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Biological Monitoring at Duwamish River Coastal America Restoration and Reference Sites: A Seven-Year Retrospective

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Key Words

Duwamish River, wetland restoration, reference sites, benthic invertebrates, avifauna, insects, emergent vegetation**.**

Biological Monitoring at Duwamish River Coastal America Restoration and Reference Sites: A Seven-Year Retrospective

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Introduction

In this report, we summarize and interpret the results of biological monitoring at four wetland restoration sites in the Duwamish River estuary, Seattle, Washington. Biological monitoring at the sites was conducted from 1993 through 1999. Restoration at three of these sites was originally funded by the federal Coastal America program and was carried out by a partnership of the Port of Seattle, U.S. Fish and Wildlife Service (USFWS), U.S. Army Corps of Engineers (USACE), and U.S. Environmental Protection Agency (USEPA). A number of ecological goals aimed at enhancing habitat for wetland plants, juvenile salmon, shorebirds, and other wildlife were identified by the project partner agencies before construction at the sites (C. Tanner, USFWS, Olympia, Washington, pers. comm.). These goals included:

1. Increase acreage of fine unconsolidated (mud/sand) flat habitat and associated functional attributes.
2. Increase acreage of brackish- and salt-marsh habitat and associated functional attributes.
3. Increase riparian habitat in terms of physical structure and biological productivity.
4. Increase length and complexity of shoreline along the +6’ to +14’ contours (relative to mean-lower-low-water).
5. Restore intertidal habitat in the form of a slough channel.

Several technical demonstration objectives were identified that embodied construction methods and specifications for the projects (C. Tanner, USFWS, pers. comm.). These methods included the following:

1. Removing fill material and regrading sites to increase intertidal flat, vegetated marsh, and channel habitats, and to increase connectivity with other habitats.
2. Using modified log booms to enhance vegetated shoreline buffers to prevent accumulation of floating debris and deflect boat wake.
3. Using modified riprap bank tops to facilitate development of robust riparian buffers.
4. Removing shading structures and debris (e.g., derelict vessels).

Two of the restoration sites are in the middle portion of the Duwamish Waterway in a region dominated by tidal influence and mixed marine and freshwater (Fig. 1). The first of these sites consists of the General Services Administration (GSA) site located adjacent to the Federal Center South, which is a long, narrow intertidal strip running parallel to the east bank of the Duwamish Waterway bordering the Seattle District Corps of Engineers (Figs. 2–4). Restoration at this site included removing rock riprap and a large over-water wharf structure to allow natural colonization by existing wetland plants, placing a log boom to decrease debris deposition and boat wake damage, constructing a sediment “bench” at 0.6-m elevation to promote use by juvenile salmon, and planting upland riparian vegetation. The second site is at Terminal 105 (T-105); this site originally consisted of a vacated street end and a large pipe that provided drainage for a small degraded wetland area and storm-water from adjacent streets. Restoration included removing debris and replacing the pipe with an estuarine channel that restored tidal flow to the area (Figs. 5–7). The third restoration site is at the upper Turning Basin at the head of the Duwamish Waterway (Fig. 1). This site comprises two restored areas: the first (Phase I), constructed in 1994 with funding from the Coastal America program, consists of an upland riparian buffer planted with native vegetation and a small regraded upper intertidal basin planted with fringing native sedge, *Carex lyngbyei*, and rush, *Scirpus maritima*. The second (Phase II), constructed by the Port of Seattle in 1999, is a similar but larger basin with associated riparian and emergent vegetation plantings. (Figs. 8–10). In 1998, a large derelict ferry boat hull was removed from the intertidal directly adjacent to the south side of the Phase I site.

Initial baseline and pilot studies of benthic invertebrates, insects, emergent vegetation, and sediment grain size took place in 1993, prior to restoration (Cordell et al. 1994). During these baseline studies, appropriate reference sites in the vicinity of the restoration sites were also chosen and sampled. In late 1993 and early 1994, construction and planting of native vegetation at the restoration sites took place. Information gained from the initial pilot studies was used to conduct post-restoration sampling in May 1995 and in April, May, and June 1996 and 1997 at the restoration and reference sites (Cordell et al. 1996, 1997, 1999a) (Table 1). The purpose of this study was to complete a final post-restoration sampling of the restoration and reference sites, conduct an initial post-restoration sampling at a new site, and compare the data with previous results. The overall goal of this study is to interpret and use the results to point toward successful strategies for monitoring wetland restoration sites.

Because of variations in year-to-year funding amount, level of effort varied among sampling years. For example, in 1995 we sampled only in the month of May (Table 1). Also, as the project progressed, we made some adjustments to the sampling protocol, such as adding higher intertidal strata that were on the physical restored substrate itself (Table 1).

Sampling was conducted in order to quantify the following ecologically important attributes at the restored and reference sites:

1. Benthic meio- and macroinvertebrates associated with mud and sand flats, especially those that are particularly abundant or are important prey resources for juvenile salmon.
2. Input of terrestrial and plant-associated insects into aquatic habitats.
3. Sediment grain size.
4. Diets of juvenile salmon captured within or near restoration sites.
5. Avifauna presence and behavior.
6. Transplanted and naturally occurring vegetation.

Methods

BENTHIC INVERTEBRATES

Table 2 summarizes sites sampled for benthic macro- and meiofauna. In 1993 (pre-restoration) and 1995, benthic sampling was conducted at or near the 0.0-m elevation on reference mud flats and relatively fine sediments associated with restoration sites. The reference sites included 0.0-m elevation mud flats at the Turning Basin and near the northeast tip of Kellogg Island (Fig. 1). In 1996, sampling was concentrated on upper intertidal vegetated habitats, but pilot sampling was also conducted at (1) the sand along the center of the constructed channel at the T-105 site, (2) the "delta" or widened area at the terminus of the constructed channel at that site (Fig. 5), and (3) at the small sand flat encompassed by transplanted *Carex* and *Scirpus* at the Turning Basin Phase I site (Fig. 8). In 1997, we conducted benthic sampling at these same sand flats plus at two constructed sediment benches—one not affiliated with the Coastal America projects and one at the GSA site (Fig. 5)—and at the reference mud flat sites that were sampled in 1993 and 1995. In 1999 both bare sediment and vegetated habitats were sampled at all of the sites, plus at the Turning Basin Phase II site (Fig. 8).

At each site, we took 10 samples located haphazardly. As in previous samplings, we used a PVC core that sampled an area of 0.0024 m^2 as recommended by Cordell et al. (1994). Cores were taken to a depth of 10 cm and were fixed in the field in a 5% buffered formaldehyde solution.

After ~1 wk of fixation in the formaldehyde solution, benthic core samples were washed through two sieve sizes: macrofauna were retained on a 0.5-mm sieve and meiofauna on a 0.153-mm sieve. Samples were then transferred to 50% isopropanol. For 1999 samples, meiofauna were sampled separately with 0.0002-m^2 core sampler to obviate fractionating the larger core samples. If subsampling was necessary, samples were split to manageable fractions. Macrofauna samples were split in a Folsom plankton splitter until at least 100 organisms were obtained. Meiofauna samples were subsampled as for the macrofauna using a Hensen's Stemple pipette. Taxa occurring as attributes in the Estuarine Habitat Assessment Protocol (EHAP) (Simenstad et al. 1991) were identified to species level or to the level identified in the EHAP. Taxa not listed as attributes in the EHAP were not identified to species unless they were particularly abundant or had been identified or hypothesized as being prey for fishes or birds.

SEDIMENT GRAIN SIZE

Grain-size sediment samples were collected haphazardly at 10 locations within each benthic sampling stratum using a 0.0024-m^2 core taken to a depth of 10 cm. Samples were placed in plastic bags, iced, and frozen upon return to the laboratory. Cores were processed in the laboratory according to the methods of Folk (1968). They were washed in freshwater to solubilize salts and then oven dried at 60°C. Sediment samples were then mechanically shaken through nested #10, #18, #35, #60, #120, and #230 sieves. The residual fines were added to the original liquid fraction and analyzed by pipet analysis.

INSECTS

In pre-restoration sampling conducted in 1993, insects were sampled using sweep nets (Cordell et al. 1994). Following recommendations from that study, insect fallout traps were used in subsequent samplings. These floating traps consist of 55-cm x 38-cm plastic storage bins that rise and fall with the tide and are kept in place by vertical PVC pipes. They are designed to catch insects that fall from the air or from riparian vegetation and, as such, measure direct input of insects to the aquatic system. The traps were filled to about 4 cm depth with propylene glycol-based antifreeze which acted as a preservative. In 1999 we switched to using water with a small amount of dish soap as a non-toxic alternative. The traps were placed haphazardly in the vegetation at each site and left for 3 consecutive days. Five traps were placed at each site. Occasionally traps capsized or were inundated with water, in which case the sample was discarded. At the end of the sampling period, the liquid in each trap was drained through a 0.153-mm sieve and the insects were removed and placed in sample jars with 50% isopropyl alcohol. Insects were identified as for benthic invertebrates.

Insect fallout traps were deployed in 1995, 1996, 1997, and 1999 at the two reference vegetation patches and three restoration sites (Figs. 1, 2, 5, 8). These sites included *C. lyngbei* in the vicinity of the Turning Basin and the small *Scirpus* patch across the channel from the northeast tip of Kellogg Island. The three restoration sites were (1) the *Carex* transplanted area at the Turning Basin Phase I site, (2) the small naturally recruiting patch of *Scirpus* at the GSA site, and (3) along the margins of the constructed channel at the T-105 site. In 1999 we also sampled insects at the Turning Basin Phase II site in areas of newly planted vegetation (Fig. 8).

JUVENILE SALMON DIETS

In 1996, juvenile salmon for stomach analyses were collected by the Muckleshoot Tribal Fisheries on 1 and 17 April and 6 June. From these collections we analyzed fish from three areas: (1) the upper Duwamish waterway near the Turning Basin (sites designated by the Muckleshoot Tribal Fisheries as “Smelt Beach” and “Turning Basin”; E.J. Warner and R.L. Fritz, Muckleshoot Indian Tribe Fisheries Dept., Seattle, Washington, unpubl. rep.); (2) the middle waterway (designated as “Oil Slick” and “Chief Seattle”); and (3) the waterway near Kellogg Island, GSA, and T-105 reference and restoration sites (designated “West Kellogg Island” and “East Kellogg Island”). In 1997 and 1999 juvenile salmon for stomach analyses were collected in the middle of April, May, and June at three sites: (1) the upper Duwamish waterway near the Turning Basin, (2) the waterway near Kellogg Island, and (3) at the T-105 created channel (Fig. 1). Samples were taken with a 37-m floating beach seine. The net consisted of two 18-m panels made of 3-cm mesh with a 2-m x 2.4-m x 2.3-m bag made of 6-mm mesh. At the first two sites, the net was deployed from an outboard motor boat parallel to shore and was pulled in by two 2-person teams. At the T-105 site, fish were captured by blocking the entrance of the created channel on a falling tide with the seine, thus capturing all fish that had been in the site. Captured fish were anesthetized in a plastic bucket in which water with a small amount of MS-222 (tricaine) had been added. All fish were then identified to species and counted. Salmonids were measured (fork length) and a subsample of 10 salmon from each 10-mm size class was preserved immediately in a 10% formaldehyde solution. All other fishes were placed in freshwater until they recovered and then were released.

In the laboratory, individual fish were measured (fork-length) and weighed to the nearest 0.01 g. Stomachs were removed and opened, and the contents were weighed in their entirety. The contents were examined under a dissecting microscope and separated into individual taxa. Prey were identified to species level for crustaceans and to the level designated in the EHAP for other taxa. Each prey taxon was enumerated and weighed to the nearest 0.0001 g. All data were entered on standard NODC (National Oceanographic Data Center) forms and analyzed using the University of Washington Fisheries Research Institute’s GUTBUGS program. This program provides summary data for each group of fish analyzed, and for this study prey weight data were taken from this summary for further graphical analysis.

AVIFAUNA

Observations were continually made from June 1995 through September 1997 and from March 1999 through September 2000 at the following four sites on the east side of the Duwamish River:

1. T-105, the most northerly of the restored sites (Fig. 1): This site has a public park and a launch for hand-carried boats. Because it is located next to a gravel plant served by barges, across from a marina for recreational boats, and is the site closest to the river’s mouth and Elliot Bay, T-105 sees regular motorized boat traffic. The area observed was approximately 84 m of shoreline with the created channel extending inland about 240 m to the east. Counts were made of birds in the intertidal area of the shoreline and of the channel.
2. Kellogg Island, a reference site 1 km upriver from the T-105 site (Fig. 1): This is the largest of the sites. Observations were made along 430 m of shoreline on the east side of the island and 360 m on the shore to the west of the island. The passage between the bank and the island receives very little boat traffic and does not have active industrial or recreational activities.

3. The Turning Basin reference site, approximately 6 km upstream from Kellogg Island (Fig. 1): This area is bounded by a foot bridge to the south and a channel formerly containing the partially burned wreck of a ferry boat to the north.
4. The Turning Basin restored area, bounded by this channel to the south and the river shore to the north of the site: It consists of a planted riparian upland, and a high intertidal created beach with plantings of native marsh vegetation.

Using 10- x 40-mm binoculars, we took scan samples in half-hour periods during daylight hours from 0700 to 1900 PST. This process involved observing the site for a fixed period of time and recording all birds using the site by species, abundance, and behavior. Scan sampling was chosen because birds tended to display one primary behavior when at a site, making focal animal sampling (recording the behaviors of a single animal over a period of time) unnecessary. Observation times were concentrated primarily in early morning and late afternoon hours and, when possible, during low tide events. The number of visits to each site varied by season to concentrate observer effort during periods of increased migratory activity. Effort also varied with the availability of qualified undergraduate volunteers from the University of Washington.

At each observing period, an initial survey of species present, the number of each species, and the behavior of individuals was made. As new individuals arrived, their presence was recorded and classified by behavior. Behaviors were classified as foraging, resting, transit, breeding, and other. In summer 1995, birds in flight were not counted unless they landed and made contact with the intertidal area, but these individuals were recorded for all subsequent observations. Birds on the water were included when they were within a rectangle bounded by the extent of the site shorelines and the midline of the river. Tides, wind speed, direction, and general weather conditions were also recorded. Notes were made of obvious disturbances such as boat traffic that caused birds to move or change behaviors.

Most data were collected from a location on the bank of the river or upper part of the intertidal area where birds could be seen with the least disturbance to them. To minimize the impact of observer presence on the bird count, observers approached the site ready to note all the birds at the site immediately, then remained in the upland area for the first 15 min of observation. If the tide was so low that the water line was not visible, observers moved toward the water's edge to spot any birds otherwise out of sight, then returned to the upland location. All species that landed on the intertidal region were recorded, as well as those on pilings and posts set in the region. The tally of birds present was sorted by species and primary behavior (e.g., for mallard ducks: "MALL resting: 5, foraging: 4, transit: 2, other: 0").

Data were sorted by species, abundance, and behavior. Abundance was graphed as the mean number of birds present across all observation periods within each season (i.e., summer 1995, fall 1996) for each site. In addition to calculating the total numbers of birds present, we compared the abundance without 14 species that were considered either introduced or native/human-associated. Introduced species were defined as known exotics, and native/human-associated species were defined as resident birds whose populations have grown as a consequence of their interaction with humans (e.g., barn swallows nest only in man-made structures, glaucous-winged gulls forage in garbage dumps). Richness, or the mean number of species present across all observations, was also calculated by site and season. Richness was calculated with the full data set, as well as without the introduced and human-associated species. Behavioral observations are presented as a percentage of all sightings, within site, to compare relative use patterns, regardless of species.

Because the success of restoration depends not only on values such as abundance and richness, but also on the particular type of species observed, data were further subdivided into three conservation categories: indigenous/native species, defined as resident birds of western Washington; non-native species, defined as known exotics; and native/human-associated species (defined above). Then pair-wise comparisons of the percentage of overlap for the three species categories at the four monitoring sites were done for each year of data. For T-105 and the Turning Basin restoration site, data were also plotted as percent occurrence of all species observed across the two sites as a function of the total number of half-hour observation periods within an observation season. Species were either grouped by guild: passerines, raptors, shorebirds, waterfowl, and seabirds or as introduced or native/human-associated.

EMERGENT VEGETATION

Field Methods

At *C. lyngbyei* sites 1, 2, and 3, and at the *S. validus* reference site (across from Kellogg Island) and GSA site, a tape measure was run parallel to shore through the center of the patch. The length of the patch and locations of any breaks in vegetation were measured. Approximately ten .25- x .25-m quadrats were placed at random distances along the tape. In each quadrat, the number of *Carex* and *Scirpus* shoots were counted, the height of the tallest shoot of each species was measured, and any other species present in the quadrat were noted.

In 1999, several large goose excluders were placed at the GSA site by People for Puget Sound. Twenty-five samples were taken inside the fenced area. This area was designated GSA2.

At the Turning Basin Phase I site, 13 quadrats were distributed through areas of the site that were protected by goose excluder devices. Shoots of *C. lyngbyei*, *S. validus*, *S. maritimus*, *and S. americanus* were counted, the tallest shoot of each species was measured, and any other species present in the quadrat were noted. The configuration of the goose excluder devices at the site changed considerably over the course of the study, so comparisons with data across time should be made with care.

The Turning Basin Phase II site contains two benches with vegetation. The upstream bench was divided into three areas and the downstream area was divided into four areas by goose exclosures. Four to six quadrats were sampled in each area using the same methods used at the Turning Basin site Phase I site.

At the T-105 site, species present in quadrats placed every 20 paces from the head of the slough to the slough mouth were recorded. In previous years, the distances from the head of the slough to new patches of recruiting species along the downstream side of the channel were recorded, but in 1999 patches were continuous enough that this was not possible after the first 14 m from the head of the channel.

Statistical Methods

Summary statistics, including sample size, mean, standard deviation, and coefficient of variation (CV = standard deviation/mean) for shoot density and shoot height were computed for each site and year. The frequency of understory species and changes in species composition were also recorded and calculated.

The intent of the final year of data analysis was to characterize the spatial and temporal variance in the variables measured from 1995 to 1999 rather than to conduct statistical hypothesis tests of differences among sites and years. Planned and unplanned changes have taken place at most of the sites that were sampled as part of this monitoring program. In particular, goose excluder devices have been added or removed or both, areas have been planted, and new sites have been constructed nearby. Although statistical comparisons among sites have been used in past reports as a way of assessing whether sample sizes were large enough to detect useful differences among sites and times, analyses of 1999 data were focused on describing the ranges of variables that were measured.

Analyses were focused on shoot density and maximum shoot height of *Carex* and *Scirpus* species found at the sites. Variance in these measures was created by several, multiple-scale factors. For example, factors that contributed to within-site, within-year variance in shoot density of *Carex* included within-patch variability in the distribution of *Carex* shoots and "measurement error."

Within-patch spatial variability was created by natural variability in physical and biotic factors such as grain size, pore-water salinity, physical disturbance, genetics, competition, and grazing. Measurement error included differences within and between samplers in their ability to detect new shoots and their criteria for distinguishing old senesced shoots from nearly senesced shoots of the current year.

Within-patch temporal variability in means was caused by differences across years in the condition of *Carex* as it was affected by differences in annual weather variables, grazing, and differences between the absolute time of sampling relative to the time of the growing season. Annual variability in the conditions of *Carex* affected the number of new shoots, the degree of trampling and grazing, the degree of senescence of the current year, and the degree to which shoots from previous years have disappeared. These factors, in turn, affected (and interacted with) within- and between-observer differences.

Between-patch within-year variance in mean shoot density was affected by cross-site differences in mean salinity, sediment grain size, disturbance, and grazing pressure. Between-patch, across-year variance was affected by all the factors that affected cross-site and cross-time variance. Measurement error likely was also affected by changes in scale, but we have not collected any data to quantify changes in the contribution of measurement to total variance at different scales.

Mean shoot density and maximum shoot height of *C. lyngbyei* and *S. validus* were plotted by site and for all sampled sites at which *Carex* and *Scirpus* were present in any year. CVs of samples within sites and years were compared with CVs of site means across years. Means and CVs of new sites were compared qualitatively with means and CVs of the original five *Carex* and *Scirpus* sites.

Variance component analysis was used to compute the percent of the total (across-year and across-site) variance in each variable that was explained by across-site, across-year, site-by-year, and within-site variance. In a variance component analysis, the theoretical variance formula[1] for

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[1] The expected mean square.

each factor in an Analysis of Variance (ANOVA) is computed so that the portion of the factor's variance that is contributed by that factor can be isolated from the contributions from other factors. A full description of this methodology can be found in standard statistics texts such as Zar (1999). The results of the variance component analysis is discussed in terms of the insights they provide about expectations for potential future restoration sites.

Results

SEDIMENT GRAIN SIZE

Sediments associated with created flats at the Turning Basin (both Phase I and II), the T-105 created channel, and the GSA sediment bench were characterized as having larger grain sizes than those at the reference mud flats (Fig. 11). In vegetated habitats, restored sites at the Turning Basin had coarser sediments than those at the Turning Basin reference site (Fig. 12). However, in the lower waterway the vegetated habitats at the GSA and T-105 sites were similar to those at the Kellogg Island reference site.

BENTHIC MACROFAUNA

1999 Taxa Richness

In benthic samples from vegetated habitats, numbers of invertebrate taxa ranged from 5 to 18 taxa (Fig.13, top panel). For each sampling date, the numbers of taxa were similar among the sites, except at the Turning Basin Phase II planted area, which always had the lowest number of taxa. At mud and sand flats, numbers of invertebrate taxa ranged from 8 to 24 taxa (Fig.13, bottom panel). Similar to the vegetated sites, the number of taxa was always lowest at the Turning Basin Phase II mud flat but was otherwise similar among sites on a given date.

1999 Assemblage Compositions

Mud and Sand Flats. The composition of benthic macrofauna at the restored sites in the lower Duwamish waterway (T-105 and GSA) differed from the Kellogg Island reference site mainly in the relatively high abundance of the spionid polychaete worm *Pygospio elegans*, which was rare at Kellogg Island (Fig. 14). The upper channel portion of the T-105 site was also unique among these sites in having relatively high proportions of the polychaete *Manayunkia aesturina.* Other abundant taxa included oligochaete worms (all lower waterway sites, all dates) and the crustacean amphipods *Corophium* spa. (GSA Bench and T-105 Channel in May and June).

At the upper Duwamish waterway (Turning Basin) sites, the 0.0-m reference and restoration mudflat sites were characterized in having invertebrates distributed fairly evenly among a variety of taxa, with the exception of March when *M. aesturina* dominated at the restoration site (Fig.14). In contrast, the higher intertidal sand flat at the Turning Basin Phase I site was always dominated by oligochaete worms and *M. aesturina*. For the amphipods *Corophium* spp., proportional composition was highest at the 0.0-m reference flat. The newly constructed mud flat at the Turning Basin Phase II site was characterized by large changes in assemblage composition from March to June. In March, taxa were distributed among a variety of taxa. However, oligochaete worms, which first appeared in April, became successively more prominent and almost completely dominated the taxa composition at this site in June.

Vegetated Habitats. In the lower waterway vegetated sites, *M. aesturina* and oligochaete worms dominated the benthic invertebrate assemblages (Fig.15). Oligochaetes were particularly prominent at the T-105 slope habitat, where *M. aesturina* was rare. Ceratopogonid fly larvae were prominent at the Kellogg Island reference and GSA restoration *Scirpus* patches in March but were relatively scarce April–June.

At the Turning Basin sites in the upper waterway, ceratopogonid larvae were relatively high in taxa composition at the reference and planted *Carex* habitats in March and April but were much lower in proportion in May and June (Fig.15). The newly transplanted vegetation at the 1999 restored site was unique in having high proportions of chironomid fly larvae that first appeared in April.

Densities[2]

Mud and Sand Flats. Among lower waterway sites, total benthic macrofaunal invertebrates combined showed a trend of increasing densities with time at restoration sites and decreasing densities with time at the Kellogg Island reference site (Fig.16, lower panel). As a result of these contrasting trends, total densities at the restored sites were less than those at the reference site until 1999 when densities at restored sites equaled or exceeded those at the reference site. The trend of increasing density with time was particularly marked for *M. aesturina* at the T-105 channel site, where 1999 densities were far greater than in previous years (Fig.16, middle panel). Large increases in 1999 densities also occurred for chironomid fly larvae and

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[2] We present data here for total invertebrates and for those mentioned in the EHAP as important prey resources for juvenile salmon or other wildlife.

Corophium spp. at the GSA bench (Fig.16, upper panel, Fig. 17, upper panel). For two other crustaceans, the gammarid amphipod, *Eogammarus confervicolus,* and the cumacean, *Cumella vulgaris*, similar trends did not occur (Fig. 17, bottom and middle panels). However, for both of these taxa, densities were similar to or greater than those at the Kellogg Island reference site.

At upper waterway Turning Basin sites, total benthic invertebrates showed an increasing trend across time at the upper sand flat at the Turning Basin Phase I restored area (Fig.18, bottom panel). This trend apparently was largely due to increases in *M. aesturina* at this site between 1997 and 1999 (Fig.18, middle panel). For this taxon and for chironomid larvae and *Cumella vulgaris* (Fig. 18, upper panel, Fig.19, bottom panel), the upper sand flat had consistently higher densities than occurred at the 0.0-m restoration and reference mud flats. In contrast, two gammarid amphipods, *Corophium* spp. and *Eogammarus confervicolus*, did not occur at all at the upper sand flat (Fig.19, middle, top panels). For these two taxa, densities were consistently higher at the reference mud flat than they were at the mud flat near the restored area. The mud flat that had been constructed in 1999 had very low densities of all taxa.

Vegetated Habitats. At lower waterway sites, total benthic macrofaunal invertebrates combined were similar between the two sampling years (Fig. 20, lower panel). The only exception was in March 1999 when total density at the Kellogg Island reference *Scirpus* patch was much higher than at any other site/time. Total density increased between 1996 and 1999 at the T-105 site, and this site had consistently higher densities than other lower waterway sites in 1999 (except for March 1999, see above). *M. aesturina* occurred only in low numbers at the T-105 vegetated site, but densities of this species at the GSA restoration *Scirpus* site were similar to those from the Kellogg Island reference *Scirpus* in both 1997 and 1999 (Fig. 20, middle). On the other hand, collembolans were relatively dense at the T-105 site but relatively rare at the other two lower waterway sites (Fig. 20, top). For chironomid fly larvae, densities at the lower waterway restoration sites were usually less than those at the Kellogg Island reference *Scirpus* site (Fig. 21, top). However, for two other dipteran taxa, dolichopodids and ceratopogonids, densities at the restoration sites equaled or exceeded those at the reference site (Fig. 21, middle and bottom).

At upper waterway Turning Basin sites, densities of total benthic invertebrates at the Phase I restored *Carex* site were higher than at the reference site in both 1997 and 1999, with the exception of May 1999 (Fig. 22, bottom). *M. aesturina* was absent from the restoration *Carex* site in 1996 but in 1999 they were much more abundant there than at the reference *Carex* site (Fig. 22, middle). Collembola were mostly absent from the restoration sites in the upper waterway (Fig. 22, top). For three species of dipteran larvae, the Turning Basin Phase I restored *Carex* site had similar or higher densities as compared with the reference site in both 1997 and 1999 (Fig. 23). Densities of all taxa were usually very low at the newly constructed Turning Basin Phase II site. However, in May and June 1999, several taxa of dipteran larvae had clearly been recruited to the planted habitats at this site (Fig. 23).

BENTHIC MEIOFAUNA

1999 Taxa Richness

Numbers of meiofauna taxa from 1999 benthic samples ranged from 5 to 30 taxa per site/date (Fig. 24). Highest taxa richness occurred at the GSA intertidal bench and at the T-105 “delta.” Lowest numbers of taxa were found at the Turning Basin Phase I upper intertidal sand flat site. Low taxa richness was also found in March and April at the newly constructed mudflat site at the Turning Basin Phase II site, but in May and June, numbers of taxa at this site were similar to those from the 0.0-m elevation Turning Basin mud flat sites.

1999 Assemblage Compositions

Harpacticoid copepods and nematode worms usually dominated the meiofauna, constituting between 40 and 90% of the numerical composition (Fig. 25). Foraminifera were also numerically important at the T-105 channel and delta sites, especially in June. The newly created mud flat at the Turning Basin Phase II site was unique in having relatively high proportions of rotifers. Harpacticoid copepods were prominent at the Kellogg Island reference mud flat, where they dominated in April and May. They were also dominant on all sampling dates at the Turning Basin sites, except for the high intertidal sand flat, where nematodes dominated. The most common juvenile fish prey harpacticoid, *Leimia vaga*, had high relative abundance at the Kellogg Island reference flat in April and May, at the Turning Basin Phase II flat in May and June, and at the 0.0-m elevation Turning Basin reference and Phase I restoration flats in May and June. Several other taxa of harpacticoids that have been noted in juvenile fish diets from the Duwamish Waterway were relatively abundant at some of the sites. These included *Huntemannia jadensis* at the T-105 site and *Pseudobradya* sp. at the Turning Basin sites (except for the Phase II mud flat site).

Densities[3]

Density of all meiofauna taxa combined was higher in 1999 than in previous sampling years (Fig. 26, bottom panel). The highest density of meiofauna occurred at the new Phase II Turning Basin site in April 1999. This site and date also had the highest abundances of harpacticoid copepod nauplii and the prominent harpacticoid taxa *Leimia vaga* and *Pseudobradya* sp. (Figs. 27, 28). Several species of harpacticoids were associated either with one site or with one area of the waterway. These included (1) *Huntemannia jadensis* at the T-105 site, (2) *Coullana canadensis* at the Turning Basin Phase I restoration mud flat, (3) *Leimia vaga* and *Pseudobradya* sp. at one or more of the Turning Basin sites, and (4) *Microarthridion littorale* at the Kellogg Island reference mud flat (Figs. 27, 28). *Harpacticus* spp. were associated almost exclusively with created sediment bench habitats in the lower waterway (Fig. 28, top panel).

INSECTS

1999 Assemblage Compositions

In March and April, fallout invertebrates were dominated by chironomid flies at most of the sites (Fig. 29). In May, insects were distributed into relatively many taxa. June samples were dominated by either chironomids or aphids. Other prominent taxa included (1) dolichopodid flies, which were particularly relatively abundant in May at the Turning Basin reference *Carex* site, (2) collembolans (springtails), (3) and amphipods (beach hoppers, family Talitridae) that occurred exclusively at the *Scirpus* sites at Kellogg Island and the north end of the GSA site.

Densities

At each site sampled in 1999, number of insect taxa captured in fallout traps increased between the March and June sampling dates (Fig. 30). For all years sampled, in the lower Duwamish waterway highest densities of four taxa of dipteran flies were almost always highest at the GSA restored *Scirpus* site (Fig. 31). There was no trend evident in these taxa across time at any of the sites. With only two exceptions, both the GSA and T-105 restoration sites had comparable or greater densities of dipterans than the Kellogg Island reference *Scirpus* patch. The established planted patch of *Scirpus* at the north end of the GSA site that was sampled only in 1999 also had lower densities of dipterans than the two other restored areas in the lower waterway. For total insects and several other taxa of fallout insects, densities at the restored sites were similar to those at the reference site (Fig. 32). Particularly high abundances were reached for aphids at the northern GSA *Scirpus* patch in June 1999 and for psyllids at the T-105 site in May 1997.

At the upper waterway Turning Basin sites, ceratopogonid flies were particularly dense in 1996 at the older restoration site, with a subsequent decrease in densities in 1997 and 1999 (Fig. 33). Densities of these and other dipterans at the restored sites were equal to or higher than those at the reference site. The 1999 constructed site had relatively high densities of ceratopogonid and chironomid flies, particularly in June (Fig. 34). This site also had high densities of fallout aphids and psyllids in June. Aphids and collembolans both appear to have increased in density between 1996 and 1999 at the restored *Carex* site at Turning Basin Phase I . Similarly to T-105 in the lower waterway, this site also had a large peak in psyllid density in May 1997. It had a large peak in juvenile homopotera in June 1997 (as reported Cordell et al. 1999a) that pushed total density to the highest seen at this site (Fig. 34).

