates using the general descriptions provided by McBride et al. (2005). Tidal channels and LWD were tallied by size class along three 50-m transects originating at the plot center and oriented at 30, 150, and 270° from north. We counted intersecting tidal channels according to width (<0.5, 0.5–2, 2–10, and >10 m), depth (<0.2, 0.2–0.5, 0.5–2, and >2 m), and bank angles (<5, 5–30, 30–75, 75–90, and >90° from horizontal) at the intersection point. We counted LWD within 10 m of each transect by length (5–15, 15–30, and >30 m) and diameter at breast height (DBH; 0.3–0.6, 0.6–1, and >1 m).

The vegetation assemblage at each sampling point was characterized at two spatial scales: 100 m² and 500 cm². At the larger scale, we established a circular plot of 5.64 m radius, centered on the marked sampling point. We documented the overall percent cover of rooted vegetation in the plot, using the cover classes 0, 1–25, 26–75, and >75%. We also recorded the dominance for each species in the plot (<25, 25–50, or >50% of vegetation present). At the smaller scale, we placed a 12.6-cm radius hoop at four distances and orientations from the plot center: 1 m at 90° from north and 4 m at 30, 150, and 270°. Within each subsample, we counted the number of shoots for emergent species and estimated the percent cover for algae, wrack, wood, or other non-emergent items. Cover classes included <1, 1–5, 6–25, 26–50, 51–75, 76–95, and >95%.

Non-native plant species of concern at PSB included *S. anglica* and *Z. japonica*. In the emergent wetland and diked habitats, *S. anglica* clones were tallied by diameter class within 1 m of the three 50-m transects. In the tideflat habitats, vegetation was sufficiently sparse to allow detection of *S. anglica* from a greater distance, and here we tallied clones by diameter class within 25 m of the plot center (1,964 m² total area). Diameter classes included <0.1, 0.1–0.5, 0.5–1, and >1 m. For *Z. japonica*, we estimated the percentage of the 100-m² plot colonized, using the classes 0, <1, 1–5, 6–25, 26–50, 51–75, and >75%, and then recorded a representative shoot density within 500 cm².

We collected benthic invertebrates at 42 sampling points: 3 in DW, 3 in EG, and 9 in each of the remaining habitats except BS. Invertebrates were collected using a 7-cm diameter corer plunged 10 cm into the sediment. Samples were placed into labeled Nalgene jars, kept on ice up to 24 hours, and then washed and separated using tap water. Contents retained in a 500-µm sieve were placed in labeled jars, fixed with 5% buffered formalin, and stained with Rose Bengal. Samples were transferred to a contractor, who sorted, counted, and identified contents to the finest taxonomic resolution possible under an illuminated dissecting microscope.

Data Processing and Analysis

Habitat boundaries were refined in ArcGIS to correspond with 2004 and 2005 field observations. Typically, refinement involved visually inspecting the aerial photographs around sampling points that differed in predicted versus observed habitat, and then adjusting the polygon boundary such that points fell within the appropriate habitat type. We calculated total area for each of these refined habitat polygons.

As a first step toward understanding how the estuary has been impacted by hydrologic modifications in the river delta, we structured our analysis to make comparisons across the landscape. Sea dikes not only exclude tidal and river flows from a majority of the historical

estuary, but also alter hydrologic, geomorphic, and sedimentary processes within the existing estuary (Hood 2004). This is thought to be particularly true for The Nature Conservancy's dike, which is situated north of the river mouth and extends farther seaward than other dikes. Thus, we divided the estuary into three geographic regions relative to our dike (North, Central, and South; Fig. 3) and designated each sampling point to a region using a spatial join in ArcGIS.

Physical and biological data were processed to generate standardized metrics for statistical comparisons. Surface elevation data were triangulated by the equipment retailer to generate elevations relative to the North American Vertical Datum (NAVD88). For channels, LWD, *S. anglica*, and other vegetation, we converted each size, angle, and cover class to its median value. We estimated channel cross-sectional area (CSA) utilizing median width, depth, and bank angles in the geometric equation for trapezoid area.² CSAs for some channels were adjusted to triangular or rectangular geometries if the trapezoid calculation was inappropriate given the coarse input data. We estimated LWD volume from median length and DBH. Areal cover of *S. anglica* clones was estimated from median diameter, using the equation for circular area. We normalized channel, LWD, and *S. anglica* counts for each sampling point to 100 m, 1000 m², and 250 m², respectively, allowing for density comparisons across habitats. We summed shoot counts from the four 500-cm² vegetation subsamples to give species densities per 0.20 m²; we normalized invertebrate densities to 100 cm² of surface area, given standard the 10-cm sampling depth. We calculated two measures of diversity for vegetation and invertebrates: richness and Shannon-Wiener diversity. Vegetation richness was determined from the 100-m² plots, whereas diversity was computed from the four subsamples.

Physical and biological metrics for 2004 and 2005 (Table 2) were compared among habitats using ANOVA followed by pairwise comparisons, with Bonferroni's correction to the p-value ($\alpha = 0.05$ for physical and vegetation metrics, $\alpha = 0.10$ for invertebrates). To test for regional differences, we excluded diked habitats (plus EG for invertebrates) and compared metrics by intertidal habitats and regions using full factorial ANOVA with Bonferroni's pairwise comparisons ($\alpha = 0.05$ for main factors, $\alpha = 0.10$ for interactions). Data were generally log or square root transformed to reduce skewness and kurtosis prior to analysis; an exception was overall percent cover of vegetation, which was arcsine square root transformed. Densities of common plant species, *Z. japonica* percent colonization, and invertebrate class densities were compared among habitats ($\alpha = 0.05$), and regions within habitats ($\alpha = 0.10$), using Kruskal-Wallis non-parametric tests followed by Mann-Whitney non-parametric pairwise comparisons, with Bonferroni's adjustment to the p-value. Frequencies of substrate classes were qualitatively compared among habitats and regions.

² The geometric equation for trapezoid area is $(b_1 + b_2) h / 2$, where b_1 represents the recorded bankfull channel width, b_2 the width of the channel bed, and h the channel depth. We computed b_2 by subtracting from b_1 the horizontal distances (d_1 and d_2) encompassed by the channel banks; d_1 and d_2 were calculated using properties of right triangles: $h * \tan[(90 - \theta) * \pi/180]$, where θ equals a recorded bank angle in degrees.

Results

Habitat mapping

Based on the refined habitat maps from 2005, the Stillaguamish estuary is dominated by UT, which comprised 1,293 ha (66%) of the intertidal area sampled (Fig 3). VT and EG contributed 249 and 165 ha, respectively. Emergent wetlands represented a combined 11% of the intertidal area, with 144 ha in LE and 82 ha in HE. BS was the smallest intertidal habitat (15 ha). Diked habitats were fairly evenly split between wetland and upland, with 31 and 29 ha, respectively.

