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## **Duwamish River Coastal America Restoration and Reference Sites: Results from 1996 Monitoring Studies**

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Approved

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## **KEY WORDS**

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

# Duwamish River Coastal America Restoration and Reference Sites: Results from 1996 Monitoring Studies

JR CORDELL, LM TEAR, K JENSEN, AND V LUITING

## OBJECTIVES

This report contains the results of 1996 sampling activities that were part of ongoing biological monitoring at three wetland restoration sites in the Duwamish River estuary, Seattle, Washington. Restoration at these sites was originally facilitated by the federal Coastal America program and was carried out by a partnership of the U.S. Fish and Wildlife Service, the U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency. Two of these sites are in the middle portion of the Duwamish Waterway in a region dominated by tidal influence and mixed fresh and marine water. The first site is the General Service Administration (GSA), which is a long, narrow intertidal strip that parallels the east bank of the Duwamish Waterway adjacent to the Seattle District Corps of Engineers. Restoration at this site included removal of rock riprap and a large overwater wharf structure to allow natural colonization by existing wetland plants, construction of a sediment "bench" at 0.0-m elevation to promote use by juvenile salmon (*Oncorhynchus* spp.), and planting of 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 drained a small degraded wetland area. Restoration included removal of debris and replacement of the pipe with an estuarine channel that restored tidal flow to the area. The third Coastal America restoration site is at the upper turning basin at the head of the Duwamish Waterway. This site comprises an upland riparian buffer planted with native vegetation and a small regraded upper intertidal basin planted with fringing native sedge *Carex lyngbyei*.

Pre-restoration baseline and pilot studies of benthic invertebrates, insects, emergent vegetation, and sediment grain size took place in 1993 (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, restoration sites were constructed and planted. Using information gained from the initial pilot studies, the first post-restoration sampling

was conducted in spring 1995 at the restoration and reference sites (Cordell et al. 1996). The purpose of this study was to continue post-restoration sampling of the restoration and reference sites. The specific objectives of this study were to conduct systematic biological sampling of long-term reference and restored sites, incorporating knowledge gained from previous samplings as follows:

1. Sample benthic invertebrates, sediment grain size, and fallout insects associated with actual on-site restored strata (i.e., high intertidal vegetation; see "Specific Tasks and Methods") and at representative reference sites.
2. Compare attribute species, as defined by the Estuarine Habitat Assessment Protocol (Simenstad et al. 1991; henceforth the "Protocol"), and important non-attribute species among these sites.
3. Analyze diets of juvenile salmon captured within restoration sites or in the vicinity of these sites to compare with invertebrate sampling data.
4. Expand and continue monitoring of bird species, numbers, use, and behavior at restoration and reference sites.
5. Continue sampling of restored and native vegetation patches.
6. Evaluate future sampling options based on the results of sampling to date.

The results of this study are intended to be used in ongoing evaluations of (1) the "recovery trajectories" of the restored areas and (2) options for future monitoring at Duwamish River sites.

## SPECIFIC TASKS AND METHODS

### *Benthic Invertebrates*

On the basis of the 1995 invertebrate studies, we recommended that upper intertidal strata that were physically part of the restoration sites be sampled in addition to or in lieu of the previously used 0.0-m elevation sites: the rationale was that any restoration effects from the high inter-

tidal plantings and habitat creation would take many years to appear in the lower intertidal strata (Cordell et al. 1996). Therefore, benthic macrofauna and sediment grain size sampling were conducted at upper intertidal vegetated strata at two reference and three restoration sites. The reference sites included *Carex* site 2 near the turning basin and the small *Scirpus* patch across the channel from the northeast tip of Kellogg Island (Fig. 1). Benthic samples were also taken at three restoration sites, including (1) the area of transplanted *Carex* at the turning basin, (2) the small naturally recruiting *Scirpus* patch at the GSA site, and (3)

along the slope of the constructed channel at the T-105 site (Fig. 1). We also conducted “pilot” sampling of the unvegetated sand flats encompassed by the created channel at the T-105 site.

Benthic sampling was conducted three times—15 April, 20 May, and 11 June 1996. These dates were chosen to encompass high invertebrate densities and use of the waterway by juvenile salmon (Cordell et al. 1994, Warner and Fritz 1996). One exception was at the turning basin where the transplanted stratum was only sampled on 11 June: on the previous two sampling dates, samples were

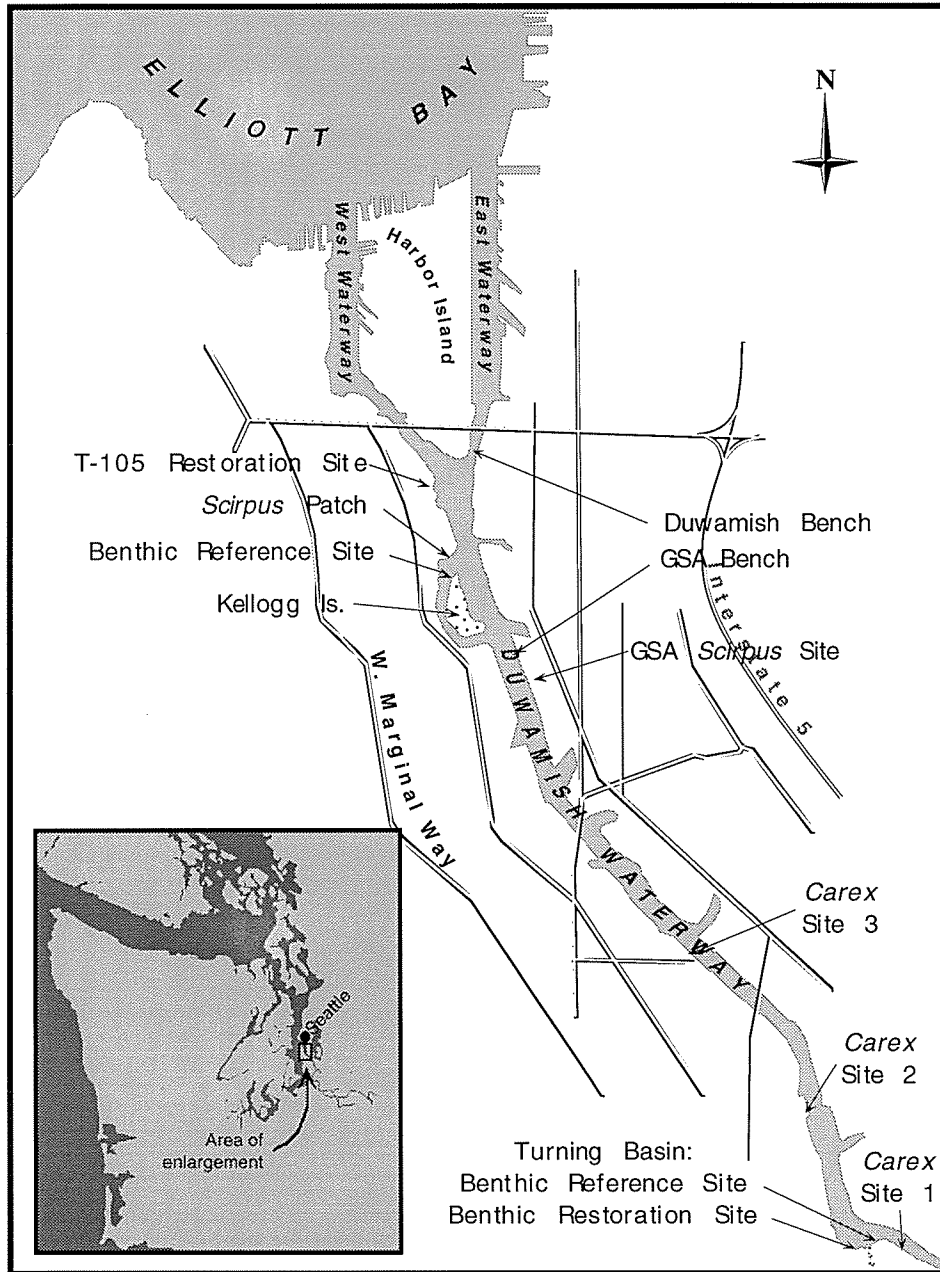


FIGURE 1.—Location of 1996 sampling sites in the Duwamish Waterway, Puget Sound, Washington.

haphazardly distributed on the site, but after transplanting, samples were stratified and taken at both the transplanted stratum and on an unplanted sand flat. At each site, we took 15 samples haphazardly in the vegetation patches. At the “pilot” T-105 sandflat stratum, we took five replicate samples. As in previous samplings, we used a PVC core that sampled an area of 0.0024 m<sup>2</sup> 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 about 1 week of fixation in the formaldehyde solution, benthic core samples were washed through two sieve sizes: macrofauna was retained on a 0.5-mm sieve, and meiofauna on a 0.153-mm sieve. Samples were then transferred to 50% isopropanol. Because of large amounts of organic debris in the samples, only five replicates from each date and stratum were processed and enumerated. If subsampling was necessary, samples were split to manageable fractions. Macrofauna samples were split in a Folsom plankton splitter (Wickstead 1976) until at least 100 organisms were obtained. All organisms were identified using dissection, and when necessary, compound microscopes. Taxa occurring as attributes in the Protocol were identified to the species level or to the level identified in the Protocol. Taxa not listed as attributes in the Protocol were not identified to species unless they were particularly abundant or had been identified or hypothesized as being prey for fishes or birds.

### *Insects*

Insects were sampled at the two reference vegetation patches and three restoration sites sampled previously in 1995. The reference sites were the *Carex* site 2 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; (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 (Fig. 1).

Fallout insects were collected beginning 19 April, 23 May, 14 June, and 25 July 1996 using the rectangular fallout traps (55 cm x 38 cm plastic storage bins) that were deployed in 1995 (as described in Cordell et al. 1996). These floating traps rise and fall with the tide and are kept in place by four 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. They were placed haphazardly in the vegetation or proposed transplant zones 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 preservative 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.

### *Juvenile Salmon Diets*

Juvenile salmon were collected for stomach analyses by the Muckleshoot Tribal Fisheries Department on 1 and 17 April and 6 June. From these collections, we analyzed fish from four areas: (1) the upper Duwamish waterway near the turning basin (sites designated by the Muckleshoot Tribal Fisheries as “Smelt Beach” and “turning basin”; Warner and Fritz 1996); (2) the middle waterway (designated as “Oil Slick” and “Chief Seattle”); (3) the waterway near Kellogg Island, GSA, and T-105 reference and restoration sites (designated “West Kellogg Island” and “East Kellogg Island”); and (4) a single sample on 17 April of four chum (*O. keta*) and seven chinook (*O. tshawytscha*) salmon captured by blocking the entrance of the T-105 created channel on a falling tide. Salmon were captured in a 30-m beach seine deployed parallel to shore, and a subsample of up to 10 individuals of each species and 10-mm length class was removed and placed in anesthetic. The fish were then fixed in a 10% buffered formaldehyde solution.

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 Protocol for other taxa. Each prey taxon was enumerated and weighed to the nearest 0.0001 g. All data was entered on standard National Oceanographic Data Center forms and analyzed using the University of Washington Fisheries Research Institute’s GUTBUGS program, which provides summary data for each group of fish analyzed. For this study, prey weight data were taken from the GUTBUGS summary for further graphical analysis.

### *Avifauna*

Observations of avifauna were made from September 1996 through February 1997, and are currently ongoing at

two restoration and two reference sites on the east side of the Duwamish river. The T-105 site is the most northerly of the restored sites (Fig. 1) and serves as 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, the T-105 site sees regular motorized boat traffic. The area observed is approximately 84 m of shoreline with a created channel extending inland about 240 meters to the east. Counts were made of birds in the intertidal area of the shoreline and the channel.

Kellogg Island is 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.

Two sites are located at the Duwamish Waterway turning basin approximately 6 km upstream from Kellogg Island (Fig. 1). The reference area is bounded by a foot bridge to the south and a channel containing the partially burned wreck of a ship to the north. The restored area is 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.

