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ECOLOGICAL STATUS OF A CREATED ESTUARINE SLOUGH IN THE CHEHALIS RIVER ESTUARY:

ASSESSMENT OF CREATED AND NATURAL ESTUARINE SLOUGHS, JANUARY–DECEMBER 1995

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KEY WORDS

Carex lyngbyei, epibenthos, estuarine habitat, fish, insects, juvenile salmon, slough, wetland monitoring

INTRODUCTION

This report describes the results of monitoring and evaluation in 1995 of a recently created estuarine slough in the brackish reaches of Grays Harbor, a coastal estuary in Washington State. As a part of the Grays Harbor Navigation Improvement Project (GHNIP), in 1990 the US Army Corps of Engineers-Seattle District (USACE-SD) constructed a 1.6-ha (~4-ac) estuarine slough in the Chehalis River delta as mitigation for loss of 0.73 ha (~1.8 ac) of shallow subtidal channel that was considered important as habitat for migrating juvenile salmon (Gwill Ging, U.S. Fish & Wildlife Service, Olympia, Washington, unpubl. rep.). The USACE-SD is committed to baseline and post-construction monitoring over 50 years beginning in 1991 to ensure that the mitigation is effectively fulfilling its designed objectives and is maintaining its integrity. Intensive monitoring studies are being supported at the site over the initial 10 years to verify that the ecological functions of the created slough, principally support of fish and wildlife, are developing as anticipated. An adjacent natural slough (Ann's Slough), which was used as an aid to the design of the created slough, serves as a *reference* or control habitat in this evaluation.

The year 1995 was the third complete year of assessing fish and wildlife functions of the created slough; assessment focused principally on the slough's function as fish and wildlife habitat. Preliminary, pre-construction baseline sampling of juvenile salmon and their predators and prey, water quality, and emergent marsh vegetation was initially conducted at Ann's Slough during spring–summer 1990 to determine the community composition and juvenile salmon use of the natural slough conditions, and to develop and test sampling designs and methods. Juvenile salmon and related parameters were subsequently monitored in April–September 1991 and repeated in March-September 1992 and 1995; further monitoring will be conducted 8 (1998) and 10 (2000) years after construction of the slough. Transplanted Lyngbye's sedge (*Carex lyngbyei*) and naturally recruiting emergent marsh plants were monitored in 1991, 1992 and 1995; further monitoring of these parameters is proposed coincident with the other monitoring schedule 8 and 10 years after slough construction. Sedimentation, site stability, and large organic debris (LOD) retention is scheduled for monitoring after the first 10 years. In addition, under separate funding from the USACE-Waterways Experiment Station (USACE-WES), intensive experiments on juvenile salmon foraging success and short-term growth were conducted in 1991 and 1992. Results from the first (1991) and second (1992) years' studies in both sloughs were reported in Simenstad et al. (1992, 1993), respectively. Also, the results of experiments using otolith microstructure to assess short-term residence and growth of juvenile salmon in the created and natural sloughs supported by the USACE-WES are reported in Miller and Simenstad (1994a, b; in press).

Results from the earlier research (1990–92) indicated that, although the created slough is still comparatively dynamic in terms of stabilization of its geomorphic structure and colonization by wetland plants and organisms, it is functioning as fish and wildlife habitat.

- The created estuarine slough has been providing rearing habitat for migrating juvenile salmon (principally chum [*Oncorhynchus keta*], chinook [*O. tshawytscha*] and coho [*O. kisutch*]) generally comparable to the adjacent (Ann's) natural slough:
  a. densities were similar,
  b. diet compositions were generally comparable (aquatic and terrestrial insects constituted the majority of the diets for chinook and coho subyearlings, but rank order [e.g., mysids] was somewhat different), although stomach fullness indices were lower in the created slough, and
  c. daily growth and residence times were not statistically significant (within the power of the tests).
- The slough's fish assemblage was slightly more diverse in the created slough but total fish densities were comparable:
  a. snake prickleback (*Lumpenus sagitta*) and starry flounder (*Platichthys stellatus*) were unique to the created slough; Dungeness crab (*Cancer magister*) were also present in the created slough;
  b. some species, including peamouth chub (*Mylocheilus caurinus*), shiner perch (*Cymatogaster aggregata*), prickly sculpin (*Cottus asper*), and Pacific staghorn sculpin (*Leptocottus armatus*) tended to be slightly more dense in the created slough than in Ann's Slough; and
  c. only northern squawfish (*Ptychocheilus oregonensis*) and steelhead (*O. mykiss*) occurred in size intervals that could represent potential predators, and no indication of predation was found.

- Invertebrate prey resources were generally comparable although the diversity of the emergent insect assemblage in the transplanted sedge at the created slough was lower than at Ann's Slough.
- Transplanted sedge (*C. lyngbyei*) shoot densities and aboveground biomass in the created slough were statistically comparable to Ann's Slough; belowground biomass in the created slough, however, continued to lag behind levels in Ann's Slough.
- Water quality parameters were broadly comparable and within accepted ranges for juvenile salmonids; however, salinities in the created slough tended to be higher by 4 to 10 ppt, depending on degree of mixing; temperature regimes were somewhat related to salinity and there was no difference in dissolved oxygen (DO).
- The created slough morphology still appeared to be dynamic, with extensive sediment accretion (lower elevations) and sloughing (higher elevations), but large organic debris (LOD) was stable or increasing.

The principal goal of the 1995 studies was to assess progress toward the ecological (fisheries) function of the created brackish–estuarine slough approximately 5 years post-construction by comparing indices of function between the created slough and Ann's slough.

DESCRIPTION OF STUDY SITE

The created slough and Ann's slough are located on the upper reach of the Chehalis River estuary, Grays Harbor, Washington (Fig. 1). Both sloughs are located in a shrub/scrub forested wetland on the floodplain of the brackish–tidal freshwater transition zone of the lower Chehalis River and estuary in the vicinity of the town of Cosmopolis (Fig. 2).

On the basis of a digitized 1991 aerial photograph, the total intertidal area of the created slough is 19,035 m^2; the *C. lyngbyei* sedge habitat presently encompasses ~4,920 m^2, and below the sedge is ~11,026 m^2 of open water over a moderate-gradient intertidal mudflat and a subtidal channel. The subtidal channel itself covers ~4,554 m^2 and until around 1995 did not dewater during the lowest spring tides. The created slough is ~366 m (1,200 ft) long, averages 30 m to 50 m in width, and encompasses intertidal and shallow subtidal habitat (Fig. 3). Basic habitat components

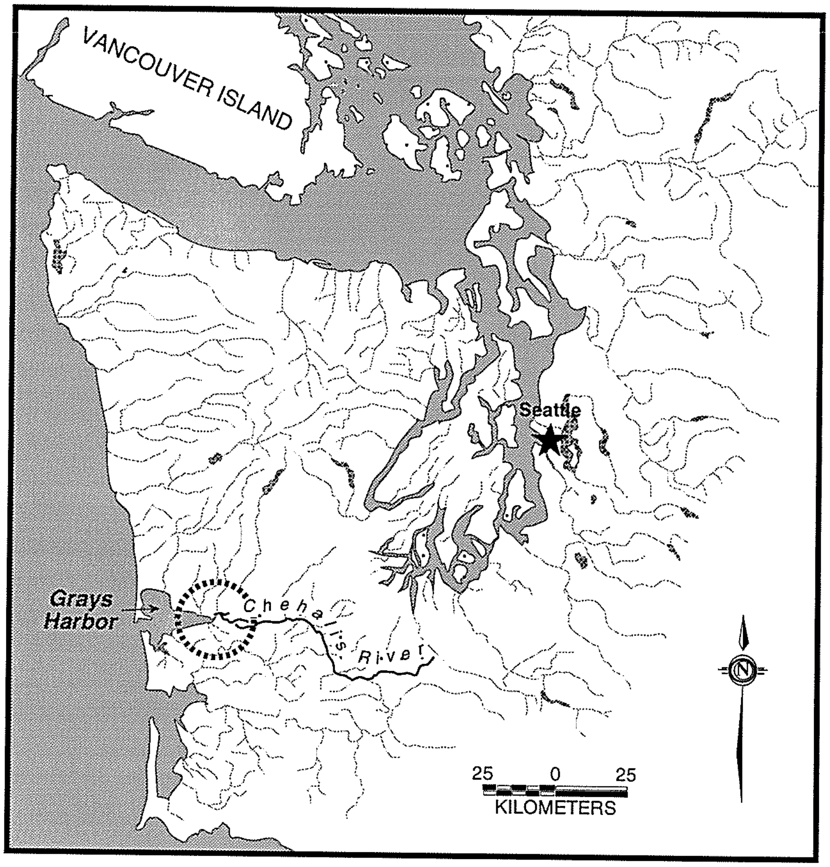

FIGURE 1.—General location of studies evaluating ecological functions of created and natural (reference) estuarine sloughs in the Chehalis River estuary, Grays Harbor, Washington.

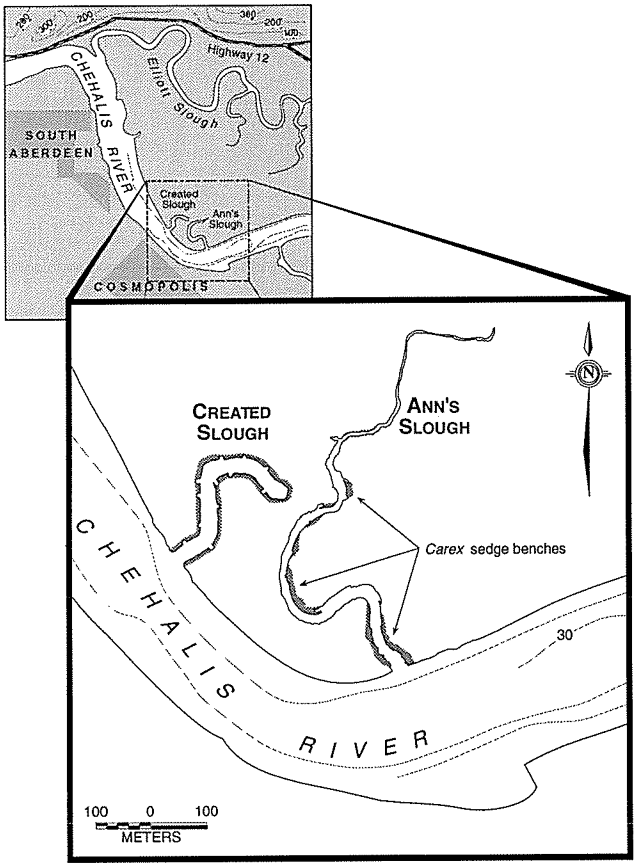

FIGURE 2.—Location of created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

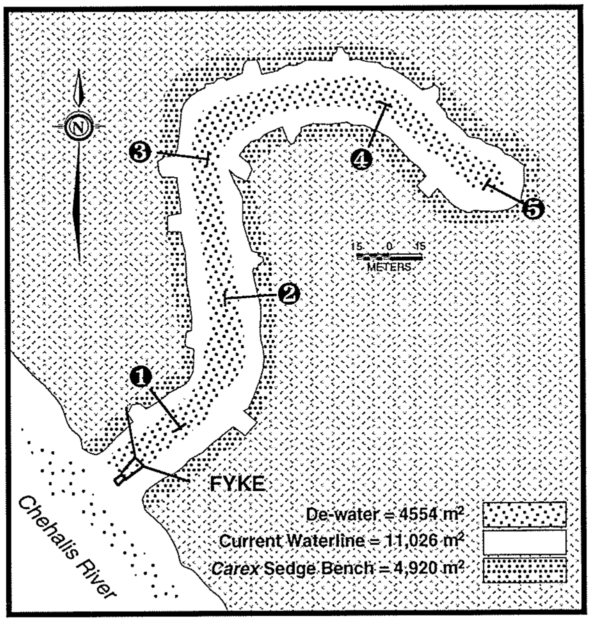

FIGURE 3.—Schematic of created slough in brackish region of Chehalis River estuary, Grays Harbor, Washington, based on digitized image from 1991 aerial photograph; circled numbers refer to sampling stations and position of tidal fyke net indicated at mouth of slough.

designed for the created slough include a shallow subtidal channel, fringing emergent marsh, unvegetated mudflat and channel margins, and a riparian buffer zone; 12 side channels are spaced along both shorelines. In addition, LOD was left or introduced into the slough during construction, and *C. lyngbyei* was transplanted into the constructed slough in spring 1991 to provide further habitat complexity considered to be beneficial for juvenile salmon. Since construction, a tidal channel draining the forested wetland has developed or become more prominent at the end of the created slough, but no freshwater drainage is evident in this channel.

The mouth of Ann's Slough is ~500 m (1,640 ft) upriver from the mouth of the created slough. The natural estuarine habitat of Ann's Slough is shallower, narrower, longer, and more sinuous than the created slough (Figs. 2, 4). In addition, Ann's Slough drains a much larger (unquantified) drainage area of forested wetland, and some level of freshwater flow is always present in Ann's Slough even during summer spring low tides. Ann's Slough is at least 1,250 m long (i.e., visible channel in aerial photo) and has a total intertidal area of 15,946 m^2; 14,489 m^2 is unvegetated, including the channel, and an additional 4,546 m^2 of sedge "bench" habitat is dominated by *C. lyngbyei* (more *Carex* bench area was underwater at the time of the aerial photo and could not be delineated).