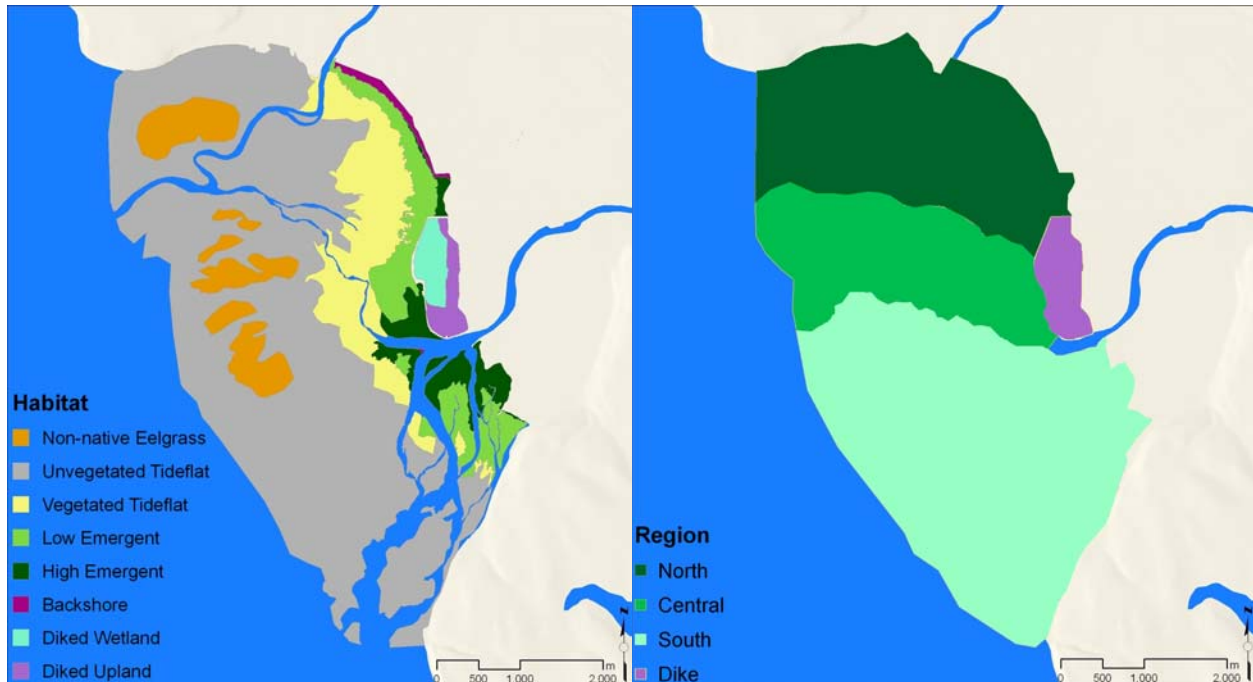


Figure 3. Groundtruthed habitats (left) and comparative regions (right) for 2004 and 2005 monitoring at Port Susan Bay.

Habitat characterization

In both 2004 and 2005, habitats differed in nearly all physical and biological metrics compared; only channel CSA and *S. anglica* metrics in 2005 were not different among habitats. Backshore was observed in the field to differ greatly from other intertidal habitats, with >60% frequency of wracked LWD, *Atriplex patula* (spearscale), *Potentilla pacifica* (silverweed), *Achillea millefolium* (yarrow), *Agrostis* spp., *Solanum dulcamara* (European bittersweet), *Brassica campestris* (field mustard), and *Lactuca serriola* (prickly lettuce). Due to time constraints, we did not quantitatively sample BS and have excluded it from this analysis.

Regional differences were observed for porewater salinity, substrate frequency, channel CSA, vegetation (percent cover, non-native species), and benthic invertebrates (species richness). Statistically significant findings are presented in detail by metric, below; however for this summary report, specific test values are not given. Descriptive statistics for all metrics by habitat are provided in Tables 3–6.

Physical Parameters

Among intertidal habitats, surface elevations were lowest in EG and UT, followed by VT, LE, and HE at consecutively higher elevations (Table 3). Overall, there were no regional differences in elevation; however within VT, elevations in North were lower than Central and South (1.4 vs. 1.7 & 1.8 m NAVD). The diked habitats were 0.9 and 0.6 m lower in elevation than HE, providing some indication of the relative subsidence that has occurred since dike construction in the 1960s.

Salinity generally decreased with increasing surface elevation in 2005, with porewater in EG and UT roughly 8 ppt more saline than in HE (Table 3). Regional comparisons showed greater salinities in North than in Central and South (12.7 vs. 6.7 & 6.4 ppt). In 2004, salinities among habitats in Central and South generally decreased with increasing elevation; however, the reverse was true for the North, and porewater within emergent wetlands was more saline in North than South (Fig. 4). Within the dike, DW

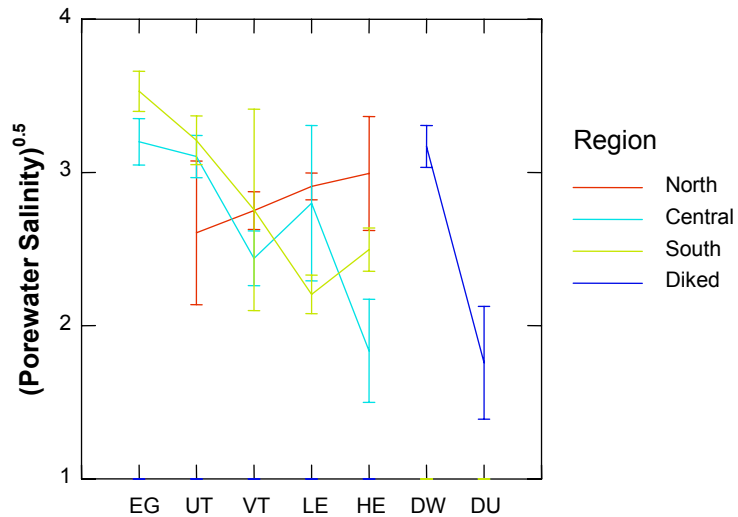


Figure 4. Porewater salinity by habitat and region in 2004. Mean salinity is centered between standard error bars.

experienced high porewater salinities, whereas DU experienced lower salinities, particularly in 2004. Increased salinity in DW could arise from evaporation of ponded water in that habitat.

Substrates qualitatively differed among habitats and regions, but in general, higher elevation habitats had finer substrates (Fig. 5). EG, UT, and VT contained intermediate to high frequencies of mixed fines and sand, whereas the emergent wetlands contained intermediate to high frequencies of mixed fines and mud. Substrates in the North were dominated by mud (94% in 2004, 78% in 2005), and those in Central and South had greater contributions of mixed fines and sand. In diked areas that were not continuously flooded, we observed greater frequencies of dry soil with high organic content.