Binoculars (10 x 40 mm) were used to scan samples in half-hour periods during daylight hours between 0700 to 1900 PST. This 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 during low tide events. The number of visits to each site varied by season to concentrate observer effort during periods of increased migratory activity. For summer 1995, fall 1996, and winter 1996–97, the number of visits per site averaged 13, 23, and 13, respectively. 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. Transit was almost exclusively swimming because land transit was usually observed while birds were either foraging or on their way to the water. Birds in flight were not counted unless they landed and made con-

tact with the intertidal area in summer 1995, but they 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 of the bird observation data were collected from a location on the riverbank or upper part of the intertidal area where birds could be seen with minimal disturbance. 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 minutes 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 of birds 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, and winter 1996–97) for each site. In addition to calculating the total numbers of birds present, we compared the abundance without 11 species that were considered either (1) introduced or (2) human-associated (see Table 1). Introduced species were defined as known exotics, and human-associated species (hereafter "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 dataset 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.

Data were also analyzed as percent occurrence of all species observed across the four sites as a function of the total number of half-hour observation periods within an observation season. Species were grouped loosely by guild: passerines, raptors, shorebirds, waterfowl, and seabirds. Because the success of restoration depends not only on values such as abundance and richness, but on the particu-

TABLE 1.—List of species observed on the Duwamish waterway. Species are grouped loosely by guild as well as resident versus seasonal where applicable. Introduced species and native but human-associated species are categorized separately. A total of 57 species were observed on the Duwamish waterway during three seasons of data collection.

Guild	Species	Abbrev.	Guild	Species	Abbrev.		
Passerines ( <i>Seasonal</i> )	Gold Finch	GOFI	Waterfowl ( <i>Seasonal</i> )	American Coot	AMCO		
	Golden-crowned Sparrow	GCSP		American Wigeon	AMWI		
	Savannah Sparrow	SASP		Barrow's Goldeneye	BAGO		
	White-crowned Sparrow	WCSP		Bufflehead	BUFF		
	Cliff Swallow	CLSW		Canvasback	CANV		
	Tree Swallow	TRSW		Cackling Goose	CAGO		
	Violet-green Swallow	VGSW		Eared Grebe	EAGR		
	Swainson's Thrush	SWTH		Horned Grebe	HOGR		
	(Resident)	Fox Sparrow		FOSP	(Resident)	Pied-billed Grebe	PBGR
		Song Sparrow		SOSP		Red-necked Grebe	RNGR
Bewick's Wren		BEWR	Western Grebe	WEGR			
House Wren		HOWR	Gadwall	GADW			
Black-capped Chickadee		BCCH	Common Merganser	COME			
Bush-tit		BUTI	Hooded Merganser	HOME			
Red-winged Blackbird		RWBL	Red-breasted Merganser	RBME			
Northern Flicker		NOFL	Seabirds	Double-crested Cormorant		DCCO	
Belted Kingfisher		BEKI		Mew Gull		MEGU	
Raptors		Bald Eagle		BAEA		Ring-billed Gull	RBGU
	Merlin	MERL	Introduced	House Finch	HOFI		
	Osprey	OSPR		English Sparrow	ENSP		
	Red-tailed Hawk	RTHA		European Starling	EUST		
	Sharp-shinned Hawk	SSHA		Domestic Duck	DODU		
Swainson's Hawk	SWHA	Domestic Goose		DOGO			
Shorebirds/ Waders	Dunlin	DUNL	Native-human-associated	Barn Swallow	BASW		
	Killdeer	KLDR		American Robin	AMRO		
	Spotted Sandpiper	SPSA		Rock Dove	RODO		
	Great Blue Heron	GBH		Mallard	MALL		
	Green-backed Heron	GBHE		Canada Goose	CAGE		
			Glaucon-winged Gull	GWGU			
			Northwestern Crow	NWCR			

lar type of species observed, data were further subdivided into three conservation categories: indigenous/native species (resident birds of western Washington), non-native species (known exotics), and human-associated species (as defined previously). Pair-wise comparisons of the percentage of overlap for the three species categories at the four monitoring sites were then done for each season of data.

### Emergent Vegetation

Five sites were sampled for emergent vegetation shoot density. Reference sites included the three *Carex* benches sampled in 1996 (Site 1, Site 2, and Site 3) and the *Scirpus* patch across the channel from the northeast end of Kellogg

Island (Fig. 1). The *Carex* benches were intended as references for *Carex* transplants at the turning basin site and recruiting vegetation at the T-105 site. The Kellogg Island *Scirpus* patch provided a reference for the small, naturally recruiting *Scirpus* patch at the GSA site. Other species present in the quadrats were also noted. At the turning basin restoration site, vegetation was monitored by a graduate student, and will be presented elsewhere (C. Crandell, University of Washington, School of Urban Horticulture). In addition, recruiting patches of vegetation at the T-105 created channel were recorded by species and distance from the head of channel.

Summary statistics were calculated for each site and comparisons to other sites and years were made using two-way

ANOVA (site, year, site x year). These parametric tests are robust to non-normalities in the data when the design is balanced (equal sample sizes at all sites).

### Sediment Grain Size

Sediment grain-size samples were collected haphazardly at 10 locations within each benthic sampling stratum using a 0.0024-m<sup>2</sup> 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 pipette analysis.

## RESULTS

### Benthic Invertebrates

#### Taxa Richness

For each sampling date, numbers of taxa were similar among the sites except at the T-105 and turning basin restoration sites, which usually had the lowest number of taxa (Fig. 2, bottom panel). Relatively high numbers of taxa were usually found at the *Scirpus* and *Carex* reference patches.

#### Assemblage Compositions

The composition of benthic macrofauna at all sites and on all dates was numerically dominated by two or three invertebrate categories (Fig. 3). On vegetated habitats, one of these categories was usually foraminifera. Nematodes made up a relatively constant 25–50% of the composition on unvegetated sites (including the single June sampling at the transplanted *Carex* site). Oligochaete worms were also prominent constituents of the benthic assemblage at most sites and on most sampling dates, but the polychaete worm *Manayunkia aestuarina* was only prominent at the two *Scirpus* patches. *Corophium* spp. amphipods were represented only at the T-105 channel site. In the April benthic samples, ceratopogonid fly larvae were particularly prominent on the sand flat at the turning basin and at the slope of the created channel at the T-105 site, and also occurred in lower proportions at the restored and reference *Scirpus* sites. Chironomid fly larvae made up over 20% of the invertebrate numbers only once—at the turning basin reference *Carex* patch in June (Fig. 3).

#### Densities

For all benthic macrofauna invertebrates combined, densities ranged from approximately  $25 \times 10^3$  (T-105 sites in May) to over  $20 \times 10^4$  individuals m<sup>-2</sup> (GSA *Scirpus* site in June; Fig. 4, bottom panel). At four of the six sites sampled on all three dates, benthic invertebrate densities were lowest in April and highest in June.

Some Protocol attribute taxa were absent or present only in very low numbers at some sites while others were relatively abundant across both sites and dates: (1) the polychaete worm *Manayunkia aestuarina* was abundant only at the two *Scirpus* sites, but oligochaete worms were relatively numerous at all sites and dates (Fig. 5); (2) the gammarid amphipods *Corophium* spp. and *Eogammarus confervicolus* were relatively numerous only in the T-105 channel (Fig. 6); and (3) chironomid fly larvae were prominent only at the *Scirpus* patch near Kellogg Island and at the turning basin reference *Carex* and restored flat sites, but dolichopodid fly larvae were relatively abundant at most of the sites and dates (Fig. 7).

Several taxa densities increased between April and June,

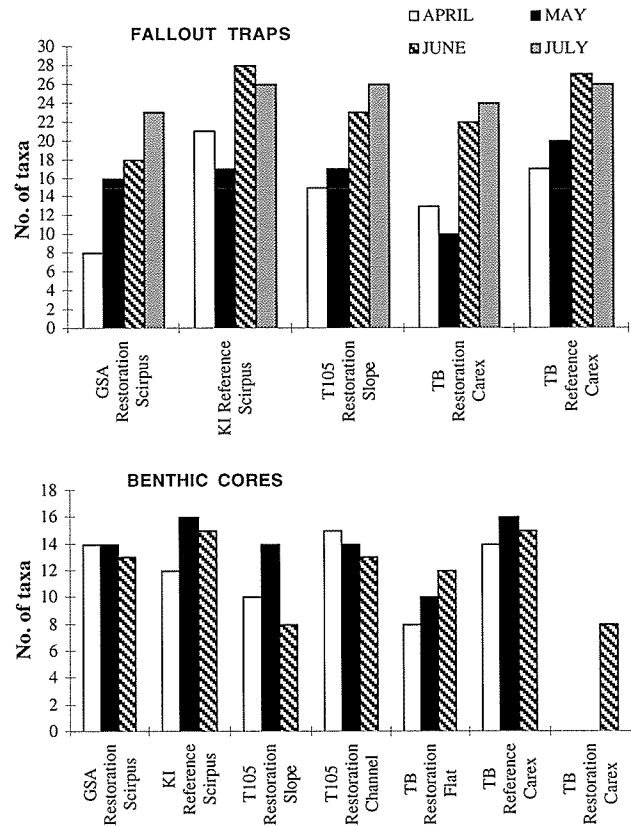


FIGURE 2.—Taxa richness from benthic cores (bottom) and insect fallout traps (top) at Coastal America restoration and reference sites, April–July 1996.

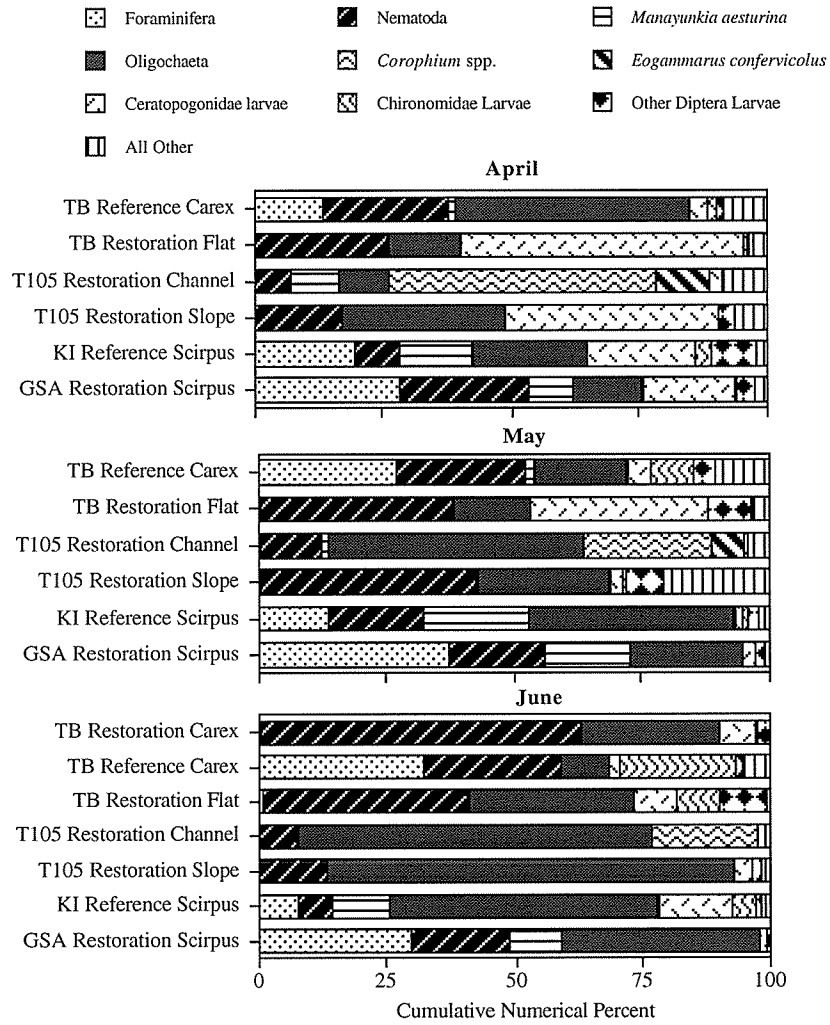


FIGURE 3.—Percent numerical composition of invertebrates from benthic core samples taken at Coastal America restoration and reference sites, April–June 1996.

including oligochaete worms, which were usually two to five times more abundant in June than in April (Fig. 5), and chironomid fly larvae, which increased in June by similar margins (Fig. 7). On the other hand, *Corophium* spp. and *Eogammarus confervicolus* decreased greatly between April and June at the T-105 channel site (Fig. 6).