METHODS

Sampling Design

In the 1995 assessment, eight parameters were chosen as direct and indirect indicators of the fisheries (habitat) function of the created and natural sloughs:

1. fish species/life history stage occurrence, diversity, density and standing stock, emphasizing migratory salmonids;
2. diets of juvenile salmon and steelhead;
3. composition and standing stock of insects (emergent, fallout, and sedge enclosure) and benthic invertebrates (meio- and macrofauna) that constitute potential prey resources of juvenile salmon and other fishes;
4. occurrence of juvenile salmon in the diets of piscivorous fishes;
5. species occurrence and density of avifauna, with particular emphasis on potential predators of juvenile salmon;

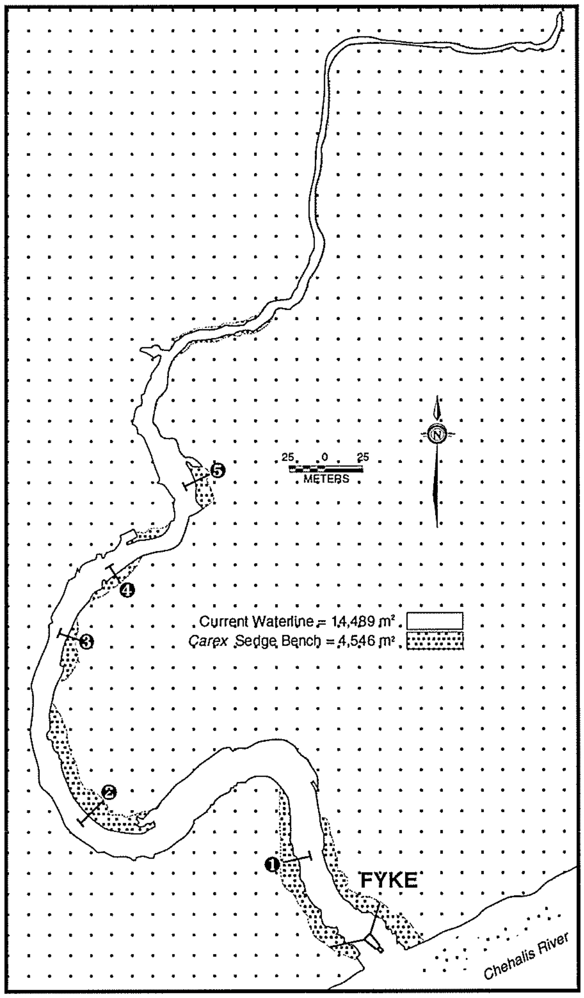

FIGURE 4.—Schematic of natural (Ann's) slough in brackish region of Chehalis River estuary, Grays Harbor, Washington, based on digitized image from 1991 aerial photograph; circled numbers refer to sampling stations and position of tidal fyke net indicated at mouth of slough.

6. shoot density, and above- and belowground biomass of *C. lyngbyei* sedge;
7. status and trends in sloughs' physicochemical structure (sedimentation, water quality, LOD); and
8. short-term comparison of fish use in created and Ann's Slough to comparable sloughs along the estuarine gradient.

These parameters were chosen to characterize the created habitat with respect to (1) use within the sloughs by juvenile Pacific salmon, as well as their prey resources and potential predators; (2) development of planted and naturally recruited emergent wetland vegetation; and (3) physical characteristics and important physicochemical processes, including sedimentation, water quality, LOD retention, and site stability. These parameters and procedures were adopted or adapted to a large degree from the US EPA's Estuarine Habitat Assessment Protocol (Simenstad et al. 1991). Simenstad et al. (1992) provide more detailed descriptions of the study design parameters and sampling schedule as applied to the assessment of the created estuarine slough.

Most sampling, except that for motile fishes, was conducted at five stations distributed approximately equidistantly along each slough (Figs. 3 and 4). Intensive sampling surveys of both sloughs occurred in March, April, May, and June, and less-intensive sampling occurred in August. Intensive sampling involved replicated (N ≥3) tidal fyke net sampling of fishes using the sloughs during flood tide periods; emergence trap, fall out trap, and sedge enclosure samples of emergent tidal marsh (*C. lyngbyei*) insects; benthic macroinvertebrates and meiofauna at different tidal elevations; bird observations; and water quality monitoring.

Less frequent sampling included sampling of *C. lyngbyei* once, during peak growing period; global positioning system (GPS) measurements of the sloughs' elevations and geomorphology; and digitizing of LOD and other habitat features of the created slough from a georeferenced aerial photograph obtained on 16 July 1995. *Carex lyngbyei* sedge habitats ("benches") and GPS measurements were obtained at Ann's Slough and the created slough on 24 August 1995. Monitoring of the *C. lyngbyei* benches was continued based on the sites and methods used at Ann's Slough in 1990–92 and was established at the same tidal elevations at each permanent sampling transect at the created slough. Thus, natural *C. lyngbyei* emergent marsh assemblage was represented by the Ann's Slough samples, and the recently transplanted sedge at the created slough was sampled in an analogous protocol (e.g., percent cover, shoot density, aboveground and below ground biomass).

Sampling and Analysis Methods

Sampling methods used in the 1995 monitoring were in most cases the same or slightly modified from those employed in 1991 and 1992, as described in detail in Simenstad et al. (1992, 1993). These and additional or significantly modified protocols are described below.

Slough Geomorphology

We used high-resolution GPS to conduct comprehensive surveys of the created slough and supplemental measurements from Ann's Slough and compared these data with conventional (laser optical) survey measurements made in November 1993. Georeferenced data were collected from the created slough and Ann's Slough on 24 August 1995 using a Trimble Real-Time Differential GPS Survey System. This system consisted of two Trimble 4000SSE GPS units, each with its own Trimtalk 900 radio for communicating between units. To achieve differential real-time GPS, we deployed one 4000SSE unit as a base station at a known latitude, longitude, and elevation, and the other (rover) unit was deployed for survey measurements. Base stations that had been long established along the Cosmopolis shoreline of the Chehalis River, and that were used previously to survey the created slough (e.g., Station "Esteban"), were recently destroyed or buried by the construction of a flood control dike. Therefore, we occupied a GPS base station at the USACE benchmark SALC25 in the city of Cosmopolis with coordinates of 46°57'28.06192" N by 123°46'30.64638" W and elevation of 11.22 relative to mean sea level tidal datum (MSL; 1.77 m or 5.8 ft relative to MLLW). Using this base station, we established a new benchmark at the mouth of the created slough; this benchmark is a 7.6-cm brass disk mounted flush into a 2.54-cm dia x 1.2-m-long steel pipe that was driven flush to the soil surface. The location of this station (Fish BS) is 46°57'37.28016" N by 123°46'16.06968" W at an elevation of 12.77 ft MLLW; horizontal and vertical precision of GPS points relative to this benchmark were 6 mm and 11 mm, respectively.

Data were recorded in the field on a Trimble TDC-1 Survey Controller connected to the roving GPS unit. Data collection for any given point consisted of the following sequence: (1) the satellite dome antenna, mounted on a 2-m staff, was held level; (2) an attribute was assigned (plant species, geomorphic feature, etc.); (3) the "enter" button was depressed on the TDC-1; and (4) after 3–10 sec, a georeferenced data point was recorded in the TDC-1 memory, after which the next data point could be collected. At the end of collection, data were downloaded onto an IBM-compatible microcomputer in the laboratory. A total of 246 points were acquired at the created slough (176) and Ann's Slough (70).

The November 1993 surveys were conducted with the assistance of Tim Abbe (UW Dep. Geology) using an Electronic Total Station™ with accuracy of about ±2.5 mm in the horizontal plane and about ±5 mm in the vertical (elevation) plane. Because a survey tie-in to a benchmark of known elevation was unavailable, all elevations were relative. A total of 280 points were acquired during this surveying.

The USACE planned to install a continuous-recording (acoustic) tide gauge at the entrance to the created slough in late 1994 or early 1995 but this was not accomplished. All tidal elevation data was, therefore, acquired relative to the USACE local tidal datum (MSL) and converted to the NOAA datum.

LOD Distribution

Changes in LOD distribution over time were monitored by analyzing aerial photography of the two sloughs. A 1"=30' print of an aerial photograph from a 16 July 1995 flight (#S950/6-3-4; time 11:56PDT) was provided by the USACE-Seattle District. This image was scanned and all recognizable LOD was digitized. Location and size of individual LOD was compared with spatially specific LOD data from 1993.

Water Quality

At least once during each sampling period, water quality parameters were monitored in each slough using a Solomat WP803 with a Sonde 803 water quality monitor. Salinity (units as "practical salinity units," psu, which are approximate to ppt or mg l^{-1}), temperature (°C), and DO (ppm) and pH (units) were recorded at the bottom, mid-depth, and near-surface at the five stations in each slough during one mid-ebb tide. In addition, these parameters were measured for ~24 hr in each slough between 1058 hr PDT on 20 April (initiated in Ann's Slough) and 1250 hr PDT on 22 April 1995.

Emergent Marsh Vegetation

Emergent marsh vegetation was sampled at the five stations in the created slough and Ann's Slough (Table 1). Prior sampling occurred on 21 August 1990 in Ann's Slough as a pre-construction baseline for the created slough, and both sloughs were sampled on 4 September 1991, 27 August 1992, and 24 August 1995.

Because of the presumed importance of *C. lyngbyei* as juvenile salmon habitat, sampling was focused on this sedge, which typically reaches peak standing stock in August. At the five sites, a 0.1-m^2 quadrat was tossed non-selectively into the middle of the *C. lyngbyei* stand. All aboveground vegetation was harvested to ground level and placed in plastic bags and labeled. A core was removed from within the quadrat; core sizes employed for this sampling were 156-cm^2 x 25 cm deep in 1991 and 1992, 79-cm^2 x 20 cm deep in 1992, and 100-cm^2 x 20 cm deep in 1995; core dimensions were altered between years to reduce sampling variability. All belowground data were standardized to g/0.1 m^2. Cores were placed in labeled plastic bags. All samples were kept cool in an ice chest or refrigerator until processed.

Because *C. lyngbyei* patches were very sparse at the created

TABLE 1. Parameters and sampling dates for sampling emergent vegetation (focused on *Carex lyngbyei*) in the created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, 1990–95; CS = created slough and AS = natural (Ann's) slough, and — = not sampled.

		Year			
Parameter	Slough	1990	1991	1992	1995
Shoot density	CS	—	X	X	X
	AS	X	X	X	X
Aboveground standing stock	CS	—	X	X	X
	AS	X	X	X	X
Live belowground standing stock	CS	—	—	X	X
	AS	X	—	X	X
Dead belowground standing stock	CS	—	—	X	X
	AS	—	—	X	X
Total belowground standing stock	CS	—	X	X	X
(i.e., live + dead)	AS	—	X	X	X
Planting success[a]	CS	—	X	—	—
Stand width	CS	—	—	X	X
	AS	—	—	X	X

[a] Measured as the increase in the number of shoots in discrete planted patches.

slough in 1991, additional samples were collected at each site. Above- and belowground biomass samples were collected in the two patches of *C. lyngbyei* nearest the point where the first quadrat was located using the non-selective toss. These latter samples provided estimates of planting "success" measured in terms of the increase in vegetation parameters (i.e., number of shoots per transplanted clump) between transplantation in April and the end of the first growing season. This type of sampling was not necessary in 1992 because the *C. lyngbyei* had spread dramatically to form relatively dense stands with little evidence of discrete patches. In 1992 and 1995, the width of the *C. lyngbyei* stand was measured at each site by extending a tape measure from the landward to the seaward edge of the stand. In 1992 and 1995, shoot density was also recorded in 0.1-m^2 quadrats tossed non-selectively 10 times at each site.

In the laboratory, aboveground biomass samples were weighed after drying to a constant weight. Live roots and rhizome material were separated from sediment and dead plant matter by rinsing on a 2-mm mesh screen, and the dry weights of the live material and dead plant matter were recorded. The sum of live and dead material was recorded as total below ground biomass; in 1990, only live belowground biomass was measured; in 1991, only total belowground biomass was measured; and in 1992 and 1995, live, dead, and total belowground biomass were measured (Table 1).

Fish Prey Resources

Benthic Meiofauna and Macrofauna.—Benthic macro- and meiofauna were sampled at stations 1, 3, and 5 in each slough on 22 March, 22 April, 17 May, and 22 June 1995. At each station, 10 replicate samples were taken on mudflats approximately 1 m below the margins of *C. lyngbei*. On 22 June, 10 replicates were also taken at the following strata at station 3 in each slough: (1) mid-channel, (2) at the lower edge of the *Carex*, and (3) in the middle of the *Carex*.

In 1995, we changed the sampling protocol for monitoring fish invertebrate prey resources from epibenthic suction pumping to benthic coring. We used recommended sampling methods modified from the Wetland Habitat Assessment Protocol (Simenstad et al. 1991, pp. 40–115; Cordell et al. 1994). The reason for this change was that a recent study in similar habitats in the Duwamish River estuary (Cordell et al. 1994) found that sediment cores sampled epibenthic taxa as well as or better than pumps and also incorporated benthic infaunal taxa. Benthic macro- and meiofauna were sampled with PVC cores of 0.0024 m^2. Cores were taken to depths of 10 cm with approximately 15 cm of water over each site and were fixed in the field in a 5% buffered formaldehyde solution.

In the laboratory, core samples were transferred to 50% isopropanol after ~1 wk of fixation in the formaldehyde solution. Benthic macrofauna were screened at 0.5 mm; meiofauna that passed through the 0.5-mm sieve were screened at 0.153 mm. If subsampling of macrofauna was necessary, samples were first separated with sieves into >2 mm and <2 mm fractions. The small fraction was then split in a Folsom plankton splitter (Wickstead 1976) until at least 100 organisms were obtained. The large fraction was examined in its entirety. Meiofauna were separated from sediments by panning with water through a 0.078-mm screen until all organisms were removed from the sediments. The meiofauna were then agitated in a 250-ml beaker with air bubbles and quantitatively subsampled using a 25-ml Hensen's Stempel pipette until at least 200 individuals were obtained. All organisms were identified using dissecting, and when necessary, compound microscopes. Taxa occurring as attributes in the protocol were identified to species. Non-protocol taxa were not identified to species unless they were particularly abundant or had been identified or hypothesized as being prey for fishes or birds.