Vegetated tideflats in 2004 supported 1.3–12.6 times greater channel densities than any other intertidal habitat (Table 3). Channels occurred at intermediate densities within LE, HE, and UT and at the lowest density within EG. A similar pattern was observed in 2005, with channel densities greater in VT and LE and lower in EG. Within tideflat habitats in 2005, there were greater channel densities in the North, but in emergent wetlands channel densities were greater in Central (Fig. 6). Based on CSA in 2004, channels were larger on average in HE, intermediate in LE and tideflats, and smaller in EG. Among regions, channels were smaller in North than in Central and South (0.7 vs. 2.8 & 4.1 m²). The same regional pattern was observed in 2005, and was particularly pronounced in the emergent wetlands (Fig. 6). Channels occurred at low densities within the diked habitats, with low to intermediate CSAs.

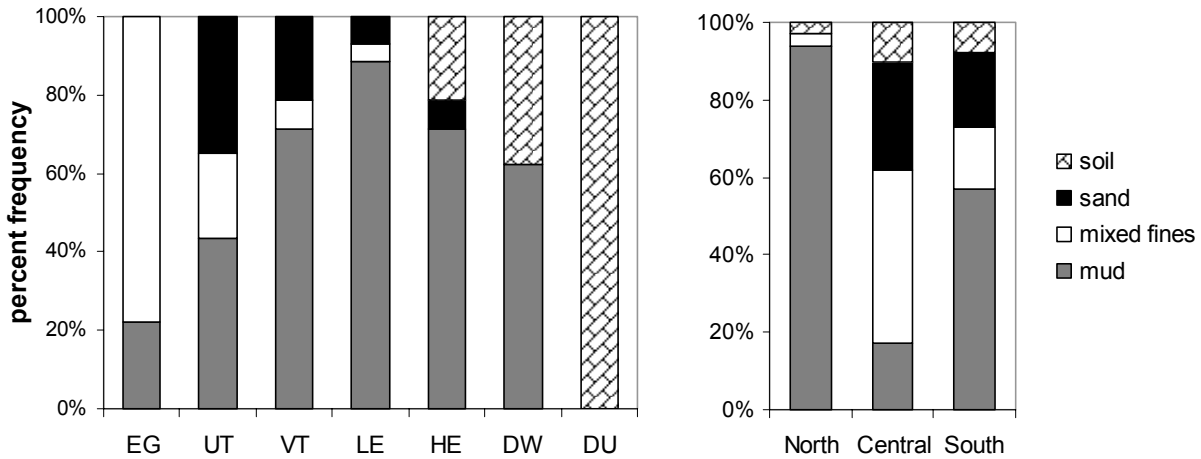


Figure 5. Percent frequency of substrates by habitat (left) and region (right) for 2004.

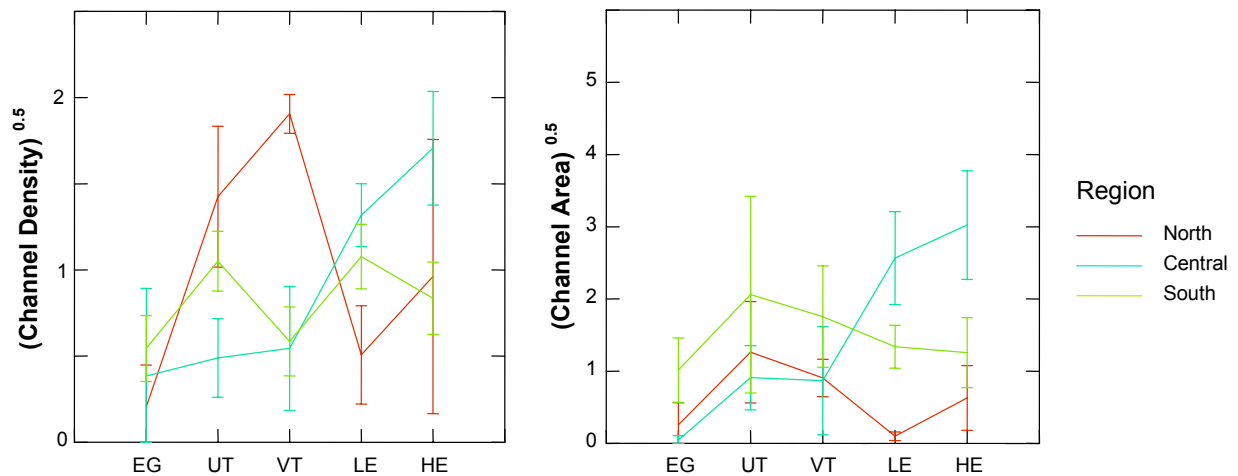


Figure 6. Channel density (left) and channel CSA (right) by habitat and region in 2005. Mean value is centered between standard error bars.

LWD occurred at the greatest volumes within HE (Table 3). This finding was expected because HE occurs in the upper intertidal, where LWD that is deposited on the highest tides would experience less frequent opportunities to be resuspended and deposited elsewhere. Intermediate LWD volume was found in LE, whereas EG, UT, and VT presented very low volumes. LWD did not occur in the diked habitats.

Vegetation

Vegetation metrics were generally consistent with habitat definitions and expectations. We encountered 87 plant and algal species in 2004, and 84 species in 2005. Total percent cover and shoot density were greatest in HE, intermediate in EG and LE, and least in the tideflats (Table 4). Vegetation cover differed by regions within habitats: EG had greater cover in the North, whereas LE supported greater cover in the South (Fig. 7). Vegetation richness and Shannon-Wiener

diversity were greatest in HE and least in UT. Regional patterns in richness differed by habitat: South supported greater species richness than the North for EG and HE habitats, whereas the North offered greater species richness than Central within VT (Fig. 8). North produced greater diversity than South for UT and LE, but South produced higher diversity than North in HE. For the diked habitats, vegetation cover in DU was high. DU produced greater shoot densities than all other habitats in 2004 and supported relatively high species richness and Shannon-Wiener diversity in both years. DW contained consistently low vegetation cover and shoot densities; however, diversity metrics were low in 2004 and intermediate in 2005. This observation could be due to continued colonization of the wetland by estuarine species.

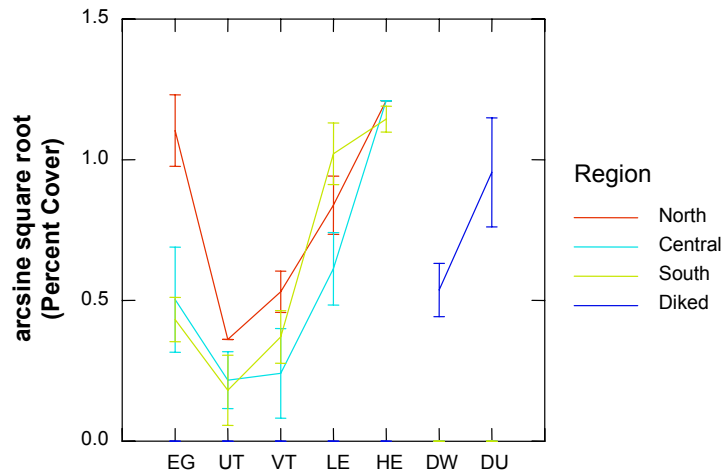


Figure 7. Percent vegetation cover by habitat and region for 2005. Mean cover is centered between standard error bars.