JUVENILE SALMON DIETS

Fish Catches at T-105

Because the block seine completely occluded the T-105 channel, we were able to record total numbers of fish residing in the channel during each tide fished. Pacific staghorn sculpin, *Leptocottus armatus*, were the most abundant fish captured, followed in order by chum salmon, *Oncorhynchus keta*, shiner perch, *Cymatogaster aggregata*, and chinook salmon, *O. tshawytscha* (Table 3). Other fish species were relatively rare. The highest catch for any single species was for chum salmon on 19 April 1999, when 518 individuals were captured.

Chinook Salmon

In juvenile chinook salmon captured in 1996, prey was distributed into a variety of groups in April samples (Fig. 35). During this period prey were derived mainly from benthic (insect larvae, bivalve siphons, benthic crustaceans) and water column (fish larvae and other plankton) sources. In May, prey was less diverse and consisted mainly of benthic crustaceans. In all groups of chinook salmon analyzed from 1996, terrestrial insects were a minor source of prey. In contrast, diets of chinook caught in 1997 were often dominated by terrestrial insects (Fig. 36). Two exceptions were at the Turning Basin Phase I site in April

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[3] We present data here for total meiofauna and for harpacticoid copepod taxa that have been found to be important prey for juvenile salmon and other estuarine fish.

and May when benthic crustaceans dominated. Terrestrial insect prey consisted mainly of adult dipteran flies in April and June. In May, the dominant prey item was psyllids, especially at the T-105 site, where they constituted more than 75% of the prey weight in two size classes of juvenile chinook.

Chum Salmon

Juvenile chum salmon diets were characterized by relatively large differences in both within- and between-year diet composition and among sites on a given date. In 1996, two prey taxa occurred in juvenile chum salmon relatively consistently across both sites and dates. First, dipteran larvae made up >25% of the prey weight in fish from at least one lower waterway and one middle waterway site on each date (Fig. 37). Second, benthic crustaceans (amphipods and tanaids) were also present on each sample date in fish from both down waterway and middle or upper waterway sites. Two other groups, zooplankton and harpacticoid copepods, dominated the diet on several 1996 dates/sites. Chum salmon consumed few terrestrial insects in 1996. As with chinook, insects were much more prominent in the diets in 1997 (Fig. 38). Also similar to chinook, chum salmon from the T-105 channel in May had diets that consisted mainly of psyllids. Other important terrestrial insect prey items were adult dipteran flies and aphids. In 1997, benthic prey, mostly amphipods, were important only in April samples. In 1999, the diets of chum salmon were quite variable (Fig. 39). In March, May, and June, terrestrial insects were relatively important. On the two April sampling dates, benthic and planktonic taxa made up most of the prey.

AVIFAUNA

With the culmination of the 1999–2000 field season, 14 seasons and 42 months of data collection have been completed on the Duwamish waterway (Fig. 40). During the last five seasons of monitoring, 55 species were observed on the Duwamish Waterway (Table 4). Four were newly sighted species and the total number of species observed throughout the study was 80. Of those species, 20 are considered residents as they are seen at all times of the year (Table 4). Like previous years, the greatest number of species seen on the Duwamish occurred in spring (43 in spring 1999 and 39 in spring 2000) and the fewest species seen occurred in summer (28 in summer ’99). In fact, in 1999–2000, species diversity at all sites was lower than any previous year (Table 5).

Calculating richness without the 14 introduced and human-associated species (see Table 4) for the last five seasons lowers mean species richness by 41–60% (Fig. 37a-d). Mean richness at both Kellogg Island and Turning Basin restored sites still declined the least—41% and 47%, respectively—while T-105 and Turning Basin control sites show the greatest decline—58% and 60%, respectively. For the restored sites, Turning Basin had the highest and most stable proportion of native species, 58–61%. At T-105 the proportion of native species was not only lower but also more variable, ranging from 33 to 54%. The Kellogg Island, Turning Basin restored, and T-105 sites have shown relative stability in species richness over the years (Fig. 41a-c), while at the Turning Basin control site (Fig. 41d), a decline in richness has further contributed to the already low species diversity.

As in previous years, site-specific abundance varied tremendously by site (Fig. 42a-d). Mean abundance was still highest at Kellogg Island (106–119 birds/half-hour observation period), but mean annual abundance was much lower in 1999 and 2000 than in previous years (Table 5). Much like the decline in abundance observed at T-105 during and after construction of a rendering plant, increased disturbance and habitat alteration from shoreline restoration work west of Kellogg Island has at least temporarily reduced the number of birds that utilize that area. Mean abundance at T-105 and Turning Basin control has remained low and variable, 14–45 birds/half-hour observation period for T-105 and 7–26 birds/half-hour observation period for the Turning Basin control site. At the Turning Basin restored site, mean abundance has shown a slight increase over the years (Table 5) and less variability during the last five seasons of data collection than the other three sites (42–58 birds/half-hour observation period).

When mean abundance for the last five seasons is calculated without the introduced and human-associated species, it drops 45–72% (Figs. 42a–d.). At Kellogg Island and T-105, introduced and human-associated birds made up 70% and 72% of the total birds seen while at Turning Basin, the introduced and human-associated populations were smaller: 52% at Turning Basin control and 45% at Turning Basin restored.

The last five seasons of behavioral observations showed very little change from previous years (Fig. 43a-d). Birds in transit were seen most frequently at Turning Basin control site (mean for all 4 years = 21%), followed closely by T-105 (mean = 17%). Direct site use (foraging and resting) continued to be greatest at Kellogg (annual means range from 95% to 96%) followed by the Turning Basin restored site, where direct use was slightly more variable (annual means range from 83% to 92%). Over the last 4 years, the Turning Basin restored site has had the most consistent level of foraging activity of all the monitored sites, with the annual mean for foraging ranging from 46% to 50%. Seasonal use of the sites also remained consistent with past years. All sites had more foraging/resting behavior during the summer months and the least in the winter.

As in 1997 and 1998, the overlap of native species in 2000 was still greatest between Turning Basin restored and Kellogg Island sites, but the degree of overlap was much less than in previous years (Table 6). The proportion of overlap between the Turning Basin control site and all the monitored sites went down in 2000, reflecting the decline in richness at Turning Basin control. The proportion of overlap for non-native species remains high. However, Brown-headed Cowbirds and California Quail were not seen as often as in previous years. As in 1997, native but human-associated species observed in 1999–2000 were seen evenly across all sites.

EMERGENT VEGETATION

Patch Sizes

All patches showed some variation in length over the course of the 5-year monitoring period (Table 7). *Carex* bench 1 was longer in 1996 than in 1995 but was gradually diminished in both length and width. *Carex* bench 2 was also longer in 1996 than 1995 and maintained its length in subsequent years although the downstream portion (below a fence) was sometimes narrow and patchy. *Carex* bench 3 varied in length and patchiness, not apparently from grazing, but rather because of wave action and the deposition of multiple rounds of large, destructive pieces of garbage. The Reference *Scirpus* site appeared to add approximately 1 m to its length in the second year of sampling and to maintain that through subsequent years. In 1997, a large piece of concrete was removed from the center of the patch and it was apparent that, in 1999, new shoots of both *Scirpus* and *Carex* had moved into the new area. The GSA bench experiences intense wave action and deposition of debris. Goose excluder devices placed by People for Puget Sound should reduce grazing and erosive pressures.

Carex lyngbyei–*Shoot Density*

In three cases, Site 1 in 1997 and 1999 and Site 2 in 1999, no *C. lyngbyei* shoots were present in one or more of the randomly placed quadrats at a site. These two sites are the most stressed of the three *Carex* sites. The increasing number of bare areas and the decrease in patch length at Site 1 are both signs of the effects of grazing pressure and other physical and biological stressors at this site.

For these cases, summary statistics were computed with and without the zero valued samples. When only quadrats in which *C. lyngbyei* was present were used in calculations, mean shoot density at sites in the Duwamish Waterway between 1995 and 1999 ranged between approximately 26 shoots and 47 shoots/0.625 m^2 (Table 8, Fig. 44). Within-year coefficients of variation (CV) ranged between 0.32 and 0.72 and within-site, between-year CVs ranged from 0.50 to 0.55 (Table 9). Including zero-valued samples in calculations for the sites and years in which *Carex* was not present in all quadrats had the obvious effect of lowering mean shoot density and raising the standard deviation and CV (Tables 10 and 11).

When only quadrats with *Carex* are used, the number of *C. lyngbyei* shoots appeared to decrease from 1995 to 1997 but rose again in 1999 to 1995. Over all the years, shoot density was highest at Site 2 and lowest at Site 3. Within-site variance seemed to fluctuate over the years at sites 2 and 3 and to increase through 1999 at Site 1 where the patch is decreasing in size and condition because of goose grazing. Increases in variance indicate that the distribution of *Carex* shoots is becoming patchier so that some quadrats have very few shoots while others have many.

Carex was also present at the Turning Basin Phase I site and the *Scirpus* reference site. Mean shoot density at these two sites was on the lower end, but within the range, of densities compared with sampling from previous years. The CV for shoot density at the Turning Basin Phase I site was low compared with the CV at other sites. *Carex* at this site is protected from grazing by goose excluder devices and from boat wake by a large berm, and it is growing in sediments that are quite uniform and salinities that are fresher than at most other sites.

Variance component analysis indicated that variance due to differences between years accounts for approximately 42% of the total variance in shoot density, variance due to differences between sites accounts for approximately 36% of total variance, and variance within sites accounts for approximately 23% of total variance (Table 12). Variance due to site-by-year interactions is negligible.

Carex lyngbyei–*Shoot Height*

Mean maximum shoot height ranged from 48 to 130 cm at the reference *Carex* sampling sites (Table 8, Fig. 44). Within-year CVs were lower than the CVs for shoot density (Table 9, Fig. 44) and ranged between 0.15 and 0.44 except at Site 1 in 1997. Within- and between-observer error is likely lower for shoot height than for shoot density, and this may explain why CVs for maximum height tended to be lower than CVs for density. Within-site, between-year CVs were quite low (~0.20) at the two downstream sites and higher (0.47) at the Boeing bench.

In 1999, at several of the sites, two distinct height classes of *Carex* were observed (Table 13). The average difference between the two height classes was approximately 20 cm and may represent two goose grazing "events" or two different recruitments of shoots. The Turning Basin Phase I site had two height classes and, since this site is protected from grazing, the two classes likely represent two shoot sets. *Carex* bench 2 was sampled approximately 2 wk later than the other sites and a new set of shoots (mean number of new shoots = 13.5, stdev new shoots = 9.2) had just broken ground at that site when sampling occurred.

Variance component analysis indicated that variance due to differences between years accounts for approximately 4% of the total variance in shoot height, variance due to differences between sites accounts for approximately 78% of total variance, and variance within sites accounts for approximately 6% of total variance and variance due to site-by-year interactions accounts for approximately 12% of total variance (Table 14).

Scirpus validus—*Shoot Density and Height*

Both shoot density and maximum shoot height had site-specific distributions at the Duwamish Reference and GSA sites that were consistent over the course of the monitoring program. Each year, shoot density was higher and maximum shoot height was lower at the GSA site than at the Reference Site (Table 15, Fig. 45). Mean shoot density increased in 1999 over previous years at both sites while maximum shoot height fell.

Through 1997, within- and between-year CVs of shoot density were higher at the GSA site (0.63–0.68) than at the Reference site (0.44–0.57) while within- and between-year CVs for maximum shoot height were slightly higher (not significantly) at the Reference site (0.34–0.41) than at the GSA site (0.28–0.34) (Table 16, Fig. 45). In 1999, the CV for shoot density at the GSA site was almost half its value in previous years. The CV for shoot height at the Reference site was almost twice its value in previous years. Within- and across-year CVs were comparable at both sites.

Shoot density at the Turning Basin Phase II benches was lower than at either of the two original *Scirpus* sites, and mean maximum shoot height fell between the means of the other two sites. The difference in shoot density is not unexpected since Turning Basin is a multispecies site. The similarity in shoot height indicates that after the first growing season, the maximum shoot height of *S. validus* already falls between the shoot height of the stressed GSA site and the less impacted reference site.

Shoot density. Variance component analysis indicated that variance due to differences between years accounts for approximately 24% of the total variance in shoot density, variance due to differences between sites accounts for approximately 71% of total variance, and variance within sites accounts for approximately 4% of total variance (Table 17). Variance due to site-by-year interactions is negligible.

Shoot height. Variance component analysis indicated that variance due to differences between years accounts for approximately 4% of the total variance in shoot height, variance due to differences between sites accounts for approximately 94% of total variance, and variance within sites accounts for approximately 3% of total variance (Table 18). Variance due to site-by-year interactions is negligible.

OTHER SPECIES

Carex *and* Scirpus *Sites*

Eighteen species, other than *C. lyngbyei*, *S. validus*, *S. maritimus*, and *S. americanus*, were found at the regularly sampled *Carex* and *Scirpus* patches (Table 19a). More species were present at the *Scirpus* sites than at the *Carex* sites—likely because *Scirpus* shoots tend to be placed farther apart than *Carex* shoots. Since 1995, understory species were present at both *Scirpus* sites and *Carex* Site 3 (low shoot density), since 1996 at *Carex* Site 1, and since 1997 at Site 2 (Table 15b). Eight species were found at both *Carex* and *Scirpus* sites (*Atriplex patula, Cotula coronopofila, Lilaeopsis* sp.*, Plantago marina, Potentilla palustris, Scirpus cernuus, Spergularia marina,* and *Triglochin maritimum*). *Distichlis spicata*, *Grindelia integrifolia*, *Salicornia virginica*, and *Ranunculus repens* were seen only at the *Scirpus* sites, while *Aster subspicatus*, *Eleocharis parvula*, *Callitriche heterophylla*, *Polygonum hydropiperoides*, and *Vaucheria* sp. were seen only at the *Carex* sites.

The average number of understory species per quadrat declined in 1999 compared with previous years (Table 20).

T-105

The T-105 site is the most downstream of all the sites sampled and has a very different configuration than the other sites. Most or all of the originally transplanted vegetation had not survived and the relatively steep slopes limit the width of the intertidal vegetation that develops there. In 1996, patches of *Atriplex patula, Salicornia virginica*, *T. maritimum*, *C. lyngbyei*, *D. spicata*, and *Spergularia marina* had begun to develop in this narrow band, mostly on the downstream channel margin. In 1997, *Atriplex* dominated the intertidal vegetation. *S. maritimus, Plantago marina, D. spicata, S. marina, S. virginica,* and *Juncus effusus* were found in a few samples. In 1999, the previously patchy distribution of vegetation at T-105 had become more continuous and more diverse. A relatively continuous patch of *S. maritimus* started 4 m from the head of the channel and extended for approximately 20 m. From 4 to 14 m, the *Scirpus* was taller than it was from 14 to 20 m. From 20 m to the mouth of the slough, 10 species were found in 25 quadrats placed every 20 paces (Table 21).

Turning Basin Phase I Site

At the 1994 constructed Turning Basin site, species richness was not as great in 1999 as compared with 1997 (Table 22). Protection from goose grazing may have allowed *Carex, Scirpus,* and *E. palustris* to flourish and other understory species to be replaced.

Turning Basin Phase II Sites

The downstream bench of the Turning Basin Phase II site had greater species richness (19 species) than the upstream bench (7 species, Table 23).

GSA2

The areas at the GSA that were protected from goose grazing and that were first sampled in 1999 had six understory species and two algal species (Table 24).

Discussion

INVERTEBRATES

Sampling Strategies

Sample Stratification and Replication. Because most wetland attributes have heterogeneous spatial distributions, when attempting to detect change over time it is important to carefully choose sampling strata and return to the same locations at each sampling date. Sampling designs, location of sampling units, and replication should be appropriate to the question of interest and the natural variability of the attributes being measured. On the basis of our 1993 pilot studies and review of appropriate literature, we based our subsequent sampling designs on the following questions:

1. What variables will be used as indicators of the functioning of the system? Which of these are the most important?
2. Are these variables heterogeneously distributed (e.g., are there areas of greater and lesser abundance, or are different morphologies or life-history stages found in different areas)?
3. What sampling methods are appropriate for measuring the variables of interest? What biases may be introduced by these methods?
4. Do any data exist that can provide information about how the populations of interest are distributed and/or what sample sizes are required to detect differences?

For benthic invertebrates, stratification into upper vegetated and lower unvegetated habitats appeared to be a good choice. The assemblages sampled within each of these strata were very different and each were dominated by different taxa that are prey for juvenile salmon. Upper strata had high numbers of important dipteran insect larvae such as chironomids whereas in the lower strata, crustaceans such as *Corophium* and *Eogammarus* were relatively abundant. Despite relatively high replication for benthic core samples (n = 10–15 depending on sampling year), variances around means remained very high throughout the study, and meaningful differences based on parametric statistics would probably not be detectable among sites or between sampling periods. Additional work needs to be done to identify the sources of variation at sites like these so that sampling designs can be optimized in future studies. In cases of high variability, another alternative would be to lower within-site replication to increase the number of sites sampled. This would be the case when variability within each site was so high that decreasing the replication would not result in much loss of interpretive power.

Effort Allocation. One unavoidable confounding factor in designing biological monitoring strategies at the Coastal America Duwamish Waterway sites in particular and wetland restoration sites in general was variable between-year funding levels. Funding for this project ranged from $31,000 to more than $100,000 per sampling year. This had two primary effects: (1) attenuating sampling in some years and (2) alternating sampling strategies among years.

The first case is illustrated by our choice in 1995 to restrict invertebrate sampling to the month of May only. We chose this option instead of reducing sample sizes at a given site to reduce the typically high between-sample variances experienced in invertebrate data from this system. This kind of decision is worth revisiting given the fact that, despite relatively high within-site/stratum replication (e.g., n = 10 for benthic invertebrates), confidence intervals around means are still so high as to make parametric statistical comparisons unproductive in most cases. Variances among sites are also very high. For example, in our pilot studies in 1993 we found that the number of samples required to detect a 50% difference in means for *Corophium* spp. was only six at the Turning Basin but was 77 at Kellogg Island (Cordell et al. 1994). In cases such as this, sampling with lower replication but on more dates and/or at more strata would yield information about (a) temporal shifts in assemblage structure, (b) differences in assemblage structure between strata, (c) determination of whether means of important attributes at restored sites fall within those at reference or natural sites, and (d) large changes in densities among sites and across time.

The second case—alternating sampling strategies among years—was exemplified by our decision to add and exclusively sample invertebrates at higher intertidal habitats associated with vegetation in 1996: in other years, only lower intertidal habitats were sampled and in the final year with a relatively high funding level, both strata were sampled. The rationale for adding the vegetated strata was that these were the locations within a site at which the actual physical restoration was constructed. Therefore, sampling there would measure performance of the restored habitat rather than indirect effects on adjacent lower intertidal habitats that may take a number of years to become detectable (e.g., increased benthic productivity due to export and aggregation of detritus adjacent to restoration sites). In addition, sampling at higher vegetated elevations targets a different suite of benthic organisms that do not occur at lower elevations but are important ecologically (e.g., larvae of several types of dipteran flies). The arguments cited in the paragraph above also apply to this case: in situations of limited sampling capability, reducing sample replication and increasing strata may increase the amount of desirable information acquired. It may also be better to sample every year possible at rapidly changing sites (such as newly transplanted strata) because large between-year differences in mean densities would be likely to occur at these sites. A good example of this is the dominance of psyllids in both insect traps and juvenile chinook and chum salmon at the T-105 site in only 1 month and year, May 1997. This taxon was common but never as abundant at any other site or season.

Abundances and Composition

T-105 Site. The sediments in the channel and the “delta” region near the mouth of the T-105 site have developed total invertebrate taxa richness and densities similar to those found at the other restored and reference sites. This is also the case for densities of ecologically important taxa that are identified in the EHAP, including amphipod taxa *Corophium* spp. and *Eogammarus confervicolus* and the polychaete *M. aesturina*. This is notable because the T-105 sites are at higher elevations than the benthic reference flats and might have been expected to have lower densities because of this difference. Coarser grain size distribution at this site may also contribute to increased abundance of some taxa. For example, the polychaete *Pygospio elegans* occurs almost exclusively at this site and at one other coarse-grained site (GSA). Our data also indicate that total benthic macroinvertebrate densities have increased with each sampling period at the T-105 site.

Similar to the macroinvertebrates, total meiofauna taxa richness and densities at the T-105 site have increased across time and are similar to or greater than densities at the reference and other restored sites in the waterway. This site also has the highest densities of the harpacticoid copepod *Huntemannia jadensis*, another species occurrence probably related to grain size (*H. jadensis* is a common inhabitant of relatively coarse sandy beaches in many parts of the world).

Why does the relatively high elevation T-105 site support taxa richness and densities of benthic invertebrates that rival those at lower elevation reference site? One reason may be that invertebrates at this elevation and inside of the constructed channel habitat may have a partial refuge from predation, resulting in higher densities. The created channel at this site also provides low-gradient habitat that does not become completely dry when the tide recedes. This may provide a refuge from desiccation for invertebrates. Another possibility is that the reference site elevation (0.0 m) was inappropriate for comparison to the higher elevations sampled at the restored sites. We chose to continue using this elevation as a reference after expanding sampling to higher elevation strata as an “ideal” comparison because it had densities and taxa richness that were similar or greater to higher elevations in our 1993 pilot studies (Cordell et al. 1994). It is also an elevation identified in the EHAP as being productive for juvenile salmon prey invertebrates. However, we recommend that in future restoration monitoring, sites of similar elevation to restored sites be chosen as references because these will ultimately be better for one-to-one comparisons with restoration sites.

Similarly to the sand flat fauna at T-105, the benthic invertebrate abundance in the vegetated habitat approximately doubled between the two sampling years (1996, 1999), and 1999 taxa richness exceeded that at the other lower waterway sites. Interpreting these findings based on only two sampling years is difficult because of possible natural interannual variation. However, the fact that a similar between-year density increase was not seen at the reference site, and the apparent recruitment of taxa to the site that were almost absent in 1996 (e.g., collembolans), may indicate that the increases are due to development of a vegetation-associated invertebrate assemblage at this site.

Fallout insect data at the T-105 site has been characterized by high between-year variations. In our 1997 data, we noted a shift from 1996 data in fallout insect composition at the T-105 site (Cordell et al. 1999a). The insects there went from being dominated by various dipteran flies in 1996 to a large dominance by aphids, psyllids, and other homopterans in 1997. We conjectured that the increase in these obligate plant feeders was due to an increase in riparian and emergent vegetation at the site between 1996 and 1997. However, in 1999 data, the dominance shifted back to chironomids and other dipteran flies. It is impossible to pinpoint the reason for these large, between-year differences, but there are several possibilities. First, interannual variation such as natural cycles of the animals or weather-related survival of overwintering stages may be taking place. Second, the vegetation assemblages that the insects inhabit may not yet be stable, resulting in unstable insect assemblages. Third, offsite nearby changes in the landscape may have influenced insect assemblages in different years. For example, between the 1997 and 1999 sampling years, upland vegetation adjacent to the restoration site was removed for construction of a rendering plant. This may have resulted in the decrease in plant-dwelling insects noted in 1999. For total fallout insects and several taxa of dipteran flies, the T-105 site had its highest densities of any of the three sampling years in 1999. However, because of very high between-sample variability (as evidenced by generally very large confidence intervals) and the interannual variability discussed above, we can not say if this site will continue to increase its production of fallout insects, continue to experience high variability, or reach some stable state.

GSA Site. Like the T-105 sediment habitats, the constructed sediment bench at the GSA site has experienced increased total invertebrates across the monitoring period, and in 1999 had high invertebrate densities and taxa richness relative to the reference sites. In particular, it has developed high proportions and densities of the ecologically important amphipod *Corophium* that was sometimes prominent in fish diets. Despite having lower meiofauna densities than other sites, the GSA sediment bench and another similar bench that was sampled on one occasion were the only habitats sampled where the important juvenile salmon prey harpacticoid *Harpacticus* was found. However, this taxon is more marine in its distribution than most of the harpacticoids that were more common in this study, and is an important prey resource for juvenile salmon outmigrating through marine habitats such as eelgrass beds. The scarcity of *Harpacticus* in the Duwamish Waterway was probably because the sites there had salinities that were too low for this copepod.

Unlike the T-105 site, the GSA sediment bench is not enclosed and does not retain water at low tide, and therefore does not have the same potential for providing refuge. Hence, it appears that these created sediment habitats become colonized with ecologically important benthic invertebrates even in the absence of such factors.

The *Scirpus* patch at the GSA site also appears to be productive for ecologically important benthic invertebrates in relation to the reference site. In particular, it had high densities of *M. aesturina*, a polychaete worm that is identified in the EHAP as being a prey source for shorebirds. Densities of invertebrates did not increase at this site between 1996 and 1999 as they did at other sites and strata in the lower waterway. However, this site differs from other sites in that it consists of a pre-existing relict *Scirpus* patch that already had associated invertebrate assemblages. Therefore, we suggest that the way to look at sites such as this is to relate increase in benthic invertebrate productivity to expansion or contraction of the vegetation patch instead of distinguishing among per-unit-area abundances based on core samples compared to reference densities.

Insects at the GSA *Scirpus* patch were more consistent in their assemblage structure than at the other two lower waterway sites (T-105 and the Kellogg Island reference *Scirpus*). Insects at this site usually consisted mainly of chironomids and other dipteran flies. At the reference site, insects were usually distributed into additional categories such as amphipods, collembolans, aphids, and a variety of other insects. This was also true for another established patch of transplanted *Scirpus* that we sampled at the north end of the GSA site in 1999. The high relative diversity of insects at these two sites is probably the result of their settings because they are both located adjacent to a shoreline with considerable riparian vegetation consisting of grasses, blackberries, and various trees and shrubs. In addition, they are also located in low current velocity areas (the Kellogg Island patch is behind the island, and the northern GSA *Scirpus* patch is in a created “pocket” beach) that appear to accumulate plant detritus that supports the amphipods and collembolans that were numerous at these sites. In contrast, the Coastal America GSA restoration site is located adjacent to the main river channel, is bounded on the shoreward side by a pier structure, and has little riparian vegetation associated with the *Scirpus*. For many of the EHAP-identified insect taxa and for total insects, mean densities at the GSA site compared favorably with those at the reference and other sites. However, as with the T-105 site, the data should not be assumed as being indicative of statistically meaningful trends because of high between-sample and between-year variability in abundances.

Turning Basin Site. The elevations of the restored habitats at the Turning Basin Phase I site are too high to have large numbers of benthic crustaceans such amphipods and harpacticoids that were prominent at the 0.0-m elevation reference and restoration flat sites. Taxa richness is also lower at these sites than at lower elevation sites. However, they do have relatively high densities of total invertebrates and several important benthic taxa such as *M. aesturina* and several types of dipteran larvae. On the basis of the two periods in which it was sampled (1997, 1999), the sand flat enclosed by transplanted *Carex* at this site has seen increases in invertebrate numbers, and it consistently had much greater invertebrate densities than the other upper waterway sites in 1999. The reasons for this are unknown but could be related to refuge from predation (see above), increasing productivity of the site, or interannual variation. Although increases across time were not evident for benthic invertebrates within the transplanted *Carex* at the Turning Basin Phase I site, densities and taxa richness were similar to those from other vegetated sites in the waterway.

It is not surprising that the Turning Basin Phase II site that was constructed in winter 1999 had markedly lower densities and taxa richness as compared with other sites because the site construction finished only 1 month before sampling began. However, there was rapid recruitment to both sediment and vegetated habitats by some invertebrates as evidenced by increases of total invertebrates and chironomids across the four 1999 sampling months. There were also very high abundances of several taxa of harpacticoid copepods in April, May, and June that indicate the potential of recruitment of these taxa to the site.

As with the T-105 site, the Turning Basin Phase I restoration site had an insect assemblage that shifted first from being dominated by various dipteran flies in 1996 to a large dominance by aphids, psyllids, and other homopterans in 1997, and then back to dipterans in 1999. This is not what might have been expected, because this site has seen the largest increases in both riparian and emergent vegetation, and vegetation-associated insects would have been expected to increase as well. However, the success of the vegetation may have also been particularly beneficial to dipterans in providing benthic habitat and refuge in their roots and food in the form of detritus. Overall, this site consistently had the highest overall insect abundances of any site in the study. As with the other sites, between-sample variability was high and the results should be interpreted with caution.

Summary

A major dilemma in measuring ecological function of restored estuarine habitats is that it may take longer to reach maturity than the time span available for monitoring. Some habitat attributes such as avifauna may respond quickly to space being made available, but benthic invertebrates may take much longer (Simenstad and Cordell 2000). While the Duwamish Waterway Coastal America sites have been monitored for longer than at most other restored sites in the region (which often have no associated monitoring at all), they are probably still at a relatively early developmental stage. The problem is compounded in the Duwamish Waterway because of the lack of appropriate reference sites. The reference sites used were relict patches embedded in an industrialized landscape and undoubtedly have compromised function themselves. Reference sites outside of a restored habitat's system may be problematic because of high between-system variability at the landscape level (Simenstad and Thom 1996). However, it is interesting to compare data from 1997 studies in which invertebrates were sampled concurrently in the Duwamish Waterway and at a breached-dike restored site in the Snohomish River estuary near Everett Washington (Cordell et al. 1999b, Figs. 46, 47). Percent composition was quite different at the two sites (Cordell et al. 1999a, b): in the Snohomish estuary, chironomids usually dominated, whereas in the Duwamish Waterway, a variety of insects occurred, but chironomids were usually not relatively abundant. In unit-area densities, Snohomish estuary sites also had higher values for chironomids than did those in the Duwamish Waterway. This finding did not apply to other major prey taxa. For example, for ceratopogonid and dolichopodid flies, densities at Duwamish Waterway sites equaled or exceeded those at Spencer Island (Fig. 46). This was also true for prey taxa from benthic core samples where Duwamish Waterway densities of *Corophium* amphipods and the larvae of ceratopogonid and chironomid flies were comparable to or greater than those in the Snohomish estuary (Fig. 47). The Snohomish estuary site presents a very different landscape from the Duwamish Waterway in that it is heavily vegetated with both native and exotic emergent plants, and this may be the reason for higher and more uniform chironomid abundances there. Whitehouse et al. (1993) found a clear relationship between amount of vegetation and chironomid abundance at transplanted and naturally vegetated sites in the Fraser River estuary, British Columbia—more were found in marshes with successfully transplanted vegetation relative to sites where transplants failed or to sand/mud locations. While some measures of site-specific performance as indicated by invertebrate densities are encouraging, it seems unlikely that restoration will change the Duwamish Waterway landscape enough to be reflected on larger scales (such as a diet "signal" in fish—see discussion below).

The Coastal America restoration sites are continuing to develop, and we do not know what invertebrate assemblages will ultimately become established and persist. First, the extent of both intertidal and riparian vegetation colonization and the subsequent input of organic matter will affect the amount and quality of food available for benthic invertebrates. Sites that become heavily vegetated by emergent marsh plants (e.g., Turning Basin Phase I upper flat) will probably be dominated by detritovores such as insect larvae and oligochaete worms whereas habitats that remain unvegetated (e.g., intertidal benches) will support proportionally more deposit and/or suspension feeders such as *Corophium* and certain polychaete worms. Second, grain size, elevation, and accretion rates will be important in determining assemblage structure. Accretion may be particularly important at sites like the high intertidal flat at the Turning Basin Phase I site, which appears to be accreting fined-grained sediments. Sites that now have relatively coarse sediments (e.g., T-105 channel and "delta," GSA intertidal bench) have characteristic species that may change if fine sediments accrete there. Third, some of the animals that occupy the sites now may be early colonizers that will give way to other species as the sites stabilize. Fourth, position within the estuary will continue to play an important part in defining benthic assemblage structure. Sites in the vicinity of the Turning Basin will be characterized by relatively large numbers of a few species that are tolerant of oligohaline and tidal–freshwater conditions while those downstream will be more diverse.