### Insects

#### Taxa Richness

Insect taxa richness increased from spring (April–May) to summer (June–July) samplings at all sites (Fig. 2, top panel). The highest number of insect categories were usually found at reference *Scirpus* and *Carex* patches, and the differences between restored sites and their reference vegetation patch were sometimes large (e.g., April and June for the *Scirpus* patches).

#### Assemblage Compositions

In April and May, the sites fell into two groups based on assemblage compositions (Fig. 8). At the turning basin transplant site and the GSA restoration *Scirpus* patch, the insect assemblage was dominated by only one or two taxa (>50% of the numerical composition): ceratopogonid flies at the turning basin transplant and ceratopogonid and chironomid flies at the GSA site. At the other sites, insect assemblages were composed of more categories of lower percentages (no single category >25%).

In June, three insect categories—chironomid, dolichopodid, and ephydrid flies—dominated the insect composition, comprising over 75% of the insects at all sites.

In July, the sites again fell into two groups based on taxa composition. At the reference and transplanted *Carex* sites at the turning basin, chironomid flies dominated

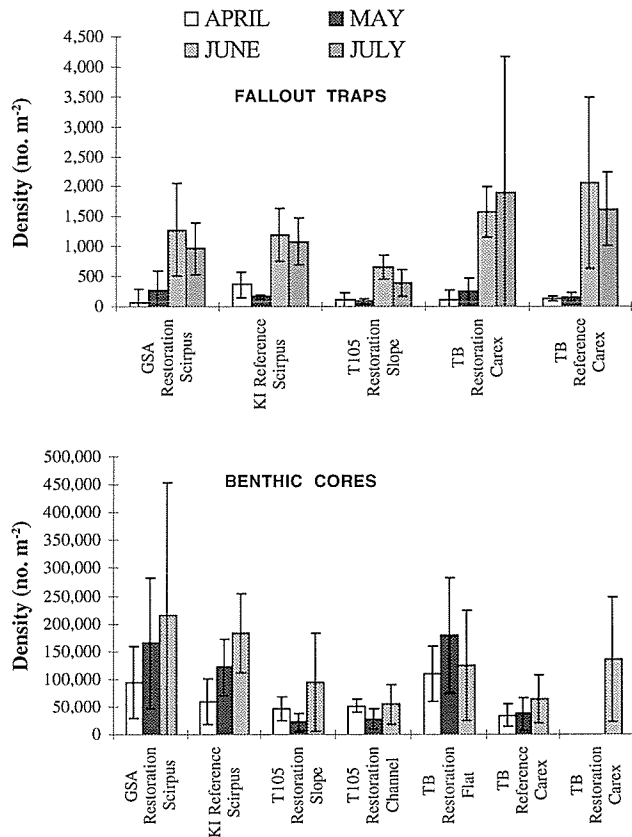


FIGURE 4.—Densities of all taxa combined from benthic cores (bottom) and insect fallout traps (top) at Coastal America restoration and reference sites, April–July 1996.

(>50% of the numbers). At the other sites, insects were distributed more evenly among taxa.

#### Densities

As in 1995, the sites fell into three categories based on the mean number of insects per fallout trap, especially in June and July when insects were most abundant (Fig. 4, top panel). First, the *Carex* reference site and turning basin transplant area had the highest mean densities, exceeding  $1.5 \times 10^3$  individuals  $m^{-2}$ . Second, the *Scirpus* patches across from Kellogg Island and at the GSA site had intermediate numbers of insects ( $1.0$ – $1.5 \times 10^3$  individuals  $m^{-2}$ ). Third, the T-105 channel margin had the lowest insect densities ( $<1.0 \times 10^3$  individuals  $m^{-2}$ ).

The following trends were noted for densities of Protocol attribute insect taxa:

1. Chironomid flies were much more abundant at the turning basin reference and transplanted *Carex* sites in June and July compared with April and May and were also much more abundant at these sites than at the other sites in June and July (Fig. 9, bottom panel).

2. Dolichopodid flies were most abundant in June and July, but in contrast to chironomids, they were relatively more abundant at the two *Scirpus* sites and the T-105 channel slope compared with the turning basin sites (Fig. 9, middle panel).
3. Ceratopogonid flies had a more complex pattern of abundance than the previous two taxa because they did not consistently peak in abundance during any time period: this taxon was most abundant at the GSA *Scirpus* and turning basin transplanted *Carex* sites (Fig. 9, top panel).
4. Ephydrid flies occurred predominantly in June and July and were most abundant at the GSA *Scirpus* and the two turning basin *Carex* sites (Fig. 10, bottom panel).
5. Aphid densities were relatively low throughout the study but increased between April and May at all sites: they were also most abundant on each date at the turning basin reference *Carex* site (Fig. 10, middle panel).
6. Collembola (springtails) also occurred in low densities compared with other insect taxa but were most abundant at the reference *Scirpus* patch near Kellogg Island: at this site collembolans were most abundant in July (Fig. 10, top panel).

#### Juvenile Salmon Diets

Catches consisted almost entirely of juvenile chum and chinook salmon. Adequate numbers of coho salmon for stomach analysis occurred only at the turning basin site on 17 April.

#### Chum Salmon

Two prey taxa occurred in juvenile chum salmon relatively consistently across sites and dates. First, chironomid flies made up 25–60% of the prey weight at a minimum of one lower waterway and one middle waterway site on each date (Fig. 11). Second, *Corophium* spp. were also present on each sample date in fish from lower waterway and middle or upper waterway sites.

In several instances, prey weight was dominated by a single prey category: (1) on 1 April at the upper waterway site, the planktonic cladocerans *Daphnia* spp. made up about 80% of the prey weight; (2) on 17 April at the West Kellogg Island site, the planktonic calanoid copepod *Eurytemora americana* was virtually the only prey item consumed and also constituted about 50% of prey weight at this site on 6 May; (3) at the upper waterway site on 6 May, *Corophium* spp. made up over 80% of the prey

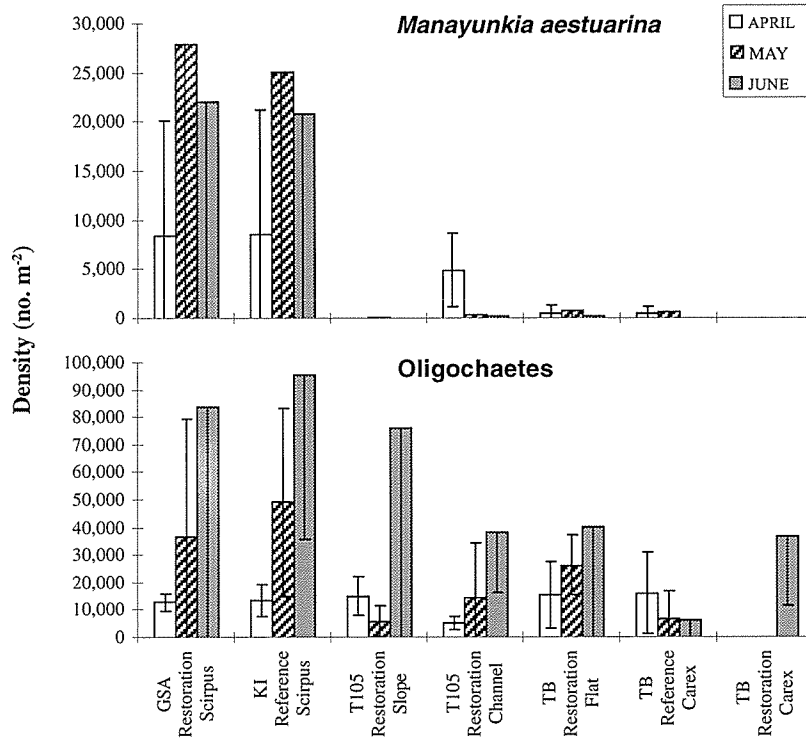


FIGURE 5.—Densities of prominent annelid worms from benthic core samples taken at Coastal America restoration and reference sites, April–June 1996. Vertical lines are 95% confidence intervals: only negative intervals are shown for some means.

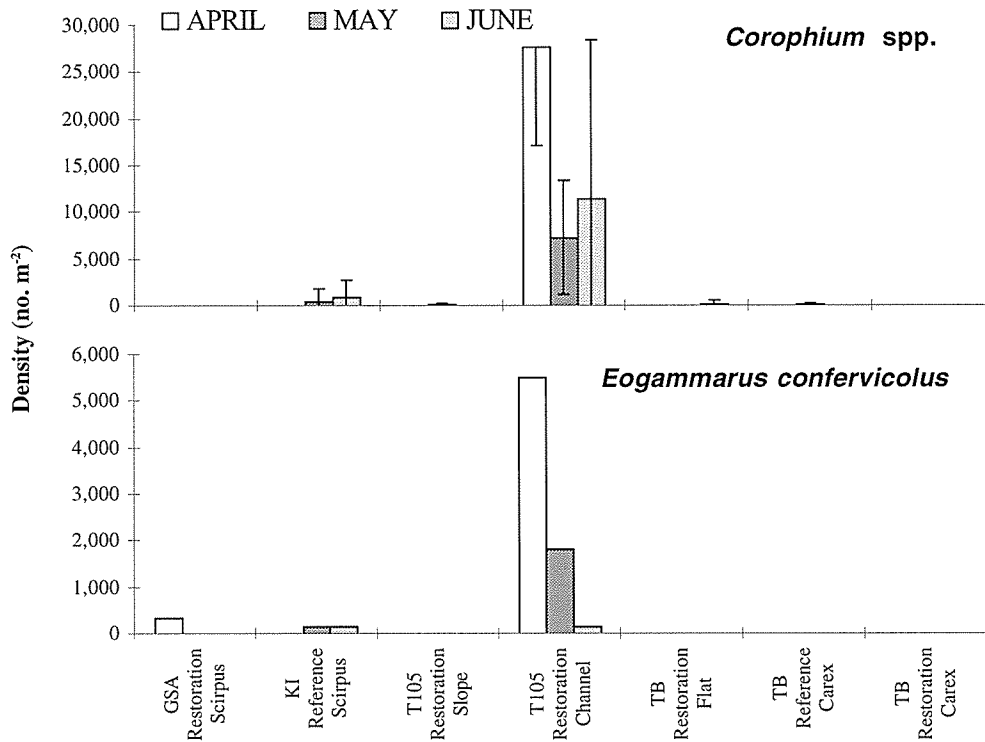


FIGURE 6.—Densities of prominent amphipod crustaceans from benthic core samples taken at Coastal America restoration and reference sites, April–June 1996. Vertical lines are 95% confidence intervals: only negative intervals are shown for some means.