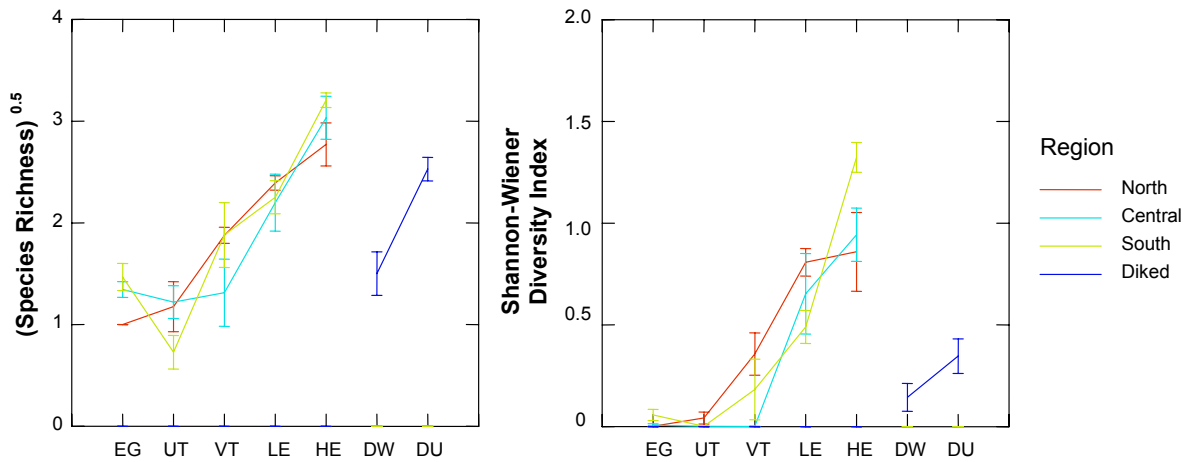


Figure 8. Vegetation species richness (left) and diversity (right) by habitat and region for 2004. Mean value is centered between standard error bars.

Densities of vegetation species contributed to and were consistent with the patterns observed above. Based on shoot density, 22 species occurred at $\geq 20\%$ frequency in at least one habitat and year (Table 5). For intertidal habitats, 14 species exhibited density differences between adjacent habitats in 2004, and 10 of these same species differed in 2005 (Table 5, differences shown in bold). Diked habitats differed from emergent wetlands in 14 and 9 species in 2004 and 2005, respectively.

Zostera japonica comprised 100% of the vegetation density in EG and UT habitats, though EG contained greater densities than UT (Fig. 9). VT was dominated by *S. americanus* in 2004, with

greater densities occurring in North than Central (10.5 vs. 3.7/0.2 m²). In 2005, we observed high densities (i.e. carpets) of *Eleocharis acicularis* (needle spikerush)³ in addition to *S. americanus* in VT. *E. acicularis*, *S. americanus*, and *S. maritimus* dominated the LE habitat, though *S. americanus* was more dense in Central and South (117.9 & 131.3 vs. 12.0/0.2 m² in North), and *S. maritimus* was more dense in the North (29.3 vs. 1.9 & 0.6/0.2 m² in Central & South). High emergent wetlands were characterized by *Agrostis* spp., *J. balticus*, *C. lyngbyei*, *S. americanus*, and *E. acicularis*. Within HE, greater densities of *E. palustris*, *S. americanus*, and *Triglochin maritimum* (sea arrow-grass) occurred in South than North (33.9, 25.7, & 17.5 vs. 0, 0.3, & 2.4/0.2 m², respectively). Species composition in DW appeared to shift from 2004 to 2005. In 2004, *Agrostis* spp. and *Distichlis spicata* (seashore saltgrass) characterized the habitat. In 2005, major species included *Cotula coronopifolia* (brass buttons), *S. maritimus*, *Agrostis* spp., and *Salicornia virginica* (pickleweed). Finally, DU was dominated by *Agrostis* spp., *Agropyron repens* (quackgrass), and in 2005 *A. patula*.

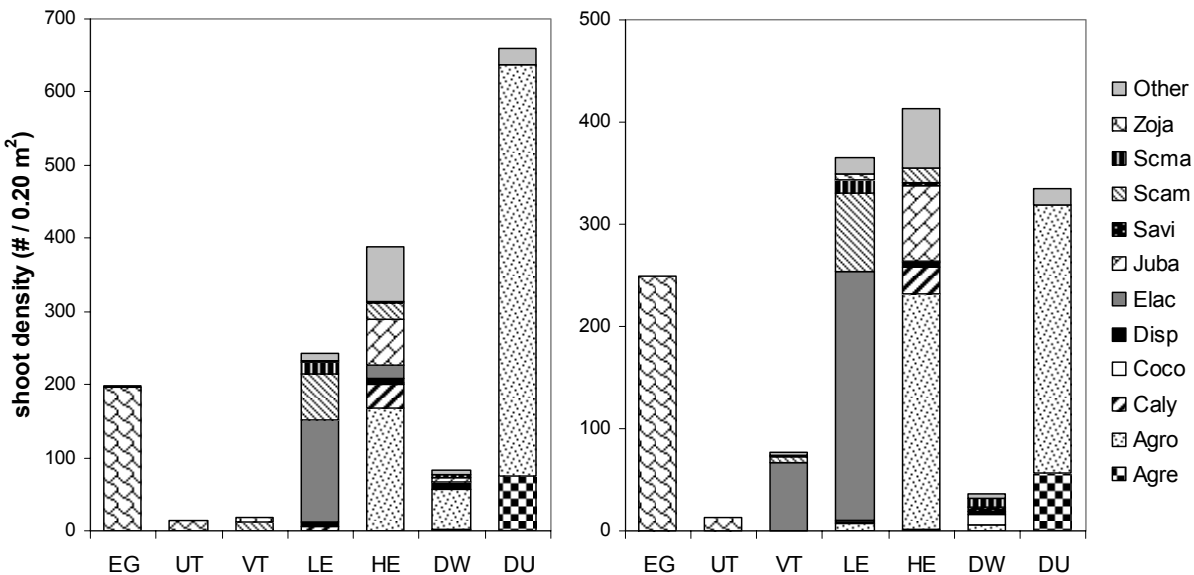


Figure 9. Average vegetation shoot density by habitat for (a) 2004 and (b) 2005. Agre=*Agropyron repens*, Agro=*Agrostis* spp., Caly=*Carex lyngbyei*, Coco=*Cotula coronopifolia*, Disp=*Distichlis spicata*, Elac=*Eleocharis acicularis*, Juba=*Juncus balticus*, Savi=*Salicornia virginica*, Scam=*Scirpus americanus*, Scma=*Scirpus maritimus*, Zoja=*Zostera japonica*, Other=combined densities of other vegetation species.