JUVENILE SALMON DIETS

Despite variable fishing effort within and among years, a picture of juvenile salmon diets is emerging for the Duwamish Waterway: chum salmon diets were characterized by large variability in types of prey consumed among sites and across time (both annual and interannual scales). At a given date or time, chum salmon prey weight was dominated by such different prey as planktonic crustaceans, harpacticoid copepods and amphipods, benthic insect larvae and worms, or terrestrially derived insects. The results were similar for juvenile chinook salmon—they consumed a variety of prey from terrestrial, water column, and benthic/epibenthic sources. Several prey taxa that are not typical of estuary-feeding chinook—polychaete worms and bivalve siphons—were sometimes prominent in the diet of juvenile chinook in the Duwamish Waterway. This is quite different from another recently restored oligohaline-brackish habitat in the Snohomish River estuary that has been monitored over the same time period, in which juvenile chum and chinook salmon fed almost exclusively on pupal and emergent chironomid flies and fallout insects on most sampling dates (Cordell et al. 1998, 1999b, 2001).

Prey in Duwamish Waterway juvenile salmon is not only different from other estuaries in its consistency over time but also in its qualitative makeup. In other natural and restored estuaries in the Pacific Northwest, the insect portion of both juvenile chum and chinook diets has been dominated by chironomid flies (larvae, pupae, and emergent adults) and aphids in other studies (Congleton 1978; Cordell et al. 1998, 1999b; Levings et al. 1995; Miller and Simenstad 1997; Northcote et al. 1979; Shreffler et al. 1992). In contrast, in the Duwamish Waterway, insects in the diets were much more likely to consist of collembolans, psyllids, ants, wasps, a variety of adults flies, and other insects. These differences likely result from habitat differences between the Duwamish Waterway and other study areas. In most other estuaries studied, sites were dominated on a landscape level by emergent vegetation such as *Carex lyngbei*, which supports associated populations of chironomids and aphids (Simenstad et al. 1993, 1997; Whitehouse et al. 1993), whereas in the Duwamish estuary such vegetation is rare and remains restricted to small isolated patches. These small patches apparently do not contribute enough of these prey items to be consistently detected as a signal in juvenile salmon diets. However, there is one instance in our data in which there is a clear signal of prey production within a restoration site occurring in juvenile salmon diets.

On the 23 May 1997 sampling date at the T-105 channel, there was a remarkable overlap between the chum and chinook salmon diets and insect fallout trap samples. In the insect samples, psyllids made up over 50% of the numbers, and in the fish diets they constituted up to 80% of the prey weight. However, psyllids were relatively rare in both invertebrate and fish diet samples otherwise. Determining whether recruitment and growth of emergent vegetation at existing and new restoration sites in the Duwamish Waterway will be reflected in juvenile salmon diets will require continued monitoring of fish use and diet. Diet data of fish caught on-site represent perhaps the most valuable information that is easily obtainable on site-specific function. The fish provide information about how they used the site—fullness and diet data give us information about how successful fish foraging was and which habitats within the restored area produced the prey eaten. Therefore, we recommend that, if function for juvenile salmon is a priority, and if the configuration of a site allows it (e.g., a narrow enough entrance to block with a net), fish use and diet data be given a high priority in habitat monitoring.

AVIFAUNA

With the completion of the spring 2000 field season, 14 seasons and 42 months of data collection have been completed on the Duwamish waterway. The Duwamish waterway hosts a diverse bird population and every year new species are sighted. However, species diversity for all sites in 2000 was lower than for any previously recorded year. A number of variables including natural population dynamics, construction activity, and fewer volunteer student observers, all of which could have been contributing factors. Until all construction near the restoration sites is complete and new plantings have matured, the impacts of these factors will be difficult to accurately assess.

People were more frequently seen at all sites in 1999–2000 than in previous sampling years. An increased level of human activity appeared to have a negative impact on both bird abundance and diversity. Construction west of Kellogg Island might be correlated with lower abundance, but there was no apparent change in diversity. At T-105, increased levels of recreational use and the construction of a rendering plant probably correlated with lower diversity. The removal of a derelict ferry at the Turning Basin reference site appears to have resulted in no short-term improvement in that habitat, as richness has steadily declined there. Over the last 4 years, the Turning Basin restored site has shown the greatest degree of stability for both abundance and richness and should improve with the creation of the new restored area in 1999.

The timing of data collection could be a contributing factor to the higher richness number for 1999. Overall richness was probably lower than the numbers suggest since data were collected in the spring and summer months when the number of species observed is generally greater.

Four years of data collection have shown consistent patterns in behavior and habitat use. Despite the changes taking place along the waterway, how birds use each site has remained unchanged throughout the study. The behavioral data continue to suggest that Kellogg Island and Turning Basin restored sites are the most ecologically important for birds.

The overlap of native species between sites remains variable but was much lower in 2000 than in previous years. Even though some introduced species (e.g., brown-headed cowbird and California quail) were seen less frequently than in the past, the numbers of starlings, English sparrows and house finches were higher in 2000, especially at the Turning Basin restored site. Native but human-associated species were consistently seen at all sites as the degree of overlap suggests, but (with the exception of rock doves) their numbers have remained much the same over the years. There have been fewer rock dove sightings since the removal of a ferry hulk at the Turning Basin.

Even with 4 years of data, there are inherent problems in evaluating the “success” of the restoration sites on the Duwamish Waterway. Construction of the rendering plant at T-105 appears to have undermined at least some of the habitat restoration efforts there. Until other shoreline restoration is complete, it is difficult to differentiate between natural trends and those influenced by disturbance. Public access has increased at all sites over the last 4 years, and while this may fill some societal needs, it may run counter to restoration success for birds. With the installation of additional trails (Kellogg Island area) and the removal of buildings (Turning Basin restored site), the Duwamish waterway is steadily becoming more accessible to the public. Many of the people spoken to by the observers were there to watch birds. Proper signage to educate the public about the wildlife could help to alleviate the negative impacts often associated with increased disturbance. Monitoring is an important tool for evaluating the effects of restoration, but the time scale of monitoring is crucial. An incomplete temporal series of data provides little conclusive information. Until some endpoint in both commercial and restoration construction is reached and environmental equilibrium attained, the true function of restored habitats will remain unknown, and we have provided only an interim picture. Measuring avifauna use of Duwamish Waterway habitats at a regular interval is thus crucial in providing a picture of whether or not habitat restoration is beneficial to avifauna.

EMERGENT VEGETATION

Carex site 1 is decreasing in patch size, shoot density, and maximum shoot height and is in danger of disappearing. From our anecdotal observations, this appears to be due to increased goose grazing on this patch accompanied by erosion of fine sediments and packing of remaining sediments. As goose exclosures have proven to be quite effective elsewhere in the waterway, this site should be protected from grazing in order to improve the chances that *Carex* will persist there.

Of the three *Carex* sites, site 3 has the sparsest shoot density. It is the furthest down stream of the sites and is frequently disturbed by wave action from boats in the waterway. We often have observed large pieces of industrial and woody debris in the *Carex* at this site. In the past, it has appeared that pioneering species may have more occasion to recruit to this disturbed site than to other sites with greater *Carex* cover, but in 1999 the frequency and number of understory species decreased from previous years, and we do not know the reason for this. Site 3 also has the tallest *Carex* shoots of the three sites and shoot height is relatively stable (relatively low CV across years) at this site. We have seen little evidence of goose grazing at this site, and it may be restricted because of the physical and human disturbances there.

Site 2 appears to be the most stable and least disturbed *Carex* site, but even at this site CVs are high—over half the mean shoot density. Maximum shoot height at this site is relatively stable and may indicate consistent grazing pressure across years.

The *Scirpus* reference site has consistently had lower shoot density and greater maximum shoot height than the GSA restoration site. The substrate at the reference site includes many large pieces of broken concrete that undoubtedly restrict the shoot density at the site. We have removed some concrete and used it to construct a protective berm to diminish wave intensity, which may improve shoot density at the site in the future. Shoot height at the GSA site may be decreased by several factors such as grazing, relatively high wave energy at the site, and substrate quality. If goose excluder devices at the site do not result in an increase in shoot height at this site, additional protection from waves and debris should be considered. We have often observed damage to *Scirpus* at this site from wood and other debris tossed by boat wakes. A modification of the site that encourages sediment deposition may also be considered. The current sediments are extremely hard packed, and may not contain sufficient organic matter to hold water and nutrients during low tides.

Understory species have been more frequent and diverse at the *Scirpus* sites and the downstream *Carex* site. This may be due to two factors: first, these three sites have more open space among the *Scirpus* and *Carex* shoots for understory recruitment. Second, geese may be avoiding these sites because of disturbance or higher salinity, causing a release from grazing pressure.

Variance in shoot density and shoot height in the Duwamish Waterway is affected by differences between sites and years, interaction between sites and years, within-site variance, and measurement error. If measurement error is assumed to be constant across sites and years, it appears that variance due to differences between sites is the largest contributor to total variance (over 70%) in *Scirpus* shoot density and shoot height and *Carex* shoot height. For *Carex* shoot density, between-site variance is comparable to between-year variance (35%–40% of total variance) and within-site variance is only slightly less (approximately 25%). For all other variables, within-site variance is low compared with other factors. Year-to-year variance in maximum shoot height of both species was low relative to between-site variance. Factors that change with time do not seem to have as large an effect on shoot height as factors that change over space. *Carex* shoot density, on the other hand, is equally affected by time as by space, and *Scirpus* density is also somewhat affected by space. The low contribution of the site-by-year interaction term for all variables (except *Carex* shoot height) indicates that site means of each variable are fluctuating randomly through time and different sites do not appear to be taking different trajectories. It seems that the distances over which the *Carex* and *Scirpus* sites are distributed in the Duwamish Waterway covers significant ranges of several physical factors that create site-specific vegetation characteristics.

Relatively lower variance across time as compared with space for the vegetation metrics that we measured suggests that if monitoring efforts need to be decreased, sacrificing sampling years rather than sites would be preferable. Sampling multiple sites has allowed us the opportunity to understand the importance of spatial variance and to begin to recognize traits of individual sites. For any year sampled, understanding the range of vegetation characteristics in the Duwamish Waterway is important to interpreting temporal differences.

Substrate in the Duwamish Waterway is limited by armoring of the shoreline and wind/wave action that transports large debris and erodes the shoreline. Promoting plant diversity here may require different policies in different parts of the waterway. For example, the main impediments to the spread of vegetation in upstream areas appear to be shoreline armoring and goose grazing. In downstream areas, wave action, destruction by debris, and sediment quality may be more limiting. Maintenance of existing sites by minimizing known physical stressors may be important for maintaining the sites in the face of uncontrollable stressors such as weather, climate, and water quality.

The relatively large contribution of between-site variance to the total variance in all variables indicates that it would be best to maintain a pool of reference sites in order to understand the performance of future reference sites. Because site-to-site variability is large, if only one reference site were sampled, it is likely that the reference and restoration site would be quite different and it would be difficult to interpret the success of the restoration site.

Conclusions

Has habitat restoration at the Coastal America sites in the Duwamish Waterway been a success? One way to gauge this is to examine our findings in the context of the stated ecological goals identified by the project partner agencies. These included increasing the acreage and biological function of the following habitats in the waterway: (1) fine-grained low-slope unvegetated flats, (2) salt- and brackish marshes, (3) riparian assemblages, and (4) intertidal slough channels (T-105). By these criteria, the Coastal America Restoration sites have been largely successful. The created flats appear to be stable, and in some cases (e.g., Turning Basin) appear to be actively accreting fine-grained sediment. With the help of goose exclosures, planted *Scirpus* and *Carex* have successfully established themselves at the sites, and other plant species have recruited naturally. Although we did not monitor survival and expansion of planted riparian areas, they have also appear to have become successfully established.

Not only has each site contributed acreage of one or more of the listed habitat types, but our monitoring data also show significant associated biological function. At the constructed slough channel site (T-105), where we could explicitly measure fish presence, we found that salmon and other fish accessed the site. Further, the salmon captured there were feeding on types of prey found in the restored habitat. On-site production of sediment-dwelling invertebrates was comparable to reference sites, and successful colonization of the sites by emergent and riparian vegetation was accompanied by development of marsh and terrestrial insect assemblages. It therefore follows that those technical demonstration objectives (see Introduction) associated with physical creation of sediment, channel, and riparian habitats were successful. However, we cannot evaluate the objectives associated with removing shading structures and using log booms to decrease debris deposition and wake damage because we do not have before-and-after data. But we can report anecdotally that the log booms placed at the GSA site did not appear to be effective in preventing large amounts of debris being deposited at the site.

Despite these clear indicators of success at individual sites, we do not yet have larger-scale evidence of habitat restoration success in the Duwamish Waterway. One measure of this is the aggregate data from our juvenile salmon diet studies from a number of sites in the waterway. Our results show markedly different invertebrate assemblages and salmon prey as compared with other more natural areas. A reasonable interpretation of these results is that juvenile salmon in the Duwamish Waterway encounter and feed on prey that is not typical of a natural estuary, evidenced by opportunistic feeding from habitat fragments—water column, terrestrial, benthic, etc.—as opposed to more "natural" feeding by fish on chironomids that are produced in vegetated landscapes of less industrialized estuaries. Such feeding is not necessarily detrimental to the fish: we do not have the residence time and growth data to establish this, and fish in the Duwamish Waterway may be successfully exploiting alternative prey. But it appears that the restoration efforts in the Duwamish Waterway, while producing relatively high on-site densities of prey, do not create enough wetland-specific prey to create a large "signal" in salmon diets.

Given this, is it worthwhile to attempt habitat restoration in highly industrialized estuarine landscapes? Though it may appear that restoration in industrialized sites may not be cost effective in terms of salmon habitat as compared with more natural settings, the following should be considered in evaluating the "worth" of such restoration:

1. *Habitat function at the Coastal America sites was effectively zero before restoration.* These sites consisted of developed hard surfaces such as street-ends, light industry, and overwater structures, and had neither access or prey production capabilities for juvenile salmon. Therefore, relative to the system in which they are found, these sites have resulted in a net gain of habitat usable by salmon and also by other fish, plants, and birds.
2. *Additional restoration projects may provide habitat linkages with existing projects that will create a sum of habitat function beyond site-specific levels.* There are at least eight constructed or planned restoration projects in the vicinity of the Coastal America sites. Linkages among these new habitats may begin to provide more landscape-level function. For instance, increasing riparian plantings could reach an aggregate level that would attract and support more resident birds. Also, increasing detritus production from plantings coupled with lower energy habitats such as constructed flats and basins could eventually lead to changes in benthic invertebrate assemblage structure that would ultimately be detected in fish diets.
3. *Urban restoration has value for public education.* The Duwamish Waterway is situated within the largest population center in the Pacific Northwest. Restoration efforts here thus have value for educating the public. During the period in which we monitored the Coastal America sites, we have seen increasing presence of local politicians, school classes, and citizen action groups.

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Figures

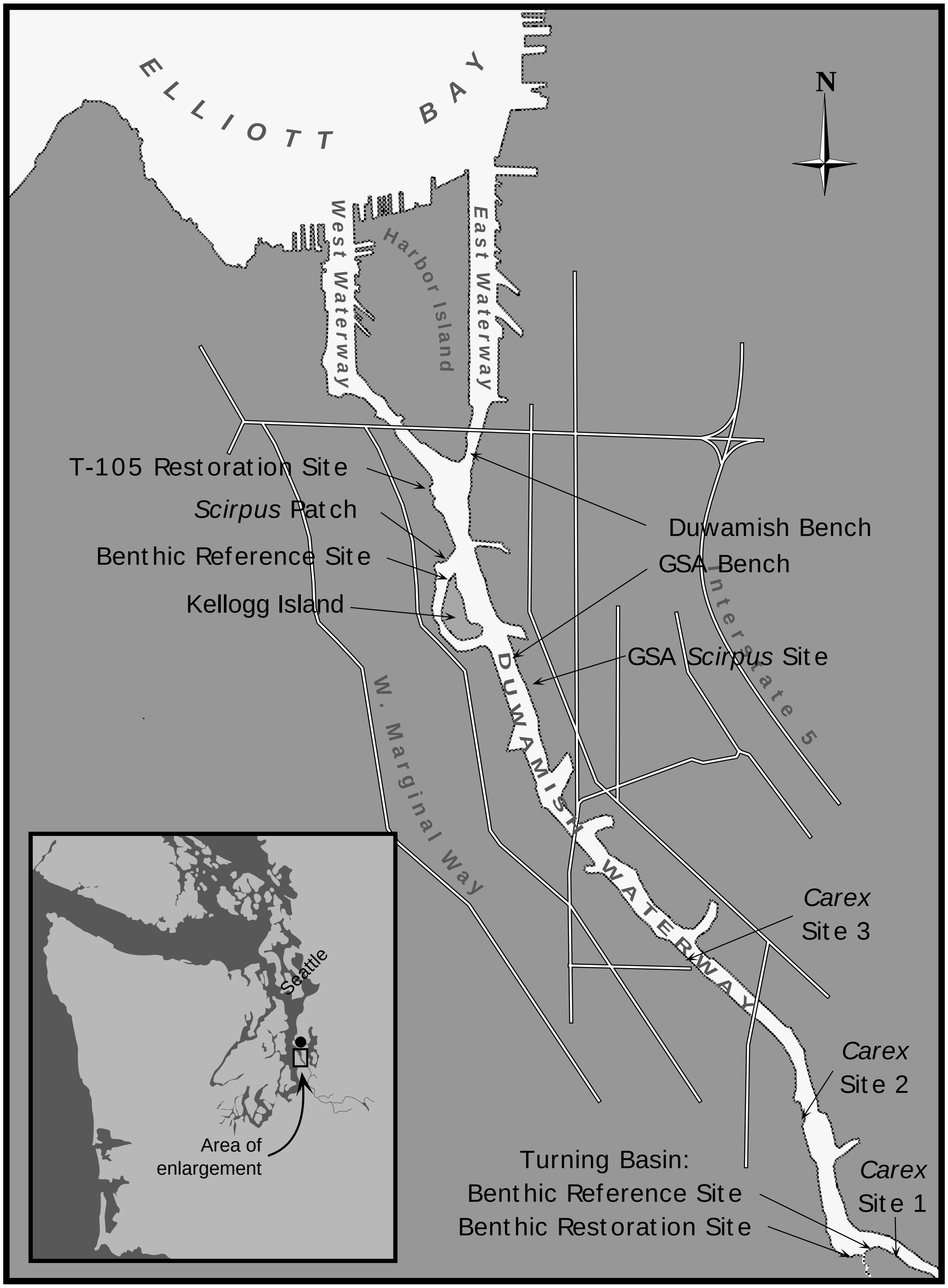


FIGURE 1. Location of sampling sites in the Duwamish Waterway.

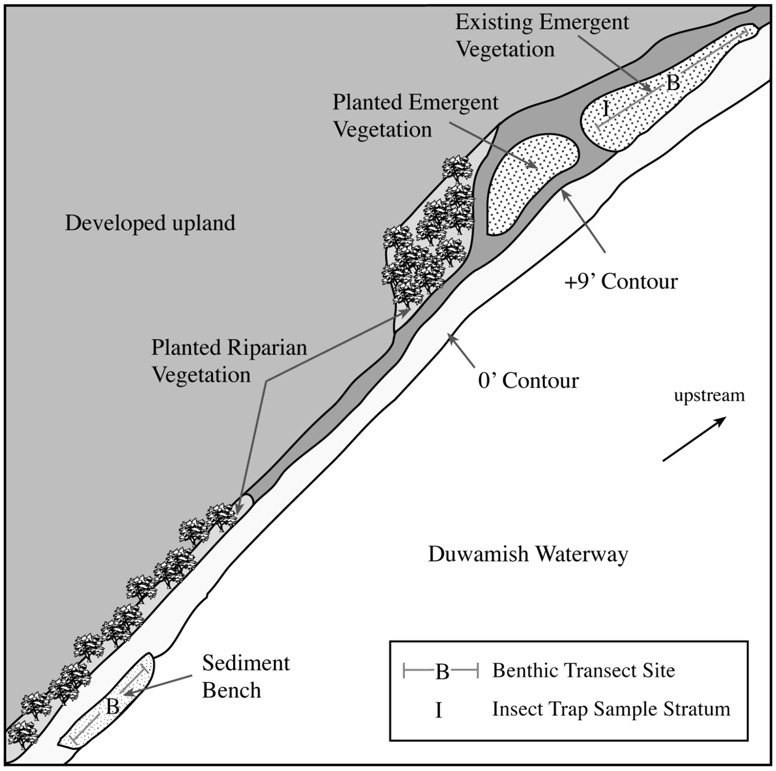


FIGURE 2. GSA Restoration Site.

FIGURE 3. (a) GSA site, pre-restoration, downriver view; (b) upriver view. Photos by C. Tanner.

FIGURE 4. (a) GSA site, post-restoration, downriver view; (b) upriver view. Photos by C. Tanner.

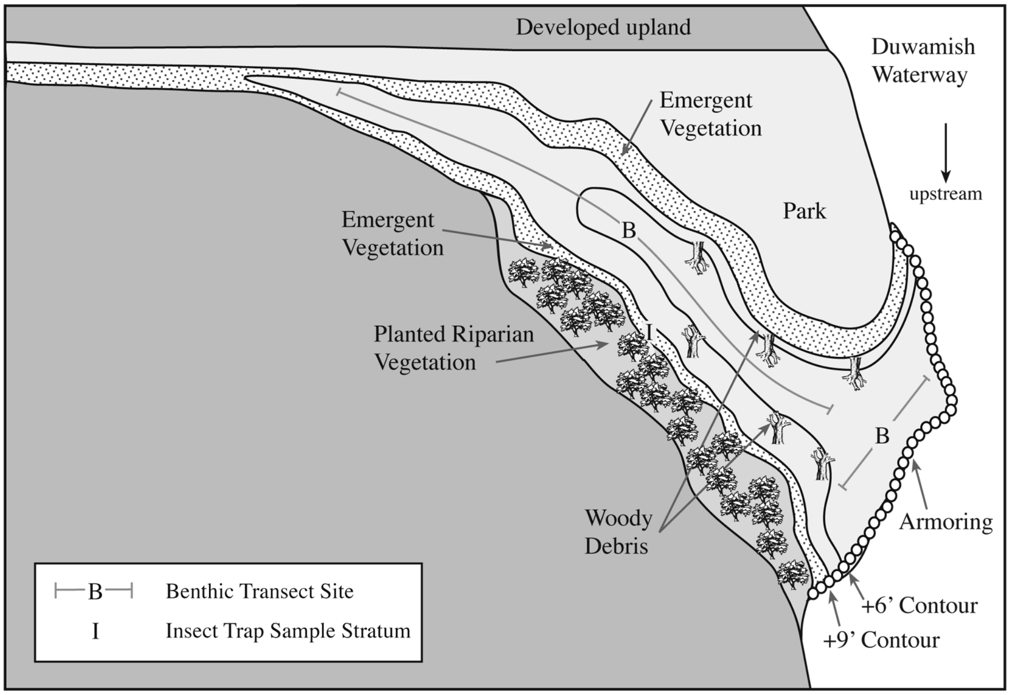


FIGURE 5. Terminal 105 (T-105) restoration site.

FIGURE 6. (a) T-105 site, pre-restoration, view from Duwamish Waterway; (b) view looking toward waterway during construction. Photos by C. Tanner.

FIGURE 7. (a) T-105 site, post-restoration, view looking up-channel; (b) view looking toward waterway. Photos by C. Tanner.

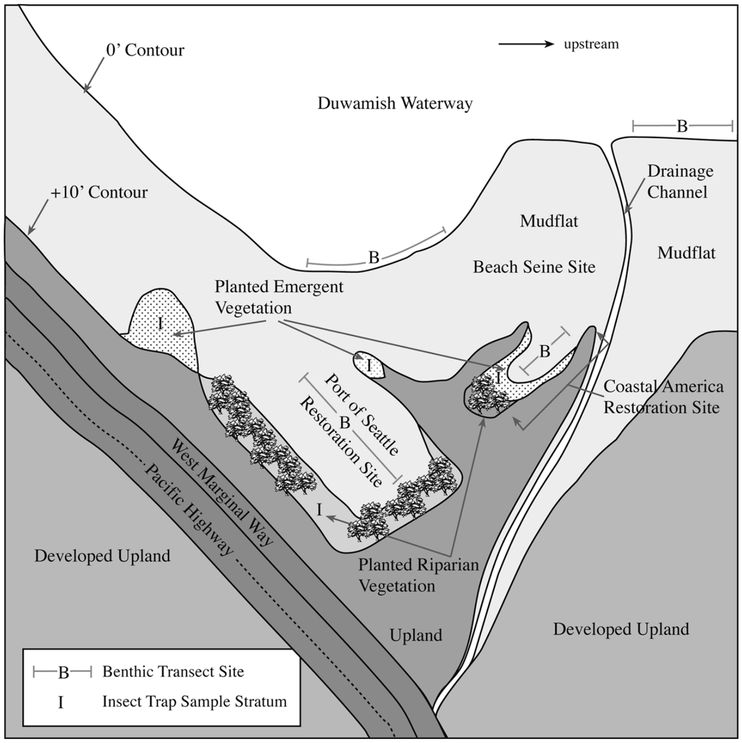


FIGURE 8. Turning Basin restoration sites.

FIGURE 9. (a) Turning Basin site, pre-restoration, aerial view; (b) removal of ferry boat hull. Photos by C. Tanner.

FIGURE 10. (a) Turning Basin Phase I site, post-restoration, view from upland; (b) view looking from waterway, showing goose exclosures. Photos by C. Tanner.

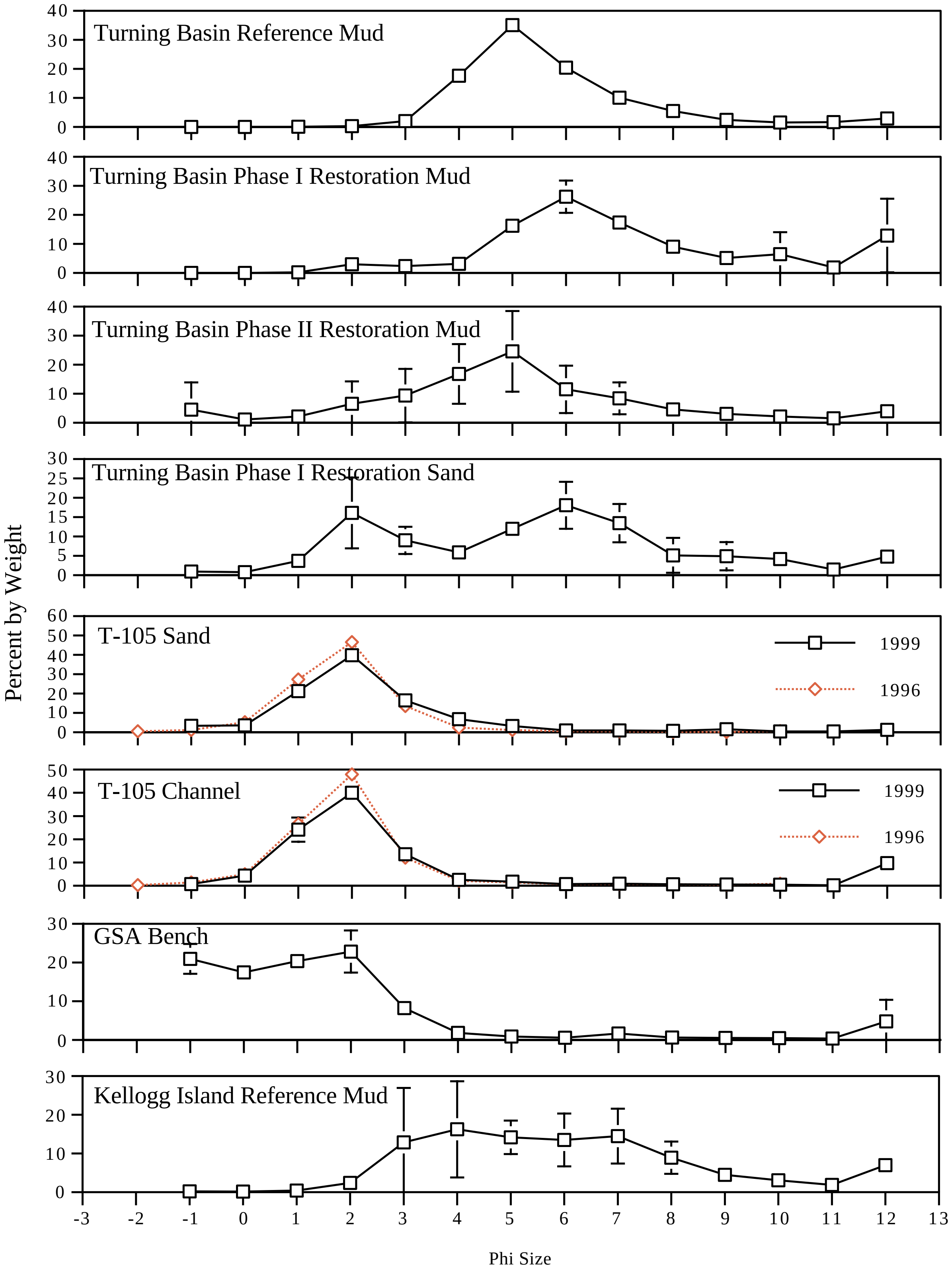


FIGURE 11. Grain size distributions for sediments from mud and sand flat habitats associated with restored and reference sites in the Duwamish Waterway. Larger phi sizes are finer sediments.

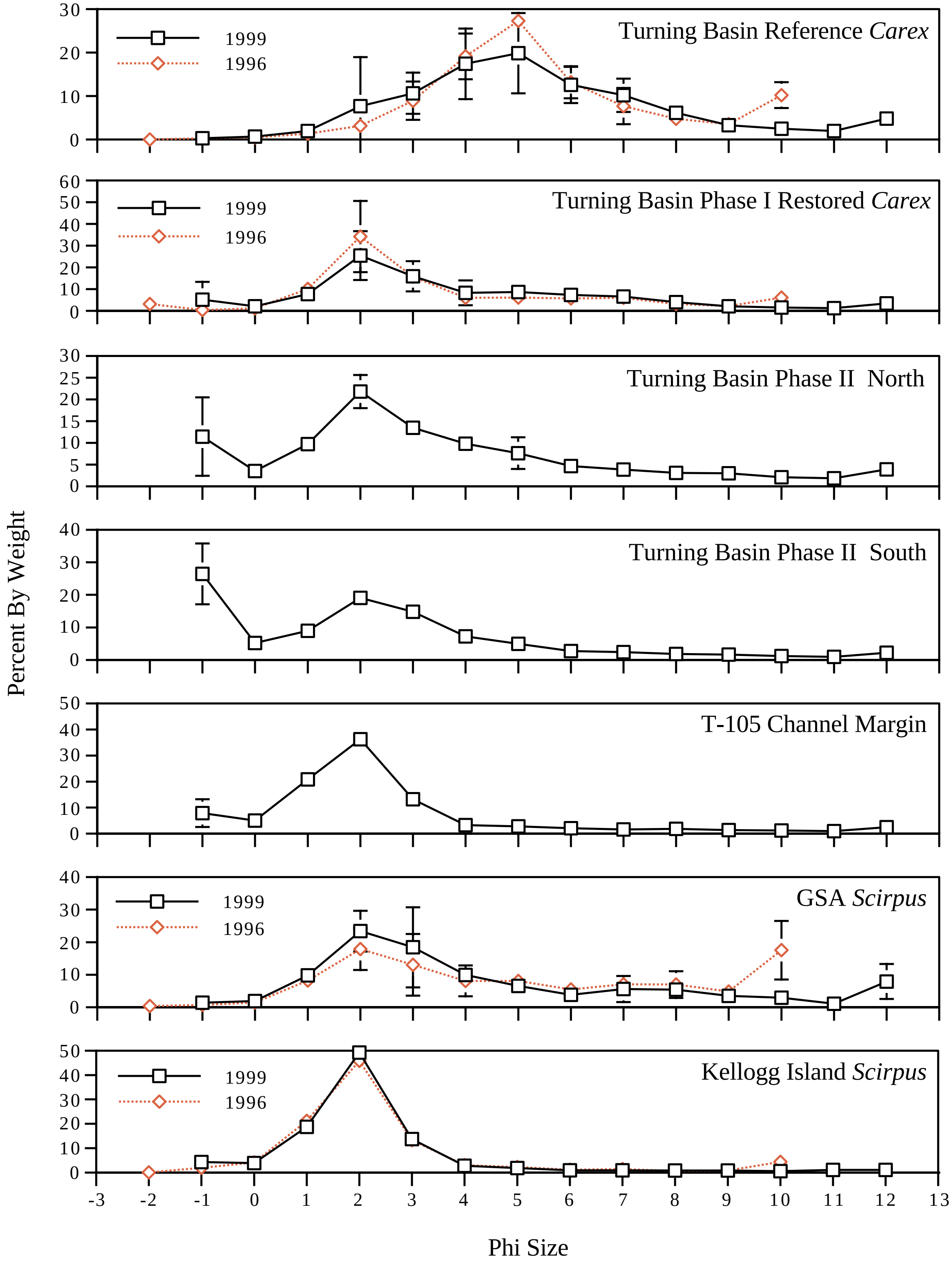


FIGURE 12. Grain size distributions for sediments from vegetated habitats associated with restored and reference sites in the Duwamish Waterway. Larger phi sizes are finer sediments..