Emergent Insects.—Insects emerging from the benthos or emergent vegetation were sampled using 0.5-m^2 emergence traps. These traps consisted of inverted cones of 0.333-μm mesh netting on a frame that would float on the water surface. The end of the net was equipped with a collecting jar with ethylene glycol, which preserved insects that entered it from the net cone. The traps were positioned at haphazardly selected locations at the same tidal elevation at each site. The traps were aligned with a metal rebar that allowed them to ride up and down with the tide over the same location. Collections in the created slough in March were not considered valid because all but one of the traps remained hung-up on the metal rebar; the design was modified to prevent this occurrence before the next collections. Collection periods lasted between consecutive low tides. In the laboratory, the samples were sorted under an illuminated stereo microscope. All organisms were identified, enumerated, and weighed to family or order (e.g., the lowest feasible taxonomic level), and life history stage. Emergence was expressed as numbers of insects emerging m^{-2} hr^{-2}.

Fallout Insect Traps.—Fallout traps consisted of 0.25-m^2 rectangular plastic basins that capture insects that fall or settle onto the surface of the water; a thin layer of ethylene glycol in the bottom of the basins prevents the insects from escaping and eventually preserves the collected insects. Each month, these traps were set in the *Carex lyngbyei* habitat during low tide and allowed to float with the tide, constrained from drifting away from that location by a corral of thin poles that were driven into the sediment adjacent to the corners of the basin. They were left to sample through at least a nocturnal tidal period; when insect catches were relatively low, they were left to sample over several tidal periods or days. Fallout trap sampling was conducted monthly from March through June.

Sedge Enclosure Sampling.—To sample insects living or crawling on *C. lyngbyei* sedge (e.g., aphids), at low tide we enclosed ~1 m^2 of sedge habitat with a Nitex net, which we left in place during the flooding tide. At high slack tide, we repeatedly swept the surface of the water inside the enclosure with a fine-mesh dip net, removing insects that had been swept off the sedges. Sedge enclosure sampling was conducted monthly from April through June.

Occurrence and Standing Stock of Fishes

Sampling of juvenile salmon and other fishes was conducted using inlet/outlet fyke nets and a beach seine. The inlet/outlet fyke nets were located at the slough mouths (Figs. 3 and 4) and covered the entire cross-sectional area of the slough at extreme high tide (Fig. 5). A fyke located in the center section of each net, covering ~3 m, was positioned over the slough channels. A live box was attached at the end of the fykes, equipped with a narrow opening and panel to prevent fish from escaping. The wings of the nets were constructed with ~13-mm (stretch mesh) nylon netting, and the fykes and live boxes were made with 6-mm mesh. The nets were primarily designed to sample fish being flushed out of the sloughs during ebb tide, but the fyke and live box could be reversed to sample fish entering the slough on the flood tide. As we detected in 1991, the net appeared to inhibit fish entry at certain stages of the tide; therefore, fish density and standing stock data presented in this report were based solely on the outlet (ebb tide) sampling after the fish had accessed and used the sloughs during flood tide.

In previous years, because the created slough did not entirely dewater during spring low tides, beach seine sampling was required in the created slough in addition to the fyke net sampling. After 1993, however, sediment accretion in the created slough raised the elevation to the extent that the slough now completely dewaters during the extreme spring tide series. As a result, we no longer need to deploy a beach seine at low tide to capture residual fishes.

During May, we attempted to deploy a beach seine as a temporary tidal fyke net in other sloughs upriver of the created and Ann's sloughs to determine whether Ann's Slough was representative of different slough geomorphologies and locations. The beach seine was the 120-m sinking seine described in Simenstad et al. (1991), which is commonly used in estuarine studies of juvenile salmon in this region.

Subsamples (e.g., >25 of each species/length interval) of fish captured in the fyke net were selected from the cod-end live box and were preserved immediately in 10% buffered formalin; remaining fishes were counted and

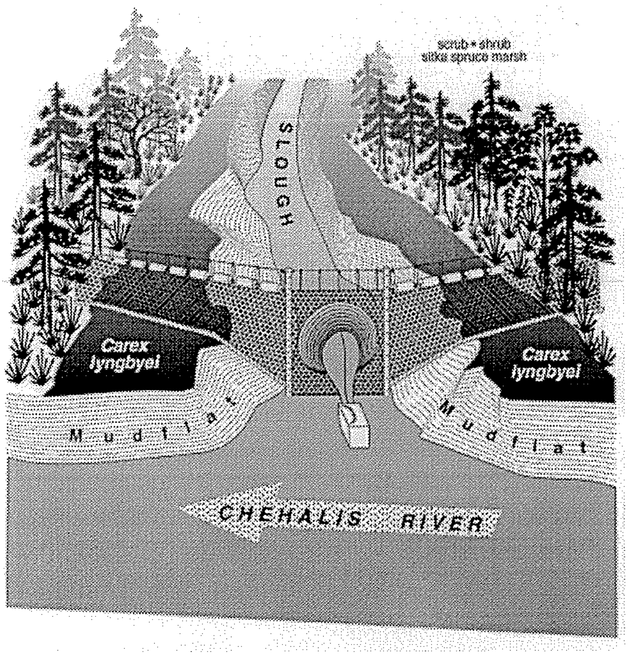

FIGURE 5.—Diagram of inlet/outlet fyke net used to sample juvenile salmon and other fishes using slough habitats in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

released alive. The abundance and standing stock of extremely large catches were estimated from systematic proportional subsampling. In the laboratory, all fish were measured for fork (salmonids and smelts) or total length to the nearest mm and weighed (preserved wet) on an electrobalance to the nearest 0.1 g. Subsamples of the processed fish were retained for stomach contents analyses.

To test whether there was a significant difference in the size or abundances of juvenile salmon entering the two sloughs, we conducted regression analyses of both untransformed and log–log transformed length–weight relationships. Statistically significant differences in intercepts of regression lines would suggest an inherent difference in the allometric "origins" of fishes in the different sloughs.

Juvenile Salmon Diets

When we captured sufficient numbers of a species and size interval, we retained representative subsamples for diet comparison between the two sloughs. Subsampled juvenile salmon retained for stomach contents analyses were preserved in 10% buffered formalin. In the laboratory, these fish were soaked in water for 24 h to leach out the formalin prior to processing. The stomachs were removed by dissection and weighed intact (damp wet weight) to the nearest 0.1 g on an electrobalance. The stomachs were then opened and the contents teased apart in water in a petri dish. The empty stomach was blotted and reweighed to provide by subtraction the stomach contents weight (wet, including digested material). Under an illuminated dissecting microscope, prey organisms composing the stomach contents were sorted to lowest taxonomic category possible counted, and weighed (blotted wet weight, to nearest 0.001 g).

Avifauna

We made observations on bird occurrence, relative abundance, and behavior coincident with any sampling on the sloughs (e.g., 6–7 d [daylight hours] per mo). Species identifications were made with the aid of binoculars when possible, but identifiable bird calls and songs were also used as aides to species identification if an unambiguous observation could not be made. All observations were recorded immediately in field notebooks and transcribed into computer file upon returning to the laboratory.

Data Management and Archiving

Field notes and data were entered into either a word processing file or a spreadsheet (e.g., Microsoft Excel) for archiving and retrieval for microcomputer analysis and graphical display. Other laboratory data (e.g., fish processing, stomach contents analyses, fish prey resource sample processing) were recorded on standardized (FRI estuarine–coastal marine fish/zooplankton formats) forms that used the format #100 series of the National Oceanographic Data Center (NODC). This format system has been used in almost all FRI sampling in Puget Sound and coastal estuaries since 1976, which provides for a widely comparable database. The system also uses the NODC taxonomic code, a 10-digit code that enables encoding of all organisms to any phylogenetic level and life history stage. Data tabulation and basic statistical description of epibenthic crustacean, benthic infauna, and neuston data were produced with the FRI computer program SUPERPLANKTON, and the fish stomach contents data with the FRI computer program GUTBUGS, both specifically developed for NODC-formatted data. Summarized data were analyzed further on a microcomputer using commercial statistical software.

All data were standardized by sampling effort (e.g., area, volume, or tidal period). For estimation of fish standing stock, the mid-tide surface area of the two sloughs (based on the digitized aerial photograph from 1991) was used—14,489 m^2 for Ann's Slough and 11, 026 m^2 for the created slough.

Stomach contents results were converted, as a product of the FRI computer program GUTBUGS, to an Index of

Relative Importance (IRI, modified from Pinkas et al. 1971; Cailliet 1977) where

$$\text{IRI} = (\%\text{F.O} \times [\%\text{N.C.} + \%\text{G.C.}]),$$

where %F.O. = percent frequency of occurrence,
%N.C. = percent numerical composition, and
%G.C. = percent gravimetric composition.

In comparing prey importance among different fish samples, we normalized the IRI to the sum of total IRI (i.e., % total IRI) to avoid variation in IRI due to sample sizes.

RESULTS

Slough Geomorphology

Surveys conducted in November 1993 provided a broad coverage of high-resolution vertical measurements of the created slough and four cross-channel profiles in Ann's Slough (Fig. 6) although they were not tied to either an absolute coordinate system or tidal elevation datum. Tidal elevation profiles across sampling transects 1–5 in the created slough and Transects 2–5 in Ann's Slough generated from these survey data illustrated the contrast between the very uniform, broader, and deeper cross-sectional profiles of the created slough (CT profiles, Fig. 7) and the narrower (by ~10–15 m), shallower (~1 m), and more structurally complex profiles of Ann's Slough (AT profiles, Fig. 7). Most evident in the Ann's Slough cross-sectional profiles are the relatively flat *C. lyngbyei* benches that occur at about +12 m relative elevation MLLW and are 12–14 m wide. Delineation of the *C. lyngbyei* elevations in the created slough in 1993 (Fig. 8) indicated that the average lower limit of *C. lyngbyei* was approximately +9 ft (2.75 m) relative MLLW, and the upper limit approximately +12.3 ft (3.75 m) relative MLLW; the lower edge of the *C. lyngbyei* distribution ranged between ~7.9 ft (2.4 m) relative MLLW and 11.0 ft (3.35 m) relative MLLW.

Compared with the initial surveys, the resurveys of the created slough and Ann's Slough with GPS in 1995 provided more georeferenced and higher spatial resolution (i.e., more survey points per transect) measurements of both the natural variation in Ann's Slough and changes associated with stabilization of the created slough (Fig. 9). During this survey, we relocated and took positions and elevations on five reference bench markers (Transects 2, 3, 4 in the created slough; Transect 2 in Ann's Slough) installed during the 1993 survey. Comparison of the 1993 relative elevation data to the 1995 GPS surveys indicated an estimated +0.505 m (±0.03 for 1 standard deviation; 0.0415 range) difference between the two surveys; that is, the relative elevations established in 1993 were 1.66 ft (±0.10 for 1 standard deviation; 0.136 range) higher than the georeferenced surveys of 1995. After adjusting the 1995 data to a common MLLW datum, and accounting for some variability in the starting position for transects that did not have a common reference bench marker, it is apparent that the monotypic 5:1 slope of the created slough cross-sectional profiles had not changed

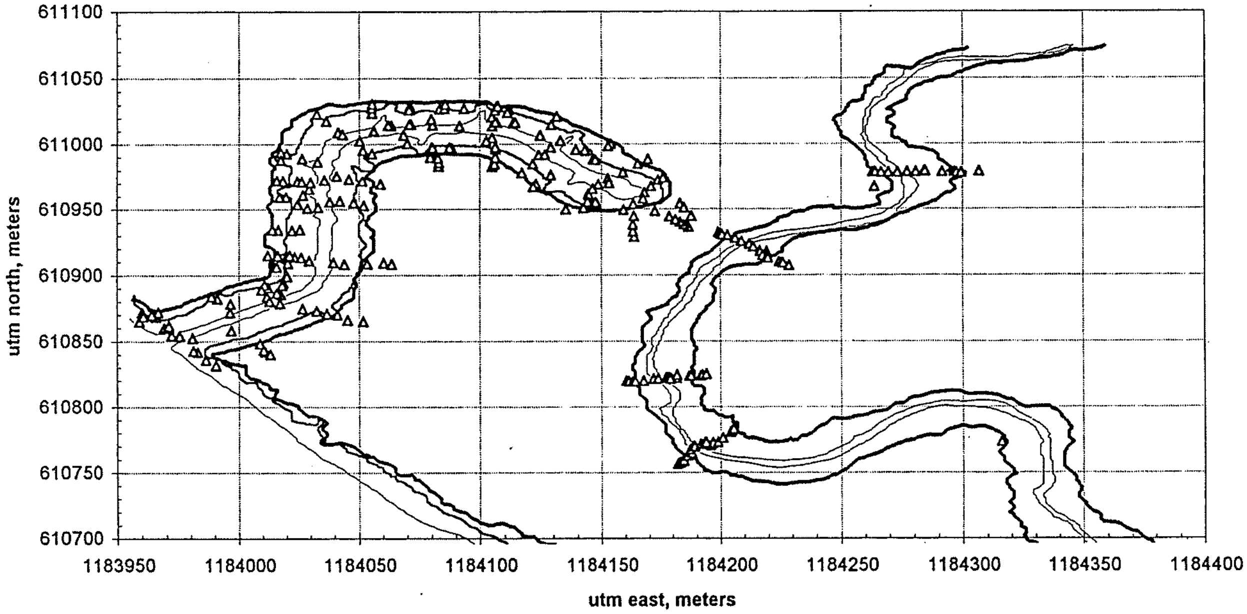

FIGURE 6.—Relative georeferenced elevation points, generated by total station surveying, in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, November 1993.