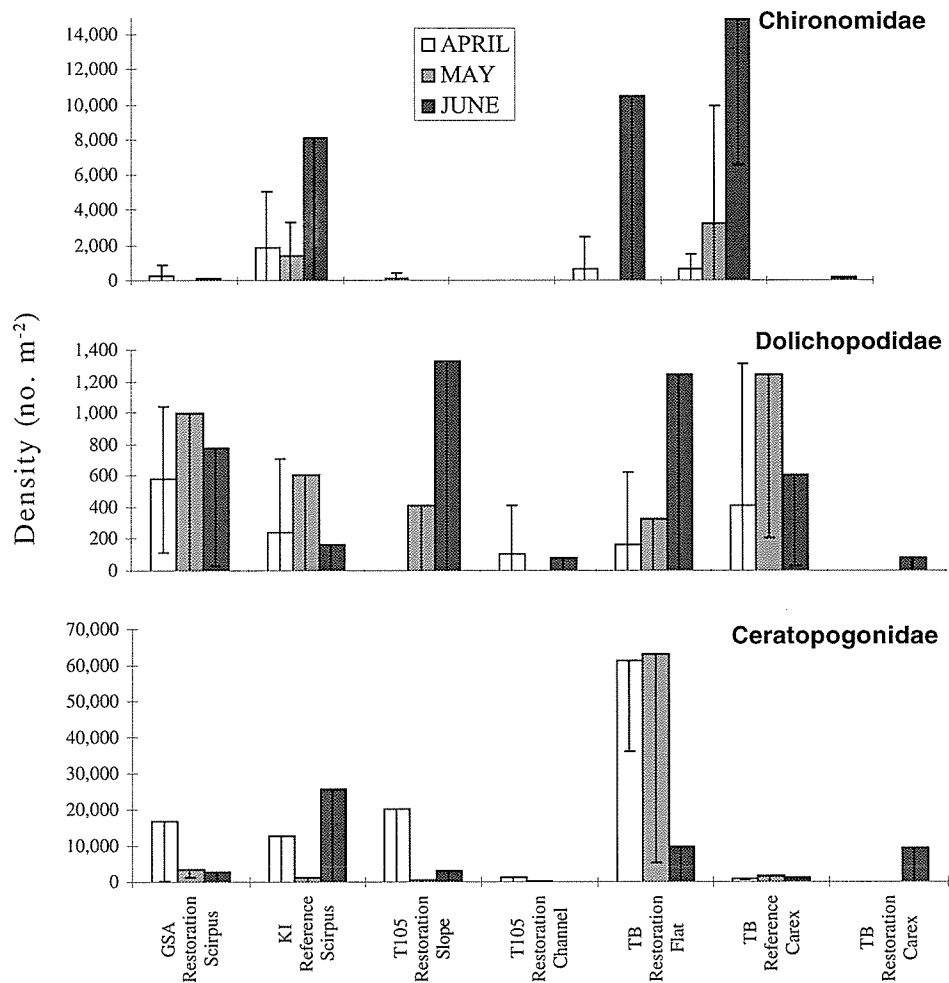


FIGURE 7.—Densities of prominent dipteran fly larvae from benthic core samples taken at Coastal America restoration and reference sites, April–June 1996. Vertical lines are 95% confidence intervals; only negative intervals are shown for some means.

weight; and (4) the epibenthic harpacticoid copepods *Leimia vaga*, *Tachidius discipes*, and *Microarthridion littorale* dominated chum salmon prey at the turning basin site on 17 April and at both middle and upper waterway sites on 6 May (Fig. 11).

At one site on 6 May (Smelt Beach in the upper waterway), two distinct size classes of juvenile chum salmon were examined for diet composition. In this case, the smaller fish fed mainly on epibenthic copepods and chironomid flies, and the larger fish diets consisted almost entirely of *Corophium* spp. and other relatively large crustaceans.

#### Chinook and Coho Salmon

In contrast to the chum salmon diets, there were no prey groups that occurred consistently across sites and dates for chinook and coho salmon. In the 1 and 17 April samples,

prey weight was distributed among relatively numerous prey categories (Fig. 12). The prey groups that constituted over 25% of prey weight for any single site and date in April samples included collembolans, fish larvae, bivalve (clam) siphons, dipteran flies, the amphipod *Eogammarus confervicolus*, polychaete and oligochaete annelid worms, barnacle nauplius larvae, and *Corophium* spp.

In 6 May samples, chinook salmon prey was dominated at all sites by four species of benthic and epibenthic crustaceans: *Corophium* spp., the cumacean *Cumella vulgaris*, *Eogammarus confervicolus*, and the mysid shrimp *Neomysis mercedis* (Fig. 12).

Similarly, the prey from the single sample of juvenile coho salmon collected on 17 April consisted almost entirely of benthic and epibenthic crustaceans, including *Corophium* spp. and *Eogammarus confervicolus*, the mysid shrimp *Neomysis mercedis*, and the isopod *Gnorimosphaeroma oregonense* (Fig. 13).

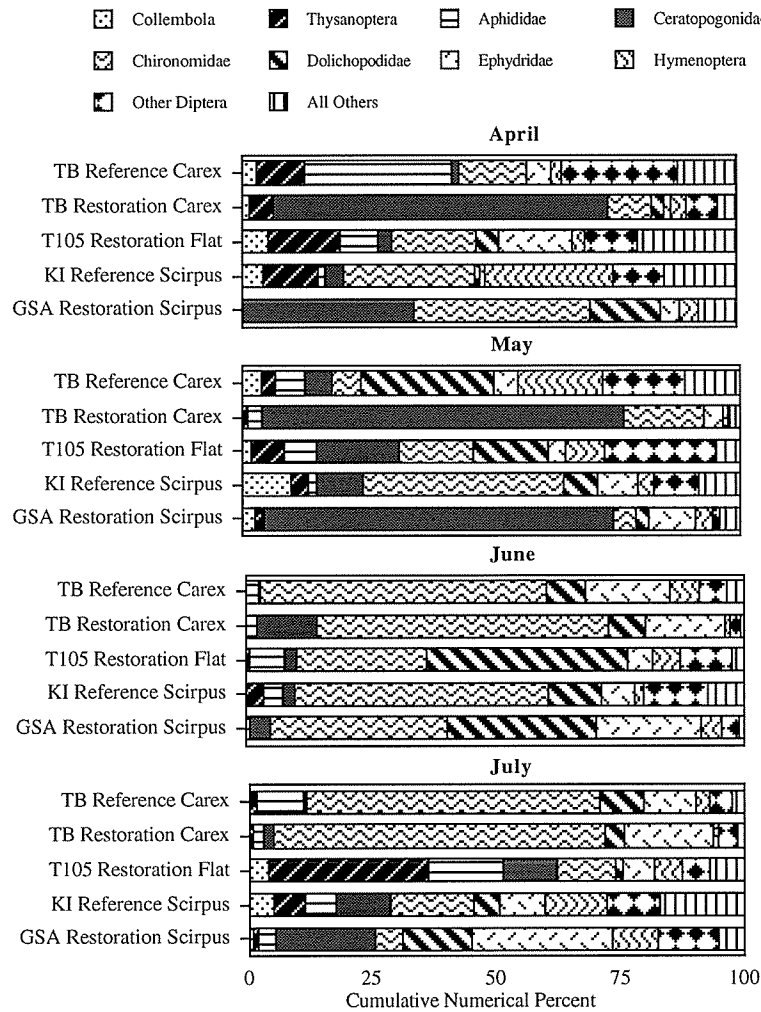


FIGURE 8.—Percent numerical composition of invertebrates from insect fallout traps deployed at Coastal America restoration and reference sites, April–July 1996.

*Avifauna*

Over three seasons of monitoring, 58 bird species have been observed on the Duwamish Waterway (Table 1). Seasonally, the greatest number of species were seen during the winter months (44 species from 12/1/96 to 2/28/97), with a similar number of species observed during the fall (42 species from 9/1/96 to 11/31/96) and the fewest species sighted during the summer (27 species from 6/1/95 to 8/31/95).

When species were grouped by guild and 11 species were also categorized as either introduced or human-associated, several trends became apparent. Passerine and raptor diversity was generally greater in fall while waterfowl diversity was greatest in winter (Table 2 a–d). Sixteen species were seen every season (Table 2 a–d) and 44% of those were categorized as either introduced or human-

associated (Table 1, 2 a–d). When introduced and human-associated species categories were removed mean richness declined 36–66% (Figure 13). Introduced and human-associated species were always seen at all four sites regardless of season (Table 2 a–d); however, introduced species were generally seen at a lower frequency than human-associated species (Table 2 a–d).

Species richness tended to be the greatest in winter at all sites and was always highest at Kellogg Island (Fig. 14). The T-105 and Kellogg Island sites had similar patterns of species richness with diversity being lowest in summer (5 species at T-105 and 8.4 species at Kellogg) and highest in winter (8 species at T-105 and 12.4 species at Kellogg). At the turning basin sites, the restored side showed no seasonal changes in diversity (6.7–7.3 species/season) while there was slightly more seasonal variation for the reference side (4.2–5.8 species/season).

*Text continues on page 14*

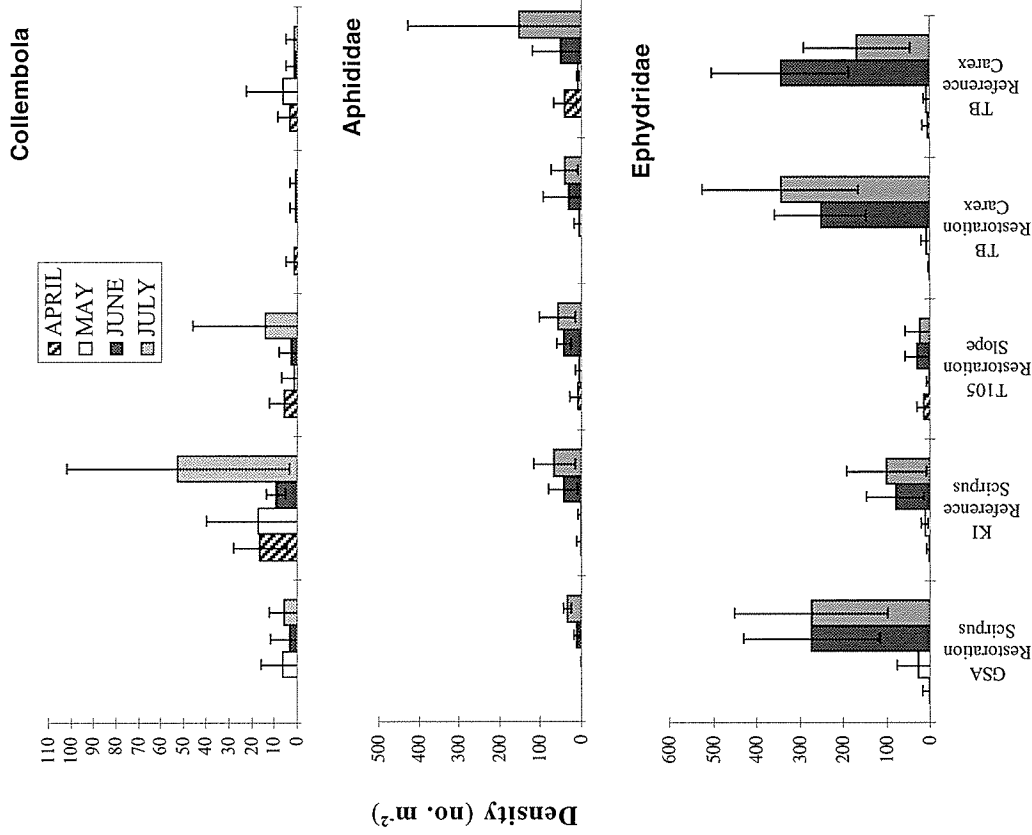


FIGURE 9.—Densities of prominent dipteran flies from insect fallout traps deployed at Coastal America restoration and reference sites, April–July 1996. Vertical lines are 95% confidence intervals.