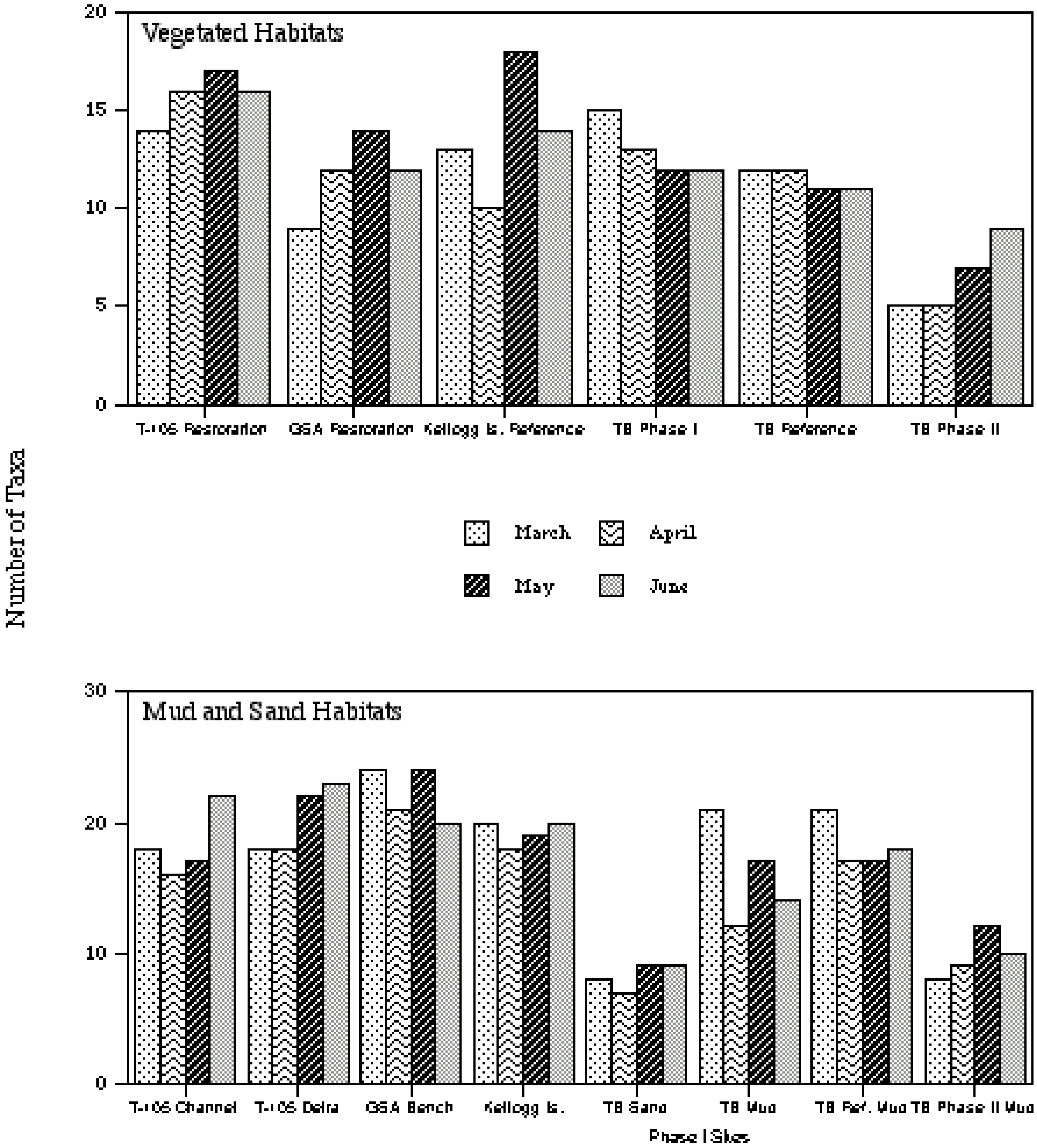


FIGURE 13. 1999 Taxa richness for benthic macroinvertebrates from vegetated habitats (top) and mud/sand habitats (bottom) at reference and restoration sites in the Duwamish Waterway.

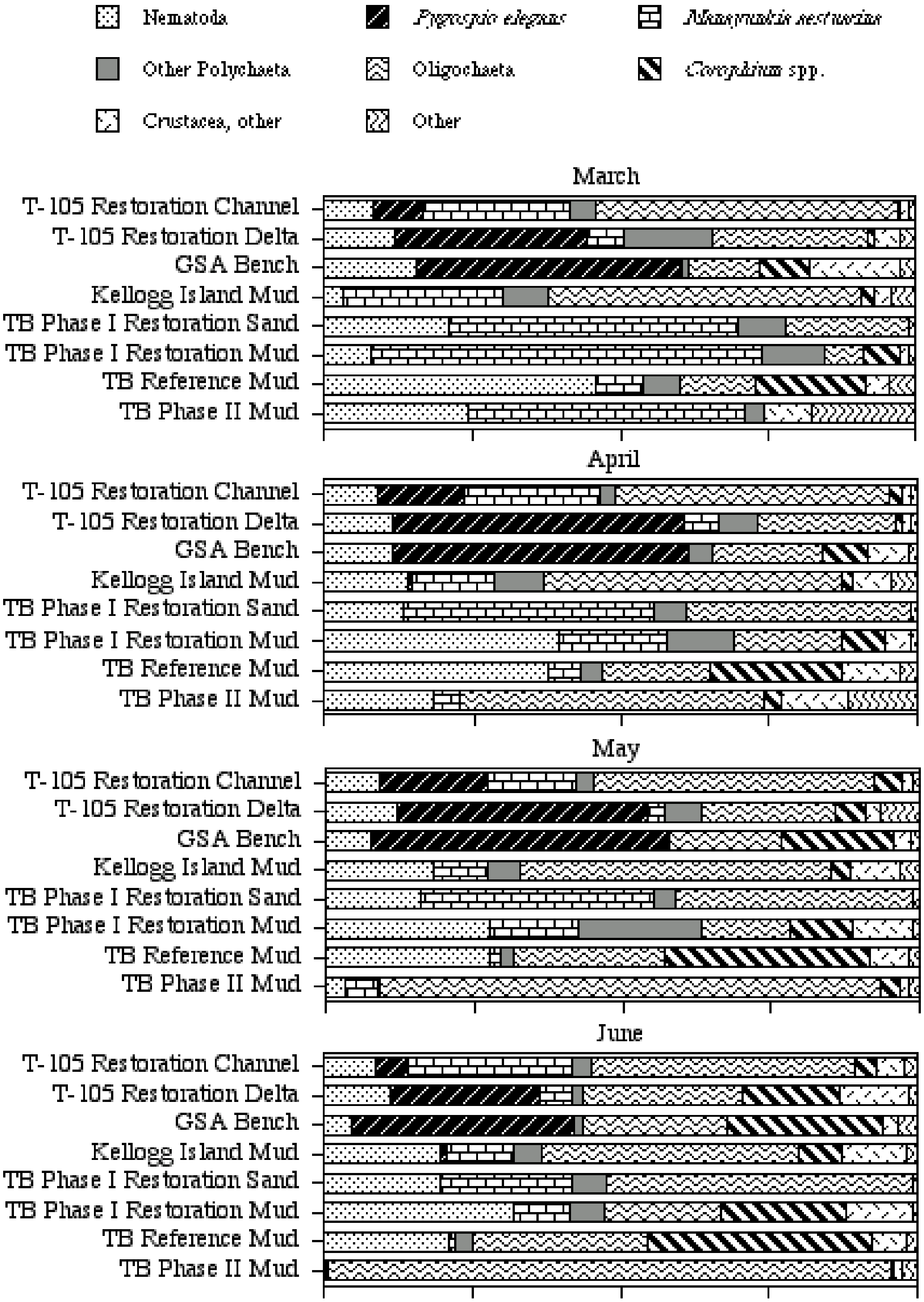


FIGURE 14. Percent numerical composition of macroinvertebrates from benthic core samples taken at Coastal America restoration and reference mud and sand sites, April–June 1999.

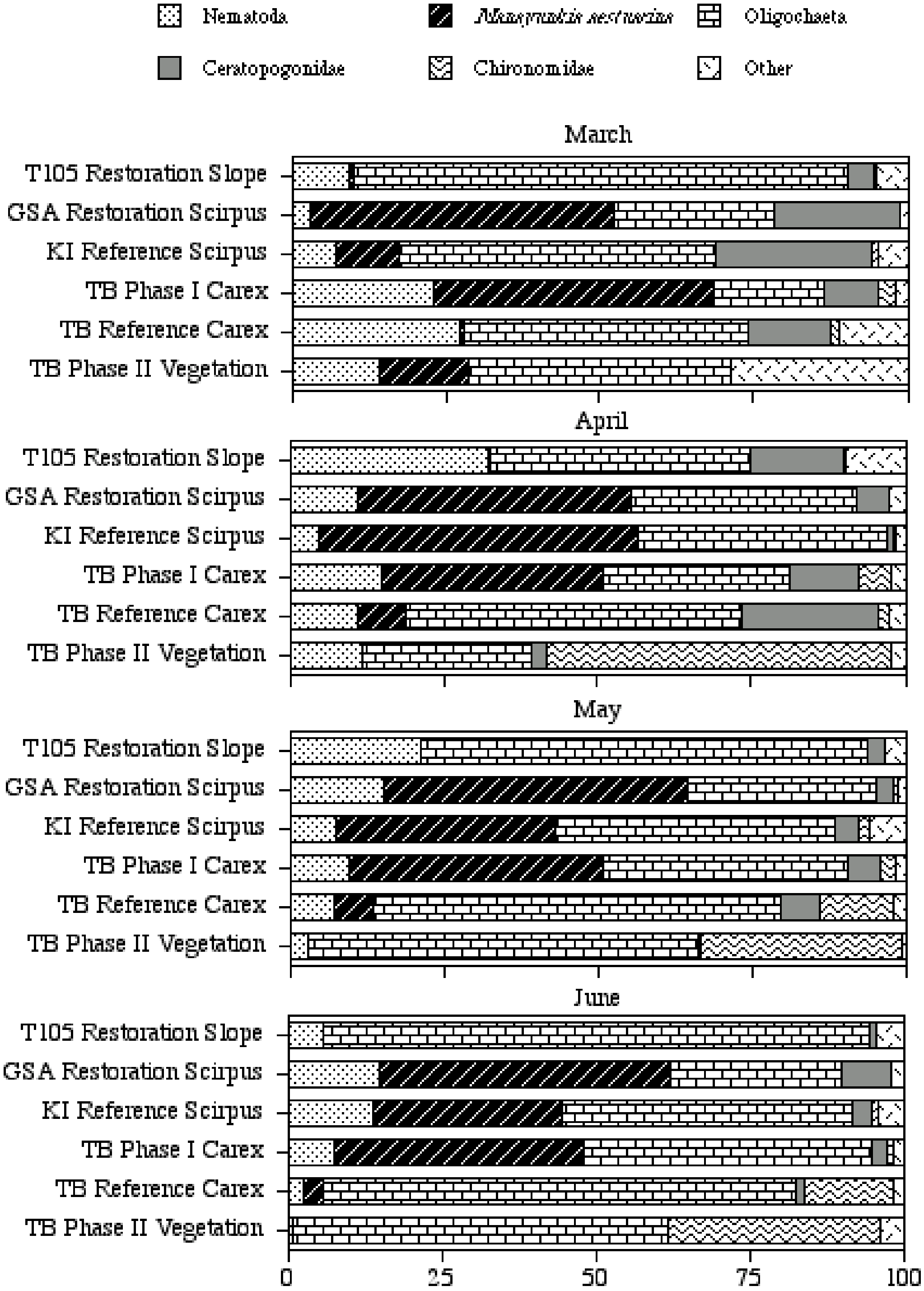


FIGURE 15. Percent numerical composition of macroinvertebrates from benthic core samples taken at Coastal America restoration and reference vegetated sites, April–June 1999.

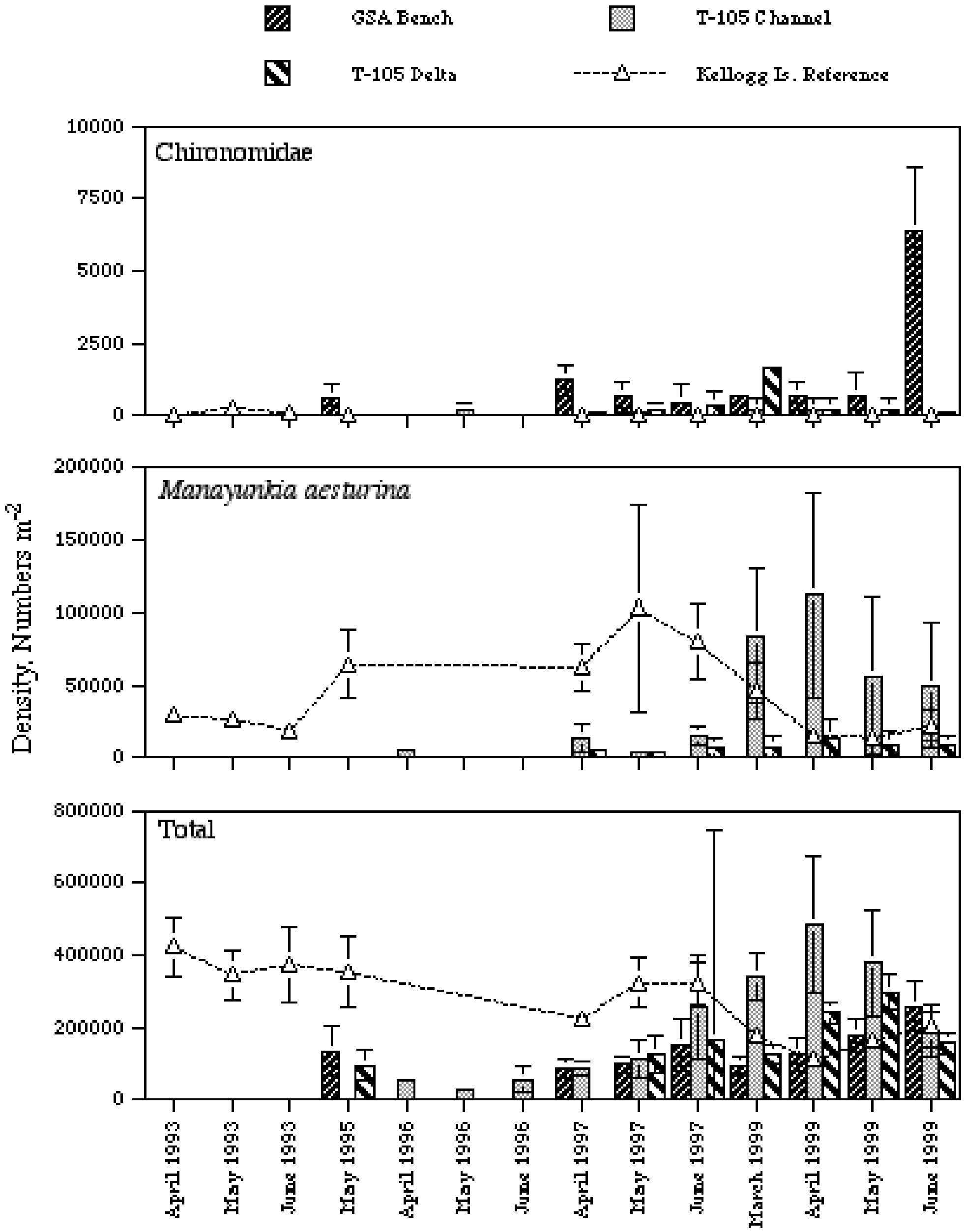


FIGURE 16. Densities of total macroinvertebrates *Manayunkia aesturina*, and chironomid fly larvae from benthic core samples taken at lower Duwamish Waterway Coastal America restoration and reference mud and sand sites, April 1993-June 1999. Vertical lines are 95% confidence intervals.

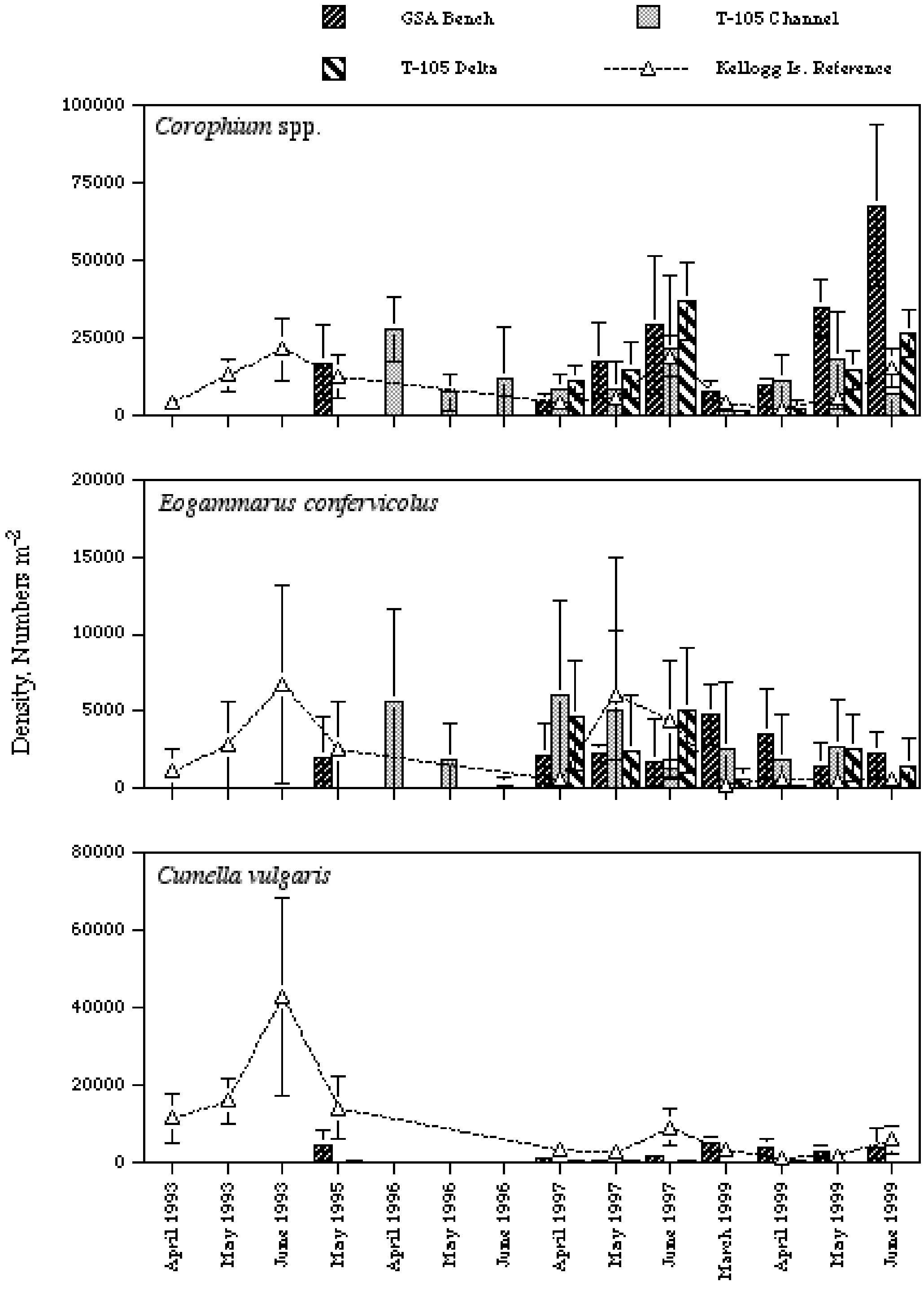


FIGURE 17. Densities of ecologically important crustacean taxa from benthic core samples taken at lower Duwamish Waterway Coastal America restoration and reference mud and sand sites, April 1993- June 1999. Vertical lines are 95% confidence intervals.

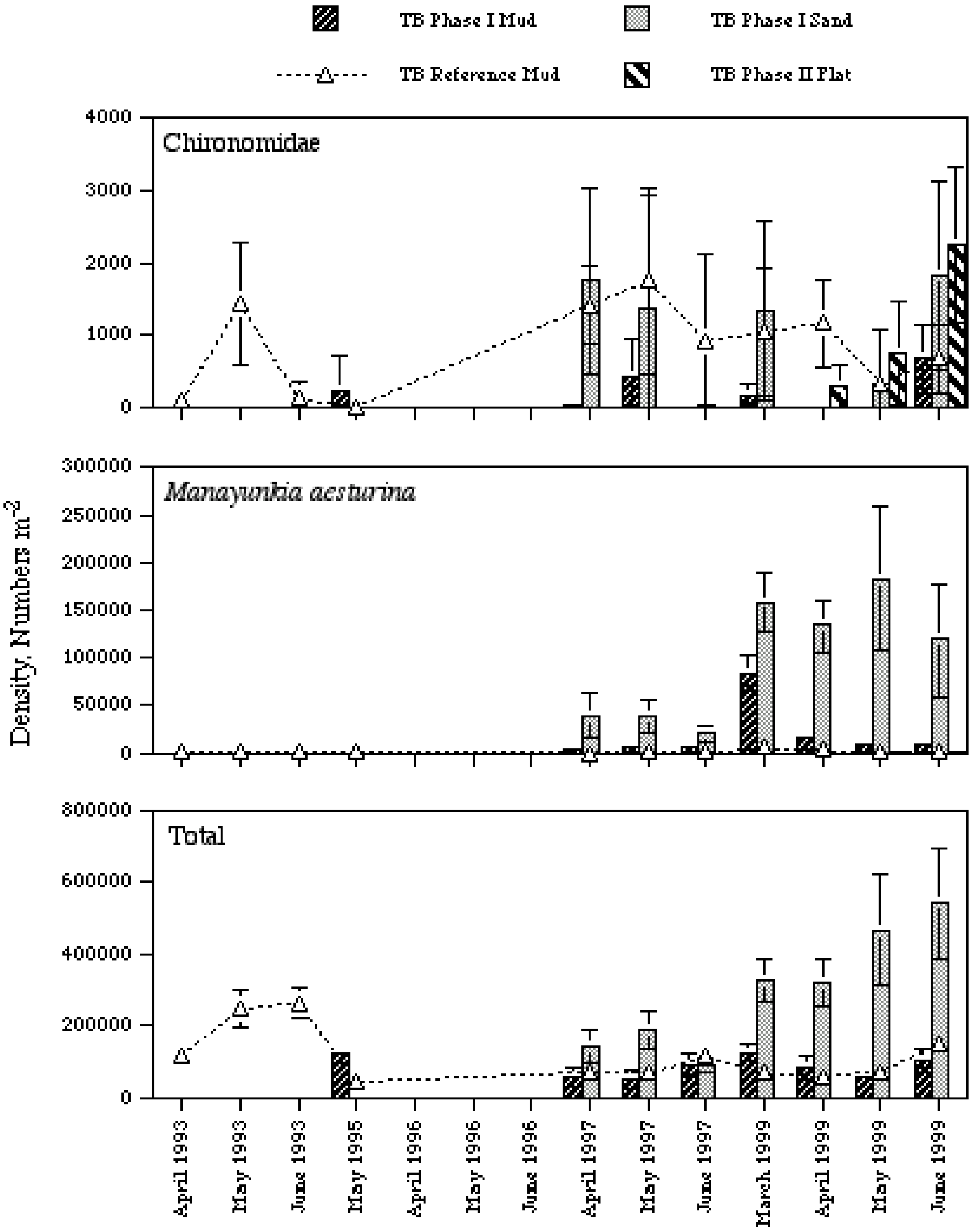


FIGURE 18. Densities of total macroinvertebrates *Manayunkia aesturina*, and chironomid fly larvae from benthic core samples taken at upper Duwamish Waterway Coastal America restoration and reference mud and sand sites, April 1993-June 1999. Vertical lines are 95% confidence intervals.

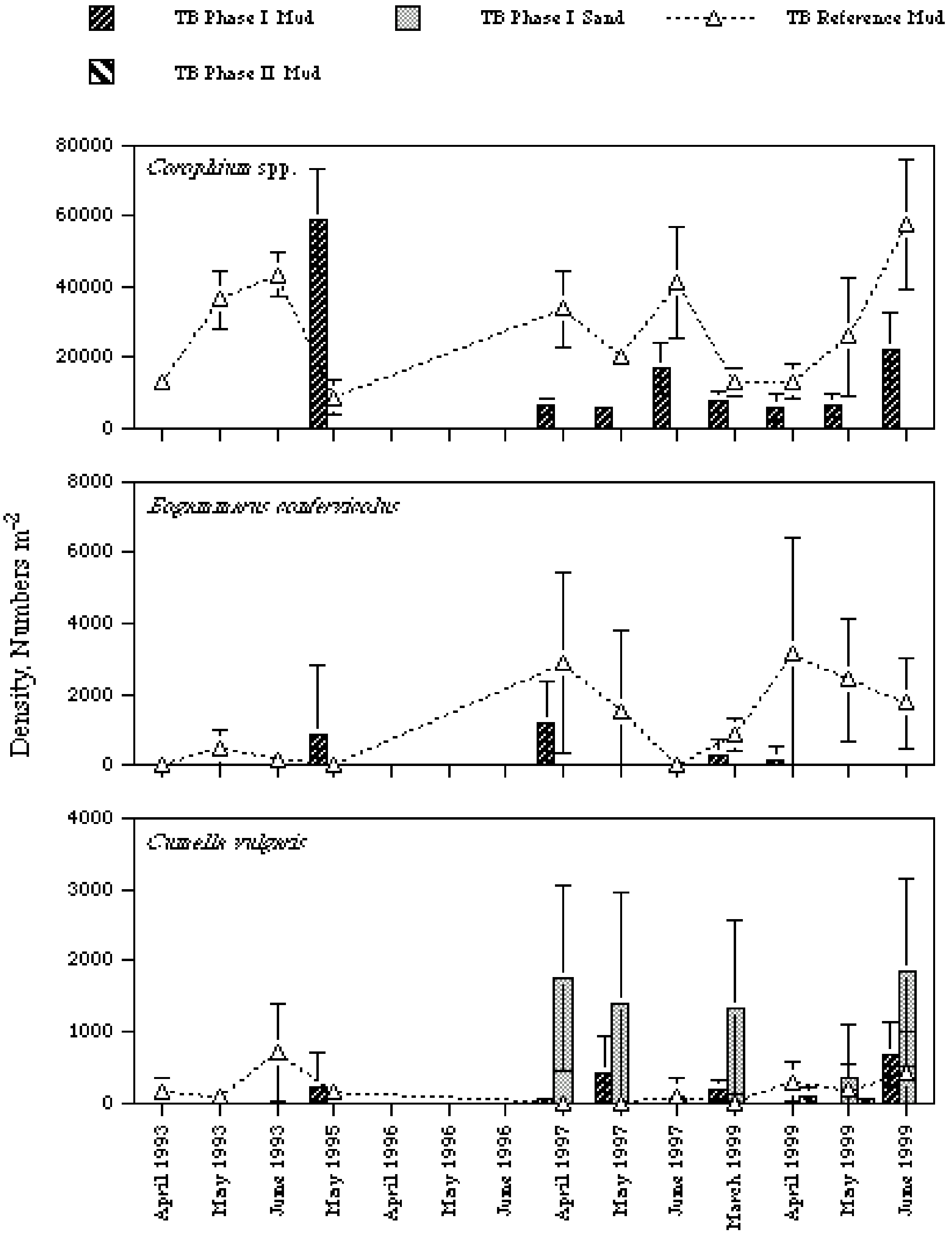


FIGURE 19. Densities of ecologically important crustacean taxa from benthic core samples taken at upper Duwamish Waterway Coastal America restoration and reference mud and sand sites, April 1993- June 1999. Vertical lines are 95% confidence intervals.

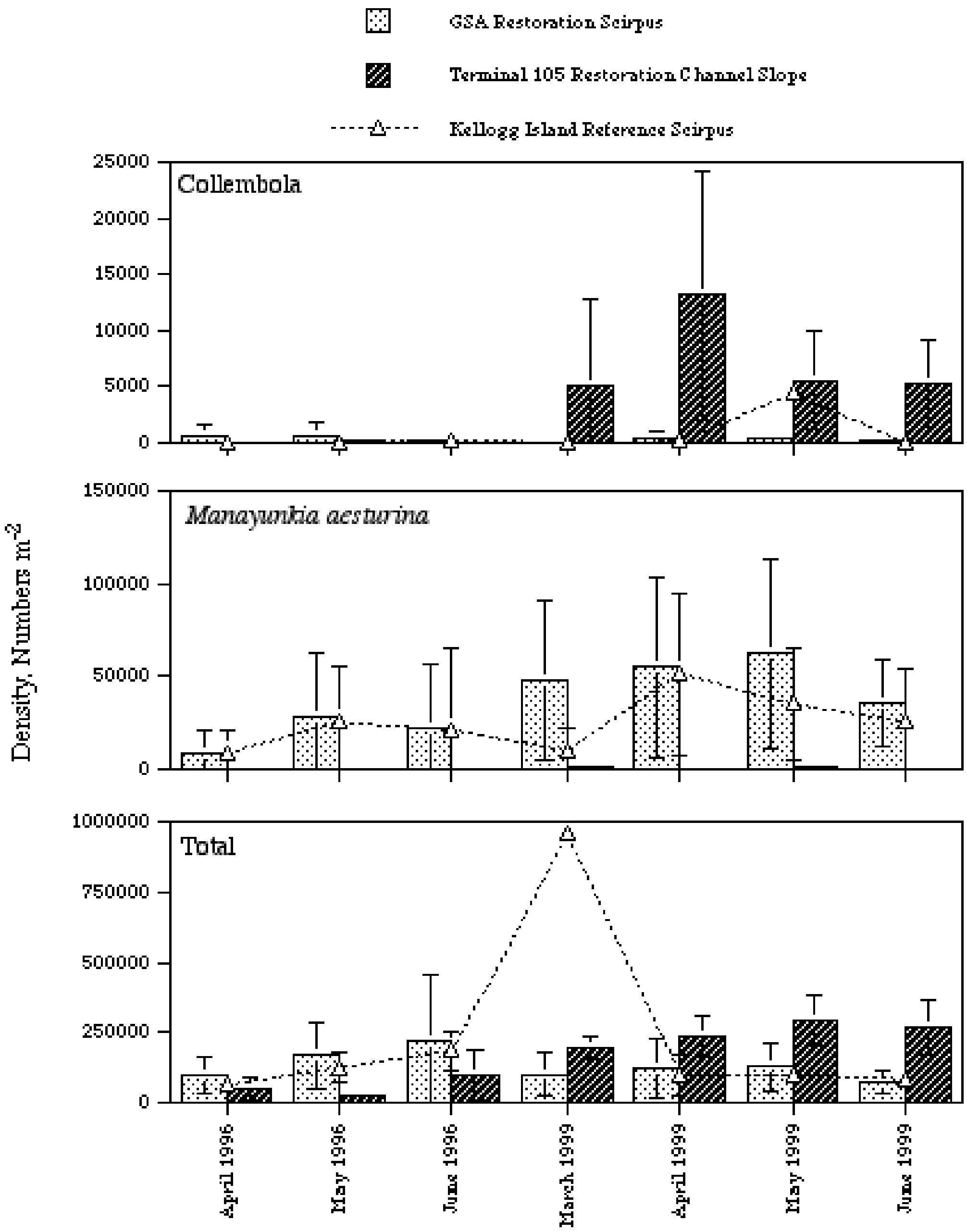


FIGURE 20. Densities of total macroinvertebrates *Manayunkia aesturina*, and Collembola from benthic core samples taken at lower Duwamish Waterway Coastal America restoration and reference vegetated sites, April 1996- June 1999. Vertical lines are 95% confidence intervals.