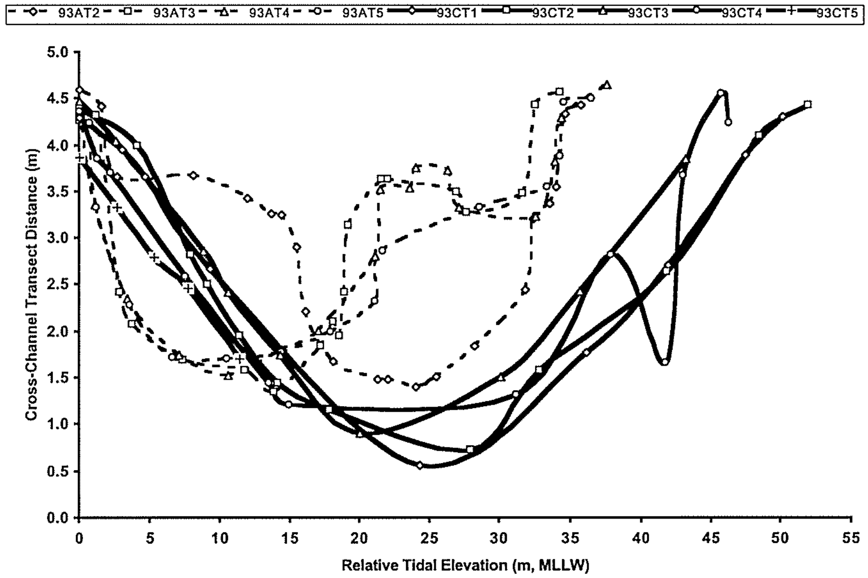

FIGURE 7.—Cross-channel elevation profiles from created (heavy solid lines) and natural (Ann's Slough; light dashed lines) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, November 1993 (93ATn and 93CTn = transect numbers for Ann's and created sloughs, respectively; see Figs. 3–4 for transect numbers and locations, and Fig. 6 for survey points).

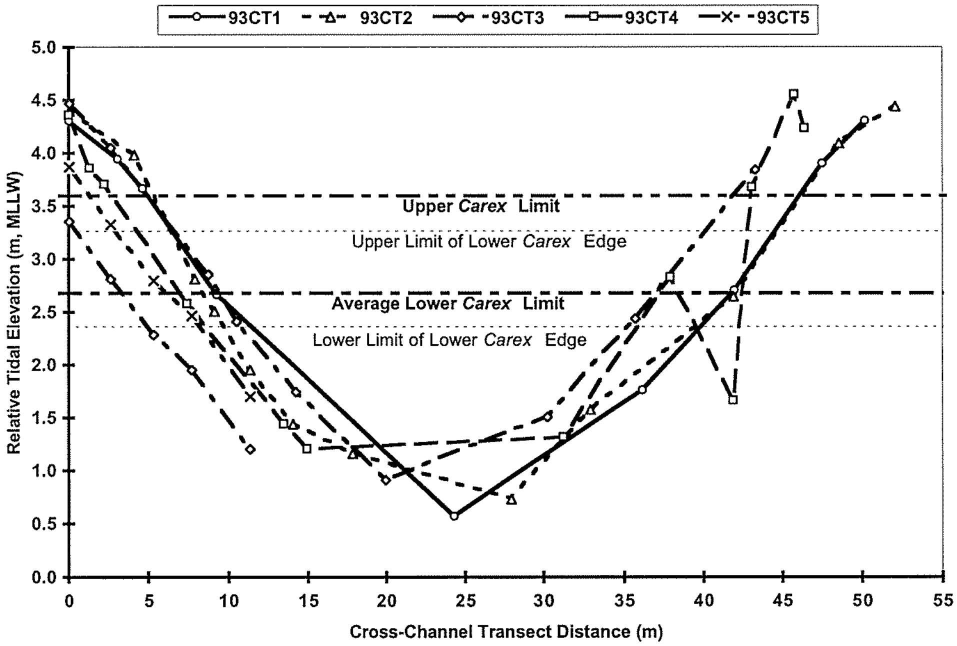

FIGURE 8.—Intertidal elevation distribution of *Carex lyngbyei* along cross-channel profiles from created slough in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, November 1993 (93CTn = transect numbers for created slough; see Fig. 3 for transect numbers and locations, and Fig. 6 for survey points).

dramatically since 1993 (Fig. 10). These profiles are contrasted to transects surveyed in Ann's Slough that illustrate the characteristic *C. lyngbyei* benches positioned between +9.5 ft (+2.9 m) and +10.5 ft (+3.2 m) MLLW (lighter lines, Fig. 10). There was essentially little or no change in elevations or profiles of either sloughs although the deepest portions of the created slough were not adequately sampled in 1993, and we cannot surmise that these missing segments might have changed (e.g., become shallower).

Since no post-construction "as built" survey data or drawings were available, the surveyed transect profiles in the created slough were compared with the USACE construction

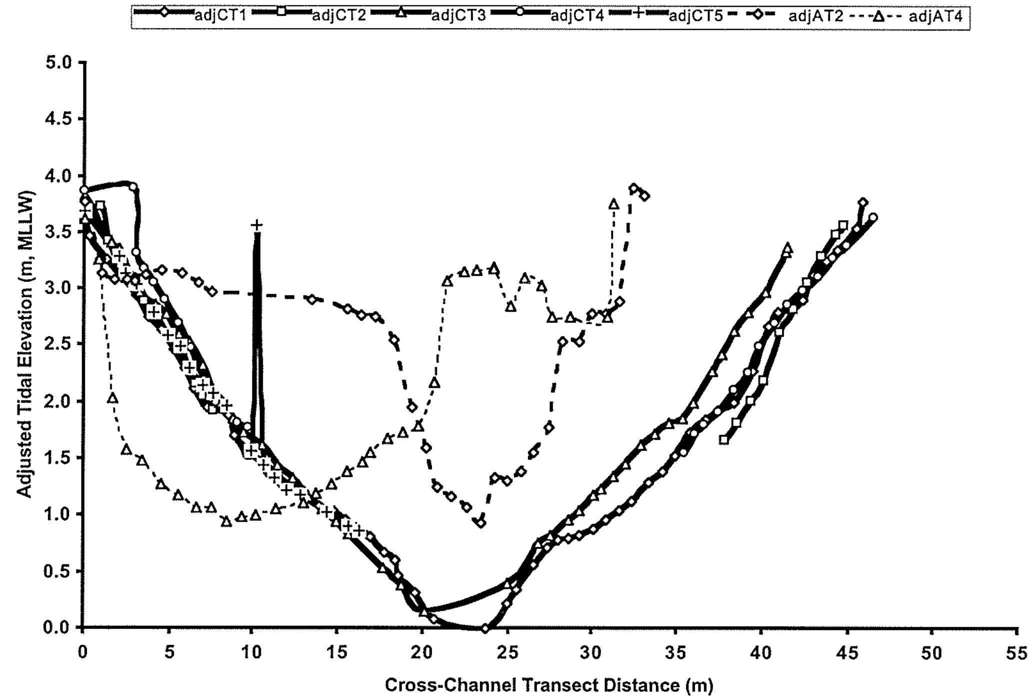

FIGURE 9.—Cross-channel elevation profiles from created (heavy solid lines) and natural (Ann's Slough; dashed light lines) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, August 1995 (adjCTn or adjATn = transect numbers for created and Ann's sloughs, respectively; see Figs. 3–4 for transect numbers and locations).

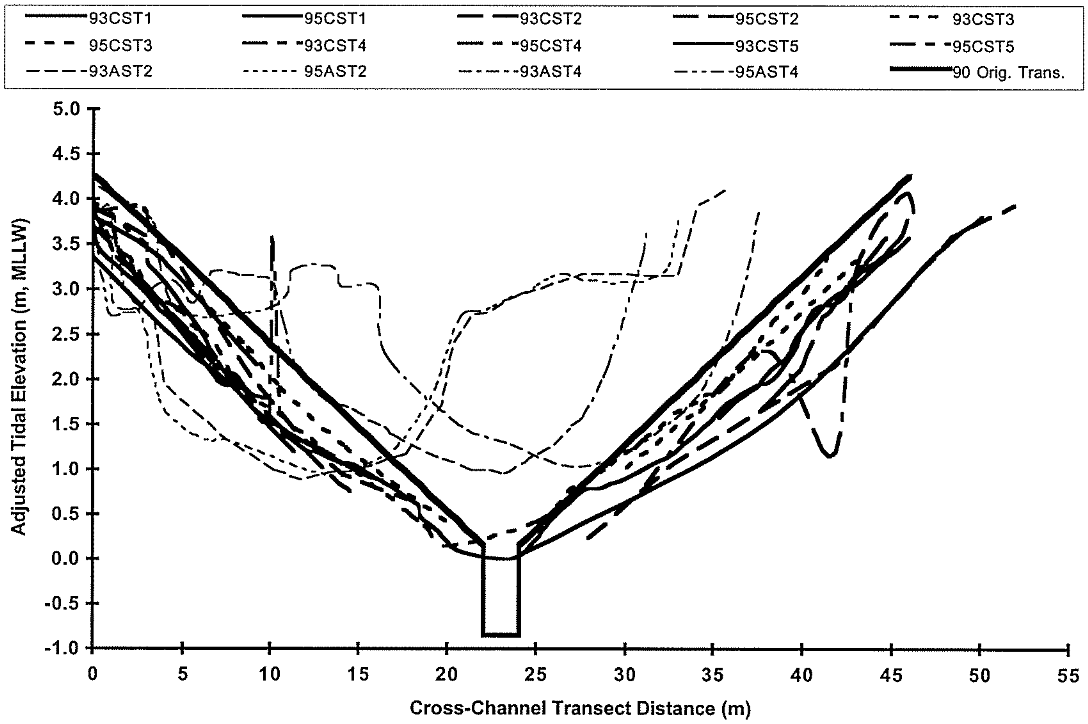

FIGURE 10.—Cross-channel elevation profiles from 1993 (dashed lines, open symbols; heavy lines) and 1995 (heavy lines) of five transects in the created slough, of two transects in Ann's Slough (light lines), and the construction drawings profile of the created slough (heavy, solid line) in the brackish region of upper Chehalis River estuary, Grays Harbor, Washington; 93/95CSTn or 93/95ASTn = transect numbers for created and Ann's sloughs, respectively; see Figs. 3–4 for transect locations).

drawing profiles (solid wide line ["90 Orig. Trans."], Fig. 10). This comparison indicates potential erosion of the sideslopes and infilling of the central channel although there is no simple means for us to verify that the vertical datum is exactly the same between the drawings and our surveys. The amount of sediment accretion characterized is likely conservative; our visual impression is that the vertical datum of the construction drawings may have been lower because over the five years we have been observing the created slough it has appeared to infill substantially.

Similar adjustment of the 1993 measurements for the elevational distribution of *C. lyngbyei* indicated that the average lower limit of sedge distribution was 7.19 ft (2.19 m) MLLW in the created slough and 6.48 ft (1.98 m) MLLW in Ann's Slough; our GPS-based measurements in 1995 indicated 7.24 ft (2.21 m) MLLW was the lower elevation limit of *C. lyngbyei* in the created slough compared with 7.12 ft (2.17) MLLW in Ann's Slough. The upper elevation limit of *C. lyngbyei* appears to be slightly higher in the created slough (10.79 ft [3.29 m] MLLW) than in Ann's Slough (9.30 ft [2.84 m] MLLW); that is, only slightly below (0.3–1.0 ft) the toe at the base of the abrupt slope transition to the shrub–scrub freshwater marsh (1993—11.4 ft [3.48 m] MLLW in the created slough and 9.68 ft [2.95 m] MLLW in Ann's Slough; 1995—10.84 ft [3.31 m] MLLW in the created slough and 9.98 [3.04 m] ft MLLW in Ann's Slough).

LOD Distribution in the Created Slough

Distribution and abundance of LOD changed only marginally between 1993 and 1995. Of 84 LOD pieces identified in the aerial photographs of the created slough (Fig. 11), 15 new pieces had appeared since 1993 and 18 had disappeared. Comparisons of the digitized sizes of LOD indicated a significant (paired t-test, $P = 0.0352$) reduction in the average (areal) size of the original (1993) LOD (i.e., 29.6 ± 21.6 m^2 in 1993; 22.1 ± 21.8 m^2 in 1995), suggesting that the LOD had decomposed or been covered by sediment in the two intervening years since 1993. Sedimentation as the primary cause is suggested by the significant "shrinkage" of large pieces that otherwise remain in exactly the same location.

Water Quality

As reported previously (Simenstad et al. 1992, 1993), the location, design, and construction of the created slough were responsible for greater intrusion of saline water and greater potential for vertical (salinity and temperature) stratification of the water column than in Ann's Slough. Similarly, in 1995 we found that, under winter high river flows in March, salt generally occured at very low concentrations but was more evident in the created slough than in Ann's Slough, and that salinity distribution generally converged by June with decreased river flow (Fig. 12). Maximum salinities in the created slough were between ~0.4 psu (March) to 2.0 psu higher than in Ann's Slough except in June when salinity at the mouth (Transect 1) of Ann's Slough was 2 psu higher than at the created slough. Except for March, the created slough was usually stratified while Ann's Slough was typically well mixed until May and June. As would be expected under strong mixing, saltier water is closer to the entrance of Ann's Slough than at stations farther up the slough.

Temperatures almost always indicated a well-mixed water column and tended to be lower in Ann's Slough compared with higher temperature maxima and strong stratification in the created slough (Fig. 13). Maximum temperatures in the created slough were almost consistently 0.25–2.5°C higher than in Ann's Slough. In addition to being strongly stratified, the vertical profiles in the created slough indicated that colder, freshwater (Fig. 12) was riding over warmer, more saline water at mid-depth in March and April; by May and June, the depth–temperature profiles reflected the intrusion of colder saline water along the bottom of the created slough. In March–May, temperatures in Ann's Slough tended to be warmer further away from the mouth of the slough, where generally colder, more saline water occurred.

Levels of DO in the two sloughs (Fig. 14) were high (above 7 ppm) even in the warmer months of May and June. There were no sharp gradients in DO profiles with depth except those associated with thermal and salt stratification in the created slough in April. Also, no consistent trends in DO concentrations were associated with transect locations along the length of the sloughs.