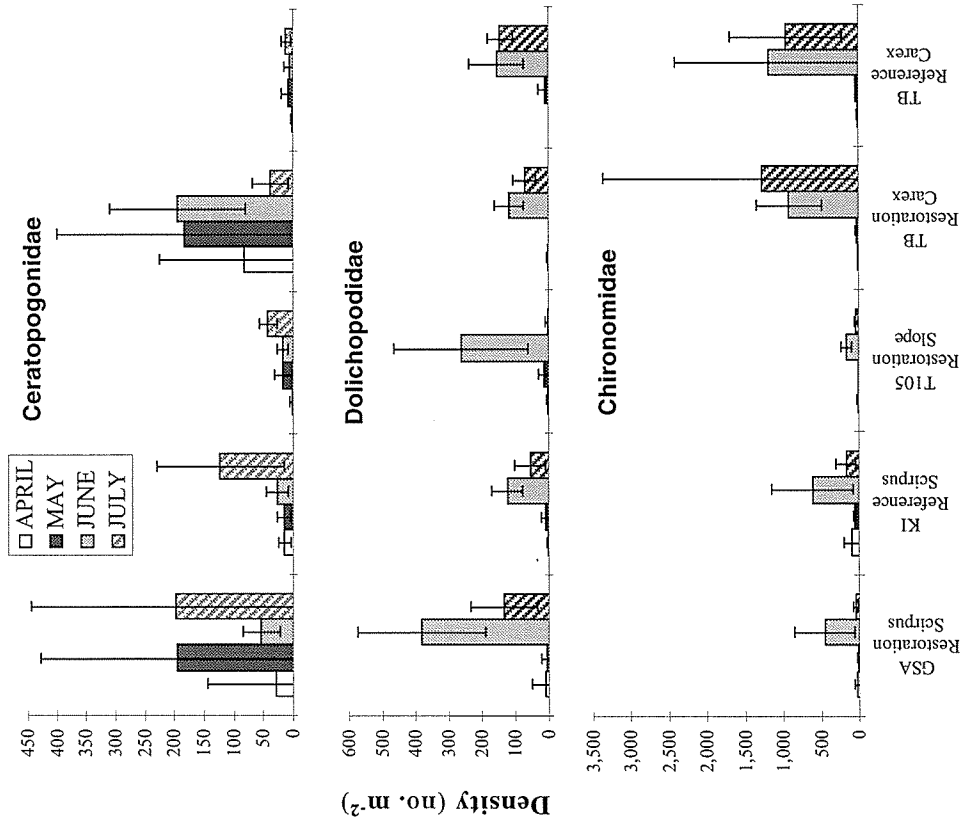


FIGURE 10.—Densities of other prominent insects from insect fallout traps deployed at Coastal America restoration and reference sites, April–July 1996. Vertical lines are 95% confidence intervals.

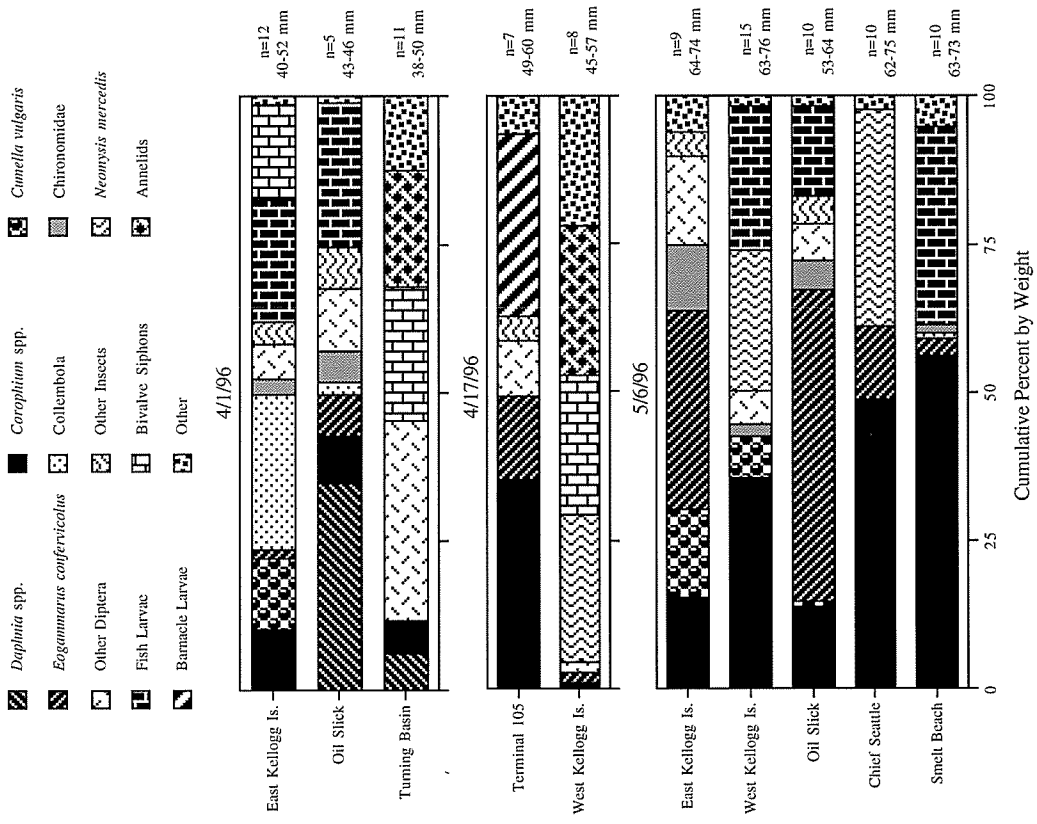


FIGURE 11.—Percentage composition by weight of prey from juvenile chinook salmon on three dates at several stations in the Duwamish Waterway, 1996: top of each graph is upper waterway, bottom is lower waterway.

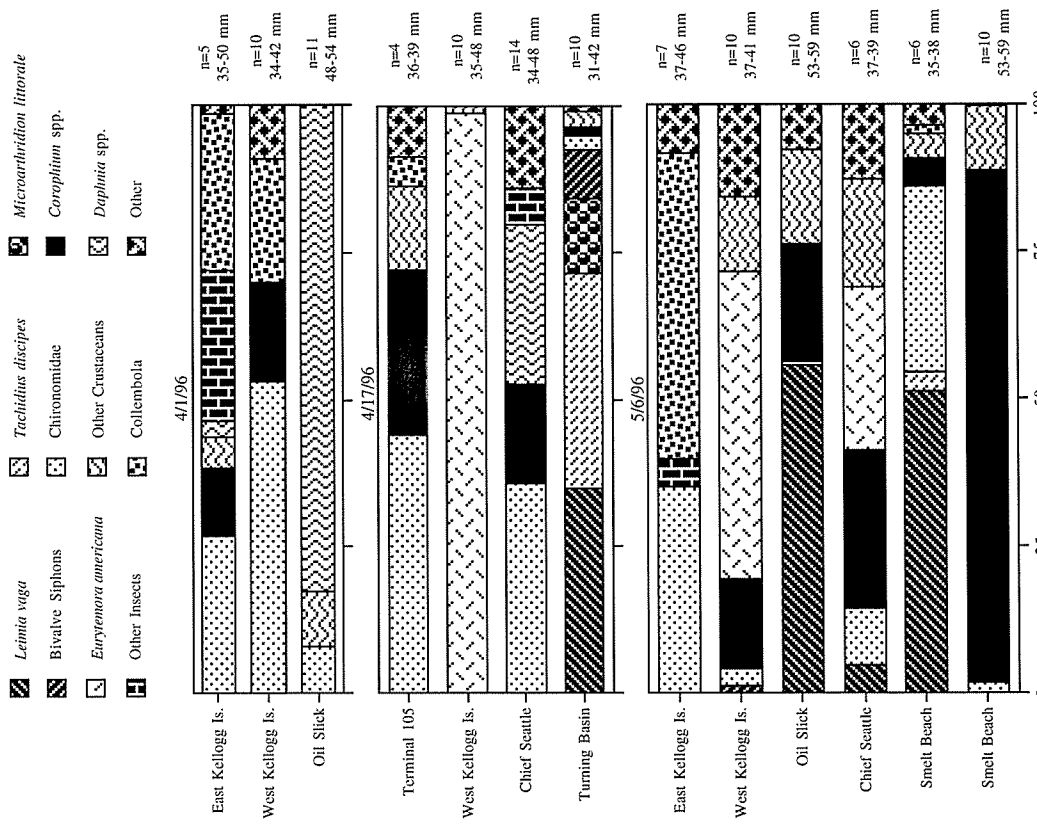


FIGURE 12.—Percentage composition by weight of prey from juvenile chum salmon on three dates at several stations in the Duwamish Waterway, 1996: top of each graph is upper waterway, bottom is lower waterway.

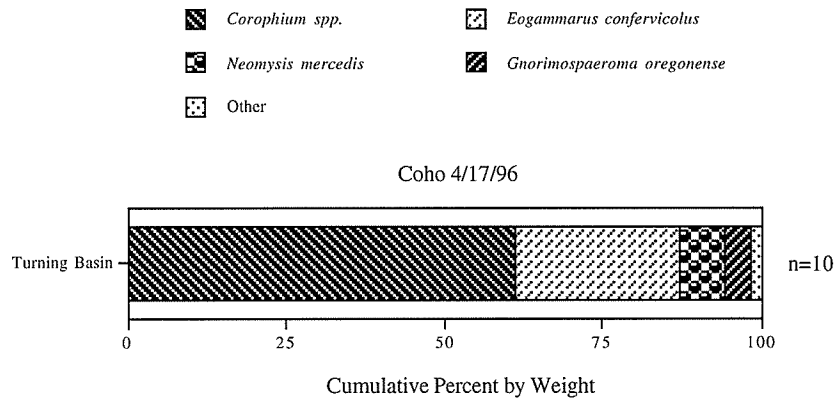


FIGURE 13.—Percentage composition by weight of prey from juvenile coho salmon at the turning basin site in the Duwamish Waterway, 17 April 1996.

Site-specific abundance varied by site and season (Fig. 15). Abundance was always highest at Kellogg Island (78–163 birds/half-hour observation) and lowest at the T-105 site (~34 birds). At the turning basin, abundance was similar for the restored and reference sites (29–71 birds at the restored site versus 16–59 at the reference site). Seasonal site-specific abundance varied for three of the four sites with the turning basin restored and reference sites being highest in summer and Kellogg Island highest in fall; the T-105 site abundance was similar across seasons.

When mean abundance was calculated without introduced and human-associated species, total abundance dropped dramatically for summer and fall observation periods—between 48 and 91% (Fig. 13). This decrease was less striking in the winter months, probably because of an influx of migratory species during the winter months rather than the departure of introduced and human-associated species.

Patch size is often regarded as a variable that influences abundance. Terrestrial area was the best predictor of abundance (Fig. 16) even though many of the birds seen on the Duwamish Waterway are rarely seen on land, suggesting surface water area should also be important. However, the fact that many of the introduced and human-associated species flock in large groups (e.g., Glaucous-winged Gull, European Starling, House Finch, Northwestern Crow) and these species are frequently seen resting or foraging on land probably strongly influences the relationship of abundance and patch size.

In order to rank the 'effectiveness' of the restored sites relative to each other as well as the reference areas, a pairwise index of association was calculated: species present at both sites/species present at either site (Table 3). Several patterns were apparent. The presence of introduced species was more widespread in summer than in winter while the pres-

ence of human-associated species was usually higher and more similar across seasons. Native species appeared to be more common across sites in fall and winter: in particular, their presence at the T-105 site was markedly greater in these seasons than the summer of 1995.

There were several differences in bird use among sites and seasons (Fig. 17). Across seasons birds in transit were seen more frequently at the T-105 site. Anecdotal reports by the observers indicated that many of the birds in transit at this site were Double-crested Cormorants and gulls that were probably using habitats on Elliott Bay and the Duwamish Waterway. Foraging activity at all sites tended to be greatest in the fall. During the winter, the level of foraging and resting was nearly equivalent within sites.

## Emergent Vegetation

### *Carex lyngbyei* Benches

All three benches were longer in 1996 than in 1995 (Table 4). Bench 1 increased in length downstream and Bench 2 increased both up- and downstream. These two benches are bordered at each end by rock armoring and now extend as far as they can in both directions. The upstream portion of Bench 3 increased slightly in length, but the downstream portion was narrower and shoots were sparser.

Shoot density showed no significant time, location, or interaction effects although mean density increased at Bench 1 and decreased at both downstream benches.

Average maximum shoot height showed a significant interaction between location and time ( $p = .023$ ; see Appendix). Maximum shoot height increased at all benches, but the increase was greatest at Bench 1.

Bench 1 thins out between 17.5 and 20 m. Shoots along the lower edge were heavily grazed, but some shoots in

TABLE 2.—Bird species observed at the Terminal 105 restoration site, the Kellogg reference site, and the turning basin restoration and reference sites. Frequencies are a percentage of total observations each species was seen. Species are grouped loosely by guild: passerines, raptors, shore and wading, waterfowl, and seabirds. Boldface type = introduced species; italic type = native-human associated species.