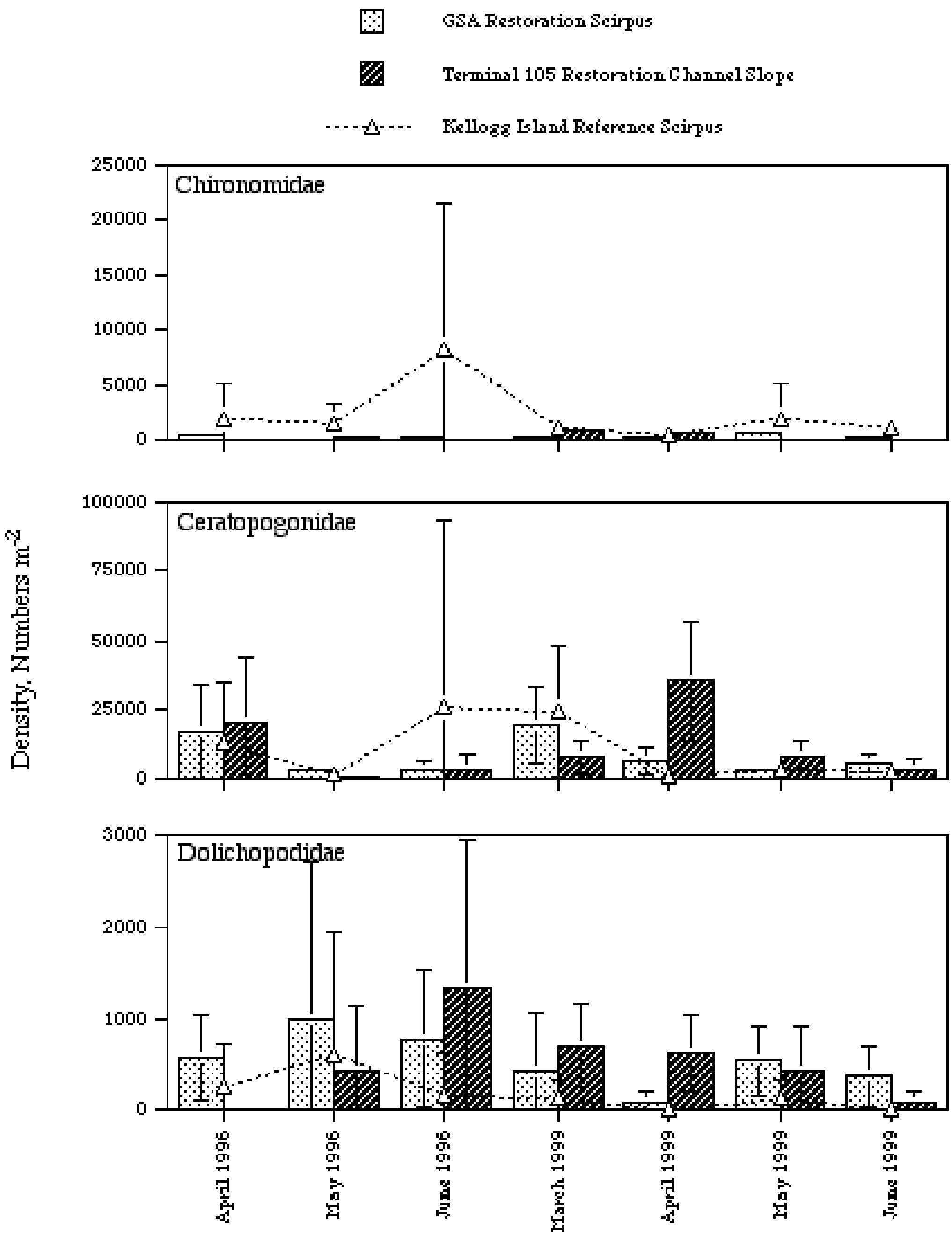


FIGURE 21. Densities of ecologically dipteran fly larvae from benthic core samples taken at lower Duwamish Waterway Coastal America restoration and reference vegetated sites, April 1996- June 1999. Vertical lines are 95% confidence intervals.

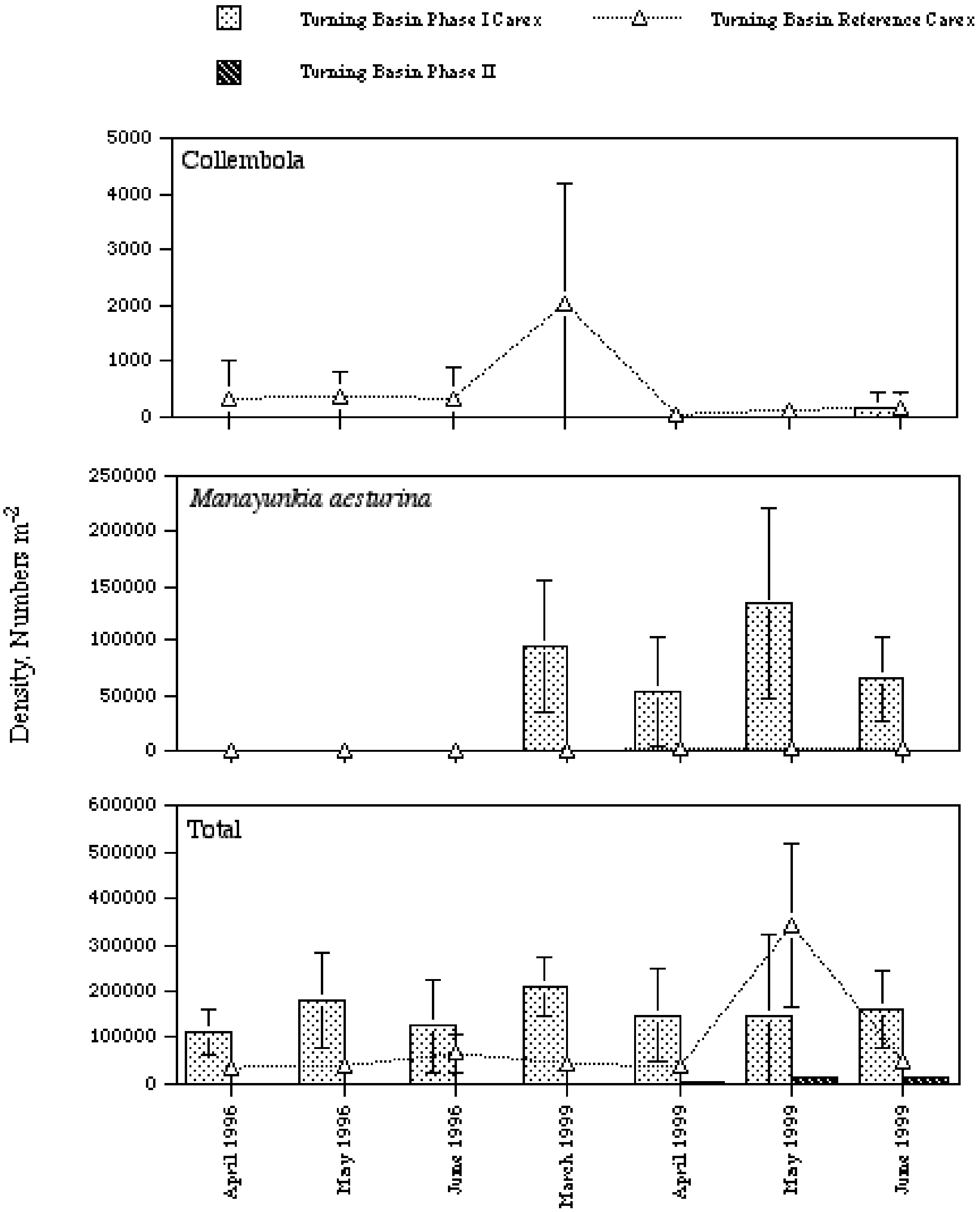


FIGURE 22. Densities of total macroinvertebrates *Manayunkia aesturina*, and Collembola from benthic core samples taken at upper Duwamish Waterway Coastal America restoration and reference vegetated sites, April 1996- June 1999. Vertical lines are 95% confidence intervals.

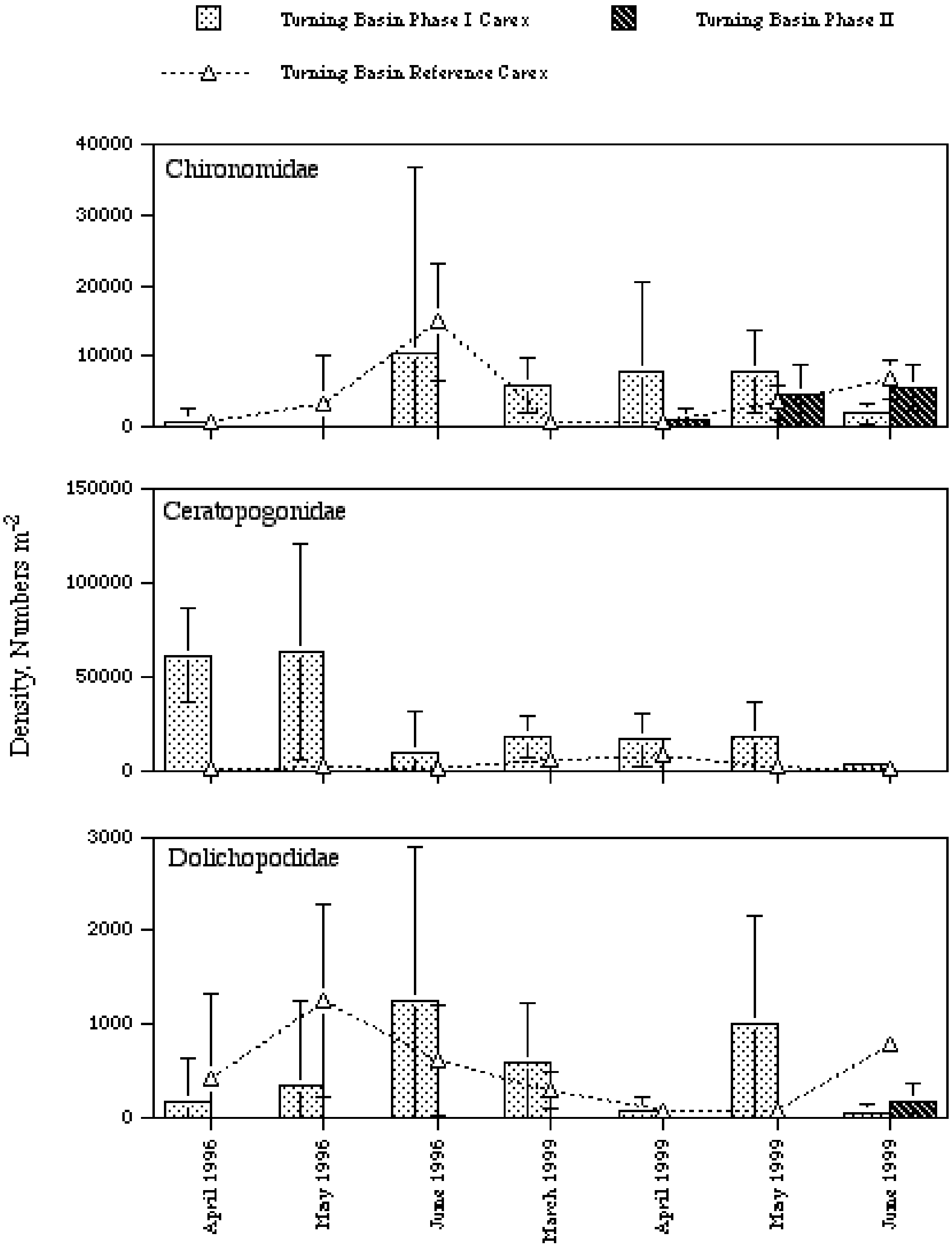


FIGURE 23. Densities of ecologically dipteran fly larvae from benthic core samples taken at upper Duwamish Waterway Coastal America restoration and reference vegetated sites, April 1996- June 1999. Vertical lines are 95% confidence intervals.

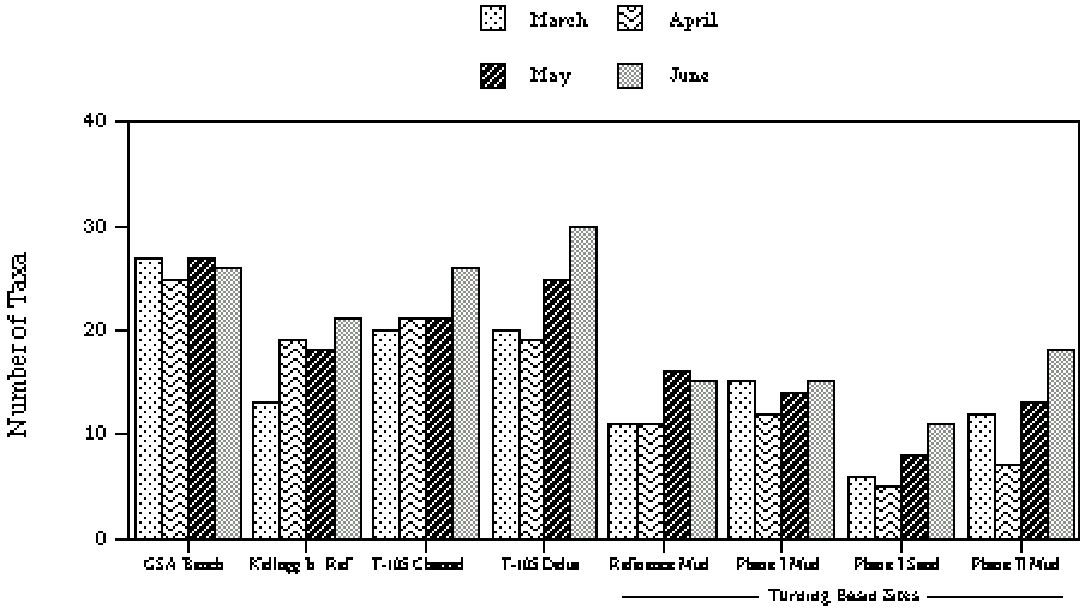


FIGURE 24. Taxa richness, 1999, for benthic meiofauna from mud/sand habitats at reference and restoration sites in the Duwamish Waterway.

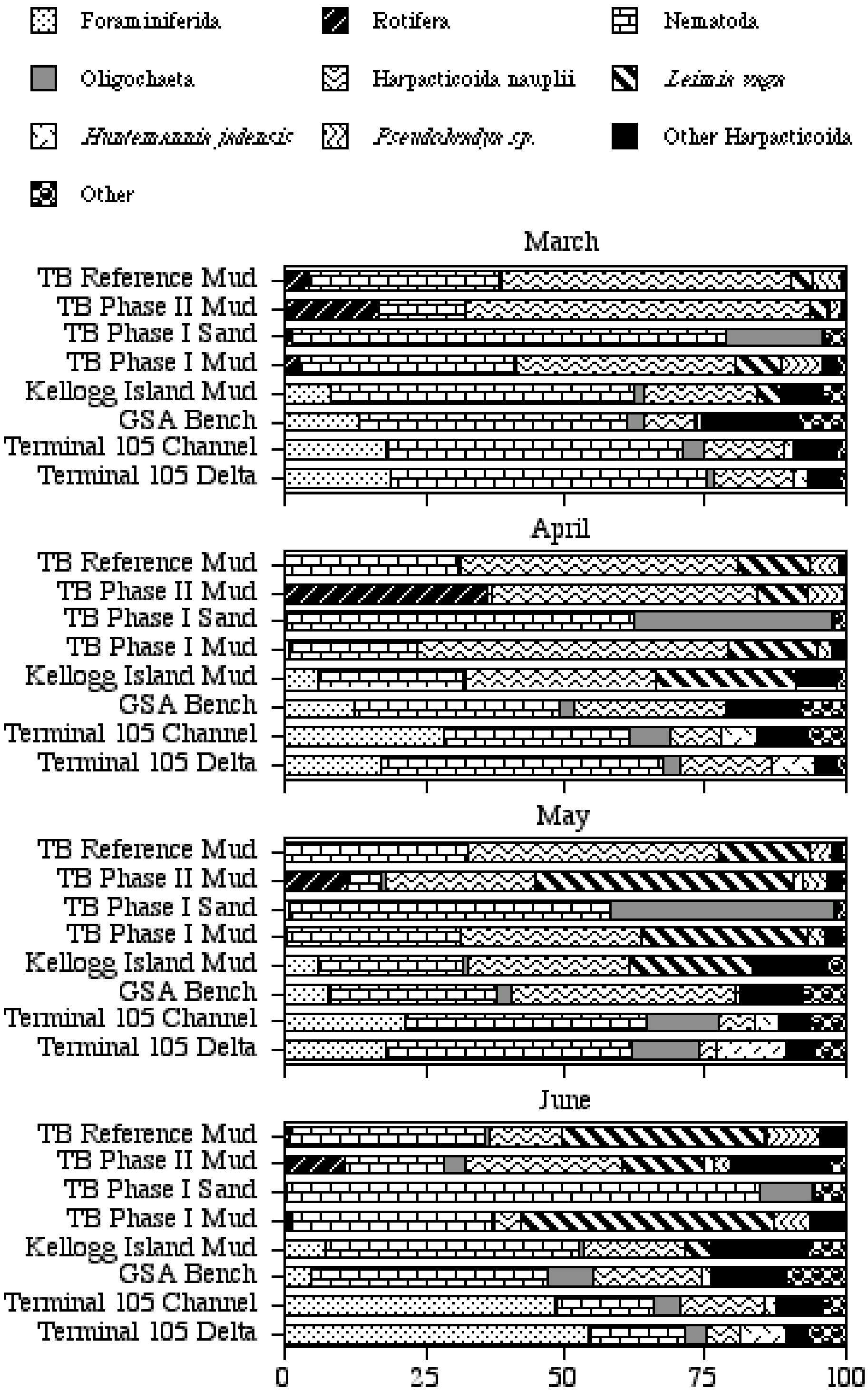


FIGURE 25. Percent numerical composition of meiofaunal invertebrates from core samples taken at Coastal America restoration and reference sites, April–June 1999.

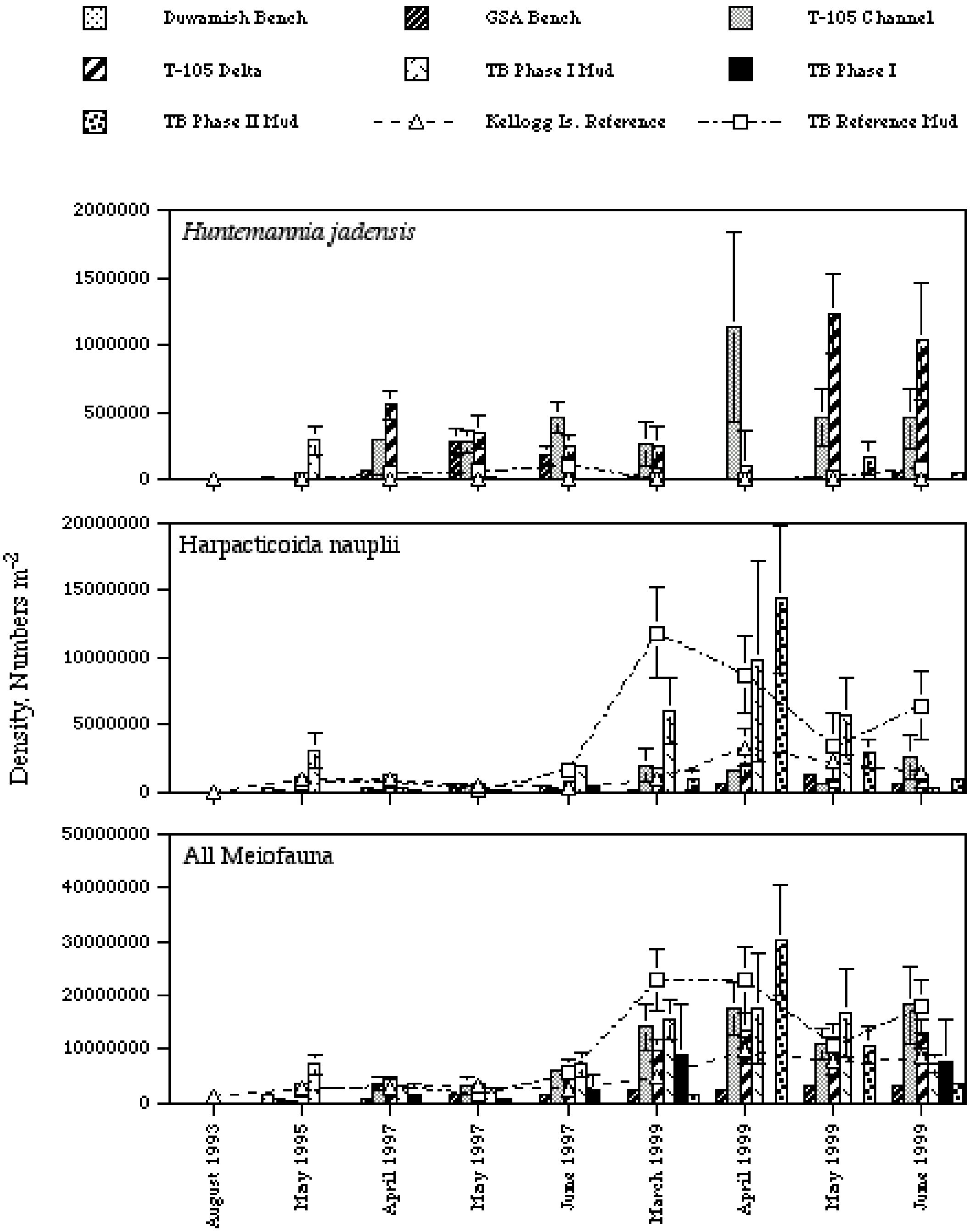


FIGURE 26. Densities of total meiofaunal invertebrates, harpacticoid copepod nauplii, and the harpacticoid *Huntemannia jadensis*, core samples taken at Duwamish Waterway Coastal America restoration and reference mud and sand sites, August 1993- June 1999. Vertical lines are 95% confidence intervals.\

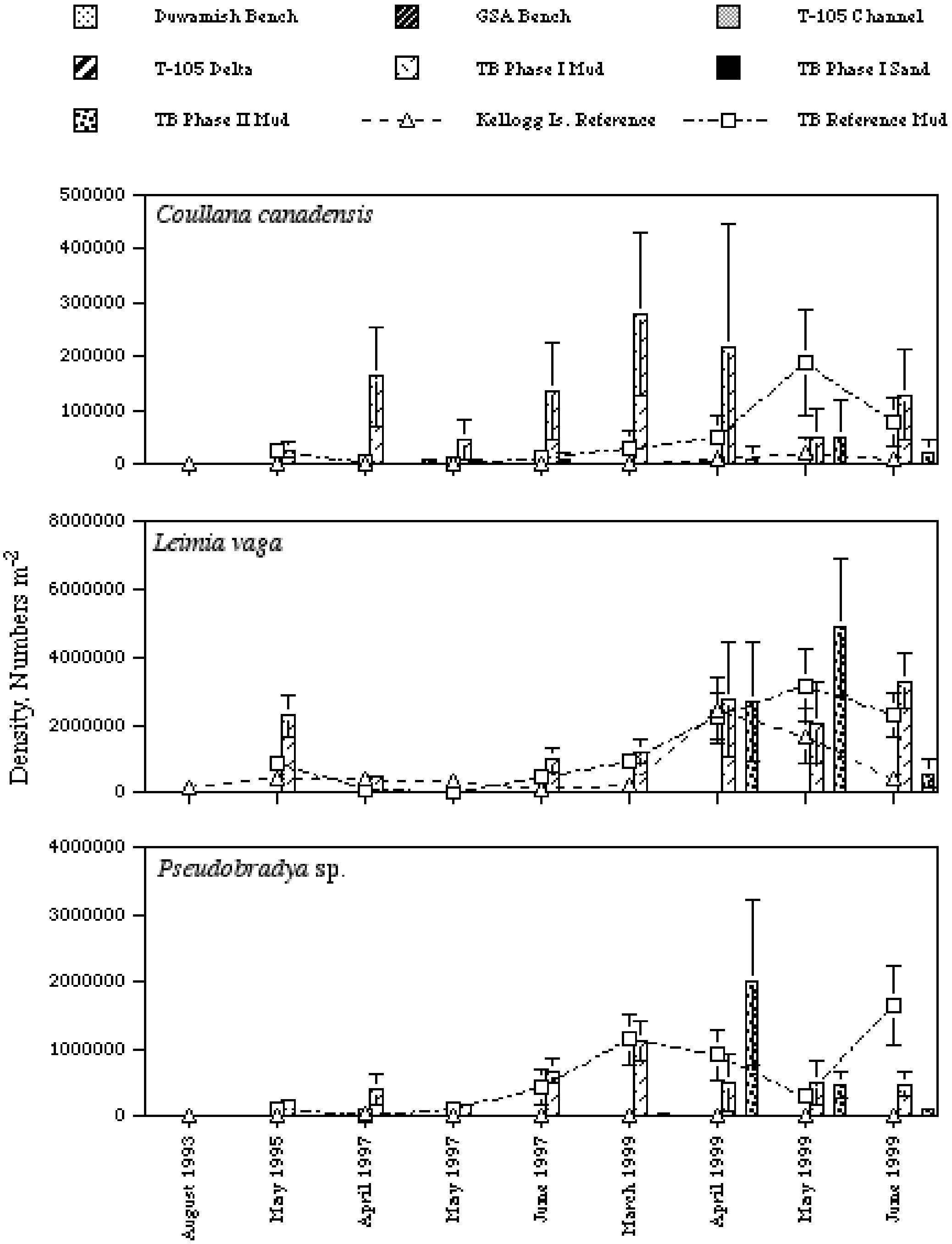


FIGURE 27. Densities of other ecologically important harpacticoid copepods from core samples taken at Duwamish Waterway Coastal America restoration and reference mud and sand sites, August 1993- June 1999. Vertical lines are 95% confidence intervals.

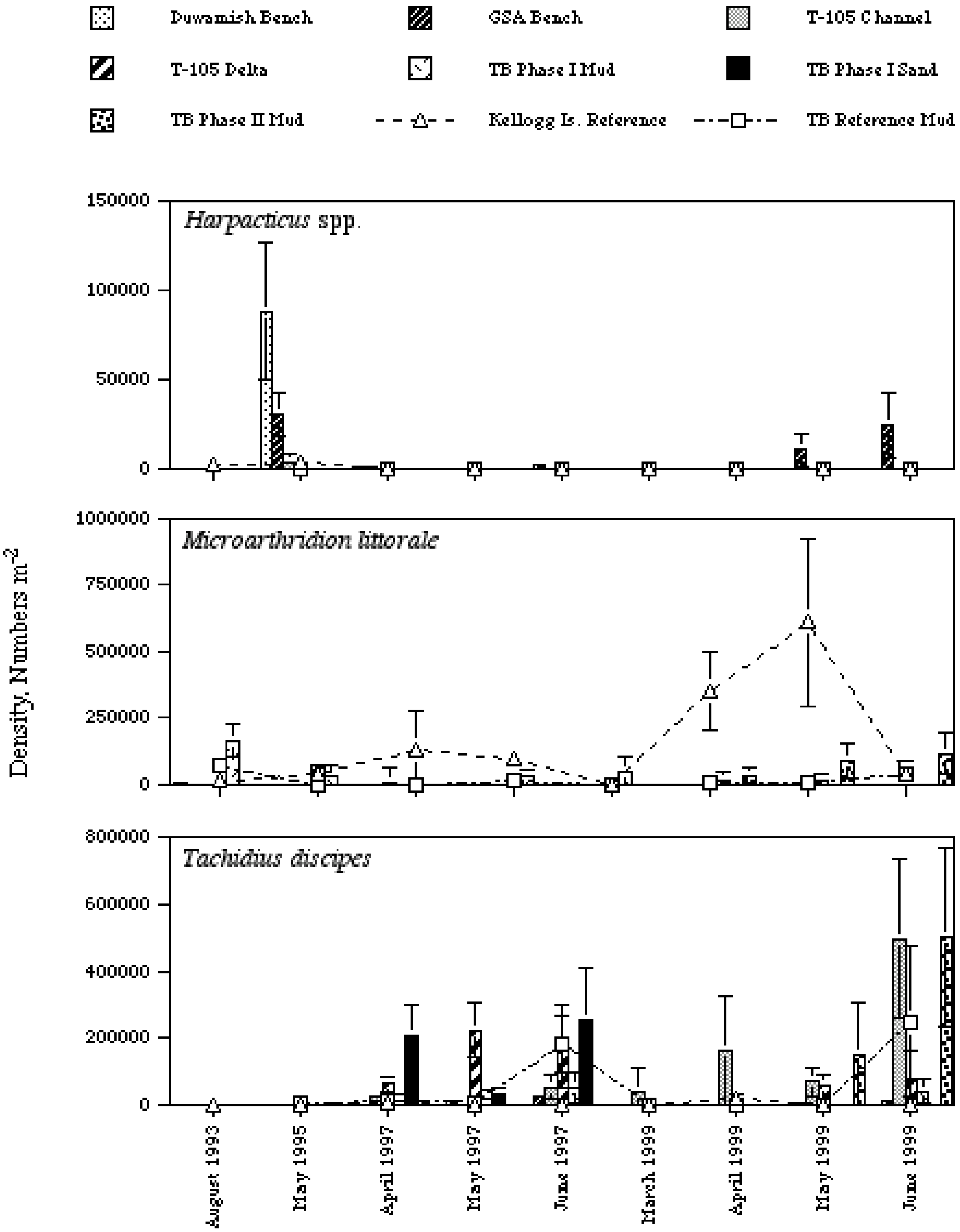


FIGURE 28. Densities of other ecologically important harpacticoid copepods from core samples taken at Duwamish Waterway Coastal America restoration and reference mud and sand sites, August 1993- June 1999. Vertical lines are 95% confidence intervals.