In the created slough, pH profiles often appeared to mirror salinity and displayed comparable levels of temperature stratification (Fig. 15). This effect may result from a combination of the buffering effect of intruding saline water masses and the effect of CO_2 production by phytoplankton.

The tidal cycle measurements of water quality parameters during 20–22 April tended to indicate more tidal fluctuations in Ann's than in the created slough (Fig. 16). Salinity, DO, pH, and temperature all demonstrated very abrupt changes in Ann's Slough, most often coinciding with rapid changes during flood tide (e.g., 1058–1313 PDT for pH and temperature) and ebb tide (e.g., 2213–0028 PDT for salinity and DO). These sharp changes likely reflect more vertically mixed water moving up and down

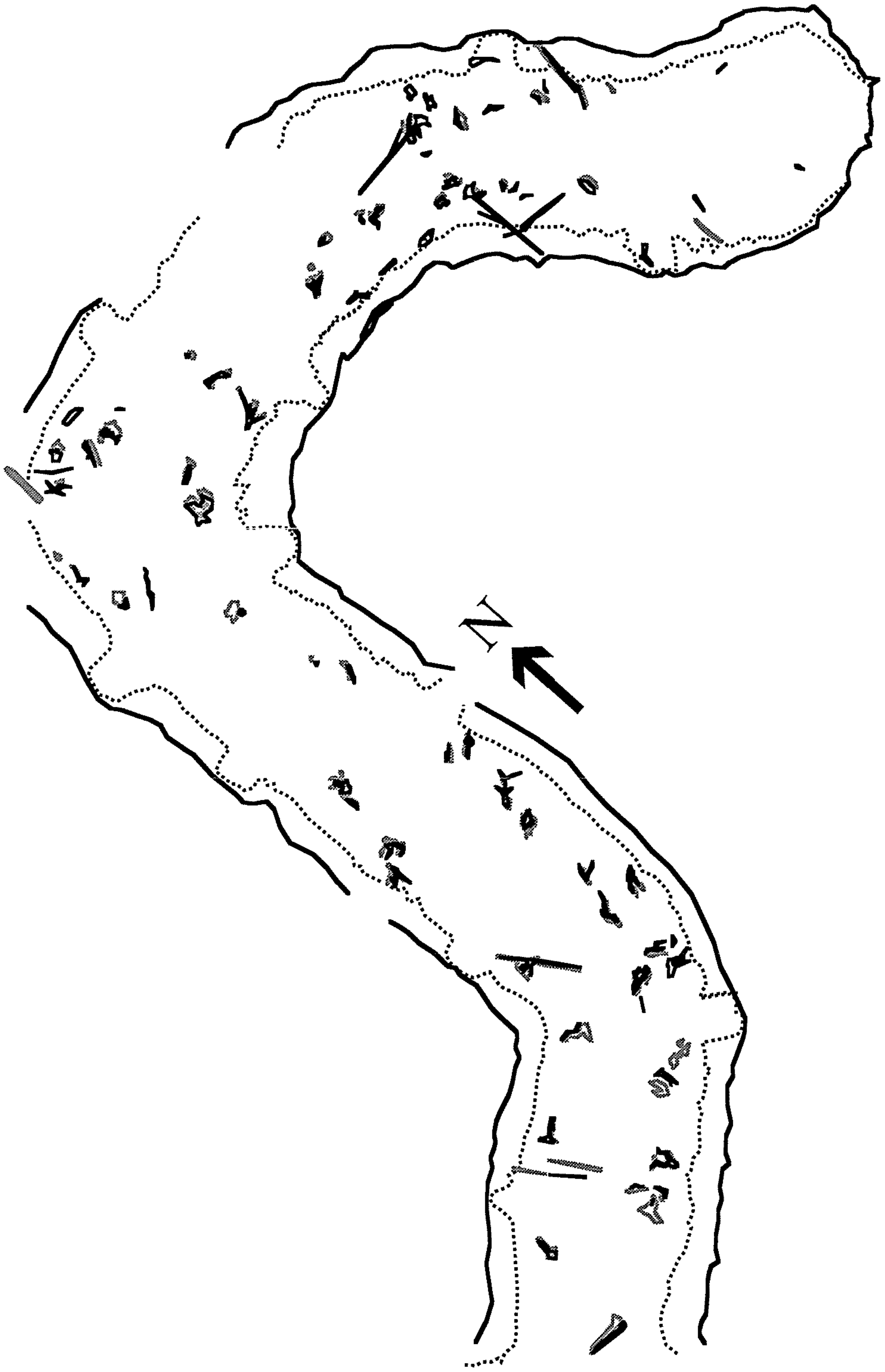

FIGURE 11.—Overlap in large organic debris (LOD) between 1993 (heavy black lines) and 1995 (light gray lines) in created slough in brackish region of upper Chehalis River estuary, Grays Harbor, Washington. The 1995 lines overlay the 1993 to best illustrate the general decrease in LOD area, which is likely due to sedimentation or settling. The solid black line (perimeter) is the edge of upland (excavated area of slough) and the dashed line is the lower edge of the *Carex lyngbyei* sedge distribution. Lines are discontinuous where aerial photo coverage was incomplete.

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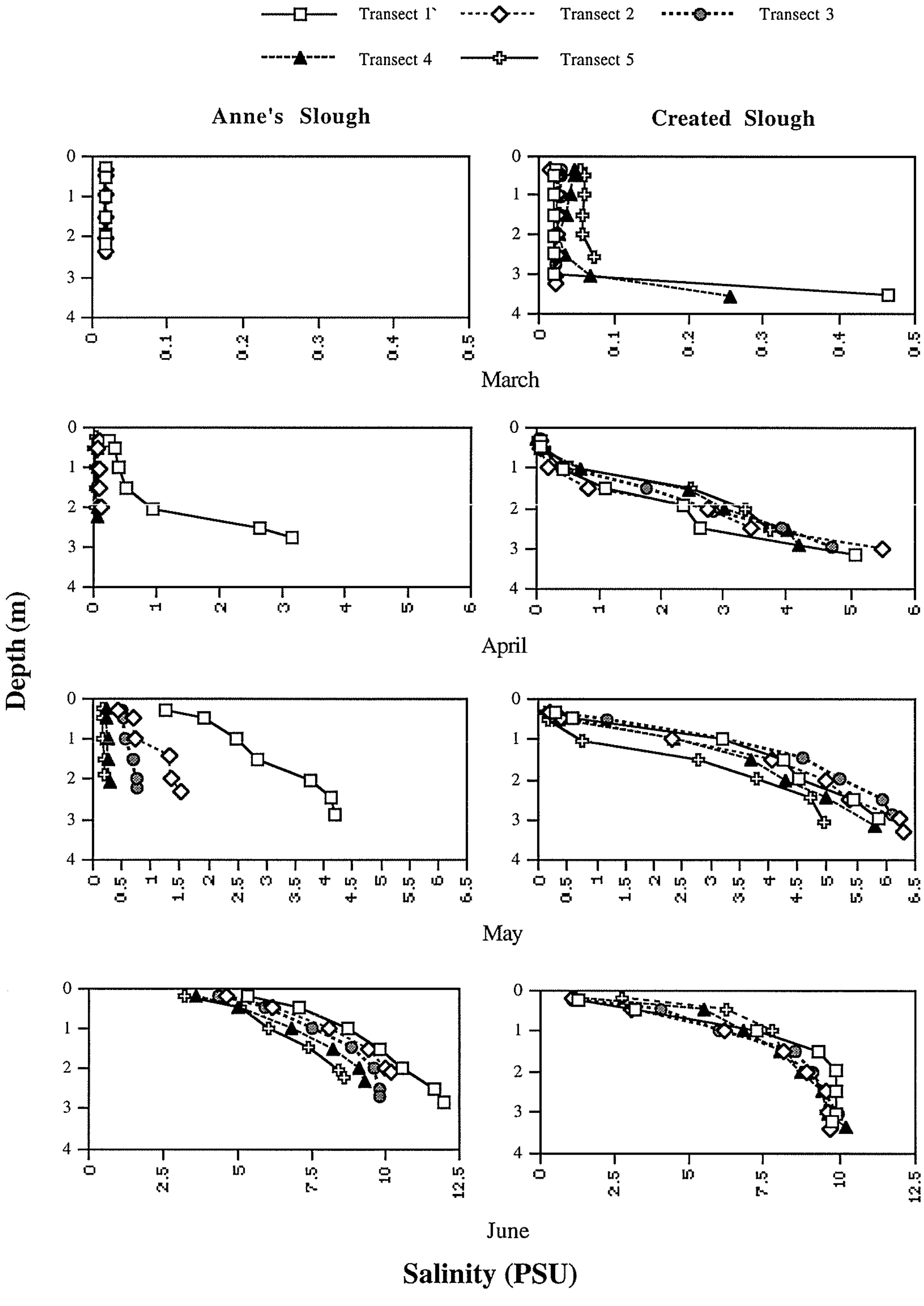


FIGURE 12.—Depth profiles of salinity (psu) at five transect stations (see Figs. 3–4) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995.

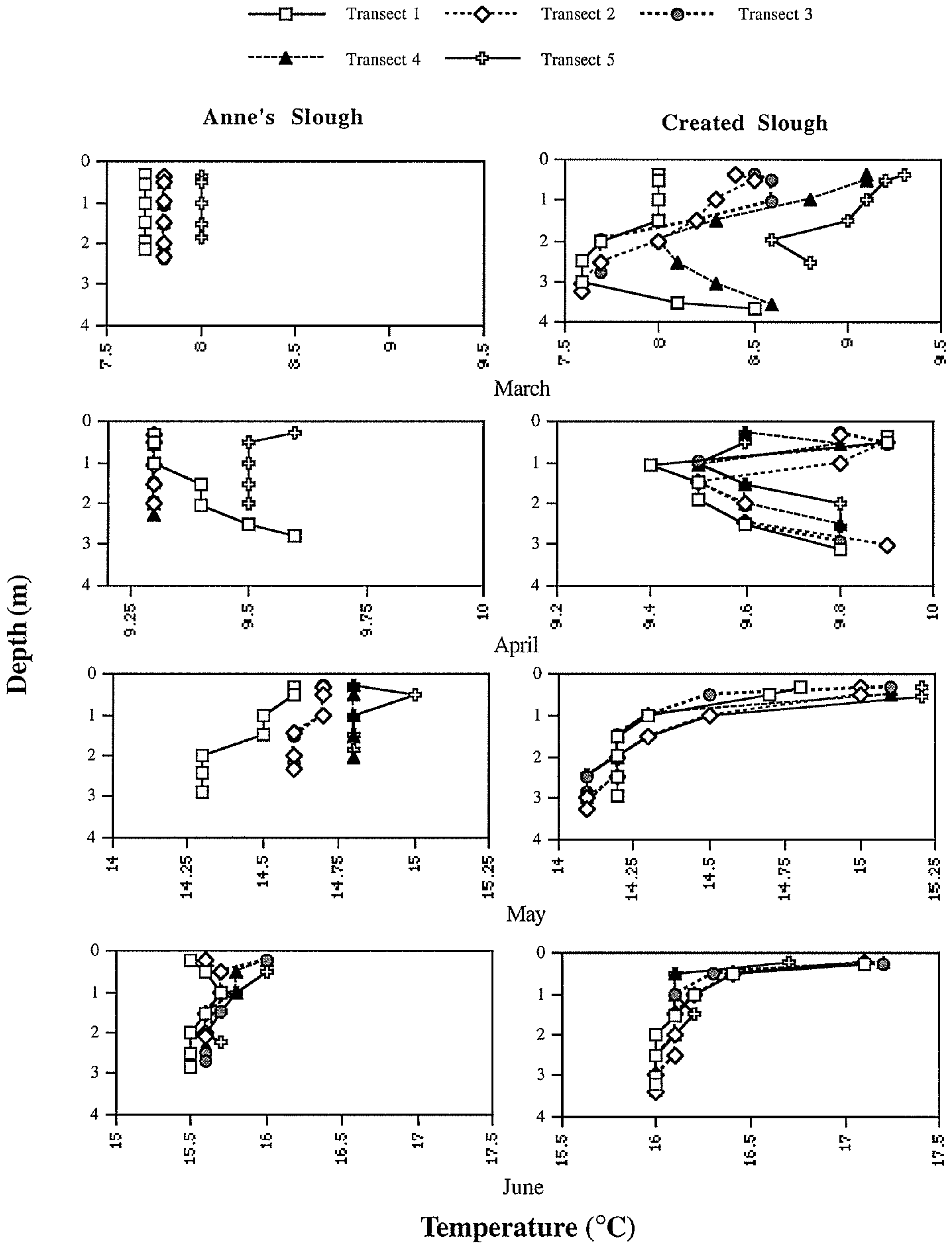


FIGURE 13.—Depth profiles of temperature (°C) at five transect stations (see Figs. 3–4) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995; see Fig. 12 for legend.