The occurrence of non-native plant species differed by habitat and region: *S. anglica* clones were most dense in LE and least dense in EG, and both *S. anglica* and *Z. japonica* were more prevalent in the North region (Table 4). Based on average areal cover, *S. anglica* clones were largest in VT and LE and smallest in EG. In all habitats except EG, *S. anglica* clones occurred at greater densities and areal cover in the North region (Fig. 10). *Z. japonica* was most prevalent in EG, less prevalent in LE, UT, and VT, and least prevalent in HE. Representative *Z. japonica* densities followed a similar trend. Within UT, VT, and LE habitats, *Z. japonica* densities were

³ The taxonomic identification of *Eleocharis acicularis* has not been confirmed. This plant is very small (~1 cm) and has only been observed flowering by TNC staff in Campbell River, BC.

greater in the North than Central and South. Non-native species of concern were not found in diked habitats in 2004, but 25 *S. anglica* clones were identified at one DW point in 2005.

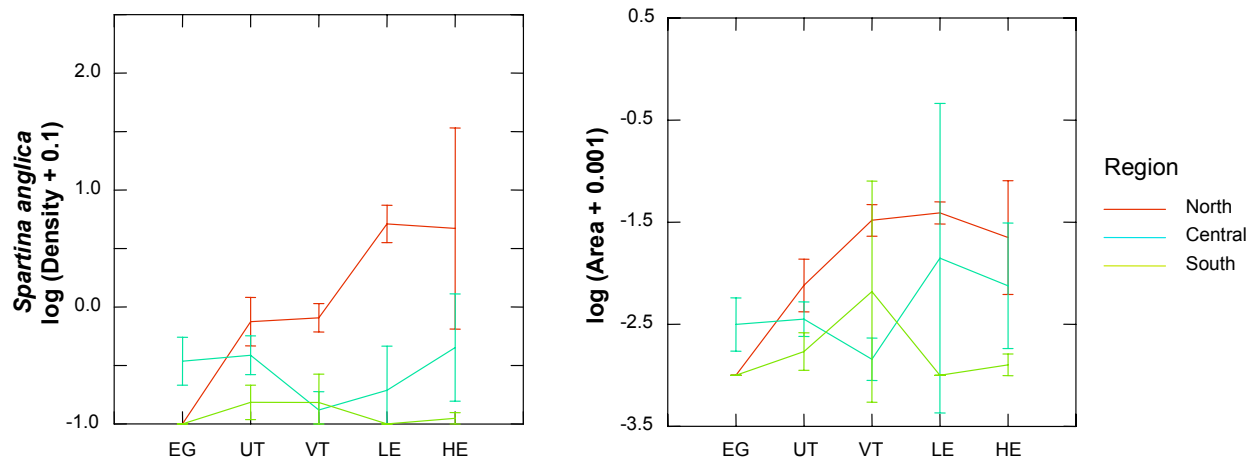


Figure 10. *Spartina anglica* density (left) and areal cover (right) by habitat and region in 2004. Mean value is centered between standard error bars.

Benthic Invertebrates

Forty-two invertebrate taxa, represented by 14 classes, were collected in 2005. LE provided greater invertebrate densities overall, whereas EG supported the greater taxa richness and diversity (Table 4). Other than the high densities in LE, all three metrics displayed a generally decreasing trend with increasing elevation. Invertebrate densities in LE were greater than VT and HE, with EG and UT intermediate. Greater taxa richness was observed in EG and UT and lower richness in HE. In addition, greater taxa richness was found in North than in both Central and South (9.3 vs. 6.0 & 7.2 taxa). EG and UT supported greater Shannon-Wiener diversity than VT and HE, with no differences among regions. DW produced lower invertebrate density than all intertidal habitats, lower richness than EG, UT, and LE, and lower diversity than EG and UT.

Ten invertebrate classes occurred in more than one sample in at least one habitat (Table 6). For intertidal habitats, five classes demonstrated density differences between adjacent habitats (Table 6, differences shown in bold). Only three taxa were collected in DW: the flies Chironomidae and Corixidae, and the ostracod Cyprididae. Polychaetes dominated the EG, UT, VT and LE samples (contributing 63–84% of the total invertebrate density), but were less dominant in HE (37% of total density, Fig. 11). Also, oligochaetes made up a substantial portion of the intertidal invertebrate densities. Besides the annelid worms, EG was characterized by Malacostraca and Bivalvia, and UT by Nematoda and Copepoda. Nematoda, Malacostraca, and Copepoda also contributed a majority of the remaining invertebrate density in LE. Finally, HE was characterized by the annelid worms plus nematodes and insects.

Overall, there were no significant trends with non-native invertebrates by habitat or region, but an incidental interaction between habitat and non-natives (ANOVA, $R^2=0.035$, $F=2.908$, $p=0.021$) suggests habitats such as EG may favor introduced species. A larger dataset and increased monitoring may reveal more significant results.

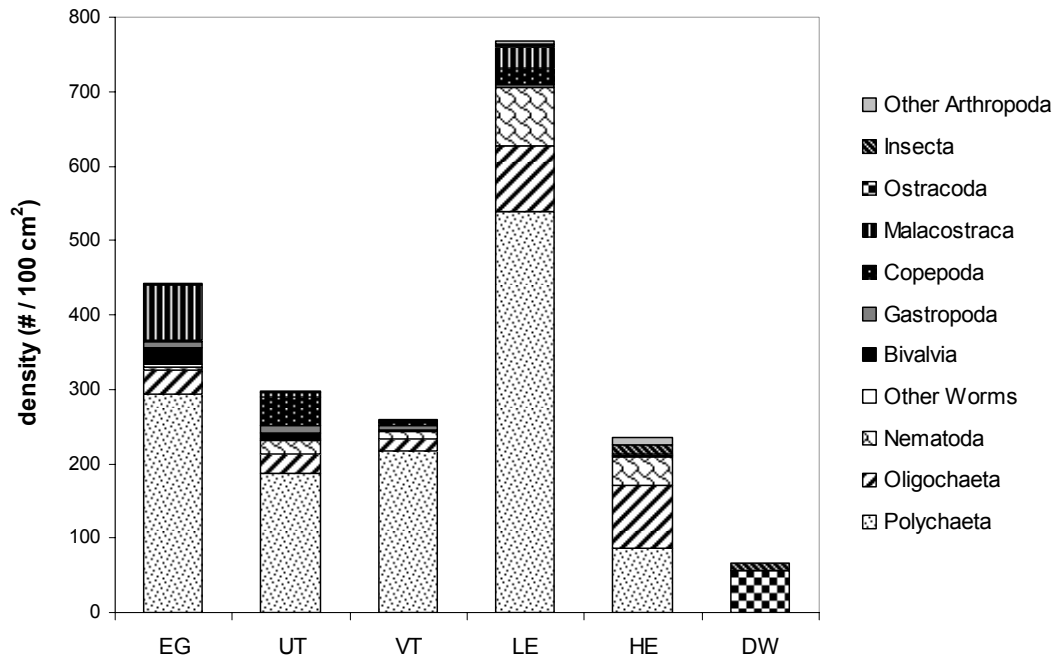


Figure 11. Average benthic invertebrate density by habitat for 2005.