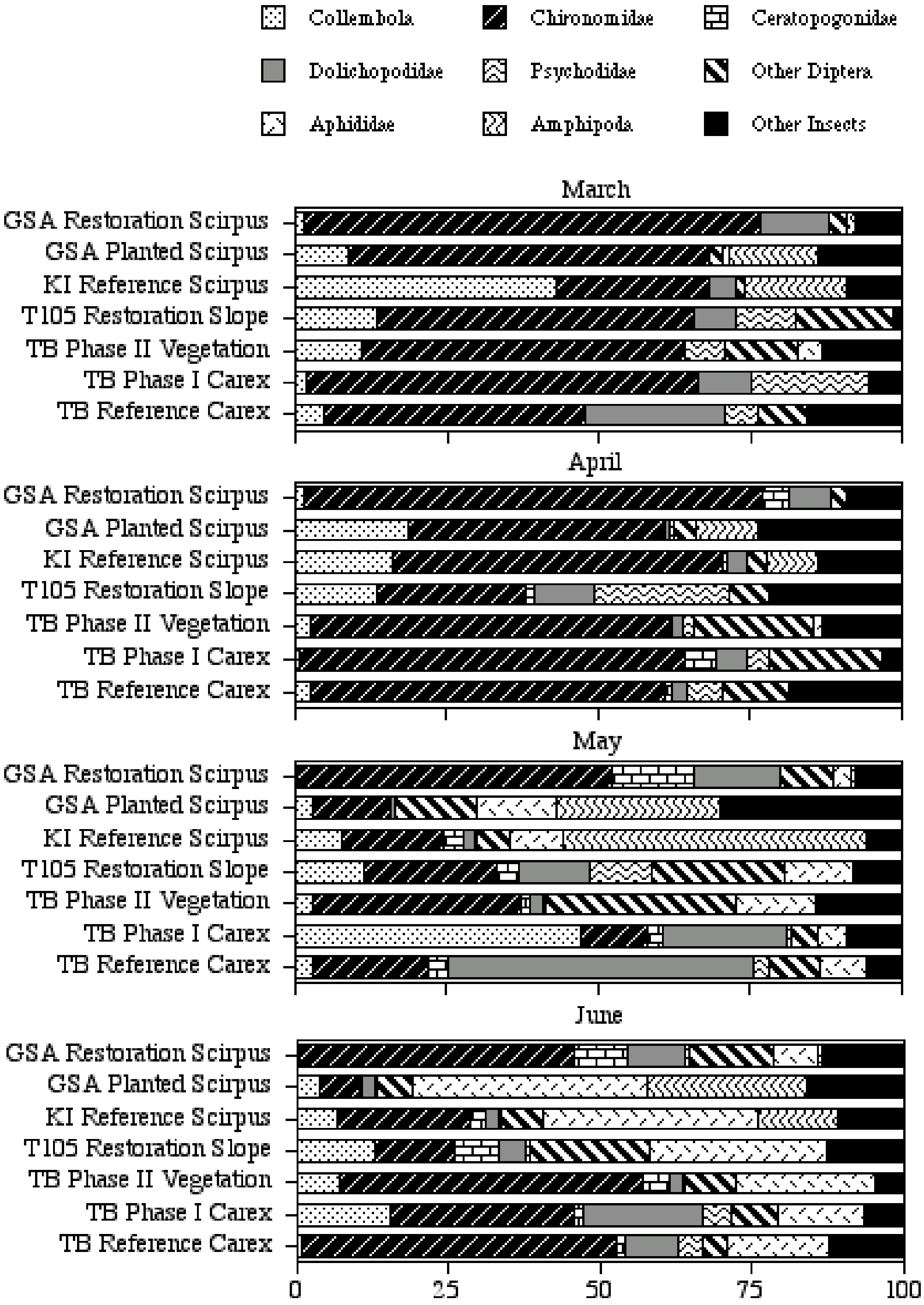


FIGURE 29. Percent numerical composition of invertebrates from insect fallout traps deployed at Coastal America restoration and reference sites, April–June 1999.

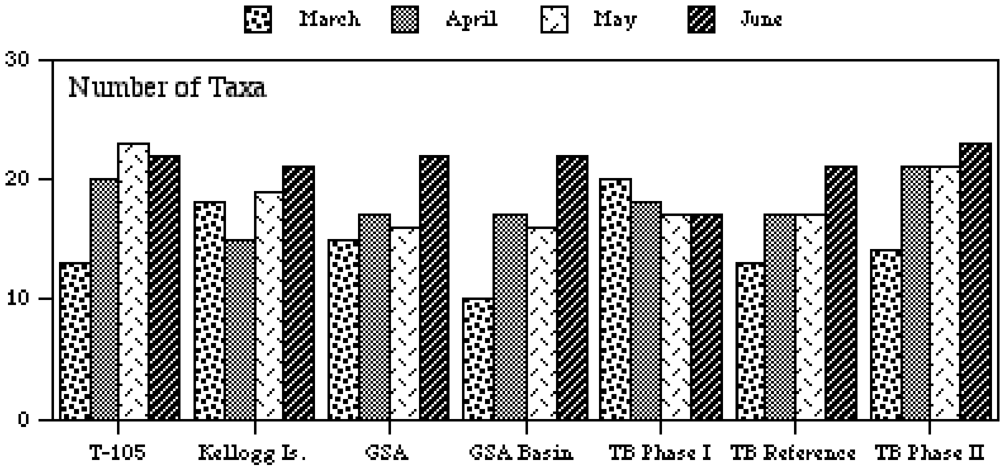


FIGURE 30. Taxa richness from insect fallout trap samples deployed at Coastal America restoration and reference sites, March–June 1999.

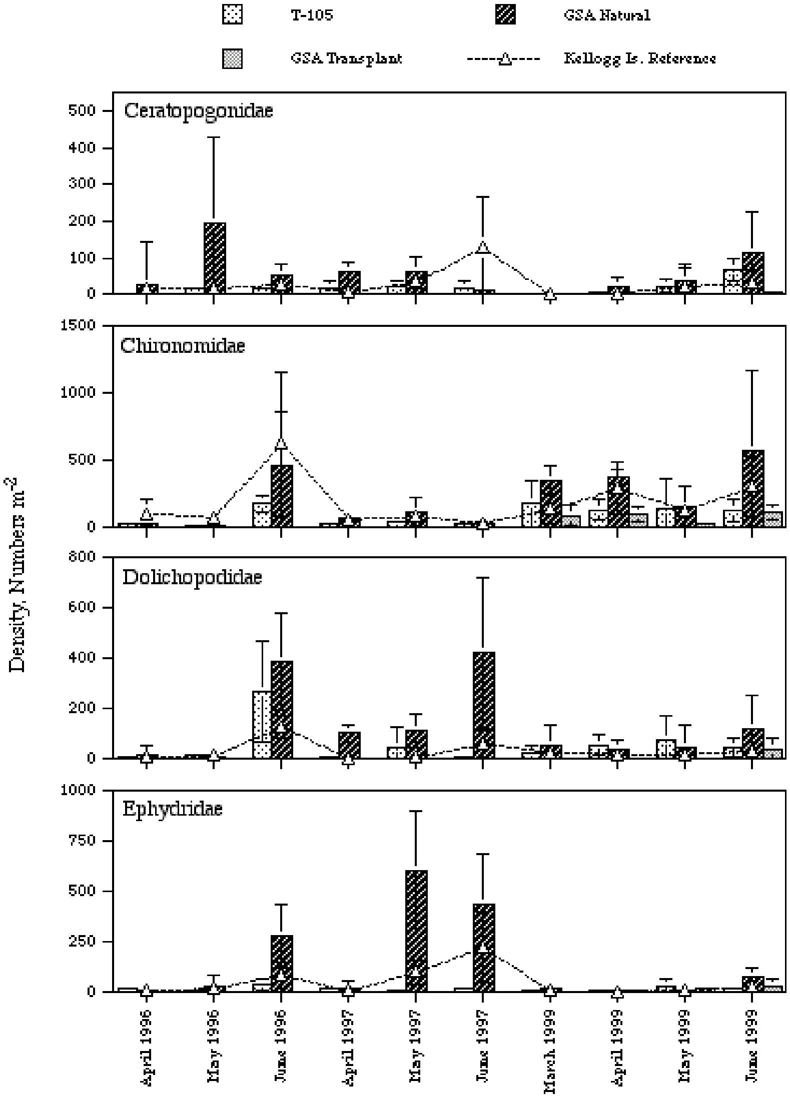


FIGURE 31. Densities of ecologically important adult dipteran flies from fallout trap samples taken at lower Duwamish Waterway Coastal America restoration and reference vegetated strata, April 1996- June 1999. Vertical lines are 95% confidence intervals.

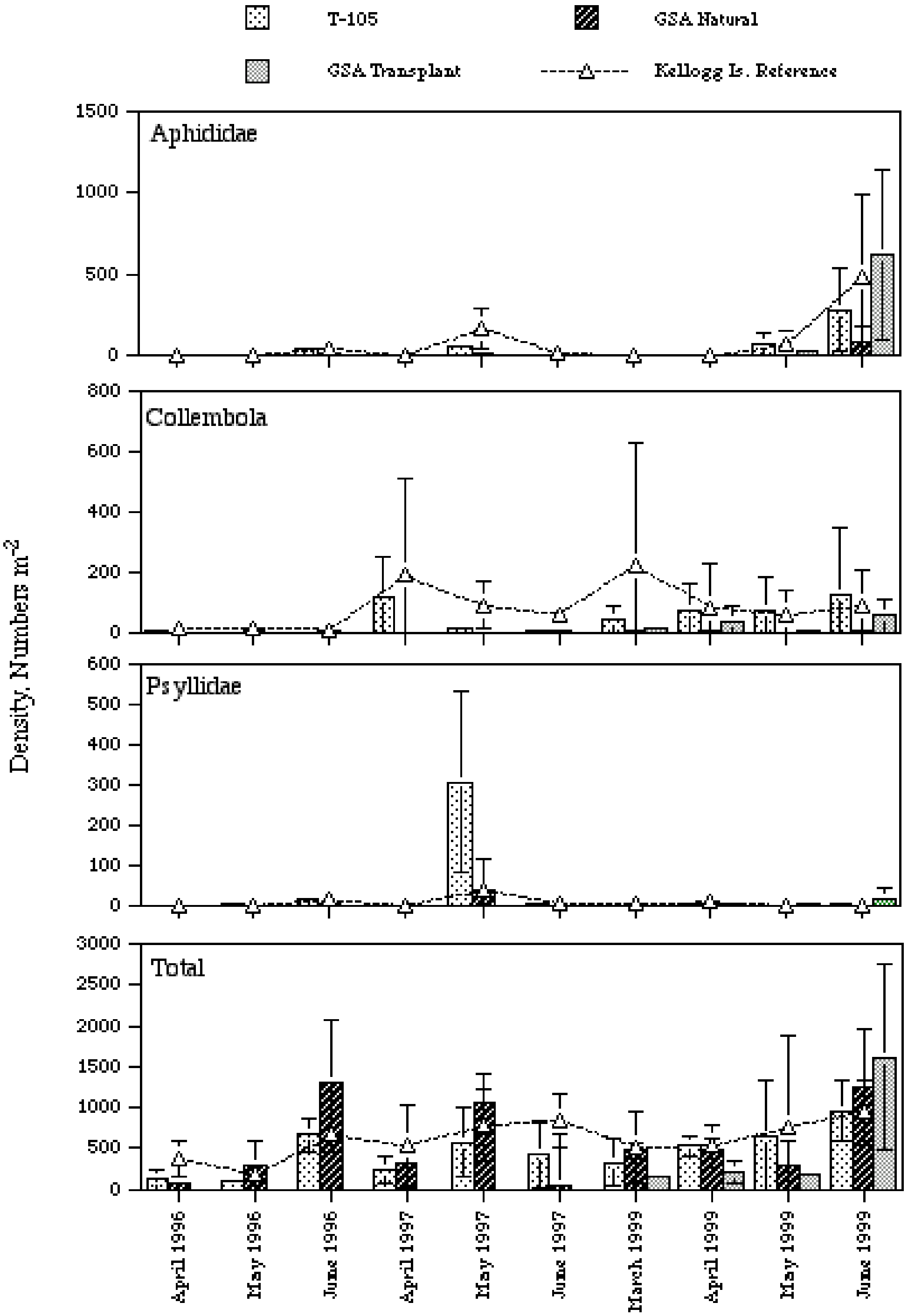


FIGURE 32. Densities other ecologically important insects from fallout trap samples taken at lower Duwamish Waterway Coastal America restoration and reference vegetated strata, April 1996- June 1999. Vertical lines are 95% confidence intervals.

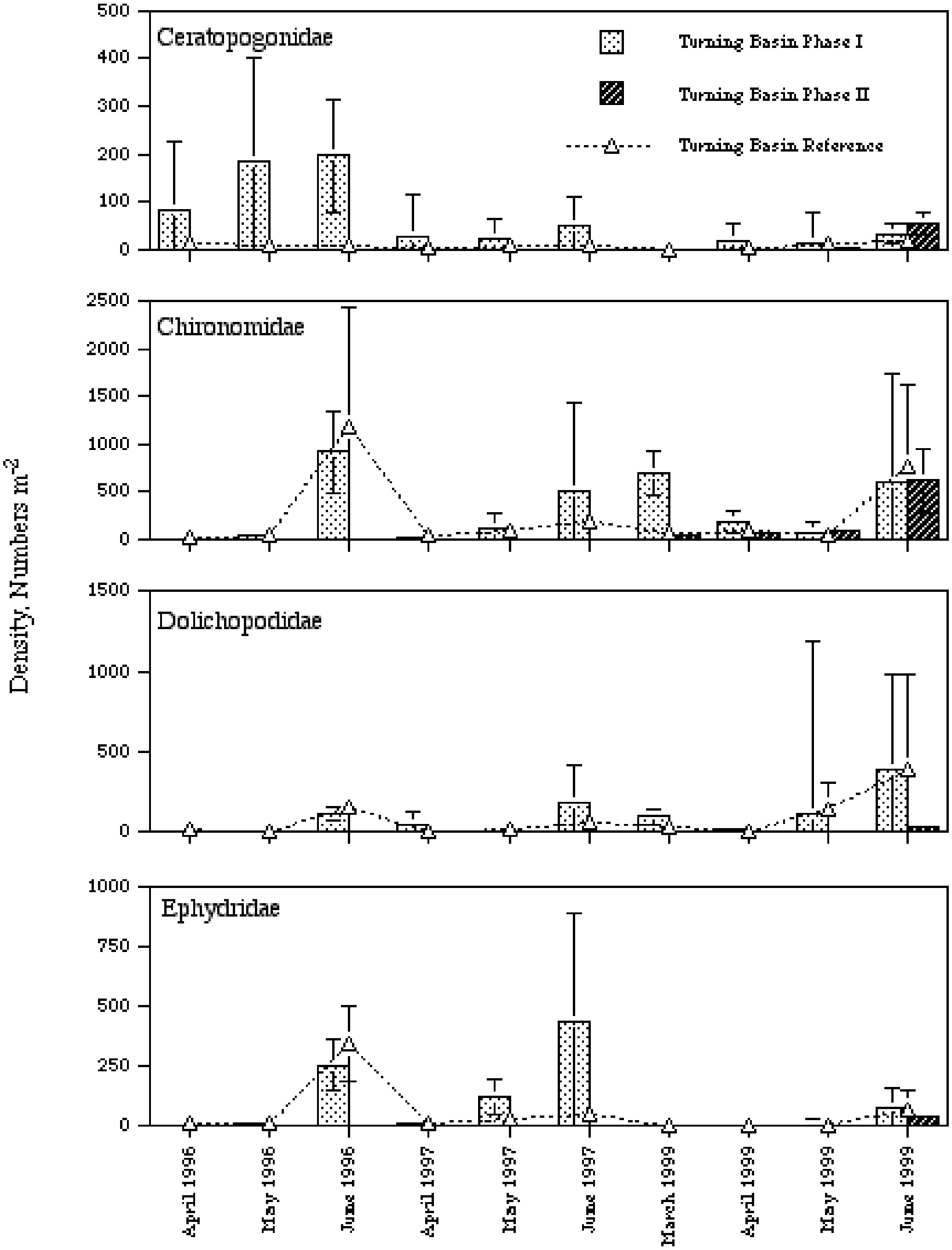


FIGURE 33. Densities of ecologically important adult dipteran flies from fallout trap samples taken at upper Duwamish Waterway Coastal America restoration and reference vegetated strata, April 1996- June 1999. Vertical lines are 95% confidence intervals.

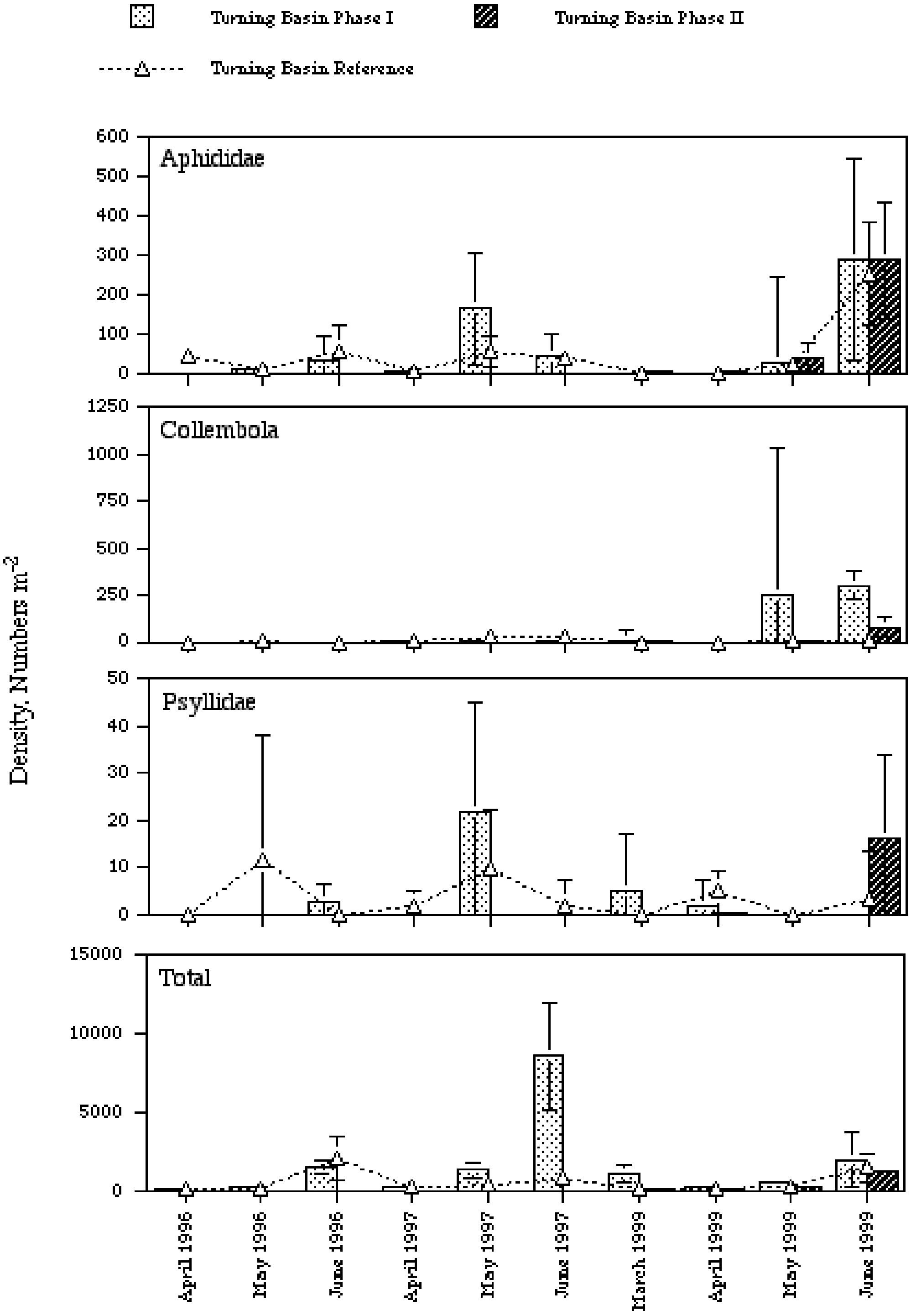


FIGURE 34. Densities of other ecologically important insects from fallout trap samples taken at upper Duwamish Waterway Coastal America restoration and reference vegetated strata, April 1996- June 1999. Vertical lines are 95% confidence intervals.

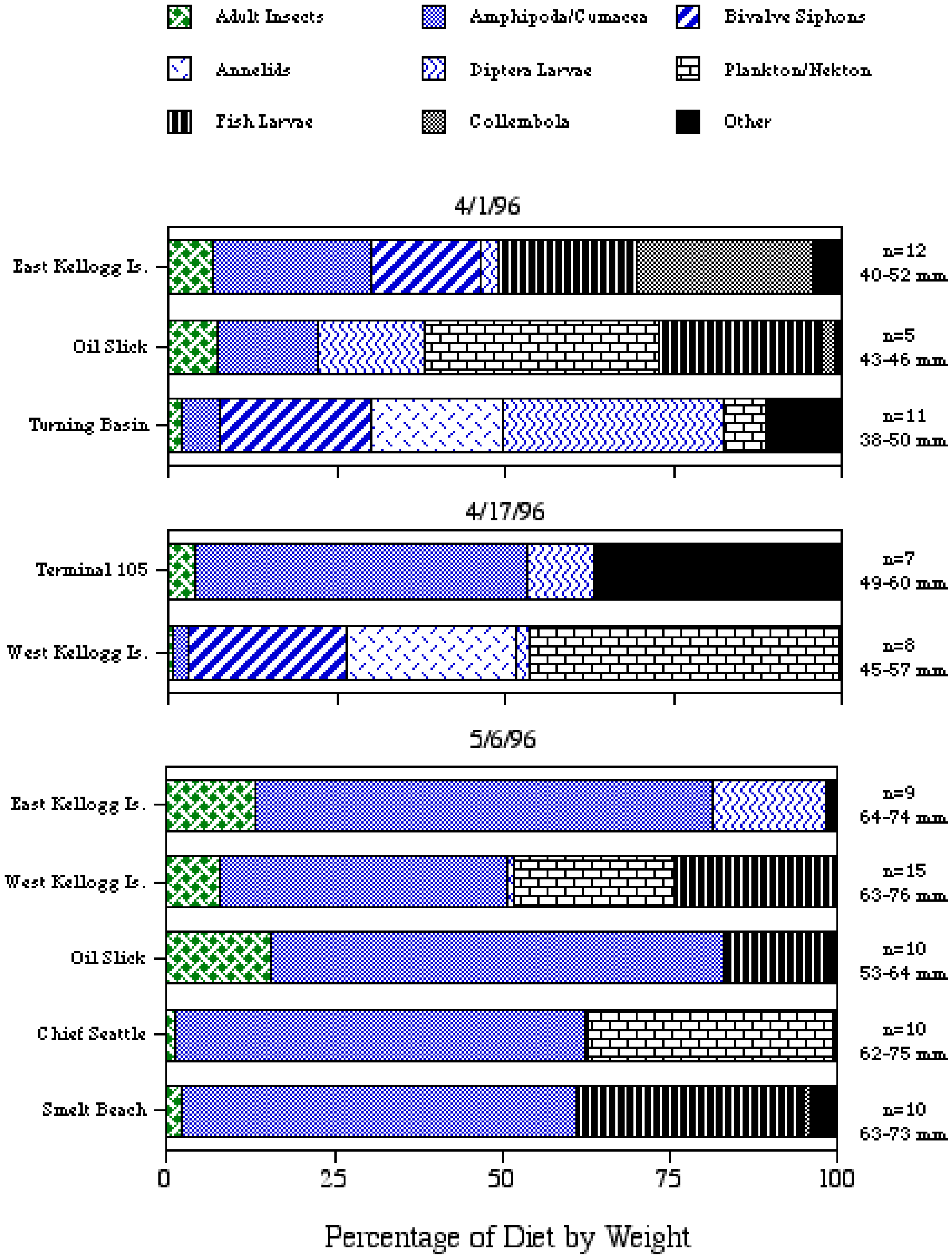


FIGURE 35. Diet composition of juvenile chinook salmon captured in the Duwamish Waterway, April-May 1996. Green patterns indicate prey derived from terrestrial sources, blue from benthic sources, and black and white from undetermined sources and zooplankton.

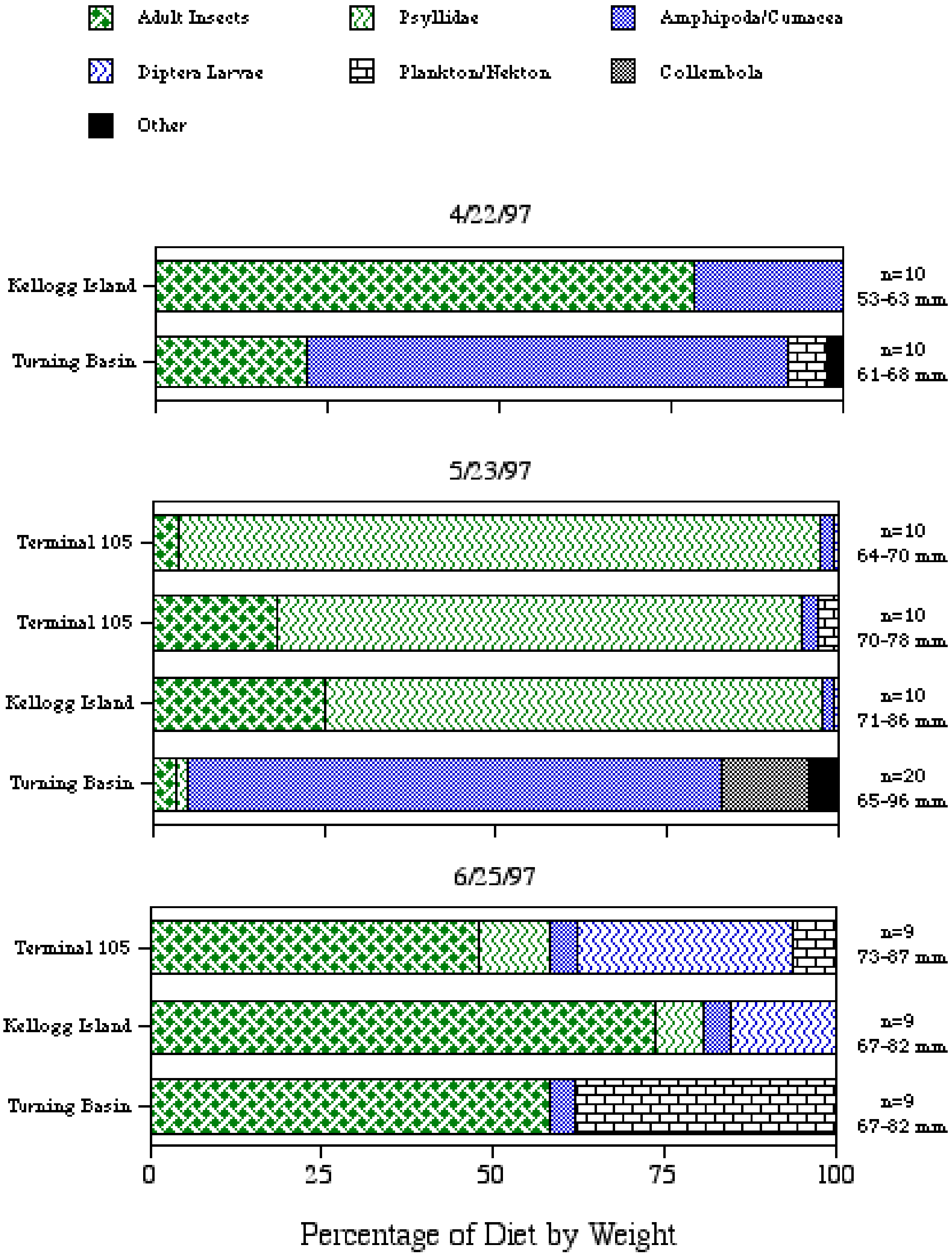


FIGURE 36. Diet composition of juvenile chinook salmon captured in the Duwamish Waterway, April-June 1997. Green patterns indicate prey derived from terrestrial sources, blue from benthic sources, and black and white from undetermined sources and zooplankton.

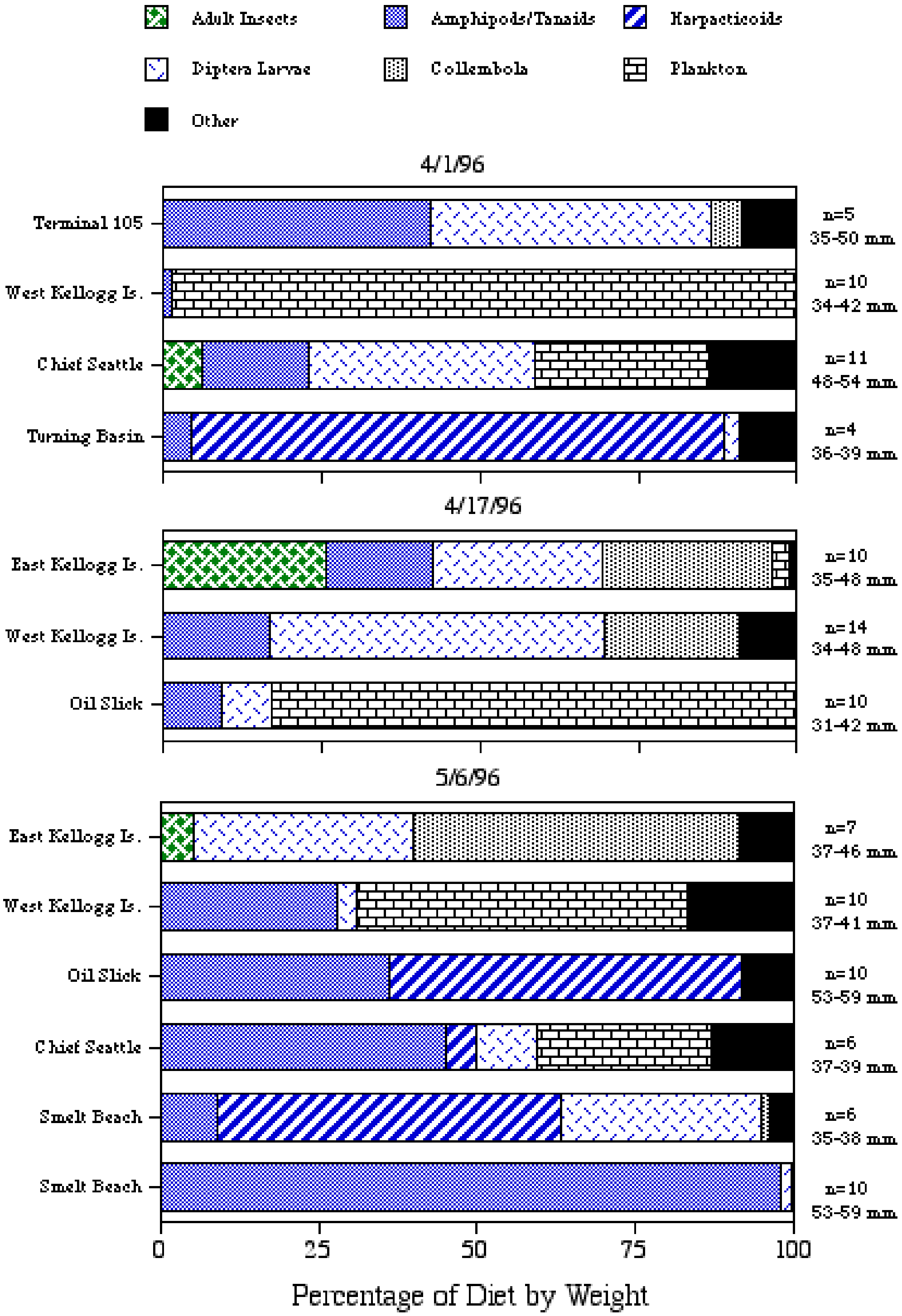


FIGURE 37. Diet composition of juvenile chum salmon captured in the Duwamish Waterway, April-May 1996. Green patterns indicate prey derived from terrestrial sources, blue from benthic sources, and black and white from undetermined sources and zooplankton.