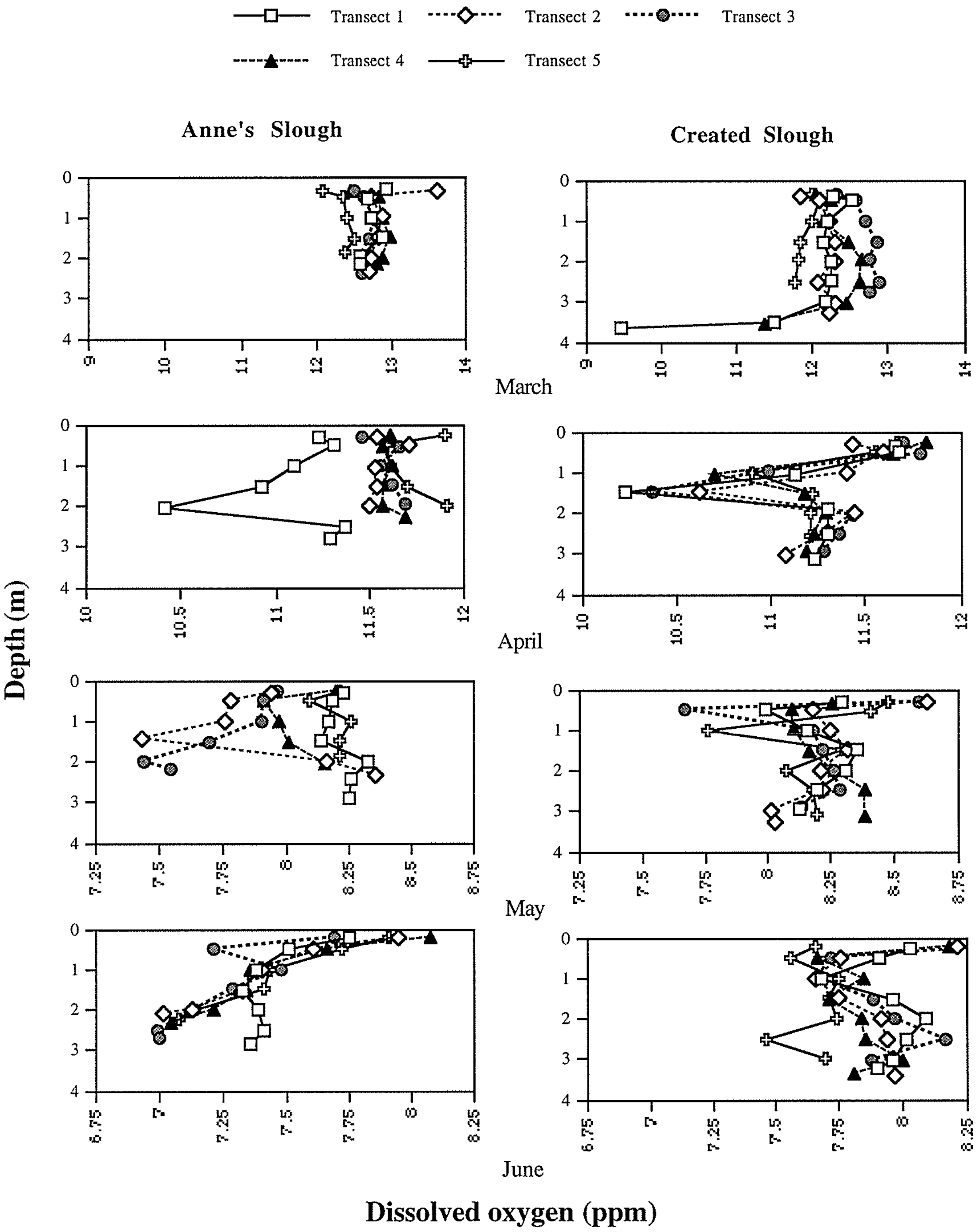


FIGURE 14.—Depth profiles of dissolved oxygen (ppm) at five transect stations (see Figs. 3–4) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995; see Fig. 12 for legend.

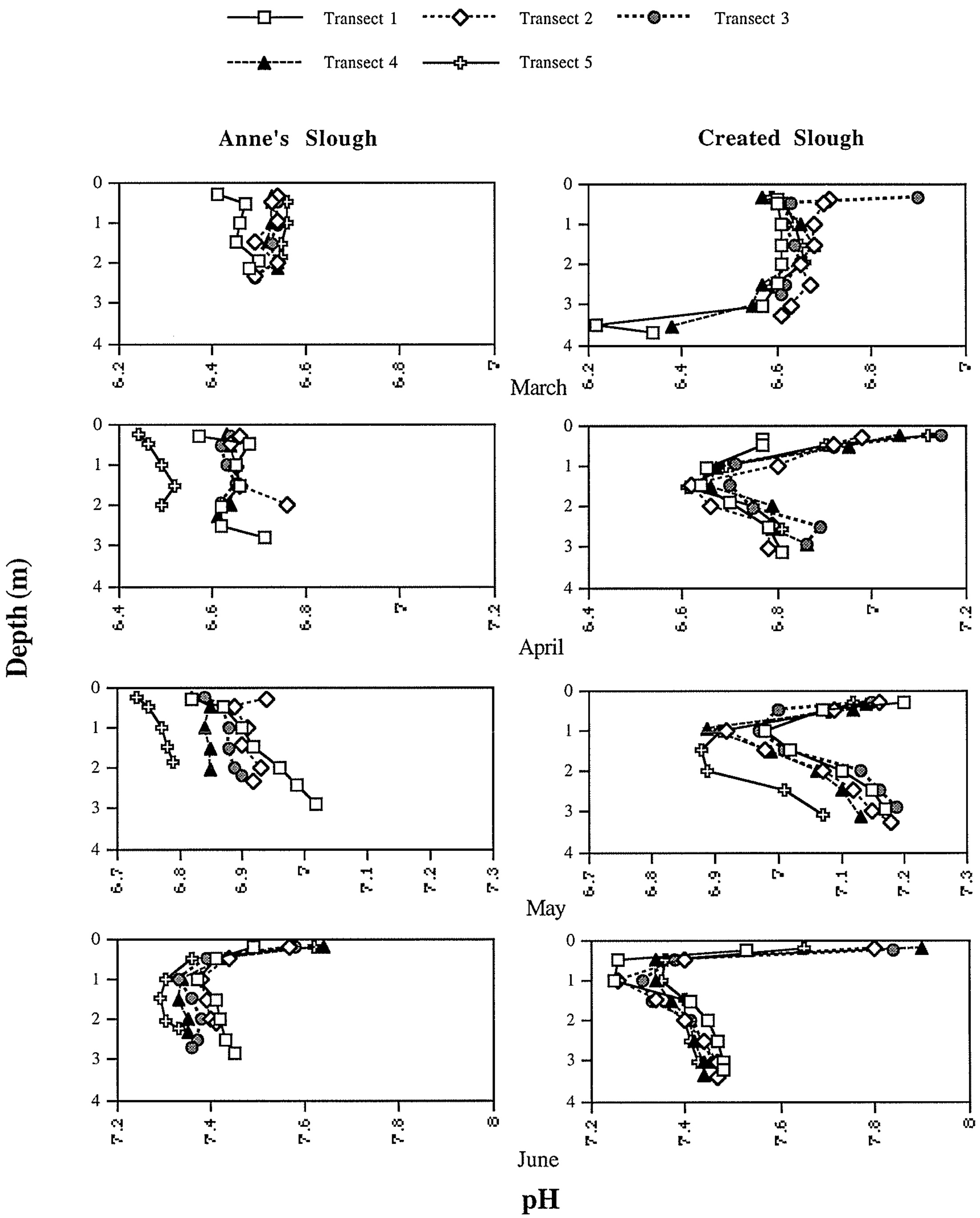


FIGURE 15.—Depth profiles of pH at five transect stations (see Figs. 3–4) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995; see Fig. 12 for legend.

Ann's Slough compared with the more stratified conditions (and thus gradual changes) passing across one point in the created slough.

Emergent Marsh Vegetation

Mean stand width of the *C. lyngbyei* benches was essentially unchanged at the created slough between 1992 and 1995, but it increased somewhat at Ann's Slough (Table 2). The greater stand width at Ann's Slough (12.4 m) as compared with the created slough (5.2 m) denotes the relatively steeper slope of the sedge benches at the created slough (see Slough Geomorphology, p. 4–5). Between 1991 and 1992, there was a marked increase in *Carex* shoot density,

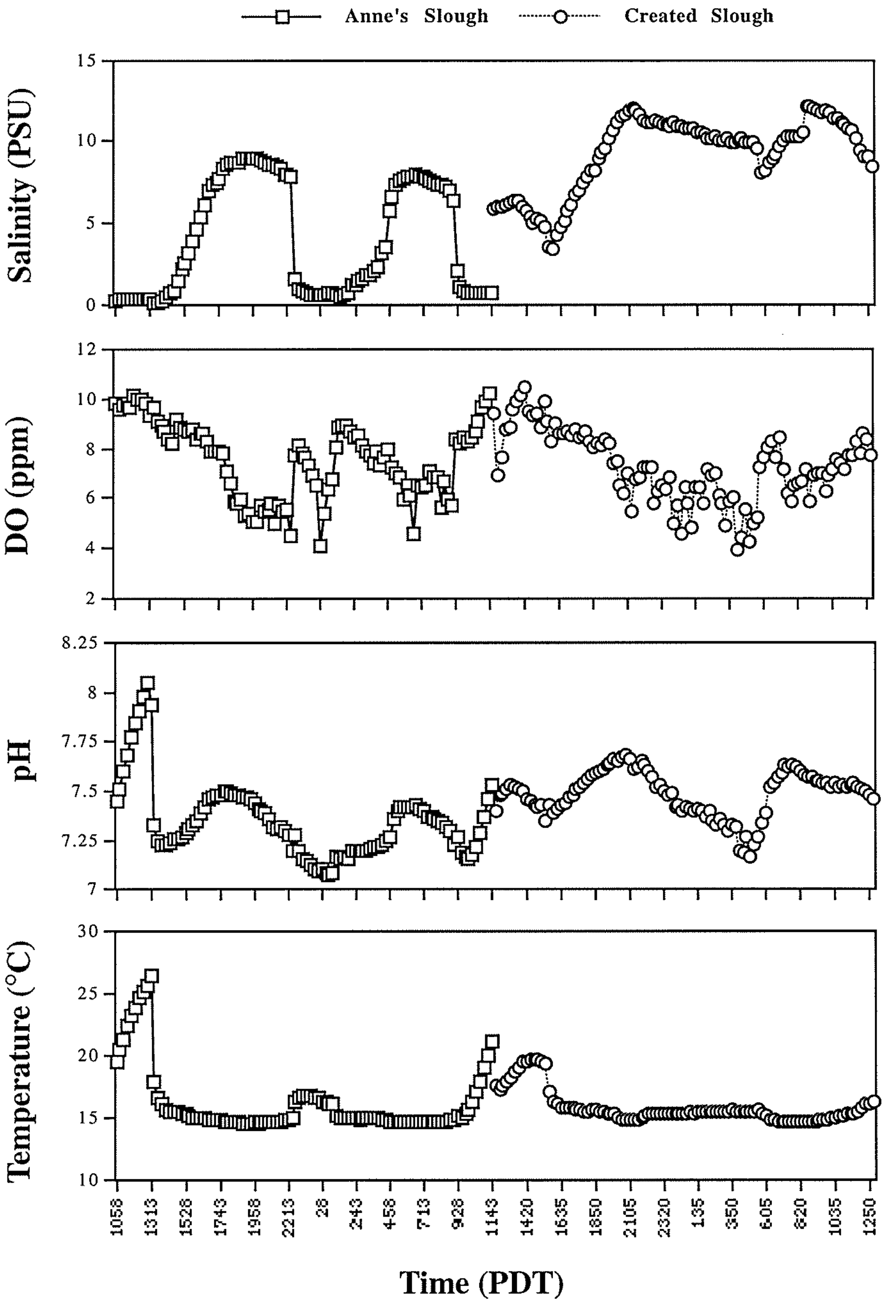


FIGURE 16.—Time series of salinity (ppt), dissolved oxygen (ppm), pH, and temperature (°C) at transect station 4 (see Figs. 3–4) during ~24 hr in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, between 1058 hr PDT on April 20 and 1250 hr PDT on April 22, 1995.

which was coupled with spread of *Carex* to fill areas between planted patches. On average, two shoots of *Carex* were planted per hole in spring 1991. By the end of the growing season that year, the average number of shoots per transplanted patch varied between 4 and 11. Overall, *Carex* shoots in the created slough increased an average of 3.7-fold between approximately May and September of 1991.

On the basis of 50 replicate samples at each slough in 1992 and 1995, shoot densities in the created slough were very similar to those at Ann's Slough sites (Table 2). By 1992, aboveground biomass was essentially the same between the two sloughs, and remained similar in 1995 (Figs. 17 and 18, Table 2). However, belowground biomass continued to differ between the sloughs in 1995 (Table 2). In

TABLE 2. Summary statistics for *Carex lyngbyei* in created and natural estuarine sloughs, Chehalis River estuary, Washington, 21 August 1990, 4 September 1991, 27 August 1992, and 24 August 1995; N = 5, except density in 1992 and 1995 where N = 50.

	Ann's Slough		Created slough	
	Mean	SD	Mean	SD
1991				
Shoot density (no. 0.1 m^{-2})	15.0	7.8	6.2	5.8
Biomass (g dry 0.1 m^{-2}):				
Aboveground (AG)	64.5	48.3	9.2	10.1
1992				
Stand width (m)	10.8	2.5	5.9	2.0
Shoot density (no. 0.1 m^{-2})	11.4	5.6	9.8	5.6
Biomass (g dry 0.1 m^{-2}):				
Aboveground (AG)	69.6	43.8	87.1	46.9
Belowground live (BGL)	884.4	910.0	742.1	682.8
Belowground dead (BGD)	670.7	171.0	30.2	14.1
Total (TBG)	1555.1	886.0	772.4	683.7
AG:BGL	0.08		0.11	
AG:BGD	0.19		2.9	
AG:TBG	0.04		0.11	
1995				
Stand width (m)	12.4	1.6	5.2	1.6
Shoot density (no. 0.1 m^{-2})	34.4	14.6	29.9	15.7
Biomass (g dry 0.1 m^{-2}):				
Aboveground (AG)	56.5	26.0	65.8	48.9
Belowground Live (BGL)	496.4	179.3	132.3	101.1
Belowground Dead (BGD)	39.4	23.6	235.3	241.8
Total (TBG)	535.8	171.5	367.6	260.4
AG:BGL	0.11		0.50	
AG:BGD	1.43		0.26	
AG:TBG	0.11		0.18	

1992, live belowground biomass was similar between the two sloughs. However, in 1995, live belowground biomass was over 3.5 times greater in Ann's Slough compared with the created slough, and three of the five sites in the created slough had a total belowground biomass less than the minimum value found in Ann's Slough. Dead belowground biomass was over 20 times greater in Ann's Slough compared with the created slough in 1992. In contrast, in 1995 dead belowground biomass was six times greater in the created slough than in Ann's Slough. Total mean belowground biomass was about twice as great in Ann's Slough in 1992, and somewhat less than that in 1995 compared with the created slough. All of the belowground parameters showed high spatial variability, as indicated by large standard deviation values (Table 2). As in other monitoring years, considerable spatial variability was evident in 1995 (Fig. 17). Total biomass showed an almost twofold difference among sites in Ann's Slough, and over a fourfold difference among sites in the created slough.