Discussion

Habitat Mapping

The Stillaguamish estuary today differs greatly from historical accounts, when some 1,120 ha of estuarine emergent wetlands and 1,190 ha of scrub-shrub wetlands occurred in the delta (Collins 2000). Emergent wetlands comprised only 226 of the 2,160 ha sampled in this study, and scrub-shrub wetlands were observed only along dike fronts, where they clearly lacked the complex geomorphic structure typical of estuarine scrub-shrub wetlands. Habitat configuration appeared to be more complex near the river, with a number of distributary channels and one blind tidal channel intersecting the emergent wetlands. North of The Nature Conservancy's dike, habitats occurred along simple elevation bands and contained few channel systems. It is worthy to note that the non-native eelgrass *Z. japonica* dominated an area (165 ha) of similar magnitude to the remaining emergent wetlands.

Habitat Characterization

Habitats differed in nearly all physical and biological metrics compared. In general, higher vegetation density and diversity were found in areas with higher surface elevations and lower porewater salinities. Benthic invertebrates demonstrated the reverse pattern, with generally higher density and diversity at lower elevations and higher salinity; however, habitats providing intermediate vegetation densities (i.e. low emergent wetlands and non-native eelgrass) supported the greatest invertebrate densities. General characteristics of the habitats documented in this study are provided below.

Intertidal Habitats

Non-native eelgrass occurred at low elevations, experienced high porewater salinity, and was more prevalent in the North. Substrates were generally mixed fines or sand, and there was low habitat complexity in the form of channels and LWD. *Z. japonica* contributed intermediate vegetation cover and density, but low species richness and diversity. Eelgrass supported relatively high invertebrate density and the highest diversity; however, more of the invertebrates may be non-native species.

Unvegetated tideflats dominated low elevations and experienced high porewater salinity. Substrates were frequently mixed fines or sand. Channels occurred at intermediate densities and CSAs, but with more and smaller channels in the North. There was overall little LWD or vegetation in this habitat, except for intermediate densities of *S. anglica* and *Z. japonica*. Benthic invertebrates were found at intermediate density, richness, and diversity.

Vegetated tideflats occurred at medium-low elevations, with slightly lower elevations in the North. Porewater was measured at intermediate salinity; substrates varied in grain size from mud to sand. Channels occurred at high densities and intermediate CSAs, with more and smaller channels in the North. Little LWD was found. This habitat was characterized by low vegetation cover and density and intermediate species richness and diversity. The most prominent species was *S. americanus*. *S. anglica* and *Z. japonica* were common, and *S. anglica* clones were typically large. Intermediate invertebrate density, richness, and diversity were documented.

Low emergent wetlands were found at medium-high elevations and experienced intermediate levels of porewater salinity and LWD volume. Substrates were predominantly mud or mixed fines. The low emergent wetlands contained channels of intermediate density and CSA, with greater density and CSA in the Central and South. Vegetation grew at intermediate cover and density, with intermediate species richness and diversity. Characteristic species included *S. americanus* and *S. maritimus*. *S. anglica* clones occurred at high densities and large sizes; *Z. japonica* occurred at intermediate densities, primarily restricted to small puddles that retained water during low tide. This habitat supported high invertebrate density and intermediate richness and diversity.

High emergent wetlands occurred at high elevations and were generally characterized by low porewater salinity and mud or mixed fines substrates. These wetlands contained high volumes of LWD and were intersected by large channels of intermediate density, with more and larger channels in the Central region. High vegetation cover, density, richness, and diversity prevailed. Characteristic species included *Agrostis* spp., *J. balticus*, *C. lyngbyei*, and *S. americanus*. *S. anglica* was documented at intermediate clone density and size; *Z. japonica* was not found within this habitat. Invertebrates occurred at intermediate densities and low richness and diversity.

Diked Habitats

Habitats within The Nature Conservancy's dike had intermediate elevations, which were lower than the adjacent intertidal habitat elevations. Channels occurred at very low densities and low to intermediate CSAs. We found no LWD and no *Z. japonica* within the dike.

Diked wetlands experienced high porewater salinity, likely due to evaporation of ponded water. Substrates within the ponded area were generally muddy; substrates that were seasonally dry contained high levels of decaying organic matter. The diked wetlands supported low vegetation cover and density as well as low to intermediate species richness and diversity. Vegetation composition differed greatly from intertidal emergent wetlands. *S. anglica* was not found in 2004 but occurred at a high density at one sampling point in 2005. Very low invertebrate density, richness, and diversity were found in the ponded area of the diked wetland.

Diked uplands had low porewater salinity and a highly organic soil substrate. This habitat was characterized by high vegetation cover, density, richness, and diversity, but with a different species composition than intertidal wetlands.

Regional Differences

We observed significant differences between the North and more southern regions, which may be indirectly attributable to the Stillaguamish dike and levee system. Such differences may result from altered hydrologic and geomorphic processes in the existing estuary and river delta. The North region contained higher porewater salinity, suggesting reduced freshwater inputs relative to the Central and South regions. The North was dominated by finer sediments, and in emergent wetlands, contained smaller channels than in Central and South, suggesting reduced hydraulic flushing and velocity. The North also contained greater densities of the non-native plant species *S. anglica* and *Z. japonica*, which could be a symptom of habitat degradation in that region. High densities and wide distribution of these non-native species could in turn cause increased habitat degradation. Ecosystem restoration at PSB may do well to address not only habitat losses behind the dikes, but also habitat degradation in front of the dikes.

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Table 2. Physical and biological attributes measured, dates of sampling, and metrics for analysis.