TERMINAL 105 RESTORATION SITE

<u>VERY RARE</u> (≤ 10%)			<u>OCCASIONAL</u> (10 < X ≤ 50%)			<u>COMMON</u> (50 < X < 80%)			<u>UBIQUITOUS</u> (≥ 80%)		
SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT
GOFI CLSW <b>HOFI</b> <i>RODO</i>	GOFI SASP SOSP WCSP HOWR <i>AMRO</i> <i>BASW</i> <i>RODO</i>	RODO	<b>ENSP</b> <i>BASW</i> <i>NWCR</i>	<b>HOFI</b>	<b>WCSP</b> <b>HOFI</b> <i>AMRO</i> <i>NWCR</i>	<b>EUST</b>	<b>EUST</b> <i>NWCR</i>	<b>EUST</b>			
	OSPR RTHA SSHA	BAEA SWHA									
SPSA	KLDR		GBH	GBH	KLDR GBH	KLDR					
	AMCO GADW HOME	<b>DOGO</b>	<b>DODU</b> <i>MALL</i>	WEGR <i>MALL</i> <i>CAGE</i>	BAGO BUFF CAGO RNGR COME HOME RBME <i>MALL</i>	<i>CAGE</i>		AMCO WEGR			
	RBGU	MEGU RBGU	BEKI	BEKI MEGU	BEKI	<i>GWGU</i>	DCCO <i>GWGU</i>	DCCO			<i>GWGU</i>

KELLOGG ISLAND REFERENCE SITE

<u>VERY RARE</u> (≤ 10%)			<u>OCCASIONAL</u> (10 < X ≤ 50%)			<u>COMMON</u> (50 < X < 80%)			<u>UBIQUITOUS</u> (≥ 80%)		
SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT
TRSW ENSP <i>RODO</i>	FOSP SOSP SWTH BEWR HOWR <i>AMRO</i> <i>RODO</i>	FOSP GCSP HOWR BUTI RWBL EUST	FOSP CLSW <b>HOFI</b> <i>BASW</i> <i>AMRO</i>	SASP BUTI <b>HOFI</b>	SOSP WCSP BCCH NOFL <b>HOFI</b> <i>AMRO</i> <i>RODO</i>	<b>EUST</b> <i>NWCR</i>	<b>EUST</b>				<i>NWCR</i> <i>NWCR</i>
	BAEA OSPR SSHA	SSHA SWHA	OSPR		BAEA						
	DUNL SPSA		SPSA		DUNL KLDR GBH		KLDR GBH		KLDR GBH		
GADW	AMWI BUFF HOME	HOGR PBGR	COME	GADW CAGE COME RBME	BAGO CANV GADW HOME RBME	<i>MALL</i> <i>CAGE</i>	WEGR	COME <i>CAGE</i>		<i>MALL</i>	AMCO WEGR <i>MALL</i>
MEGU	RBGU	RBGU	DCCO	BEKI		BEKI	MEGU	DCCO MEGU	<i>GWGU</i>	DCCO <i>GWGU</i>	<i>GWGU</i>

TABLE 2.—cont.

TURNING BASIN RESTORATION SITE

<u>VERY RARE</u> (≤ 10%)			<u>OCCASIONAL</u> (10 < X ≤ 50%)			<u>COMMON</u> (50 < X < 80%)			<u>UBIQUITOUS</u> (≥ 80%)			
SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT	
FOSP VGSW HOFI	SASP WCSP BEWR HOWR BUTI NOFL EUST BASW	FOSP SOSP HOWR BCCH AMRO	ENSP EUST NWCR	FOSP BCCH RWBL HOFI RODO NWCR	HOFI RODO NWCR	CLSW RODO						
OSPR	MERL OSPR SSHA											
	SPSA		GBH	DUNL KLDL GBH	DUNL KLDL GBH	SPSA					KLDR	
GADW	AMWI CAGO		DOGO COME	COME CAGE	BAGO BUFF GADW PBGR	CAGE		MALL CAGE		MALL	MALL	WEGR
DCCO MEGU	BEKI		BEKI	DCCO	MEGU	GWGU	MEGU	DCCO GWGU				

TURNING BASIN REFERENCE SITE

<u>VERY RARE</u> (≤ 10%)			<u>OCCASIONAL</u> (10 < X ≤ 50%)			<u>COMMON</u> (50 < X < 80%)			<u>UBIQUITOUS</u> (≥ 80%)		
SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT	SUM	FALL	WINT
SOSP VGSW ENSP NWCR	HOWR BCCH AMRO	BEWR HOWR NWCR	GOFI FOSP CLSW EUST HOFI BASW RODO	HOFI RODO NWCR	BCCH HOFI AMRO RODO						
	OSPR SSHA										
	SPSA GBHE		SPSA GBH	KLDR GBH	DUNL KLDL			GBH			KLDR
COME DOGO	CAGE	BUFF GADW EAGR WEGR RBME	CAGE	COME	COME			MALL CAGE		MALL	MALL
BEKI	MEGU	BEKI	MEGU GWGU	BEKI DCCO	DCCO MEGU GWGU						GWGU

the center of the bench were flowering. Two shoots of *Scirpus validus* occurred in one of the quadrats; *Spergularia marina*, *Plantago maritima*, *Eleocharis parvula*, and *Cotula coronopifila* were recruiting below the lower edge of the bench; and *Rumex crispus* and *Phalaris arundinacea* flanked the bench on the uphill side.

Bench 2 has an eroded area just below the fence at 39.1–40.2 m. *Lilaeopsis*, *Eleocharis parvula*, and *Potentilla palustris* were noted in the quadrats (Table 4.)

Bench 3 did not increase in size as much as Benches 1 and 2. A great deal of garbage, including large pieces of

metal and concrete, was strewn about the site. The upstream bench was matted although not heavily grazed and slightly longer than in 1995; the downstream bench was very narrow and the same length as 1995. *Spergularia marina*, *Scirpus scernuus*, *Plantago maritima*, *Atriplex patula*, and *Potentilla palustris* were present in the understory (Table 5).

*Scirpus validus*

Reference site adjacent to Kellogg Island.—The reference

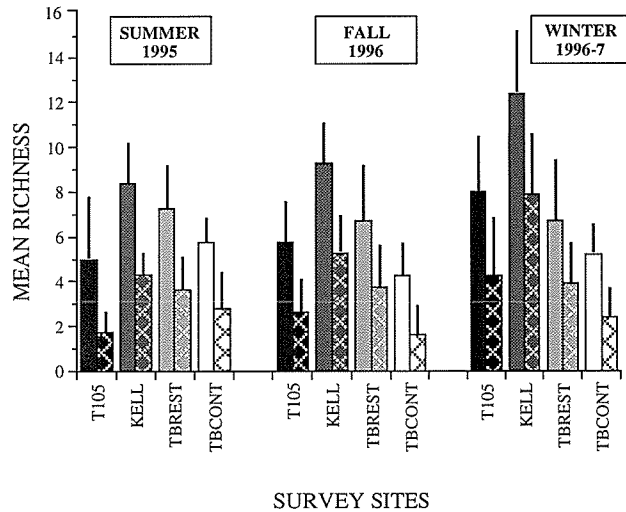


FIGURE 14.—Mean (+ SD) species richness for three seasons of bird observations at four sites in the Duwamish Waterway. Solid-filled columns represent total species richness; pattern-filled columns represent richness without introduced and human-associated species.

*Scirpus* patch near Kellogg Island increased slightly in length while the GSA patch decreased slightly (Table 6). Shoot density decreased over time at both sites, but this decrease was not statistically significant. Reference shoot density was significantly lower in both years ( $p = 0.0038$ ; see Appendix). Shoot height increased slightly but insignificantly at both sites and was greater at the reference site in both years.

As in 1995, several species were recruiting into the *Scirpus* patches. At the reference site, *Carex* was the second most abundant species and had an average of 10.9 shoots per quadrat (stdev 11.96) in the 10 quadrats sampled. The two patches share some understory species but species compositions differ (Table 7).

T105 site.—Intertidal estuarine vegetation has begun to recruit into the constructed channel at the T105 site. *Atriplex patula* was abundant along the edges of the channel with some isolated plants of *Spergularia marina* and *Salicornia virginica* (Table 8). Planted *Salix* have been surviving well near the mouth of the channel.

### Sediment Grain Size

Sediment grain size distribution was similar at four of the six benthic sites (Fig. 18). At the two T-105 sites, the *Scirpus* patch near Kellogg Island, and the reference *Carex* patch, sediment fell mostly into the 0.25-mm size class with most of the remainder distributed into the 0.5-mm and 0.125-mm size classes. At the GSA and turning basin

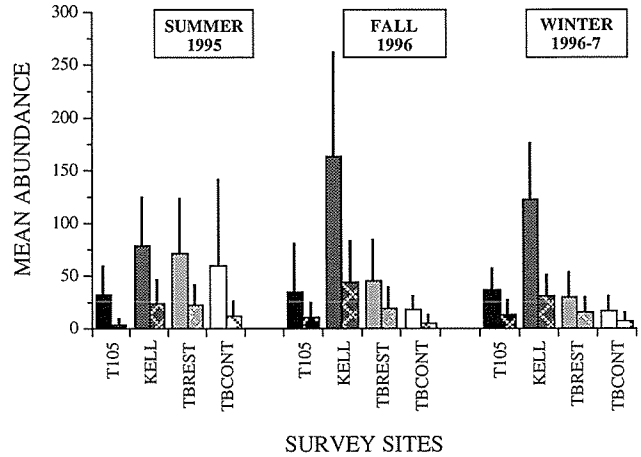


FIGURE 15.—Mean (+ SD) abundance for three seasons of bird observations at four sites in the Duwamish Waterway. Solid-filled columns represent total abundance; pattern-filled columns represent abundance without introduced and human-associated species.

restored sites, the sediments tended to be finer with a marked peak of very fine sediment at the first of these two sites.

## DISCUSSION AND RECOMMENDATIONS

### Benthic Studies

Because the elevations sampled for benthic invertebrates in this study were higher than those sampled in previous years, between-year comparisons should be interpreted with caution. However, some Protocol taxa occurred in densities similar to those seen in previous samplings. These included oligochaete worms and the polychaete *Manayunkia aestuarina* at the reference and restoration *Scirpus* patches and the amphipods *Corophium* spp. and *Eogammarus confervicolus* at the T-105 channel. The relatively high numbers of these latter two taxa may be particularly important because the T-105 site appears to lag behind all other sites in production of other benthic organisms and fallout insects (see Fig. 4). The T-105 site is unique among the Coastal America restoration sites in having a relatively sheltered sediment habitat that does not dry out at low tide (there is some freshwater flow-through from surface water drainage diverted into the head of the channel). This may benefit benthic amphipods in at least two ways: first, it may provide a region of low energy resulting in settling of organic matter that provides food for invertebrates, and second, it may for the same reason provide a sheltered habitat for the animals themselves.



TABLE 4.—Bench length (m), shoot density (count/.625 m<sup>2</sup>), and shoot height (cm) at Duwamish River *Carex* benches, August 1995 and 1996 (n = 10/site).

		bench length			shoot density			shoot height		
		Bench 1	Bench 2	Bench 3	Bench 1	Bench 2	Bench 3	Bench 1	Bench 2	Bench 3
1995		26	28	4, 10						
1996		39	42.8	5.8, 10						

		shoot density			shoot height		
		Bench 1	Bench 2	Bench 3	Bench 1	Bench 2	Bench 3
1995	Mean	32.0	46.8	38.1	91.0	93.7	123.6
	SD	13.9	14.8	19.6	24.0	14.4	25.5
	Max	60	76	75	138	120	158
	Min	17	28	20	46	78	81
	CV	0.4	0.3	0.5	0.3	0.2	0.2
1996	Mean	43.7	40.5	29.1	140.0	100.0	136.1
	SD	12.9	26.9	16.2	32.7	21.9	31.1
	Max	63	87	68	177	138	191
	Min	28	8	8	76	77	89
	CV	0.3	0.7	0.6	0.2	0.2	0.2

TABLE 5.—Other species present in quadrats at Duwamish *Carex* benches, August 1995, 1996 (n = 10/site).