On the basis of data from all samples collected between 1990 and 1995, the ratio of aboveground biomass to belowground live, dead, and total biomass was usually greater at the created slough (Fig. 19; Table 2). This means that, per unit belowground biomass, the created slough had proportionally greater aboveground biomass. In addition, the variability in these two parameters was also higher at Ann's Slough than at the created slough.

Fish Prey Resources

Benthic Meiofauna and Macrofauna

With one exception, taxa richness of both macro- and meiofauna fractions of the benthic samples and over all sampling periods and elevations was higher at Ann's Slough. The exception was from the 22 April time-series sampling, when Ann's Slough had 18 taxa-categories vs. 21 for the created slough (Table 3).

In both sloughs, benthic meiofauna was dominated

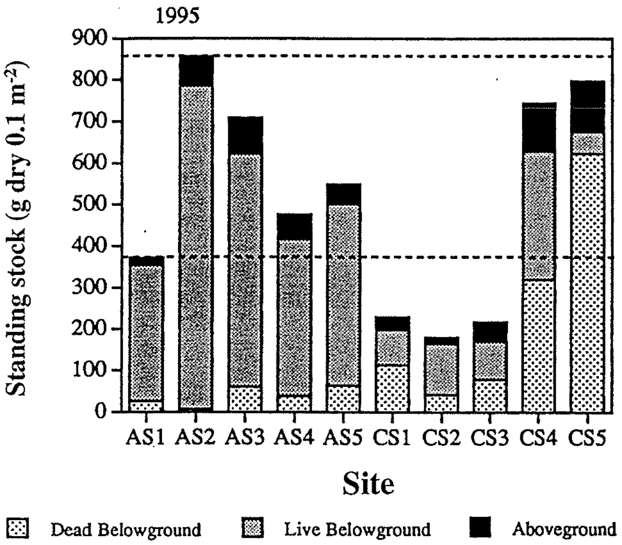


FIGURE 17.—Live aboveground, and dead and alive belowground, standing stock (biomass, g/0.1 m^2) in created (CS) and natural (Ann's Slough, AS) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–May 1995.

numerically (75% or more of the total on every sampling date) by three taxa: nematode and oligochaete worms and the brackish water harpacticoid copepod *Pseudobradya* sp. Harpacticoid nauplii larvae, the harpacticoid *Coullana canadensis* and the polychaete worm *Manayunkia aestuarina* were secondary constituents of the benthic meiofauna (Fig. 20). No dramatic differences in invertebrate composition existed between the two sloughs although at Ann's slough the proportion of nematodes decreased each month between March and June whereas at the created slough nematode proportion remained more constant. In both sloughs, oligochaetes increased in proportion between March and June. Numerical percent composition by tidal elevation and habitat strata (Fig. 21) indicated that (1) foraminiferans were almost completely restricted to within the *C. lyngbyei* in both sloughs, (2) juveniles of the polychaete *Hobsonia florida* were most prominent in the mid-channel habitat in the created slough but occurred in similar proportions in both the mid-channel and *Carex* edge strata in Ann's Slough, (3) oligochaetes occurred in the highest proportions in the channel edge and *Carex* edge strata at both sloughs, and (4) the harpacticoid *Pseudobradya* sp. was more evident in the lower elevation habitats of Ann's Slough whereas at the created slough this species occurred mainly in the upper elevation strata.

Densities of the common meiofaunal crustaceans (Fig. 22) demonstrated general overlap between the two sloughs although the harpacticoid *Coullana canadensis* was often more abundant (7 of 12 sample pairs) in the created slough, and consistently so in March and April. Conversely, ostracodes and harpacticoid copepod nauplii larvae were usually denser in Ann's Slough in the latter half of the sampling period. The harpacticoid *Pseudobradya* sp. showed an increasing density gradient from the mouth (transect station 1) to the end (transect station 5) of the created slough;

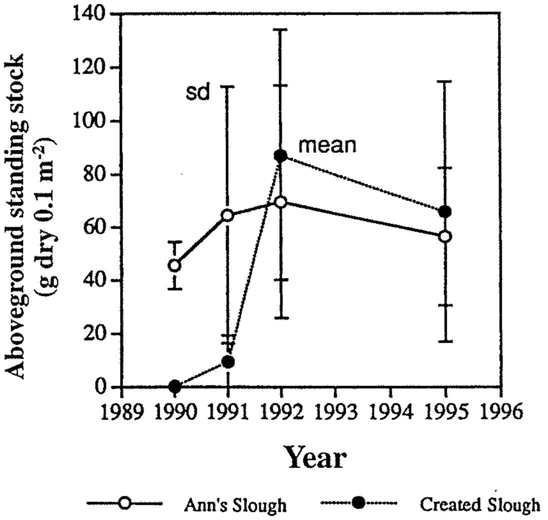
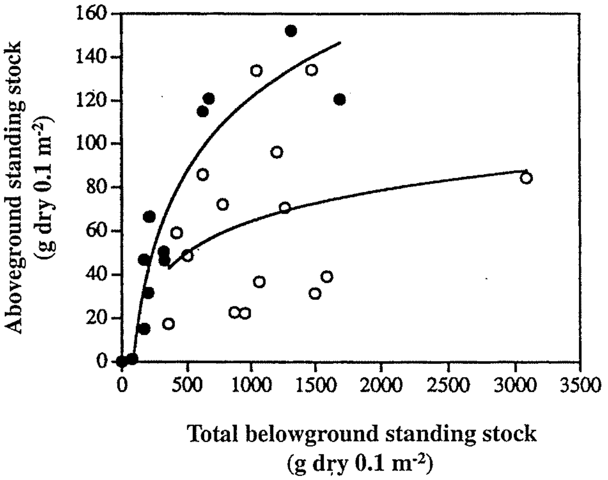


FIGURE 18.—Trend in mean aboveground standing stock (biomass, g/0.1 m^2) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, 1990–95.



y = 47.808LOG(x) - 79.064; r = 0.310; ○ = Ann's Slough
y = 111.978LOG(x) - 214.828; 4 = 0.930; ● = created slough

FIGURE 19.—Relationship between aboveground and total belowground standing stock (biomass, g/0.1 m^2) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, 1990–95.

Table 3. Taxa richness of benthic meiofauna and macrofauna in created and natural estuarine sloughs, Chehalis River estuary, Washington, March–June 1996.

	Ann's Slough					Created slough				
	Stations 1–5	Station 3				Stations 1–5	Station 3			
Date		Mid-channel	Channel slope	*Carex* edge	In *Carex*		Mid-channel	Channel slope	*Carex* edge	In *Carex*
Benthic meiofauna										
3/22/95	26					17				
4/22/95	18					21				
5/17/95	22					20				
6/22/95	21	21	17	22	18	19	13	9	17	16
Mean	22					19				
Benthic meiofauna										
3/22/95	22					22				
4/20/95	28					21				
5/17/95	21					16				
6/22/95	27	18	20	19	18	15	12	13	18	15
Mean	25					19				

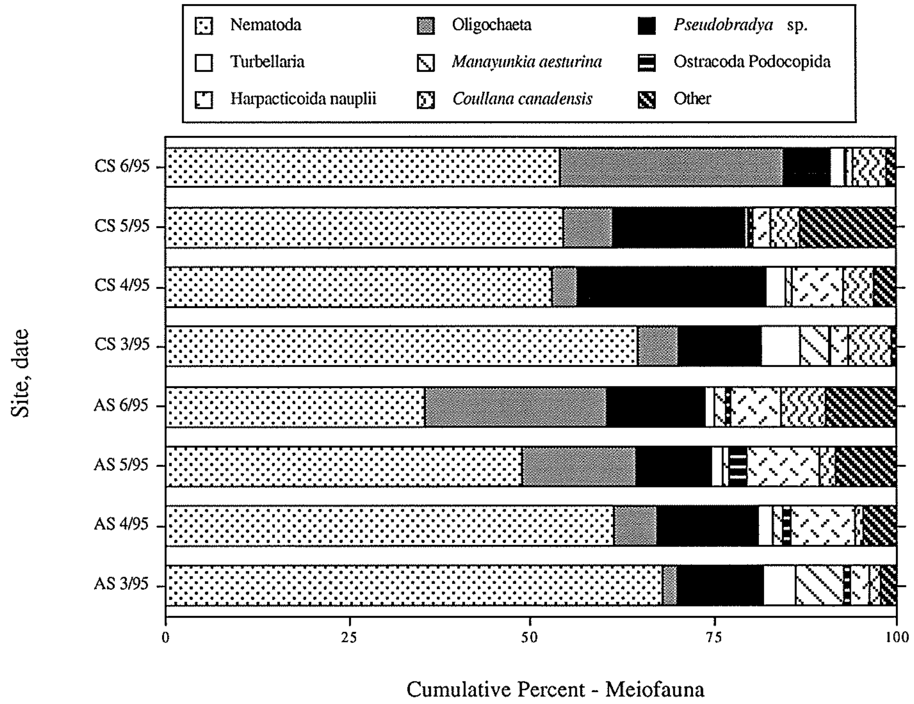


FIGURE 20.—Monthly cumulative numerical composition of benthic meiofauna in created (CS) and Ann's Slough (AS) in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995.

ostracodes showed a similar trend in Ann's Slough. Other prominent meiofauna generally displayed similar patterns in density gradients from the mouth to the end of the two sloughs (Fig. 23). Particularly evident was the consistent increase in oligochaete densities at both sloughs across the sampling period. The opposite was true for the polychaete worm *Manayunkia aestuarina*, which was most dense in March and decreased to relatively low densities for the remainder of the sampling period. *M. aestuarina* was usually (8 of 12 sampling pairs) more numerous in Ann's Slough than in the created slough, and nematodes were consistently more dense in the created slough in May and June.

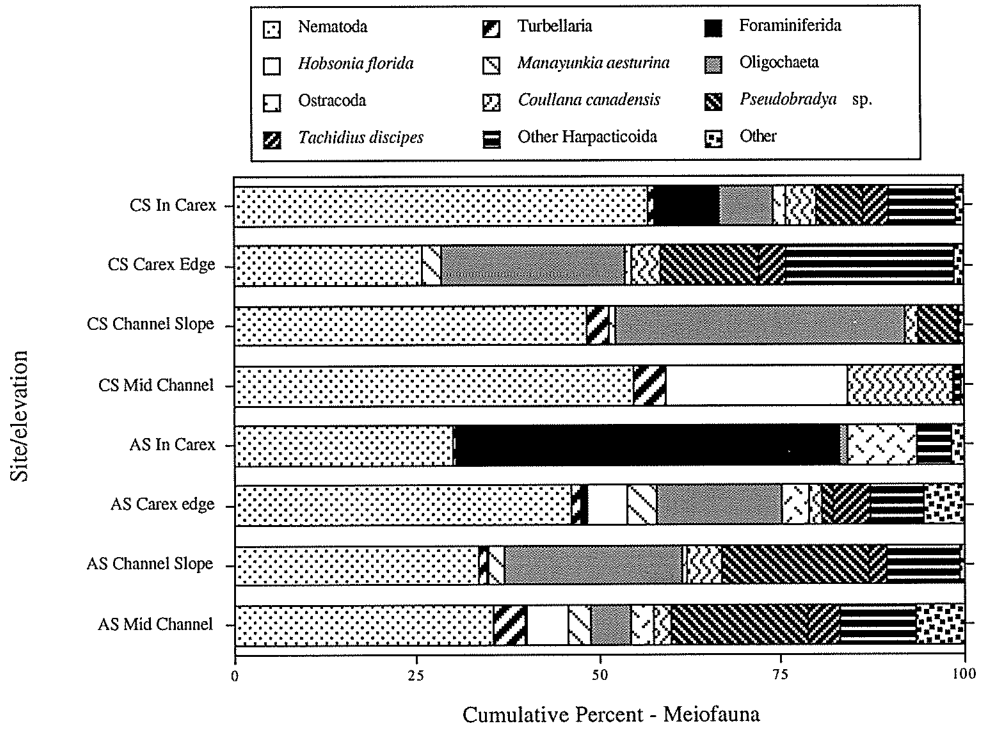


FIGURE 21.—Cumulative numerical composition of benthic meiofauna by intertidal elevation in created (CS) and Ann's Slough (AS) in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June, 1995,.

Meiofauna densities often varied greatly among tidal elevations and slough habitats (Figs. 24–26). Among the four most common harpacticoid copepods (Fig. 24), densities tended to be more uniform in the created slough than in Ann's Slough, which had large peaks of *Nannopus palustris* in the *C. lyngbyei* habitat and *Tachidius discipes* and *Pseudobradya* sp. at the lower elevations. Foraminifera and ostracodes were dramatically more abundant in the *C. lyngbyei* habitats in Ann's Slough compared with the created slough. Nematode densities showed markedly inverse trends at the two sloughs, with abundance increasing with elevation at Ann's slough and the opposite occurring at the created slough (Fig. 25). In the elevation and habitat strata samples, ostracodes and the polychaete worms *Manayunkia aestuarina* and *Hobsonia florida* were consistently more abundant in Ann's Slough. Only oligochaetes were consistently more dense in the created slough in most (all but the *C. lyngbyei*) habitats (Fig. 26).