Attributes Measured	2004	2005	Metrics Generated
Surface elevation	-	11–17 Jul	Surface elevation (m NAVD)
Porewater salinity	27 Jul–4 Aug	11–17 Jul ^a	Porewater salinity (ppt)
Substrate class	27 Jul–4 Aug	11–17 Jul ^a	Substrate percent frequency
Channel	28 Jul–8 Sep	28 Jun–18 Aug	Channel
- Abundance			- Density (# /100 m)
- Width, depth, bank angles			- Mean cross-sectional area (m ²)
Large woody debris	28 Jul–8 Sep	28 Jun–18 Aug	LWD
- Abundance			- Volume (m ³ /1000 m ²)
- Length, diameter			
Vegetation	22 Jun–8 Sep	28 Jun–18 Aug	Vegetation
- Overall percent cover			- Total percent cover
- Species dominance			- Species richness
- Species abundance/percent cover			- Shannon-Wiener diversity
			- Total density (# /0.20 m ²)
			- Species densities (# /0.20 m ²)
Non-native species	28 Jul–8 Sep	28 Jun–18 Aug	Non-native species
- <i>Spartina anglica</i>			- <i>S. anglica</i>
- Abundance			- Clone density (# /250 m ²)
- Diameter			- Mean clone areal cover (m ²)
- <i>Zostera japonica</i>	-	28 Jun–18 Aug	- <i>Z. japonica</i>
- Percent colonization			- Percent colonization
- Abundance			- Shoot density (# /500 cm ²)
Benthic invertebrates	-	12–13 Jul	Benthic invertebrates
- Taxa abundance			- Taxa richness
			- Shannon-Wiener diversity
			- Total density (# /100 cm ²)
			- Taxa densities (# /100 cm ²)

^a July 2005 porewater salinity and substrate data were lost for most VT, LE, and HE points in North region, and recollected on 9 August. Due to time constraints, these data were not collected for EG points in North and Central regions until 18 August.

Table 3. Mean values (and standard errors) for physical metrics.

<i>Metric</i>	<i>2004</i>							<i>2005</i>						
	<i>EG</i>	<i>UT</i>	<i>VT</i>	<i>LE</i>	<i>HE</i>	<i>DW</i>	<i>DU</i>	<i>EG</i>	<i>UT</i>	<i>VT</i>	<i>LE</i>	<i>HE</i>	<i>DW</i>	<i>DU</i>
Surface Elevation (m NAVD)	-	-	-	-	-	-	-	0.54 (0.10)	0.83 (0.24)	1.58 (0.06)	1.86 (0.07)	2.46 (0.05)	1.63 (0.04)	1.93 (0.03)
Porewater Salinity (ppt)	11.6 (0.7)	9.5 (0.7)	7.5 (0.6)	7.3 (0.5)	7.4 (0.8)	10.1 (0.8)	2.9 (1.1)	12.4 (2.2)	12.2 (2.1)	8.4 (1.4)	6.9 (1.2)	4.4 (0.9)	14.3 (2.6)	8.8 (1.2)
Channel Density (# /100 m)	0.25 (0.09)	1.55 (0.61)	3.40 (0.47)	0.99 (0.28)	1.20 (0.20)	0.17 (0.17)	0	0.36 (0.12)	1.11 (0.30)	2.06 (0.41)	1.33 (0.24)	1.97 (0.44)	0.53 (0.24)	1.11 (1.11)
Channel CSA (m ²)	0.21 (0.10)	1.22 (0.40)	2.35 (0.90)	2.28 (0.77)	5.48 (1.64)	4.38 (4.38)	0	0.93 (0.50)	3.85 (2.25)	3.15 (1.09)	3.44 (1.03)	6.76 (2.23)	0.41 (0.19)	3.10 (3.10)
LWD Volume (m ³ /1000 m ²)	0	0	0.09 (0.08)	4.38 (2.48)	10.05 (3.56)	0	0	0.04 (0.04)	0	1.69 (0.93)	2.53 (1.27)	7.88 (2.33)	0	0

Table 4. Mean values (and standard errors) for biological metrics.

Metric	2004							2005						
	EG	UT	VT	LE	HE	DW	DU	EG	UT	VT	LE	HE	DW	DU
<i>Vegetation</i>														
Overall Cover	-	-	-	-	-	-	-	0.385 (0.089)	0.083 (0.018)	0.206 (0.040)	0.557 (0.056)	0.841 (0.024)	0.300 (0.068)	0.650 (0.150)
Total Density (shoots/0.20 m ²)	198.0 (23.9)	14.8 (4.6)	18.9 (4.6)	242.0 (36.2)	388.7 (30.2)	82.6 (43.0)	660.2 (94.5)	250.0 (21.6)	13.4 (7.0)	76.4 (52.4)	364.9 (76.0)	412.6 (52.4)	36.7 (18.6)	334.6 (104.5)
Species Richness	2.0 (0.2)	1.3 (0.2)	3.3 (0.3)	5.6 (0.3)	10.4 (0.6)	2.9 (0.6)	6.6 (0.6)	2.3 (0.3)	3.0 (0.4)	5.9 (0.4)	7.0 (0.5)	10.9 (0.7)	4.6 (0.8)	9.0 (2.0)
Shannon-Wiener Diversity	0.03 (0.02)	0.01 (0.01)	0.26 (0.07)	0.68 (0.05)	1.19 (0.07)	0.14 (0.07)	0.35 (0.08)	0	0	0.22 (0.08)	0.60 (0.10)	0.96 (0.11)	0.46 (0.18)	0.55 (0.10)
<i>Spartina anglica</i>														
Density (clones/250 m ²)	0.13 (0.07)	0.49 (0.12)	0.86 (0.26)	6.59 (2.48)	9.38 (8.39)	0	0	0.05 (0.04)	0.57 (0.41)	1.78 (0.86)	1.46 (1.15)	1.70 (1.21)	2.08 (2.08)	0
Mean Clone Area (m ²)	0.002 (0.002)	0.007 (0.002)	0.052 (0.015)	0.111 (0.083)	0.023 (0.010)	0	0	0	0.011 (0.006)	0.026 (0.018)	0.012 (0.008)	0.003 (0.003)	0.002 (0.002)	0
<i>Zostera japonica</i>														
Portion Colonized	-	-	-	-	-	-	-	0.385 (0.089)	0.079 (0.034)	0.100 (0.033)	0.058 (0.031)	0	0	0
Density (shoots/500 cm ²)	-	-	-	-	-	-	-	61.6 (5.7)	9.6 (4.4)	7.2 (2.0)	2.4 (1.0)	0	0	0
<i>Benthic Invertebrates</i>														
Total Density (# /100 cm ²)	-	-	-	-	-	-	-	441.6 (136.4)	297.5 (62.8)	258.3 (59.4)	768.3 (192.1)	234.9 (70.9)	65.8 (56.8)	-
Taxa Richness	-	-	-	-	-	-	-	11.7 (0.9)	8.7 (0.9)	6.7 (1.3)	7.9 (0.9)	5.4 (0.6)	2.3 (0.7)	-
Shannon-Wiener Diversity	-	-	-	-	-	-	-	1.81 (0.18)	1.50 (0.10)	0.99 (0.15)	1.08 (0.16)	0.98 (0.12)	0.45 (0.30)	-

Table 5. Mean densities (and standard errors) of plant species occurring at $\geq 20\%$ frequency in at least one habitat per year. For intertidal habitats, 14 species exhibited density differences between adjacent habitats in 2004, and 10 of these same species differed in 2005 (differences shown in bold). Dashes indicates that a species occurred at $< 20\%$ frequency that year.