Species	Bench 1		Bench 2		Bench 3	
	1995	1996	1995	1996	1995	1996
<i>Spergularia marina</i>					2	1
<i>Scirpus cernus</i>					3	2
<i>Plantago maritima</i>						2
<i>Aster subspicatus</i>					1	2
<i>Atriplex patula</i>					3	3
<i>Potentilla pacifica</i>			1			1
<i>Triglochin maritima</i>					1	
<i>Lilaeopsis</i> sp.			4			
<i>Eleocharis parvula</i>				5		
<i>Scirpus validus</i>			1		1	

TABLE 6.—Patch length (m), shoot density (count/.625 m<sup>2</sup>), and shoot height (cm) at Duwamish River *Scirpus* patches, August 1995 and 1996 (n = 10/site).

		bench length	
		GSA	Reference
1995		38	10
1996		34.8	11.2

		shoot density		shoot height	
		GSA	Ref	GSA	Ref
1995	Average	37.8	16.2	73.2	118.4
	StdDev	25.7	9.3	23.0	42.7
	Max	91	34	110	171
	Min	8	6	28	58
	CV	0.7	0.6	0.3	0.4
1996	Average	25.2	14.9	77.3	129.1
	StdDev	16.6	6.6	21.3	44.5
	Max	56	30	106	200
	Min	7	7	44	82
	CV	0.7	0.4	0.3	0.3

TABLE 7.—Other species present in quadrats in Duwamish *Scirpus* patches, August 1995, 1996 (n = 10/site).

Species	Reference		GSA	
	1995	1996	1995	1996
<i>Carex lyngbyei</i>	4	7		
<i>Spergularia marina</i>	4	5	9	10
<i>Potentilla pacifica</i>	2	4		
<i>Triglochin maritima</i>		3		
<i>Scirpus cernus</i>		2	7	3
<i>Atriplex patula</i>	2	1	1	
<i>Distichlis spicata</i>		2		
<i>Ranunculus repens</i>	2	1	2	1
<i>Cotula coronopifila</i>			6	7
<i>Salicornia virginica</i>			1	2

TABLE 8.—Plant species occurring in the created channel at the T-105 restoration site, Duwamish Waterway, August 1996.

Species	Distance from culvert (m)
<i>Salicornia virginica</i>	1.4
<i>Salicornia virginica</i>	2.0
<i>Triglochin maritima</i>	2.1
<i>Carex lyngbyei</i>	5.4
<i>Distichlis spicata</i>	6.2
<i>Carex lyngbyei</i>	6.8
<i>Triglochin maritima</i>	8.1
<i>Carex lyngbyei</i>	9.7
<i>Carex lyngbyei</i>	10.5
<i>Carex lyngbyei</i>	11.8
<i>Carex lyngbyei</i>	12.0
<i>Triglochin maritima</i>	13.8
<i>Carex lyngbyei</i>	17.6
<i>Carex lyngbyei</i>	17.9
<i>Carex lyngbyei</i>	19.5
<i>Carex lyngbyei</i>	21.3
<i>Carex lyngbyei</i>	21.75
<i>Salicornia virginica</i>	28.65
<i>Spergularia marina</i>	29.2
<i>Carex lyngbyei</i>	28.9–30.4
<i>Distichlis spicata</i>	39.4

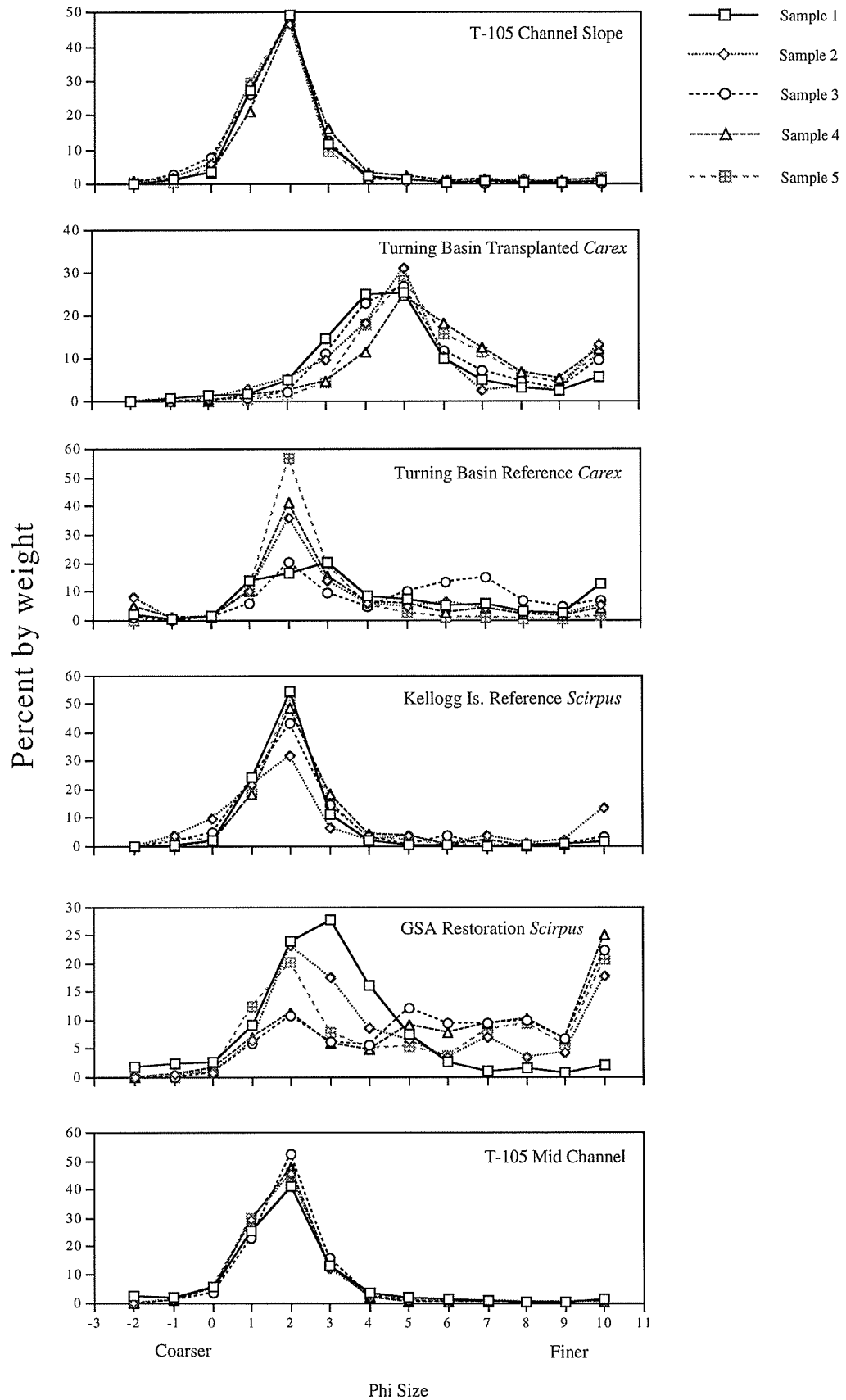


FIGURE 18.—Sediment grain size composition at Coastal America restoration and reference sites, April 1996.

Reasons for low production of other taxa observed at T-105 may include (1) relatively coarse, unstable sediments on the margins of the created channel; (2) the location of the restoration site in a highly industrialized part of the waterway, resulting in fewer insects visiting the site (and falling into insect traps) and using the site for reproduction (resulting in fewer insect larvae in the samples); and (3) little or no transplanted or naturally recruiting emergent or riparian vegetation at the site. However, habitat at this site is improving: vegetation is increasing in the form of naturally recruiting sedges and grasses beginning to establish near the head of the created channel (see Results), and upland and channel slope portions of this site have been planted recently. Continued monitoring of this site likely will show increasing diversity and densities of insects and other invertebrates as the vegetation becomes established and the site stabilizes.

For several taxa of benthic insect larvae that are important juvenile salmon prey, densities were relatively and consistently high in restored habitats. Examples included dolichopodid fly larvae at the GSA restored *Scirpus* site and T-105 created channel slope, and ceratopogonid, dolichopodid and chironomid fly larvae at the turning basin sand flat. While this data may indicate that the “performance” of these sites is similar or superior to the reference sites for these taxa, these sites usually contained far fewer of another extremely important taxon, chironomid fly larvae, than did the reference sites. Also, because this is the first year in which benthic invertebrates were sampled in higher-elevation vegetation patches, we do not know how much their populations might vary from year to year.

Because the high intertidal sand flats within the T-105 created channel and the fringing transplanted *Carex* at the turning basin restoration site appear to be accreting sediment and developing assemblages of juvenile salmon prey invertebrates (amphipods at the former, fly larvae at the latter), we recommend that these sites be sampled in future monitoring efforts to document whether these assemblages persist and continue to increase. We also recommend that reference sites at the 0.0-m elevation used in past studies be sampled as well. Despite the fact that they are at a different elevation than the restoration flats, there are several good reasons that they should be sampled as references. First, there is very little appropriate flat habitat available in the Duwamish Waterway at higher intertidal elevations: most of the habitat at these elevations consists of relatively steep sediment banks or artificial armoring. Second, retaining these reference sites will add to and increase the value of the long-term data set from these sites. Third, they will provide a “best-case” scenario

of benthic invertebrate densities with which to compare the restored habitat data.

### *Fallout Insects*

As with the benthic core invertebrates, abundances of fallout insects were much lower at the T-105 site than at other sites for all insects combined and for most Protocol prey attribute insect taxa (Figs. 9 and 10). As discussed above, we expect developing riparian and emergent vegetation that has recently recruited to or been planted at the site will result in increasing insect numbers. We recommend continued monitoring of insects at this site to document this development.

In contrast to the data from 1995, when ephydrid flies were the most abundant insect family at the turning basin restoration and reference *Carex* sites, in 1996 these sites were dominated by ceratopogonid and chironomid flies. We cannot say whether this difference is due to natural interannual variation or to some permanent change in the sites because we lack a sufficient time series of data. For ephydrids, ceratopogonids, and chironomids, the transplanted *Carex* area had abundances similar to or in excess of those at the reference *Carex* patch. However, abundances of other prey attribute insects, including dolichopodid flies, collembolans (springtails), and aphids, were consistently lower at the transplanted area. This is not surprising because the transplants from the previous year experienced poor survival owing to goose grazing, and new transplanting took place near the end of our sampling period. We expect that the new transplants (if protected with goose exclosures) will have higher survival and that higher numbers of insects (especially plant-associated types such as aphids) will be found in subsequent samplings.

Similarly to the *Carex* sites, the restored *Scirpus* patch at the GSA site had abundances of some flies (Ephydridae, Ceratopogonidae, Dolichopodidae and Chironomidae) that met or exceeded those at the Kellogg Island reference *Scirpus* patch. But also like the *Carex* sites, aphids and collembolans were fewer at the restored site.

Despite some qualitative differences between restoration and reference sites, it appears that restored *Carex* and *Scirpus* vegetation patches at the Coastal America sites are producing insects that are consumed by juvenile salmon. Whether this production is stable or on a developmental trajectory is unknown. Also, where vegetation has not become established or has been transplanted (i.e., T-105), insect populations apparently lag behind those at vegetated sites; thus, plant recruitment probably will result in more insects. Monitoring of fallout insects at these

sites is a relatively inexpensive and effective way to answer these questions.

### *Juvenile Salmon Diets*

Because our sample of fish was small—three sample dates in a single year—conclusions about juvenile salmon diets should be interpreted with caution. Examination of salmon stomachs from previous samples (archived by Muckleshoot Tribal Fisheries Department) or future fish sampling will greatly strengthen conclusions about feeding habits of salmon in the Duwamish Waterway and allow us to make more informed conclusions about whether the Coastal America restoration sites are producing salmon prey.

The created channel at the T-105 site presents a unique opportunity to sample fish that have been using the actual restoration site. The channel is relatively high in elevation and drains completely at most low tides. It is also narrow enough that it can be blocked with a standard 30-m beach seine. Therefore, all of the fish that have been residing in and presumably using the channel during a given high tide can be collected by block seining. We also assumed that most of the fish captured had been foraging in the created habitat and that food in the foregut was consumed in the channel. Therefore, we strongly recommend that this site be included in any future fish sampling that is part of monitoring at the Coastal America sites. The block seining technique might also be effective on the small sand flat that has been enclosed by transplanted vegetation at the turning basin restoration site. If the vegetation successfully establishes itself, it may form a natural enclosure that will allow placement of a net at the open end of the flat.