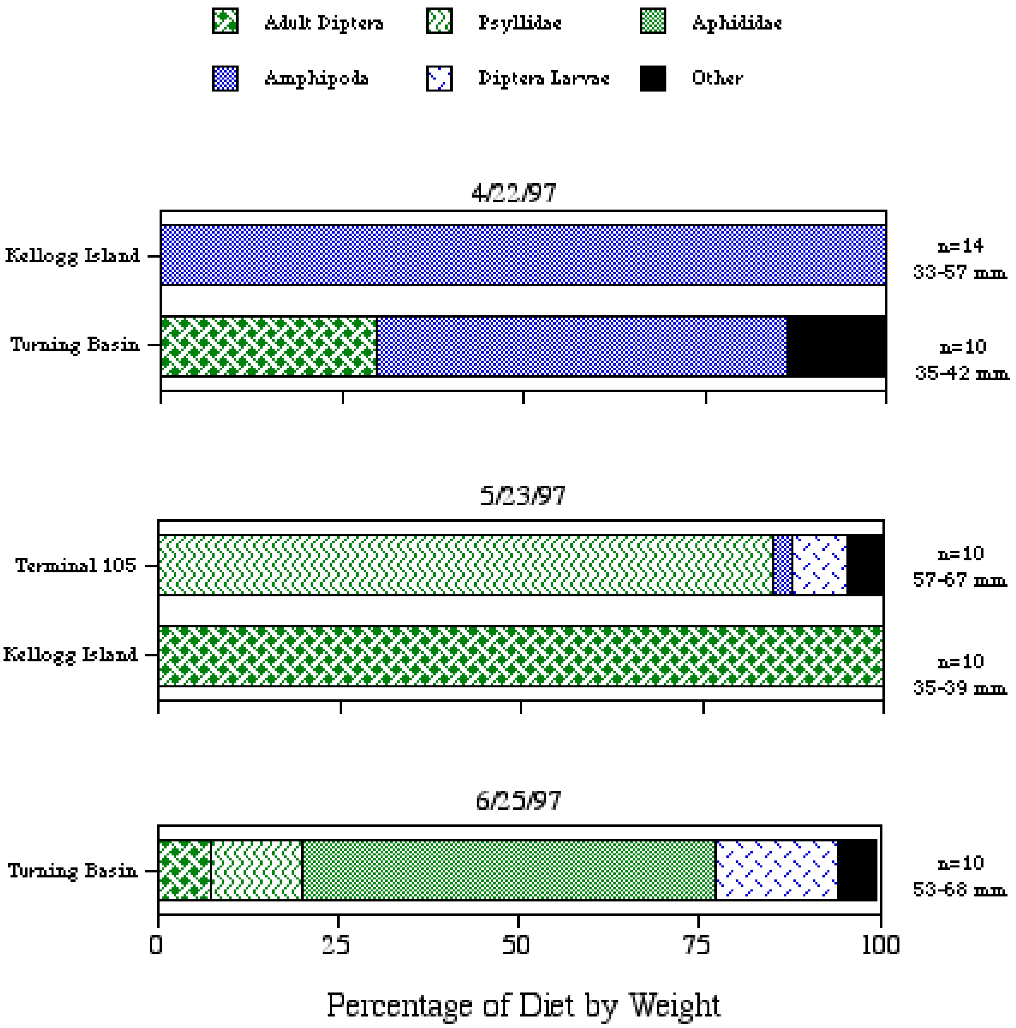


FIGURE 38. Diet composition of juvenile chum salmon captured in the Duwamish Waterway, April-June 1997. Green patterns indicate prey derived from terrestrial sources, blue from benthic sources, and black and white from undetermined sources and zooplankton.

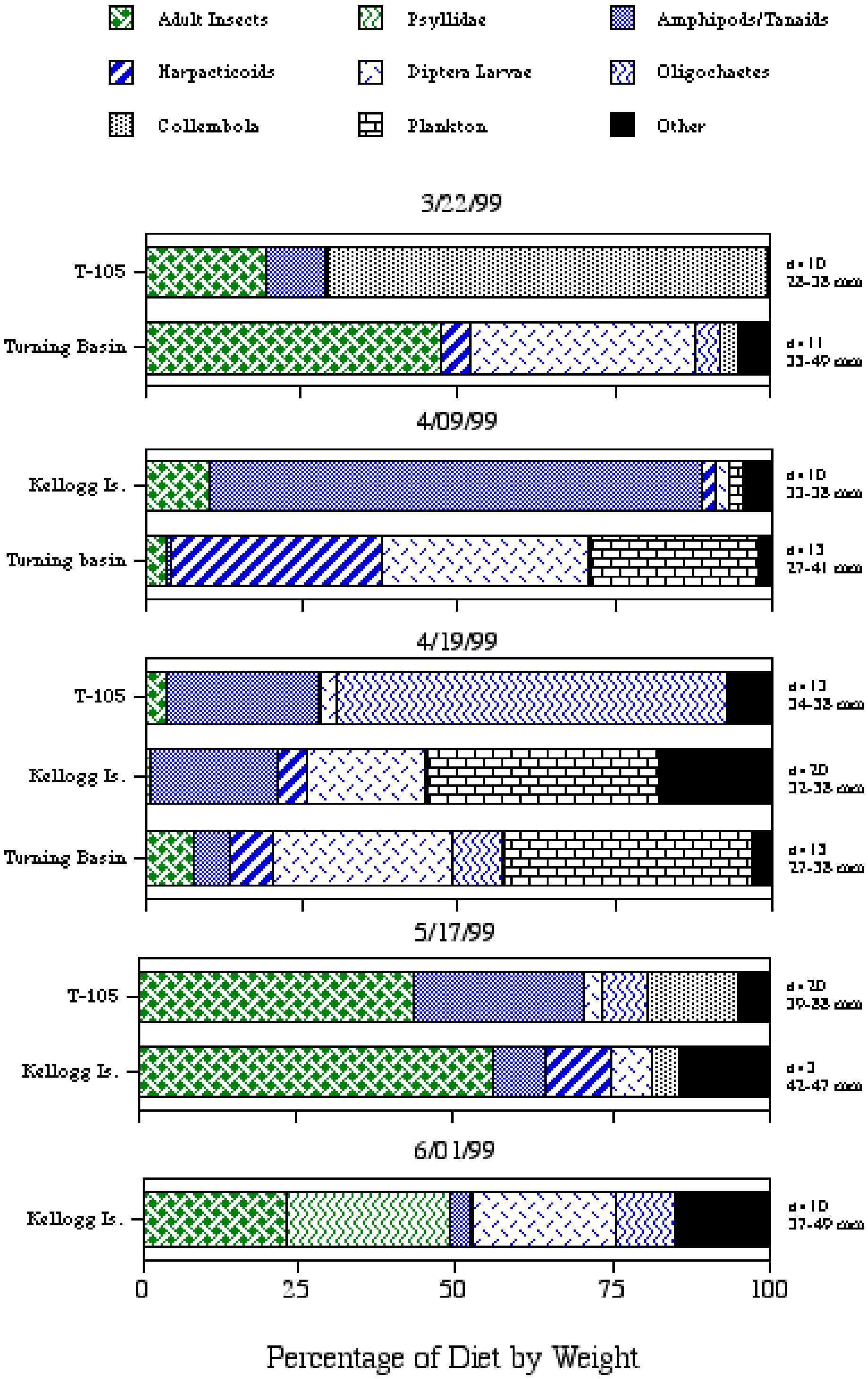


FIGURE 39. Diet composition of juvenile chum salmon captured in the Duwamish Waterway, March-June 1999. Green patterns indicate prey derived from terrestrial sources, blue from benthic sources, and black and white from undetermined sources and zooplankton.

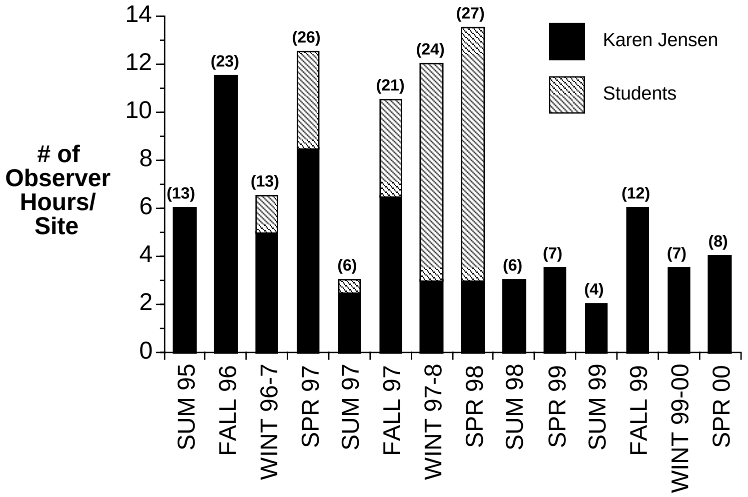


FIGURE 40. Observer effort for 14 seasons of data collection at four sites on the Duwamish waterway. (N) = # of visits/site.

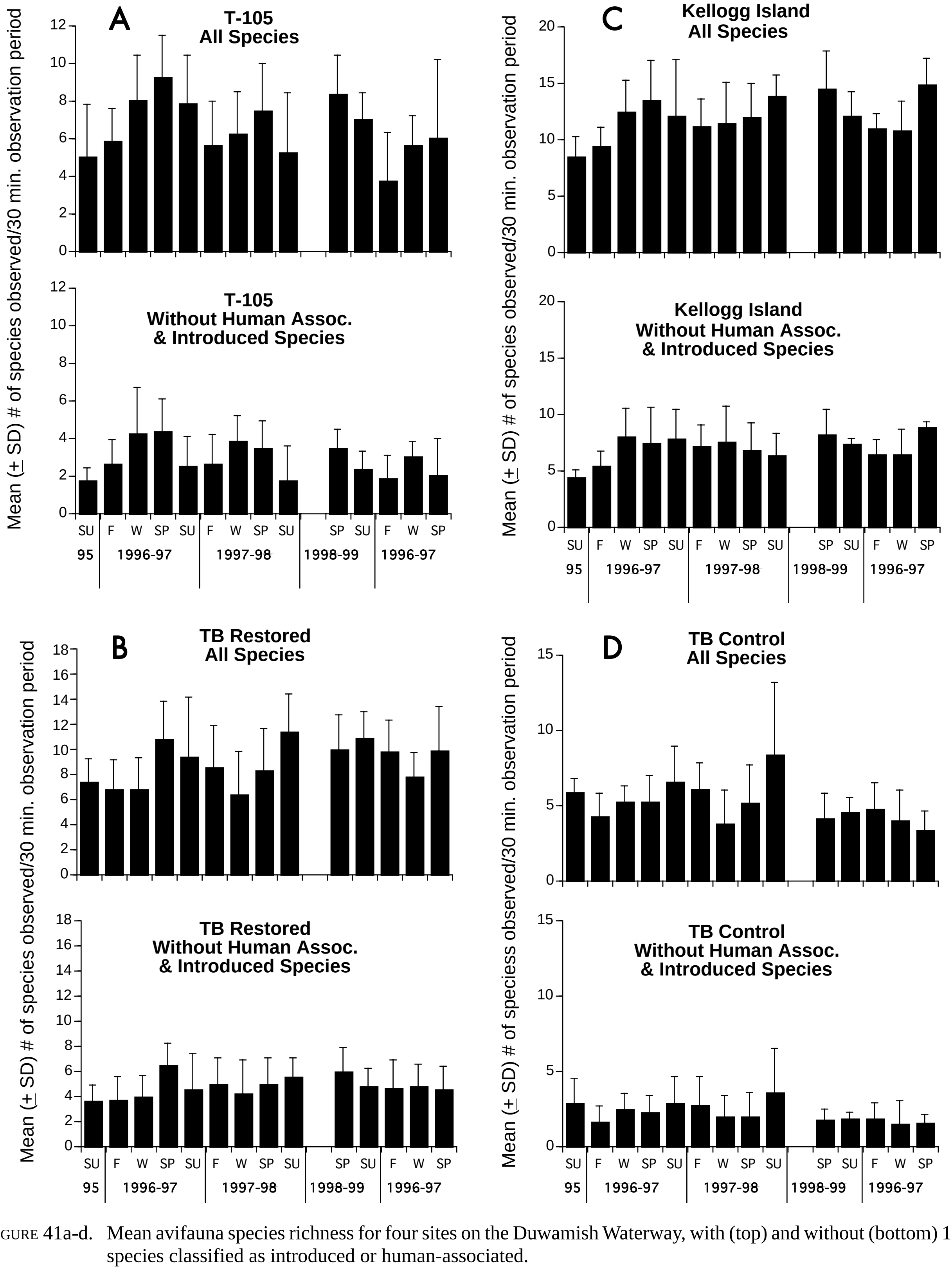


FIGURE 41a-d. Mean avifauna species richness for four sites on the Duwamish Waterway, with (top) and without (bottom) 14 species classified as introduced or human-associated.

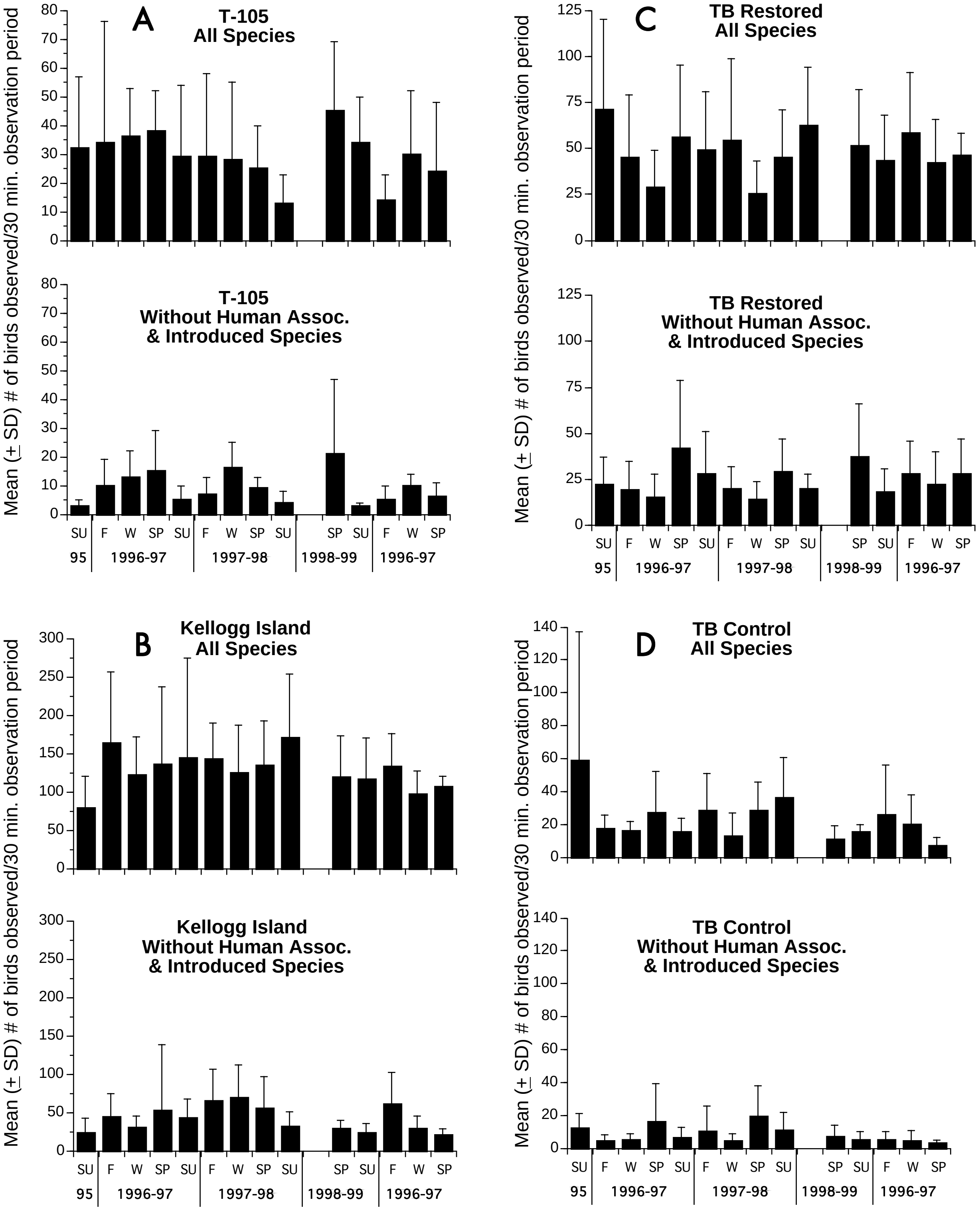


Figure 42a-d. Mean avifauna abundance for four sites on the Duwamish Waterway, with (top) and without (bottom) 14 species classified as introduced or human-associated.

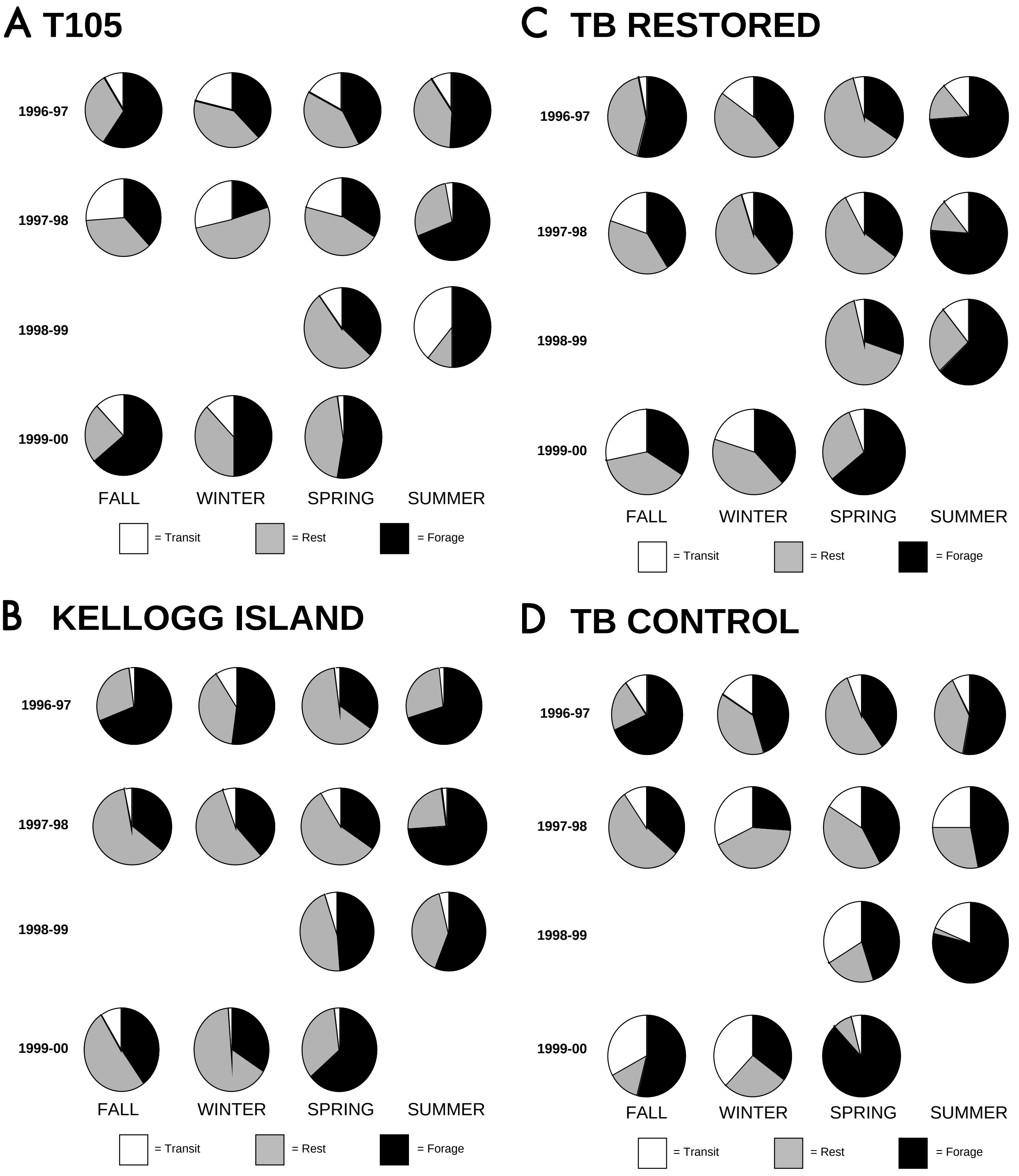
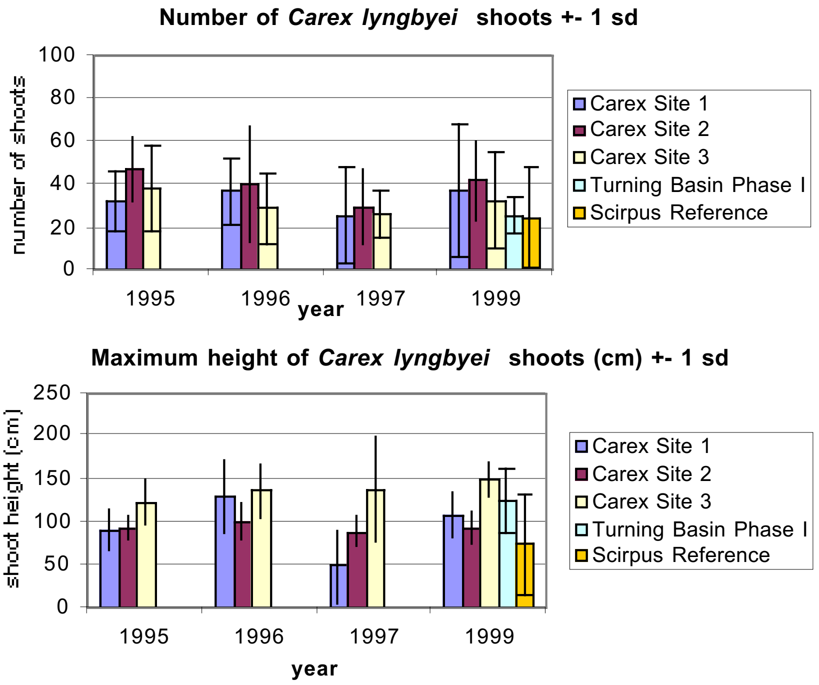


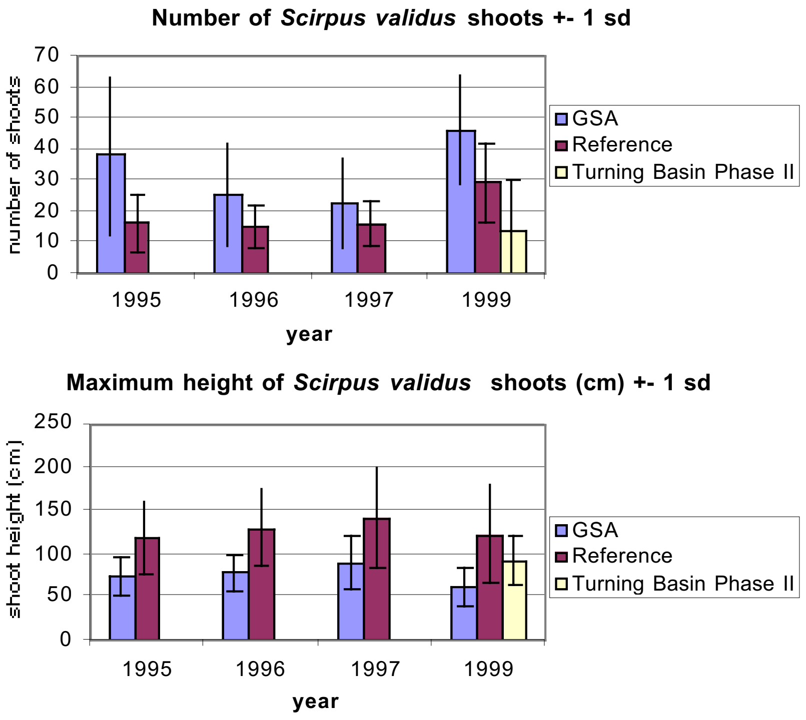
FIGURE 43a-d. Behavior of birds using four sites on the Duwamish Waterway. Data represents percent of sightings within site, season and year for all seasons.



Number of *Carex lyngbyei* shoots +- 1 sd

Maximum height of *Carex lyngbyei* shoots (cm) +- 1 sd

Figure 44. Shoot density and maximum shoot height ± 1 standard deviation of *Carex lyngbyei* at sampling sites in Duwamish Waterway. Only quadrats with Carex present used in calculations.



Number of *Scirpus validus* shoots +- 1 sd

Maximum height of *Scirpus validus* shoots (cm) +- 1 sd

Figure 45. Shoot density and maximum shoot height ± 1 standard deviation of *Scirpus validus* at sampling sites in the Duwamish Waterway.

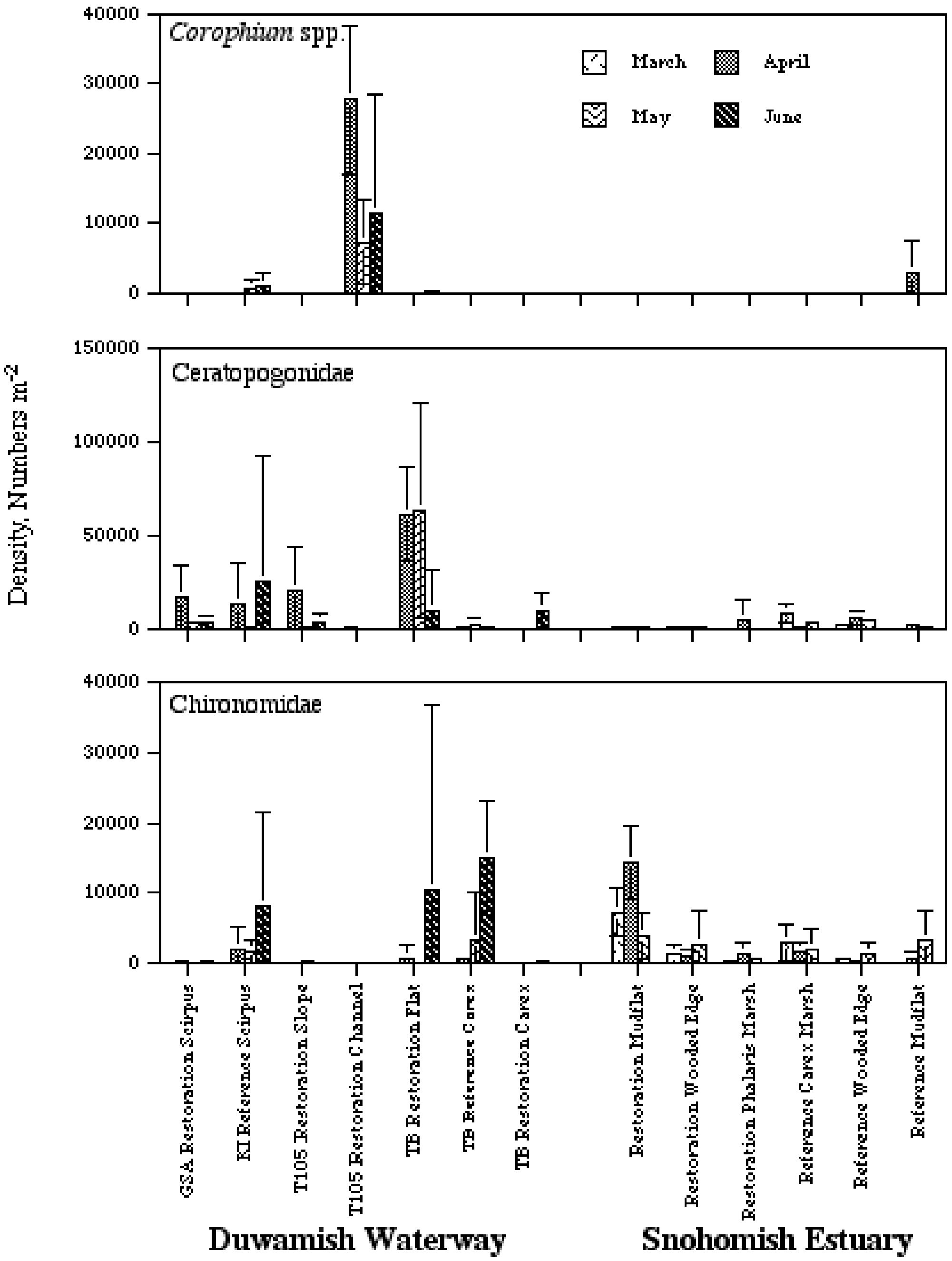


FIGURE 46. Comparison of density of three taxa of benthic invertebrates collected from various restored and reference habitats in the Duwamish Waterway and at Spencer Island, Snohomish River estuary, Washington, 1997.

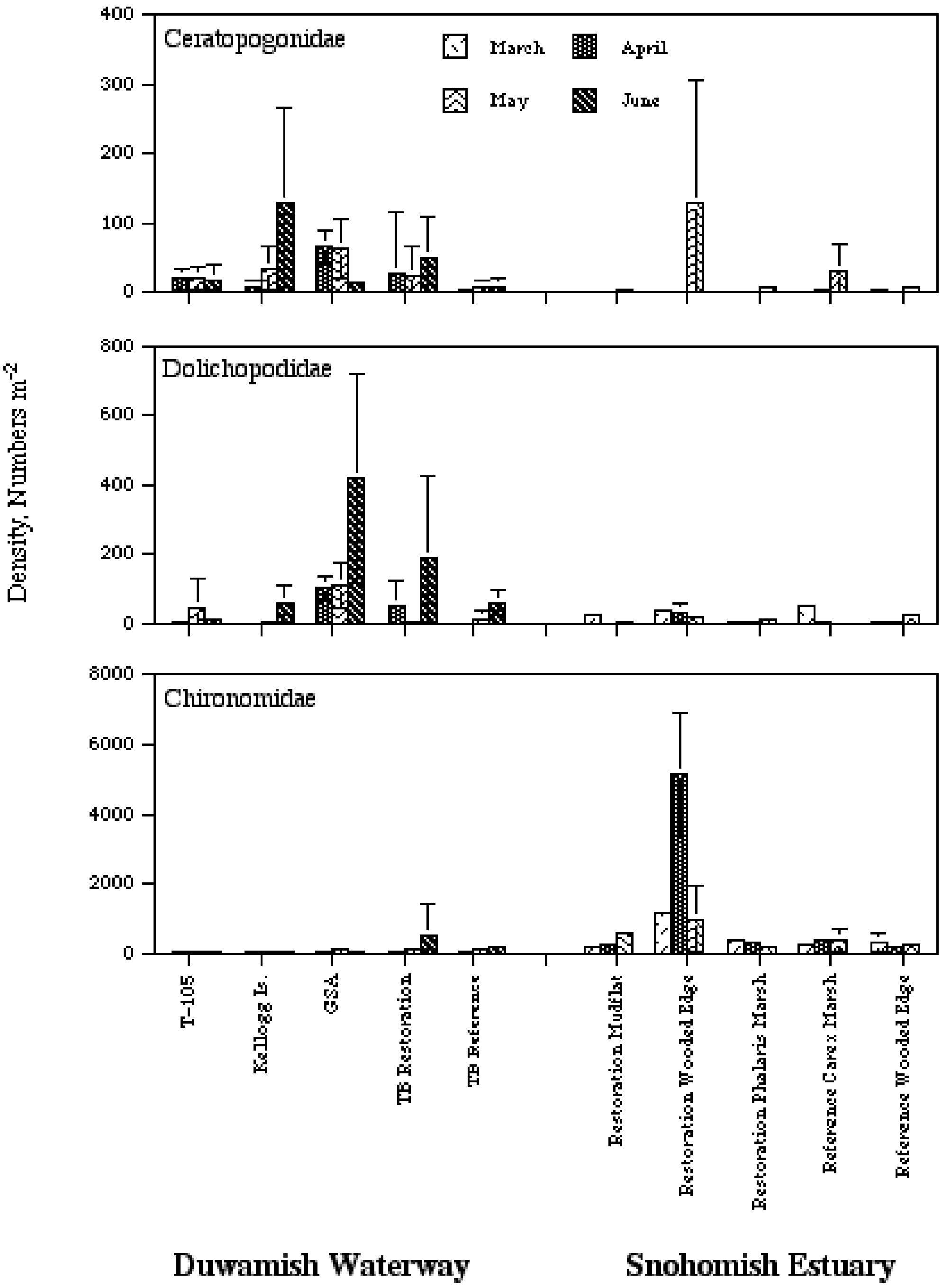


FIGURE 47. Comparison of density of three taxa of adult dipteran flies collected from various restored and reference habitats in the Duwamish Waterway and at Spencer Island, Snohomish River estuary, Washington, 1997.

Tables

TABLE 1. Sampling conducted at Duwamish Waterway Coastal America restoration and reference sites, 1993-99. [1]0-foot tide elevations sampled; [2]upper intertidal vegetated areas sampled.