Species	2004							2005						
	EG	UT	VT	LE	HE	DW	DU	EG	UT	VT	LE	HE	DW	DU
<i>Agropyron repens</i>	0	0	0	0	0.7 (0.3)	2.6 (2.6)	75.2 (35.0)	0	0	0	0	1.0 (0.6)	0	56.8 (15.8)
<i>Agrostis</i> spp.	0	0	0	0.3 (0.3)	167.5 (27.2)	53.8 (38.4)	561.8 (109.9)	0	0	0	7.3 (6.1)	231.4 (51.5)	5.6 (5.6)	261.6 (95.6)
<i>Aster subspicatus</i>	0	0	0	0	2.6 (1.1)	0	0	-	-	-	-	-	-	-
<i>Atriplex patula</i>	0	0	0	0.02 (0.02)	0.8 (0.5)	1.4 (1.3)	1.1 (0.9)	0	0	0	0	0.2 (0.2)	0.6 (0.4)	15.6 (8.2)
<i>Carex lyngbyei</i>	0	0	0	5.9 (3.1)	32.8 (5.0)	0	0	0	0	0	1.5 (1.0)	25.1 (6.0)	0	0
<i>Cirsium arvense</i>	0	0	0	0	0.02 (0.02)	0	1.9 (1.3)	-	-	-	-	-	-	-
<i>Cotula coronopifolia</i>	-	-	-	-	-	-	-	0	0	0	1.8 (1.7)	0.9 (0.7)	10.5 (10.0)	0
<i>Deschampsia cespitosa</i>	0	0	0	0	14.0 (5.1)	0	0	-	-	-	-	-	-	-
<i>Distichlis spicata</i>	0	0	0	5.2 (4.1)	6.0 (2.2)	11.1 (10.5)	0	0	0	0	3.3 (2.0)	2.4 (2.3)	0	0
<i>Eleocharis acicularis</i>	0	0	0.1 (0.1)	139.8 (36.4)	18.8 (12.4)	0	0	0	0	66.7 (48.8)	243.5 (77.1)	2.3 (1.3)	0	0
<i>Eleocharis palustris</i>	0	0	0	0.6 (0.4)	22.7 (10.1)	0	0	0	0	0	16.2 (11.4)	0	0	0
<i>Juncus balticus</i>	0	0	0	0	62.6 (14.3)	5.5 (5.5)	1.3 (1.3)	0	0	0	0	73.2 (24.7)	0	0
<i>Lilaeopsis occidentalis</i>	0	0	0	0.1 (0.1)	10.8 (3.4)	0	0	0	0	0	0.7 (0.7)	8.8 (5.7)	0	0

Species	2004							2005						
	EG	UT	VT	LE	HE	DW	DU	EG	UT	VT	LE	HE	DW	DU
<i>Potentilla pacifica</i>	0	0	0	0.2 (0.2)	6.4 (2.3)	0	4.0 (3.0)	0	0	0	2.2 (2.2)	5.9 (2.4)	0.8 (0.8)	0
<i>Salicornia virginica</i>	-	-	-	-	-	-	-	0	0	0	0	3.1 (3.1)	5.3 (5.3)	0.2 (0.2)
<i>Scirpus americanus</i>	0	0	12.9 (3.6)	63.0 (11.0)	23.1 (6.2)	0	0	0	0	6.2 (3.4)	76.6 (185)	14.4 (5.8)	0	0
<i>Scirpus maritimus</i>	0	0	0	16.9 (3.2)	1.0 (0.4)	3.6 (2.1)	0	0	0	0.9 (0.6)	13.4 (5.2)	0.4 (0.4)	8.7 (5.8)	0
<i>Sonchus</i> spp.	-	-	-	-	-	-	-	0	0	0	0	0	0	0.2 (0.2)
<i>Spergularia canadensis</i>	0	0	0.3 (0.2)	3.8 (1.9)	0.06 (0.06)	0	0	0	0	1.6 (0.9)	7.6 (3.4)	0.1 (0.1)	1.8 (1.7)	0
<i>Triglochin maritimum</i>	0	0	0	2.6 (1.1)	12.4 (2.8)	0	0	0	0	0	0.4 (0.4)	16.7 (5.2)	0	0
<i>Typha latifolia</i>	0	0	0	0	0.6 (0.3)	0	0	-	-	-	-	-	-	-
<i>Zostera japonica</i>	197.0 (23.9)	14.7 (4.6)	4.9 (2.7)	0.7 (0.4)	0	0	0	250.0 (21.6)	13.4 (7.0)	0.05 (0.05)	4.8 (3.8)	0	0	0

Table 6. Mean densities (and standard errors) for invertebrate classes that occurred in more than one sample in at least one habitat in 2005. For intertidal habitats, five classes demonstrated density differences between adjacent habitats (differences shown in bold). Only three taxa were collected in DW: the flies Chironomidae and Corixidae, and the ostracod Cyprididae.

<i>Taxa</i>	<i>EG</i>	<i>UT</i>	<i>VT</i>	<i>LE</i>	<i>HE</i>	<i>DW</i>
Oligochaeta	32.0 (12.2)	26.3 (13.4)	17.0 (6.3)	87.2 (24.6)	84.8 (21.6)	0
Polychaeta	292.6 (120.6)	186.1 (61.2)	216.7 (59.7)	539.4 (136.8)	86.9 (47.1)	0
Nematoda	5.2 (4.0)	19.6 (11.5)	8.9 (3.3)	77.9 (49.8)	37.5 (20.6)	0
Bivalvia	22.5 (3.1)	8.9 (2.6)	1.7 (0.9)	0.6 (0.4)	0	0
Gastropoda	8.7 (5.3)	8.7 (4.8)	5.5 (3.8)	3.2 (1.7)	0.6 (0.4)	0
Copepoda	1.7 (0.9)	38.7 (25.6)	4.3 (1.6)	21.4 (15.9)	0.6 (0.6)	0
Malacostraca	73.6 (40.3)	6.9 (4.1)	0.9 (0.4)	28.9 (20.0)	1.7 (1.7)	0
Ostracoda	0	0.3 (0.3)	0	2.3 (1.3)	1.4 (1.0)	57.1 (53.3)
Entognatha	1.7 (1.7)	0	0.3 (0.3)	2.6 (2.6)	10.4 (10.1)	0
Insecta	0	0.9 (0.6)	2.6 (2.6)	2.0 (0.9)	10.4 (4.7)	8.7 (3.8)