### Chum Salmon

It is not surprising that juvenile chum salmon fed primarily on epibenthic harpacticoid copepods and *Corophium* amphipods at the upper waterway sites because they feed on the same or similar species in other habitats (Simenstad et al. 1991). Also, our previous work has shown that these taxa dominate the benthic and epibenthic assemblages in the Duwamish Waterway (Cordell et al. 1994, 1996). The epibenthic harpacticoids—*Leimia vaga*, *Tachidius discipes*, and *Microarthridion littorale*—have not been previously seen as major constituents of juvenile chum diets, but we hypothesized earlier that they should provide good prey resources because of their sizes and abundances (Cordell et al. 1994). The Coastal America restoration sites do not provide habitat for direct production of these copepods because the site elevations are too high (our scans of meiofauna fractions from 1996 higher

intertidal benthic samples showed virtually no epibenthic prey harpacticoids at these sites). However, this does not preclude the possibility that the restoration sites will provide inputs of organic matter to adjacent lower intertidal areas that will, over time, result in increased epibenthic prey resources.

There is strong evidence from our data that juvenile chum salmon outmigrating through the Duwamish Waterway can find an alternative to epibenthic prey in planktonic crustaceans. This is evidenced by the complete dominance of planktonic cladocerans (*Daphnia* spp.) and calanoid copepods (*Eurytemora americana*) in the diets of several groups of chum examined.

Another important constituent of juvenile chum diets was emergent or drifting dipteran flies, especially chironomids. These insects were particularly important at lower waterway sites such as Kellogg Island, and even dominated the diet of fish caught at the created channel at the T-105 site despite being relatively sparse in fallout trap samples. Although lower waterway restoration sites at the T-105 and GSA sites produced relatively few larval and adult chironomids, the restored sand flat and associated transplant area at the turning basin had high numbers of these prey taxa.

### Chinook and Coho Salmon

The juvenile chinook salmon captured were larger than the chum and consumed fewer chironomid flies and no copepods. Their diet consisted mainly of other dipteran flies and larger prey such as adult *Corophium* and *Eogammarus* amphipods, mysid shrimp, and fish larvae. The single sample of chinook from the created channel at the T-105 site contained a large proportion of *Corophium* and *Eogammarus* species, which were unique to that site among benthic samples from the restored habitats.

Much of the diet of chinook salmon from the other sites in the Duwamish Waterway was made up of taxa that occur in lower intertidal sediments (amphipods, polychaete worms) or in the water column (mysid shrimp, *Daphnia* spp., fish larvae). Interestingly, bivalve clam siphons, which are not commonly found in juvenile chinook salmon, were abundant in diets on several occasions. We do not know whether chinook fed preferentially on these prey items or consumed them because other taxa (such as drift insects) were scarce.

The diet of coho salmon from the single sample obtained at the turning basin on 17 April consisted almost entirely of crustaceans, over 80% of which were benthic amphipods. As with benthic crustacean prey in the other salmon species, the Coastal America restoration sites probably contributed little to available prey of this type.

## Avifauna

Continuing collection of bird observations has reinforced some of the conclusions from the previous summer pilot study: Kellogg Island continues to have the highest densities and diversity of all categories of birds and the T-105 site the lowest. However, all sites had high proportions of non-native or human-associated species, and indigenous species were sparsely scattered through the sites. None of the sites appeared to attract significant numbers of shore and wading birds.

In terms of habitat use, all sites appear to provide a more important role in winter than in summer and fall. But we emphasize that much of the high winter density and diversity is from overwintering waterfowl (e.g., grebes, cormorants, ducks), which are not using the restored habitats *per se*. Given that the restoration sites are still undergoing rapid change, seasonal and interannual observations of bird richness, abundance, and behavior should continue in order to determine development and changes in restored habitat use.

Because a positive relationship exists between habitat patch size and avian species diversity, we recommend continued measurement of bird use in the Duwamish Waterway in the future as additional restoration sites are created. For example, two habitat restoration sites planned by the City of Seattle and the Army Corps of Engineers near the turning basin might functionally connect with the existing restoration site and result in markedly greater use by birds.

## Emergent Vegetation

In 1996, all of the *Carex* benches that we monitored along the Duwamish Waterway increased in length and average maximum shoot height relative to 1995. The most upstream bench also increased in mean shoot density. The reason for these increases are unknown, but it appears that further spread of the benches may be limited by erosion, garbage, and lack of suitable low-gradient substrate on the sites. Removal of riprap, creation of additional habitat, and erosion protection devices such as booms may help promote further establishment of *Carex* along the river.

As in 1995, *Carex* observed (but not measured) near Kellogg Island in the vicinity of the reference *Scirpus* patch had not yet begun to senesce and was ungrazed, as opposed to the upstream monitored patches, which were heavily grazed and dying off. It is not clear what factors may contribute to the difference in condition between up and downstream *Carex*.

The presence of new annual and perennial understory species at all but the GSA site in 1996 and the natural re-

cruitment of emergent plants to the T-105 and turning basin restoration sites indicate that plant propagules exist in the Duwamish River. In time, more natural recruitment can be expected if goose grazing pressure is decreased and if more suitable low-gradient habitat is made available. If this happens, habitat improvement alone may eliminate the need for purchasing and planting new vegetation. In fact, indiscriminate transplanting of new vegetation will probably be unsuccessful without improving habitat.

The integrity of the two *Scirpus* patches we monitored appears to be compromised by large amounts of heavy drifting debris settling in the patches. The debris consists mainly of branches, lumber, and various man-made materials. At both sites, some kind of protection would benefit the survival and growth of *Scirpus*. In the middle of the reference patch, we broke up and removed a slab of concrete and used the debris to construct a small berm just seaward of the patch. Whether this minimal protection will result in spreading of the patch remains to be seen. While there is little or no remaining natural *Scirpus* in the Duwamish Waterway, we have noted that several other patches of transplanted *Scirpus* have become established at other sites. One site is at a small created beach just downstream from the GSA site, and another is at a wetland created by the Washington State Department of Transportation upstream from Kellogg Island. These sites should be considered in future monitoring studies as additional *Scirpus* references.

## SUMMARY

1. Benthic macrofauna and grain-size core samples were collected in April, May, and June 1996 from *Carex lyngbyei* and *Scirpus validus* reference sites in the Duwamish Waterway near the turning basin and Kellogg Island. Samples were also collected from transplant or plant recruitment areas at restored sites at the turning basin, and Terminal 105, and General Services Administration sites, and at sand flats from the first two sites. Insect fallout was sampled monthly April–July at the reference *Carex* and *Scirpus* sites and at restored vegetation sites at the turning basin, along the margins of a created channel at Terminal 105, and at the GSA site. Juvenile salmon for diet analyses were collected on 1 and 17 April and 6 June at upper and lower waterway sites near the restoration projects and at one middle waterway site. Observations of avifauna were made from June through September 1996 at reference sites at the Kellogg Island and the turning basin and at restoration sites at

- the turning basin and Terminal 105. In August 1996, shoot density and height were measured from three *Carex lyngbyei* benches in the vicinity of the turning basin and from *Scirpus* patches at Kellogg Island and GSA sites. Recruitment of new vegetation at the T-105 channel was observed and recorded.
- Benthic invertebrates consisted mainly of foraminiferans, nematodes, annelid worms, and dipteran fly larvae. Densities and taxa richness were low at the Terminal 105 restoration site, but this site was unique in producing benthic amphipods that are prey of juvenile salmon. At this and the turning basin site, the development of sand flats may be important because this type of habitat is rare in the Duwamish Waterway. Several types of dipteran fly larvae were abundant at the T-105 and General Services Administration sites, but they had comparatively few of the chironomid flies that were prominent in juvenile chum salmon diets. On the other hand, reference *Carex* patches and restoration areas at the turning basin site had high numbers of chironomid larvae. The prey attribute polychaete worm *Manayunkia aestuarina* was only abundant at the two *Scirpus* patches in the lower waterway. As vegetation becomes established at the restoration sites, we expect that assemblages of benthic insect larvae and other invertebrates will increase in diversity and density.
  - As with the benthic taxa, abundances of most fallout insects at the T-105 site fell well below those at the other sites. Areas of restored *Scirpus* (GSA site) and transplanted *Carex* (turning basin) had relatively high densities of several types of dipteran flies, but these densities fell consistently below the reference sites in other prey attribute insects such as aphids and springtails. As emergent and riparian vegetation recruits and becomes established, diversity and numbers of insects will probably rise at the restoration sites.
  - Juvenile chum and chinook salmon fed on a combination of benthic and epibenthic crustaceans and drift insects. Dipteran flies (especially chironomids in the case of chum) were the dominant insect prey. With the exception of the channel at the T-105 site, the restoration sites did not produce the types of benthic crustaceans that were preyed on by the juvenile salmon because they were at relatively higher elevations and did not retain standing water. However, they all produced one or more taxa of prey insects in relatively large numbers.
  - The three *Carex lyngbyei* benches sampled had shoot densities similar to those in previous years. Shoot height was greater than in previous years, especially at the most upstream site. All three *Carex* benches were longer in 1996 than in 1995. As in 1995, upriver *Carex* patches apparently were more heavily grazed and had earlier growth peaks than downriver patches. As in 1995, shoot density and maximum shoot height were significantly different at the reference and GSA *Scirpus* patches, with shoot height greater at the reference site and shoot density greater at the GSA site. The created channel at the T-105 site is beginning to be colonized by naturally recruiting *Carex*, *Scirpus*, *Salicornia*, and *Atriplex*.
  - Fifty-eight bird species were observed between June 1996 and February 1997: the greatest number of species were seen in the fall and winter, with passerines and raptors being most abundant in the fall, and waterfowl most abundant in the winter. Much of the abundance in the summer and fall was due to human-associated and introduced species. Bird species richness and density was always highest at Kellogg Island and lowest at T-105. None of the sites appeared to be attractants to wading or shore birds, but fall and winter sampling showed higher proportions of native passerines (fall) and waterfowl (winter) than did previous summer observations. Continuing natural development of resources on the restored habitats, combined with increasing connectivity with new habitat restoration projects, may increase bird use of the Duwamish Waterway.

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## **Appendix**



Appendix 1.—Two-way ANOVA results for year (1995, 1996), location (site), and interaction (year x location) effects in shoot density and shoot height at *Carex* and *Scirpus* sites at Duwamish Waterway Coastal America restoration and reference sites.

*Carex lyngbyei* shoot density

Source of Variation	SS	df	MS	F	P-value	F <sub>crit</sub>
time	21.6	1	21.6	0.066613	0.797314	4.01954
location	1018.033	2	509.0167	1.569783	0.217437	3.168246
Interaction	1266.3	2	633.15	1.952604	0.151794	3.168246
Within	17510	54	324.2593			
Total	19815.93	59				

*Carex lyngbyei* shoot height

Source of Variation	SS	df	MS	F	P-value	F <sub>crit</sub>
time	7661.4	1	7661.4	11.62469	0.001238	4.01954
location	10951.63	2	5475.817	8.308488	0.000715	3.168246
Interaction	5323.3	2	2661.65	4.038537	0.0232	3.168246
Within	35589.4	54	659.063			
Total	59525.73	59				

*Scirpus validus* shoot density

Source of Variation	SS	df	MS	F	P-value	F <sub>crit</sub>
time	483.025	1	483.025	1.817839	0.185993	4.113161
location	2544.025	1	2544.025	9.574302	0.003804	4.113161
Interaction	319.225	1	319.225	1.201386	0.280323	4.113161
Within	9565.7	36	265.7139			
Total	12911.98	39				

*Scirpus validus* shoot height

Source of Variation	SS	df	MS	F	P-value	F <sub>crit</sub>
time	547.6	1	547.6	0.457913	0.502926	4.113161
location	23522.5	1	23522.5	19.66993	8.32E-05	4.113161
Interaction	108.9	1	108.9	0.091064	0.764565	4.113161
Within	43051	36	1195.861			
Total	67230	39				