Year	Benthic macrofauna	Benthic meiofauna	Sediment grain size	Insects	Avifauna	Emergent vegetation	Salmon diets
1993	April-July[1]	August	May	May-August		July-September	
1995	May[1]	May	May	July	June-September	August	
1996	April-June[2]			April-June	September-February	August	April-June
1997	April-June[1]	April-June		April-June	March-September	August	April-June
1999	March-June[1,2]	March-June	May	March-June	March 1999–May 2000		April-June

[1] 0-foot tide elevations sampled

[2] upper intertidal vegetated areas sampled.

TABLE 2. Benthic invertebrate sampling conducted at Duwamish Waterway Coastal America restoration and reference sites, 1993-99. Macro=macrofauna, meio=meiofauna. Sampling occurred monthly April-June, except in 1995 (May only) and 1999 (March-June).

	1993	1995	1996	1997	1999
GSA Sediment Bench		Macro, Meio		Macro, Meio	Macro, Meio
Lower Duwamish Sediment Bench		Macro, Meio			
GSA Vegetation			Macro		Macro
T-105 base of riprap	Macro, Meio				
T-105 upper sand flat				Macro, Meio	Macro, Meio
T-105 upper channel			Macro	Macro, Meio	Macro, Meio
T-105 vegetated slope			Macro		Macro
Kellogg Is. reference mud flat	Macro, Meio[1]	Macro, Meio		Macro, Meio	Macro, Meio
Kellogg Is. reference vegetation			Macro		Macro
Turning Basin reference mud flat	Macro, Meio[1]	Macro, Meio		Macro, Meio	Macro, Meio
Turning Basin reference vegetation			Macro		Macro
Turning Basin restoration mud flat		Macro, Meio		Macro, Meio	Macro, Meio
Turning Basin upper sand flat			Macro	Macro, Meio	Macro, Meio
Turning Basin vegetation			Macro		Macro

[1] Meiofauna sampled only in August.

TABLE 3. Fish captured by block seining the T-105 restored estuarine channel in 1997 and 1999. Fork lengths in mm for juvenile salmon are in parentheses.

Date	Chinook salmon	Chum salmon	Stag-horn sculpin	Shiner perch	Other fishes
23 May 1997	82 (76.0)	18 (62.9)	52	135	0
25 Jun 1997	5 (72.4)	0	350	216	5
19 Mar 1999	1 (50.0)	18 (36.4)	0	0	0
19 Apr 1999	0	518 (43.2)	25	0	2
17 May 1999	11 (77.1)	237 (43.6)	473	126	1
Total	99	791	900	477	8

TABLE 4. Bird species observed on the Duwamish waterway during fourteen seasons of data collection. Species re-sighted during 1999-2000 = bold text. New species sighted during 1999-2000 = italic text. Resident species are denoted with an asterisk. Introduced and native, but human associated species are categorized separately.

Guild	Species		Guild	Species	
PASSERINES:	**Fox Sparrow**	**FOSP***	**WATERFOWL:**	**American Coot**	**AMCO**
(25 Species)	Golden-crowned Sparrow	GCSP	(21 Species)	American Wigeon	AMWI
	Savannah Sparrow	SASP		Barrow's Goldeneye	BAGO
	Song Sparrow	**SOSP***		**Common Goldeneye**	**COGO**
	White-crowned Sparrow	**WCSP***		**Bufflehead**	**BUFF**
	Cliff Swallow	**CLSW**		Cackling Goose	CAGO
	Tree Swallow	**TRSW**		**Canvasback**	**CANV**
	Violet-green Swallow	**VGSW**		Green-winged Teal	GWTE
	Purple Martin	*PUMA*		**Gadwall**	**GADW**
	American Goldfinch	**AMGO***		*Northern Pintail*	*NOPI*
	Anna's Hummingbird	ANHU		*Shoveler*	*SHOV*
	Bewick's Wren	**BEWR**		**Horned Grebe**	**HOGR**
	House Wren	**HOWR**		**Eared Grebe**	**EAGR**
	Black-capped Chickadee	**BCCH***		**Pied-billed Grebe**	**PBGR**
	Bushtit	**BUSH***		Red-necked Grebe	RNGR
	Dark-eyed Junco	DEJU		**Western Grebe**	**WEGR**
	Northern Flicker	**NOFL**		**Pacific Loon**	**PALO**
	Northern Shrike	NOSH		Red-throated Loon	RTLO
	Orange-crowned Warbler	OCWA		**Common Merganser**	**COME**
	Yellow-rumped Warbler	*YRWA*		**Hooded Merganser**	**HOME**
	Pine Sisken	PISI		**Red-breasted Merganser**	**RBME***
	Red-winged Blackbird	**RWBL***			
	Ruby-crowned Kinglet	RCKI	**SEABIRDS:**	**Caspian Tren**	**CATE**
	Rufous-sided Towhee	**RSTO**	(4 Species)	**Double-crested Cormorant**	**DCCO***
	Swainson's Thrush	SWTH		**Mew Gull**	**MEGU***
				Pigeon Guillemot	PIGU
RAPTORS:	**Bald Eagle**	**BAEA**		Ring-billed Gull	RBGU
(7 Species)	Cooper's Hawk	COHA			
	Merlin	MERL	**INTRODUCED:**	**Brown-headed Cowbird**	**BHCO**
	Osprey	**OSPR**	(7 Species)	**California Quail**	**CAQU**
	Red-tailed Hawk	**RTHA**		**Domestic Duck**	**DODU**
	Sharp-shinned hawk	SSHA		Domestic Goose	DOGO
	Swainson's Hawk	SWHA		**English Sparrow**	**ENSP***
				European Starling	**EUST***
SHOREBIRDS/	**Dowitcher**	**DOWI**		**House Finch**	**HOFI***
WADERS:	Dunlin	DUNL			
(9 Species)	**Great Blue Heron**	**GBHE***	**NATIVE, BUT**	**Barn Swallow**	**BASW**
	Green-backed Heron	GBHE	**HUMAN ASSOC.**	**American Robin**	**AMRO***
	Killdeer	**KILL***	(7 Species)	**Rock Dove**	**RODO***
	Lesser Yellowlegs	LEYE		**Northwestern Crow**	**NOCR***
	Sanderling	SAND		**Mallard**	**MALL***
	Spotted Sandpiper	**SPSA**		**Canada Goose**	**CAGE***
	Belted Kingfisher	**BEKI**		**Glaucous-winged Gull**	**GWGU***

TABLE 5. Mean annual bird abundance and richness at four sites on the Duwamish waterway.

	T-105	Kellog	TB restored	TB control
	ANNUAL RICHNESS (Mean ± S.D.)			
1997 09/96-08/97	7.7±1.4	11.8±1.8	8.4±2.0	5.3±0.9
1998 09/97-08/98	6.1±1	12.1±1.2	8.6±2.1	5.8±1.9
1999 03/99-08/99	7.8±1.9	13.5±3.1	10.2±2.5	4.1±1.7
2000 09/99-05/00	5.5±2.5	11.3±2.5	8.4±2.5	4.0±1.8
	ANNUAL ABUNDANCE (Mean ± S.D.)			
1997 09/96-08/97	35±4	141±17	45±11	19±6
1998 09/97-08/98	24±7	143±20	47±16	26±10
1999 03/99-08/99	41±21	118±51	48±28	11±8
2000 09/99-05/00	20±17	114±39	49±27	20±21

TABLE 6. Pair-wise comparisons (% overlap) for three species categories at the four Duwamish monitoring sites.

Category		TBCont/ TBRest	TBCont/ Kell	TBRest/ Kell	TBCont/ T-105	Tbrest/ T-105	Kell/ T-105	Year
Native		61	54	89	66	93	83	1997
		68	60	89	90	75	67	1998
		58	50	59	39	52	50	2000
Non-native		80	100	80	80	100	80	1997
BHCO	ENSP	50	50	80	50	100	80	1998
CAQU	EUST	100	75	75	75	75	100	2000
DODU	HOFI							
DOGO								
Human-assoc.		100	100	100	100	100	100	1997
BASW	RODO	100	100	100	75	75	75	1998
AMRO	NWCR	100	100	100	100	100	100	2000
CAGE		100	100	100	100	100	100	1997
MALL		100	100	100	100	100	100	1998
GWGU		100	100	100	100	100	100	2000

TABLE 7. Sampling date, transect length, and vegetation patch characteristics at Duwamish Waterway sites.

Site	Sampling date	Transect length (m)	Patch length (m)	Notes
Carex Bench 1	8/1/95	26	26	some netting remaining from last year, COCO coming in under net in previously patchy area, CALY senescing, heavily grazed
	8/16/96	39	39	patch in 2 contiguous sections; upriver section approx. 23 m. COCO in foreground, some SPMA,PLMA, ELPARV, RUCR, PHAR upland Very thin @17.5-20 m. patch ends on riprap, some flowering.
	8/20/97	39.2	39.2	lots of trampling, put transect through water edge untrampled areas. One exclosure found. Seems like drop off from bench is not as high.
	8/20/99	39	23.4	Carex appears to have been grazed twice - 2 identifiable levels in each quadrat. No Carex downstream of 15.6 m - only ELPAR with patches of LIL (0 at downstream end).
Carex Bench 2	8/1/95	28	28	
	8/17/96	42.8	42.8	Transect now extends downstream of fence, eroded from 39.1 - 40.2 m
	8/20/97	42.8	42.8	Transect now extends downstream of fence
	9/12/99	42	42	Transect length 42 m long, 33.3 m from upstream to fence. Vaucheria in lower intertidal, LIL on some higher, very narrow benches just outside the CALY. Caly grazed. Many new, ungrazed shoots. 5:10 pm, water at edge of bench.
Carex Bench 3	8/1/95	14	4, 10	Transect in two parts, 4 m (upstream portion) and 10 m (downstream), through ungrazed portions. Bench divided, heavily grazed on lower portions, large log in front of downstream portion, ATPA, ASSU, SPMA, SCCE moving in.
	8/17/96	15.8	5.8, 10	Transect in two parts, 5.8 m (upstream portion) and 10 m (downstream). Access difficult, lots of garbage, large metal and concrete pieces. ATPA, ASSU, SPMA, SCCE moving in, downstream portion very narrow.
	8/20/97	15	5, 10	upper bed, 5 m 10 cm.
	8/20/99	16.4	6, 10.4	Upper bench 6 m, bare from 6-9 m, lower bench 9-19.4 m. Access difficult, lots of garbage, large metal and concrete pieces. ATPA, ASSU, SPMA, SCCE moving in
Scirpus Reference	8/1/95	10	10	first 5 m of transect has other sp, shore side of patch taller (max height - 211). lots of JUsp, DISP, ASSU and small CALY (not yet senescing) bench on upland
	8/17/96	11.2	11.2	first 5 m of transect has other sp, more CALY than last year. Shore side of patch taller (max height - 220 cm (211 cm last year). Lots of JUEF, SCMA, ASSU, and short CALY (not yet senescing) bench on upland
	8/20/97	11.4	11.4	
	8/20/99	11.4	11.4	taller half downstream (0-6 m), tallest ~ 240 cm.
Scirpus GSA site	8/1/95	38	22, 0.9, 1.6	Transect length 38 m with breaks at 29.0-30.6 and 22.4-23.3
	8/17/96	34.8	18.7, 6, 8	Transect length 34.8 m with breaks at 25.3 - 26.75 and 18.7 - 19.3
	8/20/97	34.8	25.5, 8	Transect length 34.8, breaks at 25.5-26 (channel coming in).
	8/20/99	35.5	35.5	Sampled regular transect and 25 samples in Goose excluder devices that have been added by PPS. Many species in this area - called GSA2.
T-105	8/1/95			**no sampling - counted planted willows**
	8/17/96			**measured distances from mouth of slough to new patches of vegetation.**
	8/20/97			**Samples every 5 paces from head to mouth on downstream side, back toward head on upstream side to small stair**
	8/20/99			Samples every 20 paces from head to mouth on downstream side, back toward head on upstream side to small stair
New Turning Basin	8/20/99			**Sampled upstream and downstream benches. Downstream bench larger and more diverse.**

TABLE 8. Summary statistics for Shoot density and Maximum shoot height of *Carex lyngbyei* at Duwamish Waterway sites. Only quadrats with *Carex* used in calculations. Statistics in shaded cells change when all samples used.

Site	Data	1995	1996	1997	1999	Grand total	1999**
1	Sample size	10	15	15	10	50	Total including new shoots
	Number of quadrats with *Carex*	10	15	13	8	46	
	Mean shoot density*	32	37	30	47	36	
	Mean maximum shoot height*	91	130	55	109	97	
	StdDev of shoot density	13.9	15.4	21.3	27.1	19.6	
	StdDev of shoot ht	24.0	42.0	40.4	25.2	45.8	
2	Sample size	10	10	10	11	41	
	Number of quadrats with *Carex*	10	10	10	11	41	
	Mean shoot density*	47	41	30	42	40	108
	Mean maximum shoot height*	94	100	89	94	94	
	StdDev of shoot density	14.8	26.9	17.4	18.3	20.1	25.9
	StdDev of shoot ht	14.4	21.9	18.5	19.5	18.5	
3	Sample size	10	10	10	10	40	
	number of quadrats with *Carex*	10	10	10	9	39	
	mean shoot density*	38	29	27	36	32	
	mean maximum shoot height*	124	136	137	149	136	
	StdDev of shoot density	19.6	16.2	10.7	20.3	17.0	
	StdDev of shoot ht	25.5	31.1	60.7	20.1	37.7	
Scirpus Reference	Sample size				10	10	
	Number of quadrats with *Carex*				3	3	
	Mean shoot density*				24	24	
	Mean maximum shoot height*				74	74	
	StdDev of shoot density				23.6	23.6	
	StdDev of shoot ht				58.4	58.4	
1994 Turning Basin	Sample size				13	13	
	Number of quadrats with *Carex*				13	13	
	Mean shoot density*				26	26	
	Mean maximum shoot height*				125	125	
	StdDev of shoot density				8.3	8.3	
	StdDev of shoot ht				36.7	36.7	

*Mean of quadrats with Carex present.

**In 1999, Site 2 was sampled later than other sites and a new set of shoots was just emerging.

TABLE 9. Coefficient of variation for shoot density and maximum shoot height of *Carex lyngbyei* at Duwamish Waterway sites. Only quadrats with *Carex* used in calculations. Statistics in shaded cells change when all samples used.

Site	Data	1995	1996	1997	1999	Grand total	1999*
1	cv shoot density	0.43	0.41	0.72	0.57	0.55	Total including new shoots
	cv maximum shoot height	0.26	0.32	0.73	0.23	0.47	
2	mean shoot density	0.32	0.66	0.59	0.44	0.50	0.24
	mean maximum shoot height	0.15	0.22	0.21	0.21	0.20	
3	cv shoot density	0.51	0.56	0.40	0.56	0.52	
	cv maximum shoot height	0.21	0.23	0.44	0.13	0.28	
Scirpus Reference	cv shoot density				0.97	0.97	
	cv maximum shoot height				0.79	0.79	
1994 Turning Basin	cv shoot density				0.32	0.32	
	cv maximum shoot height				0.29	0.29	

* In 1999, Site 2 was sampled later than other sites and a new set of shoots was just emerging.

TABLE 10. Summary statistics for Shoot density and Maximum shoot height of *Carex lyngbyei* at Duwamish Waterway sites. All quadrats used in calculations. Values in shaded cells differ from values in TABLE 2.

Site	Data	1995	1996	1997	1999	Grand total	1999*
1	Count of ht	10	15	15	10	50	Total including new shoots
	Average of shts	32	37	26	38	33	
	Average of ht2	91	129.9	47.9	87.0	89.0	
	StdDev of shts	13.9	15.4	22.3	31.1	21.2	
	StdDev of ht2	24	42.0	42.2	50.9	51.2	
2	Count of ht	10	10	10	11	41	
	Average of shts	47	41	30	42	40	108
	Average of ht2	93.7	100	89	94.2	94.2	
	StdDev of shts	14.8	26.9	17.4	18.3	20.1	25.9
	StdDev of ht2	14.4	21.9	18.5	19.5	18.5	
3	Count of ht	10	10	10	10	40	
	Average of shts	38	29	27	33	31.6	
	Average of ht2	123.6	136.1	136.9	134	132.7	
	StdDev of shts	19.6	16.2	10.7	22.3	17.6	
	StdDev of ht2	25.5	31.1	60.7	50.8	43.0	
Scirpus Reference	Count of ht				10	10	
	Average of shts				7	7	
	Average of ht2				22.3	22.3	
	StdDev of shts				16.2	16.2	
	StdDev of ht2				45.3	45.3	
1994 Turning Basin	Count of ht				13	13	
	Average of shts				26	26	
	Average of ht2				125.4	125.4	
	StdDev of shts				8.3	8.3	
	StdDev of ht2				36.7	36.7	

*In 1999, Site 2 was sampled later than other sites and a new set of shoots was just emerging.

TABLE 11. Coefficient of variation for shoot density and maximum shoot height of *Carex lyngbyei* at Duwamish Waterway sites. All quadrats used in calculations. Values in shaded cells differ from values in Table 3.

Site	Data	1995	1996	1997	1999	Grand total	1999*
1	cv shoot density	0.43	0.41	0.87	0.82	0.65	Total including new shoots
	cv maximum shoot height	0.26	0.32	0.88	0.59	0.58	
2	mean shoot density	0.32	0.66	0.59	0.44	0.50	0.24
	mean maximum shoot height	0.15	0.22	0.21	0.21	0.20	
3	cv shoot density	0.51	0.56	0.40	0.68	0.56	
	cv maximum shoot height	0.21	0.23	0.44	0.38	0.32	
Scirpus Reference	cv shoot density				2.22	2.22	
	cv maximum shoot height				2.03	2.03	
1994 Turning Basin	cv shoot density				0.32	0.32	
	cv maximum shoot height				0.29	0.29	

*In 1999, Site 2 was sampled later than other sites and a new set of shoots was just emerging.

TABLE 12. Analysis of Variance of *Carex lyngbyei* shoot density (site and year as random factors) and percent variance explained by each factor.

Source		Type III sum of squares	df	Mean square	F	Sig.	Variance component	% variance explained by factor
Intercept	Hypothesis	155279.706	1	155279.706	104.953	0.000		
	Error	5988.071	4.05	1479.522				
SITE	Hypothesis	1522.110	2	761.055	5.223	0.047	615.336	0.356
	Error	900.420	6.18	145.719				
YEAR	Hypothesis	2600.898	3	866.966	5.937	0.030	720.934	0.417
	Error	908.532	6.22	146.031				
SITE * YEAR	Hypothesis	866.258	6	144.376	0.369	0.897	0.000	0.000
	Error	46526.103	119	390.976			390.976	0.226
a	.997 MS(SITE) + .998 MS(YEAR) - .991 MS(SITE * YEAR) - 3.597E-03 MS(Error)						1727.246	1.000
b	.995 MS(SITE * YEAR) + 5.445E-03 MS(Error)							
c	.993 MS(SITE * YEAR) + 6.712E-03 MS(Error)							
d	MS(Error)							

TABLE 13. Mean difference between first and second height classes of *Carex lyngbyei* at Duwamish Waterway sites 1999.

Site	Mean	Std	Count
1	20.0	12.2	7
2	22.2	6.7	4
3	24.6	14.3	9
1994 Turning Basin	15.8	9.7	12
Average	20.7		

TABLE 14. Analysis of Variance of *Carex lyngbyei* shoot height (site and year as random factors) and percent variance explained by each factor.

Source		Type III sum of squares	df	Mean square	F	Sig.	Variance component	% variance explained by factor
Intercept	Hypothesis	1419731.959	1	1419731.959	57.426	0.015		
	Error	51352.795	2.08	24722.966				
SITE	Hypothesis	47585.056	2	23792.528	5.383	0.046	19372.224	0.781
	Error	26611.062	6.02	4420.304				
YEAR	Hypothesis	16254.794	3	5418.265	1.227	0.378	1001.856	0.040
	Error	26608.519	6.02	4416.409				
SITE * YEAR	Hypothesis	26622.265	6	4437.044	3.257	0.005	3074.587	0.124
	Error	162132.347	119	1362.457			1362.457	0.055
a	.997 MS(SITE) + .998 MS(YEAR) - .991 MS(SITE * YEAR) - 3.597E-03 MS(Error)						24811.124	1.000
b	.995 MS(SITE * YEAR) + 5.445E-03 MS(Error)							
c	.993 MS(SITE * YEAR) + 6.712E-03 MS(Error)							
d	MS(Error)							

TABLE 15. Summary statistics for shoot density and maximum shoot height of *Scirpus validus* at Duwamish Waterway sites.

Site	Data	1995	1996	1997	1999	Grand total		
GSA	Sample size	10	10	10	11	41		
	Mean shoot density	38	25	22	62	37		
	Mean maximum shoot height	73	77	90	46	71		
	StdDev of shoot density	25.7	16.6	14.1	21.7	25.1		
	StdDev of shoot ht	23.0	21.3	31.0	17.4	28.0		
Reference	Sample size	10	10	10	10	40		
	Mean shoot density	16	15	16	29	19		
	Mean maximum shoot height	118	129	141	113	125		
	StdDev of shoot density	9.3	6.6	7.0	12.8	10.6	downstream patch	upstream patch
	StdDev of shoot ht	42.7	44.5	57.2	67.6	52.9		
1999 TB	Sample size*				12		6	6
	Mean shoot density				13		19	8
	Mean maximum shoot height				92		102	82
	StdDev of shoot density				16.7		17.9	15.1
	StdDev of shoot ht				29.7		34.3	22.9

*Footnote?

TABLE 16. Coefficient of variation for shoot density and maximum shoot height of *Scirpus validus* at Duwamish Waterway sites.

Site	Data	1995	1996	1997	1999	Grand total		
GSA	cv shoot density	0.68	0.66	0.63	0.35	0.67		
	cv maximum shoot height	0.31	0.28	0.34	0.38	0.39		
Reference	cv shoot density	0.57	0.44	0.44	0.44	0.56	downstream patch	upstream patch
	cv maximum shoot height	0.36	0.34	0.41	0.60	0.42		
1999 TB	cv shoot density				1.25		0.97	1.85
	cv maximum shoot height				0.32		0.34	0.28

TABLE 17. Analysis of variance of *Scirpus validus* shoot density (site and year as random factors) and percent variance explained by each factor.

Source		Type III sum of squares	df	Mean square	F	Sig.	Variance component	% variance explained by factor
Intercept	Hypothesis	54481.876	1	54481.876	10.540	0.105		
	Error	8621.236	1.67	5168.860				
SITE	Hypothesis	3906.060	1	3906.060	16.948	0.026	3675.581	0.711
	Error	691.796	3.00	230.479				
YEAR	Hypothesis	4480.854	3	1493.618	6.480	0.080	1263.137	0.244
	Error	691.442	3.00	230.481				
SITE * YEAR	Hypothesis	691.442	3	230.481	1.031	0.384	6.938	0.001
	Error	16318.636	73	223.543			223.543	0.043
a	MS(SITE) + 1.000 MS(YEAR) - 1.000 MS(SITE * YEAR)						5169.199	1.000
b	1.000 MS(SITE * YEAR) + 2.673E-04 MS(Error)							
c	MS(SITE * YEAR)							
d	MS(Error)							

TABLE 18. Analysis of variance of *Scirpus validus* shoot height (site and year as random factors) and percent variance explained by each factor.

Source		Type III sum of squares	df	Mean square	F	Sig.	Variance component	% variance explained by factor
Intercept	Hypothesis	834941.831	1	834941.831	14.756	0.149		
	Error	60772.356	1.07	56582.374				
SITE	Hypothesis	54582.134	1	54582.134	276.534	0.000	54384.755	0.938
	Error	594.664	3.01	197.380				
YEAR	Hypothesis	6593.363	3	2197.788	11.156	0.039	2000.775	0.035
	Error	591.038	3.00	197.013				
SITE * YEAR	Hypothesis	591.038	3	197.013	0.126	0.945	0.000	0.000
	Error	114561.282	73	1569.333			1569.333	0.027
a	MS(SITE) + 1.000 MS(YEAR) - 1.000 MS(SITE * YEAR)						57954.862	1.000
b	1.000 MS(SITE * YEAR) + 2.673E-04 MS(Error)							
c	MS(SITE * YEAR)							
d	MS(Error)							

TABLE 19. (a) Understory species in *Carex* and *Scirpus* patches, by species.

	Site	1995	1996	1997	1999
Aster subspicatus	#3: Lombardi	1	2	2	2
Atriplex patula	#2: DSB				2
	#3: Lombardi	1	3	1	
	GSA	1		1	
	GSA2				2
	Reference	2	1	1	
Callitriche heterophylla	# 1: Boeing			2	
	#2: DSB			2	
Carex lyngbyei	GSA2				2
	Reference	4	7	6	3
Cotula coronopofila	# 1: Boeing			1	
	#2: DSB				1
	GSA	6	7	9	2
	GSA2				15
	Reference	1			1
Deschampsia caespitosa?	#2: DSB			1	
Distichlis spicata	Reference		2	4	
Eleocharis parvula	# 1: Boeing			4	1
	#2: DSB			3	
Enteromorpha linsa	GSA2				1
Grindelia integrifolia	GSA			2	
	Reference				1
Lileopsis sp.	#2: DSB			3	4
	GSA	3	7	10	8
	GSA2				2
Plantago marina	#3: Lombardi		2	3	1
	GSA			2	
	Reference			4	
Polygonum hydropiperoides	#2: DSB			2	1
	#3: Lombardi			1	
Potentilla palustris	#2: DSB			2	1
	#3: Lombardi		1	1	
	GSA			1	
	Reference	2	4	6	1
Ranunculus repens	Reference	2			
Salicornia virginica	GSA	1	2	1	
Scirpus cernuus	#1: Boeing				1
	#3: Lombardi	3	2	4	
	GSA	6	3	2	3
	GSA2				2
	Reference		2		
Scirpus maritimus	GSA2				16
Scirpus validus	# 1: Boeing		2		
	GSA2				2
Spergularia marina	# 1: Boeing			1	
	#3: Lombardi	3	1	2	
	GSA	9	10	10	9
	GSA2				17
	Reference	4	5	2	1
Triglochin maritimum	#3: Lombardi	1			
	GSA2				3
	Reference		2		
Vaucheria sp.	#2: DSB				4
	GSA2				2

Table 19. (b) Understory species in *Carex* and *Scirpus* patches, by patch.

Site	Species	1995	1996	1997	1999	No. species
# 1	*Callitriche heterophylla*			2		1
	Cotula coronopofila			1		2
	Eleocharis parvula			4	1	3
	Scirpus validus		2			4
	Spergularia marina			1		5
	Scirpus cernuus				1	6
#2	*Atriplex patula*				2	1
	Callitriche heterophylla			2		2
	Cotula coronopofila				1	3
	Deschampsia caespitosa?			1		4
	Eleocharis parvula			3		5
	Lileopsis sp.			3	4	6
	Polygonum hydropiperoides			2	1	7
	Potentilla palustris			2	1	8
	Vaucheria sp.				4	9
#3	*Aster subspicatus*	1	2	2	2	1
	Atriplex patula	1	3	1		2
	Plantago marina		2	3	1	3
	Polygonum hydropiperoides			1		4
	Potentilla palustris		1	1		5
	Scirpus cernuus	3	2	4		6
	Spergularia marina	3	1	2		7
	Triglochin maritimum	1				8
GSA	*Atriplex patula*	1		1		1
	Cotula coronopofila	6	7	9	2	2
	Grindelia integrifolia			2		3
	Lileopsis sp.	3	7	10	8	4
	Plantago marina			2		5
	Potentilla palustris			1		6
	Salicornia virginica	1	2	1		7
	Scirpus cernuus	6	3	2	3	8
	Spergularia marina	9	10	10	9	9

TABLE 20. Average and standard deviation of number of other plant species per quadrat.

	Average 1995	1996	1997	1999
Carex 1			0.9	0.6
Carex 2	1.1	1.1	1.2	1.2
Carex 3			1.4	0.3
Scirpus Reference	1.5	2.4	2.3	0.7
GSA	2.6	3.0	3.8	2.0
	Standard deviation			
Carex 1			0.8	0.8
Carex 2	0.9	1.1	0.9	0.7
Carex 3			1.1	2.2
Scirpus Reference	2.0	2.0	1.8	1.3
GSA	1.0	0.9	1.1	0.8

TABLE 21. Number of quadrats containing each plant species at T-105 site, 1999. Total number of quadrats sampled = 25.

Species	No. quadrats
Spergularia marina	19
Atriplex patula	18
Salicornia virginica	10
Plantago marina	8
Grindelia integrifolia	4
Cotula coronopofila	3
Deschampsia caespitosa	3
Scirpus validus	2
Achillea millefolium	1
Scirpus maritimus	1

TABLE 22. Summary statistics for *Scirpus* species found at Turning Basin Phase II benches.

		New downstream	New upstream	Grand total
Scirpus americanus	Count of # shoots	3	3	6
	Average of # shoots2	32	30	31
	StdDev of # shoots2	25.6	42.6	31.4
	Average of height (cm)	97	66	81
	StdDev of height (cm)	28.8	16.2	26.8
Scirpus maritimus	Count of # shoots	4	7	11
	Average of # shoots2	3	10	8
	StdDev of # shoots2	1.8	9.3	8.1
	Average of height (cm)	81	79	80
	StdDev of height (cm)	18.5	23.5	20.9
Scirpus validus	Count of # shoots	6	6	12
	Average of # shoots2	19	8	13
	StdDev of # shoots2	17.9	15.1	16.7
	Average of height (cm)	102	82	92
	StdDev of height (cm)	34.3	22.9	29.7

TABLE 23. Understory species at newly sampled sites.

Site	Species	1995	1996	1997	1999	No. species
GSA2	*Atriplex patula*				2	1
	Carex lyngbyei				2	2
	Cotula coronopofila				15	3
	Enteromorpha linsa				1	4
	Lileopsis sp.				2	5
	Scirpus cernuus				2	6
	Scirpus maritimus				16	7
	Scirpus validus				2	8
	Spergularia marina				17	9
	Triglochin maritimum				3	10
	Vaucheria sp.				2	11
Reference	*Atriplex patula*	2	1	1		1
	Carex lyngbyei	4	7	6	3	2
	Cotula coronopofila	1			1	3
	Distichlis spicata		2	4		4
	Grindelia integrifolia				1	5
	Plantago marina			4		6
	Potentilla palustris	2	4	6	1	7
	Ranunculus repens	2				8
	Scirpus cernuus		2			9
	Spergularia marina	4	5	2	1	10
	Triglochin maritimum		2			11
Turning Basin Phase I	*Aster subspicatus*			7	1	1
	Atriplex patula			2		2
	Carex lyngbyei			3		3
	Conioselinum pacificum			1		4
	Cotula coronopofila			3		5
	Eleocharis palustris			7		6
	Eleocharis parvula			1	8	7
	Glaux maritimus			3	3	8
	Gnapthalium			5		9
	Grindelia integrifolia			1	1	10
	Unidentified Juncus			1		11
	Melilotus alba			1		12
	Plantago marina			2		13
	Rumex crispus			1		14
	Spergularia marina			7		15
	Tanacetum bipinnatum			1		16
	Typha latifolia			1		17
	Unidentified grass			2		18
	Unidentified grass			4		19
Turning Basin Phase II Upstream	*Atriplex patula*				1	1
	Echinochloa crusgalli				1	2
	Eleocharis palustris				4	3
	Glyceria sp?				1	4
	Melilotus alba				3	5
	Spergularia marina				1	6
	Typha latifolia				1	7
Turning Basin Phase II Downstream	*Agrostis sp.*				3	8
	Callitriche heterophylla				2	9
	Cotula coronopofila				1	10
	Echinochloa crusgalli				3	11
	Eleocharis parvula				9	12
	Eleocharis parvula				2	13
	Juncus bufonius				2	14
	Lileopsis sp.				1	15
	Plantago marina				2	16
	Potentilla palustris				1	17
	Rhizochlonium				4	18
	Typha latifolia				4	19