Trends in numerical percent composition of benthic macrofauna were more consistent between the two sloughs than for the meiofauna (Fig. 27): *Manayunkia aestuarina* consistently became less, and oligochaetes more prominent from March through June. There were, however, two major differences in taxa composition between the two sloughs: first, there was larger representation of the harpacticoid copepod *Coullana canadensis* in the created slough, and second, the tube-dwelling amphipods *Corophium* spp. occurred at Ann's Slough but were virtually nonexistent in terms of percent composition in the created slough assemblage.

There were also two main differences in numerical percent composition between the two sloughs in the elevation/habitat strata samples (Fig. 28): First, *Corophium* spp. constituted more than 50% of the benthos in the mid-channel habitat, and almost 20% in the *C. lyngbyei* habitat of Ann's Slough, but they were virtually nonexistent or constituted <10% in all habitats in the created slough. Second, nematode proportions showed opposite trends in the two sloughs: at Ann's Slough, nematodes made up the smallest proportion in the mid-channel habitat and the highest proportion in the *C. lyngbyei* whereas the inverse was true at the created slough. For other benthic fauna, trends at the two sloughs were similar: (1) oligochaetes were prominent in all habitats, (2) the polychaete worms *Hobsonia florida* and *Manayunkia aestuarina* were most common in the channel slope and *C. lyngbyei* edge habitats, (3) dipteran larvae were relatively abundant only in *C. lyngbyei* edge and interior habitats; and (4) aphids were represented only in *C. lyngbyei* interior samples.

Areal densities of several benthic macroinvertebrates differed prominently (Figs. 29–30): (1) the created slough appeared to have more stable abundances and Ann's Slough more fluctuations, (2) chironomid larvae and the polychaetes

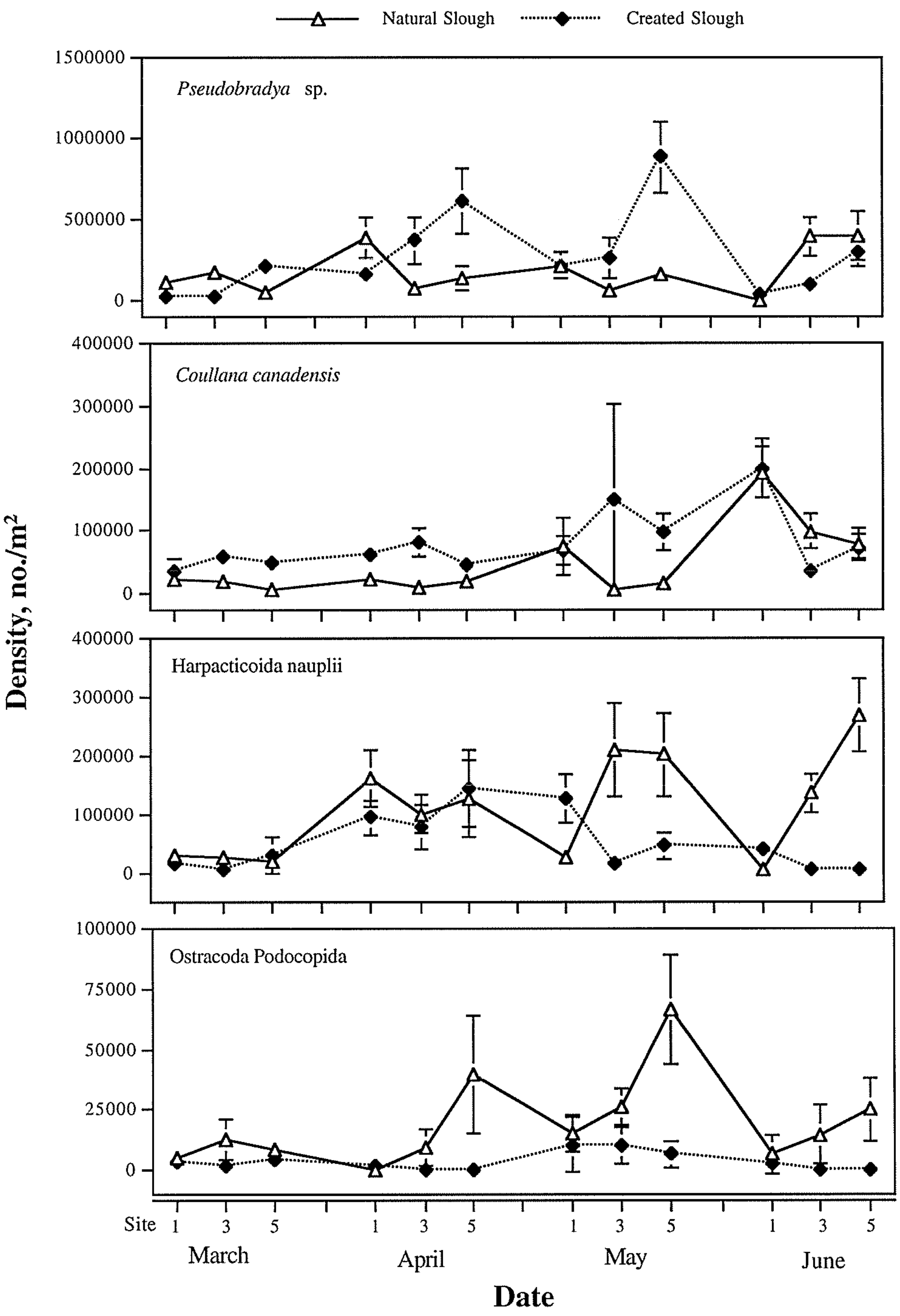


FIGURE 22.—Densities (no./m^2) of prominent crustacean meiofauna in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

Manayunkia aestuarina and *Hobsonia florida* usually occurred in higher densities in Ann's Slough, (3) *Corophium* spp. increased in Ann's Slough in May and June but did not do so in the created slough, and (4) the clams *Macoma* spp. were consistently and greatly (by as much as 500X) more abundant in the created slough than in Ann's Slough.

Most tidal elevation and habitat trends in benthic macrofauna density were similar for the two sloughs: fine-sediment-dwelling taxa such as worms, clams, and *Corophium* were most abundant in the channel habitats, and insects were most abundant in the *C. lyngbyei* habitats (Figs. 31–32). However, in specific strata the sloughs diverged

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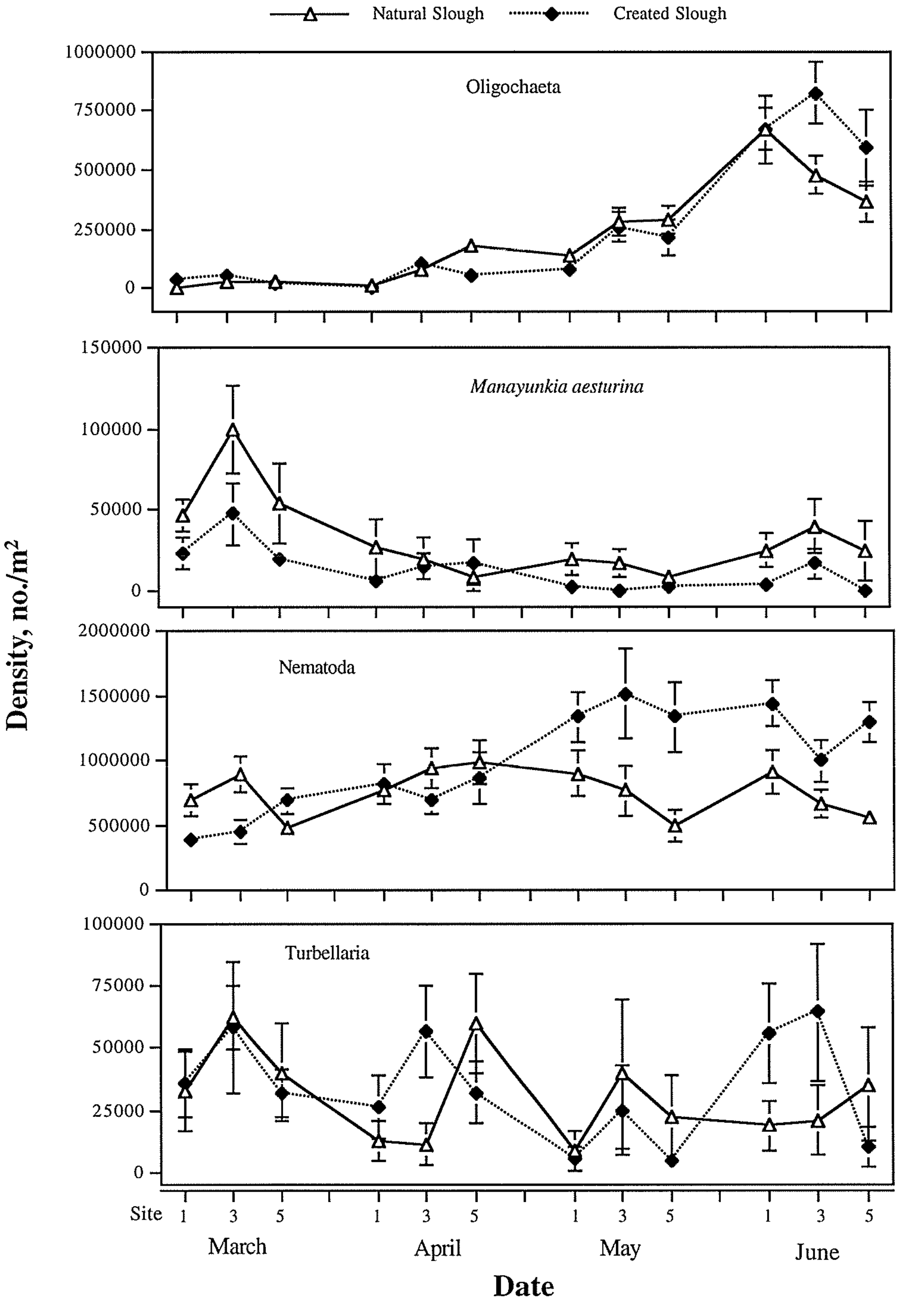

FIGURE 23.—Densities (no./m^2) of prominent non-crustacean meiofauna in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

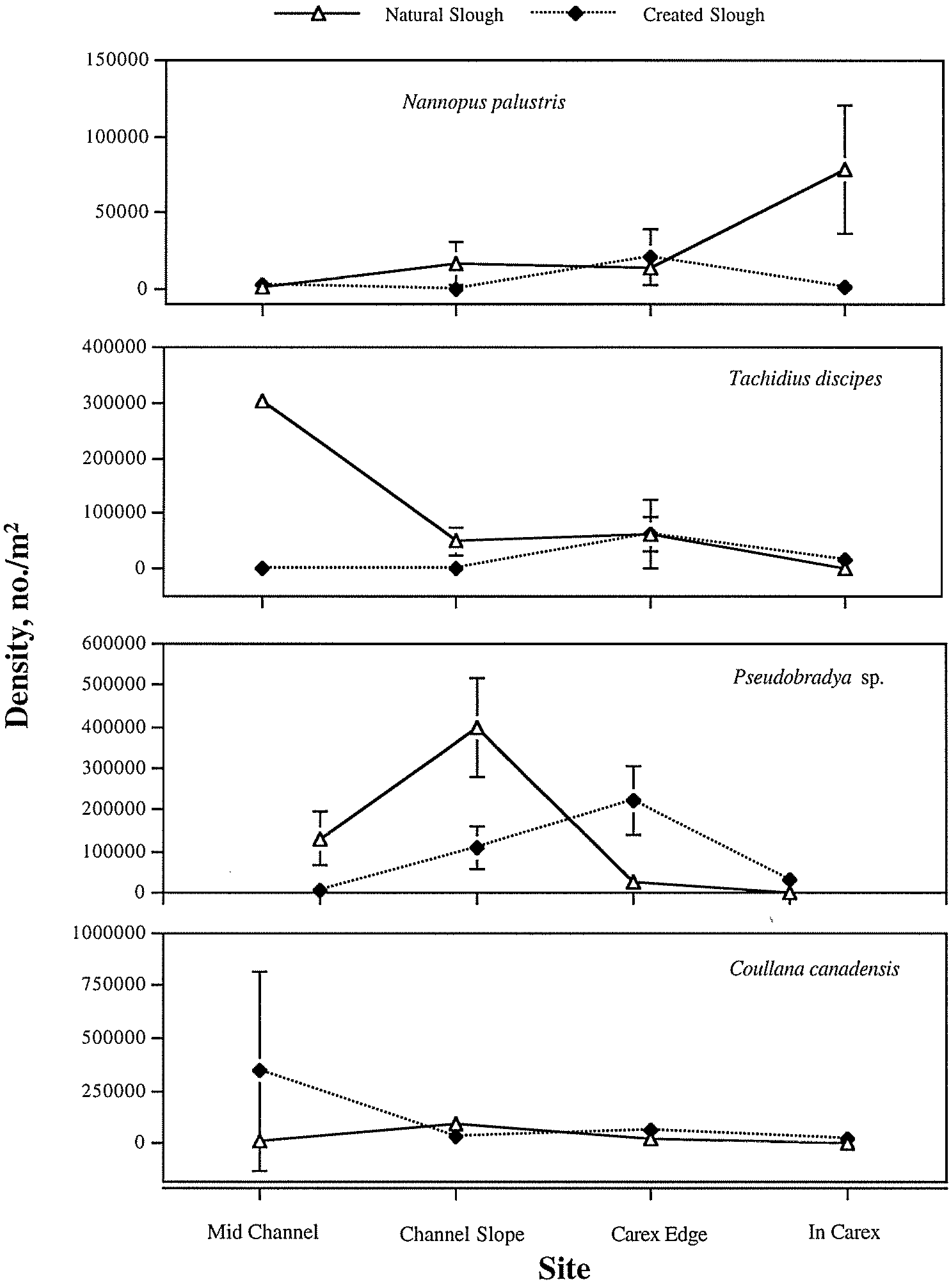

FIGURE 24.—Densities (no./m^2) of benthic meiofaunal harpacticoid copepods in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

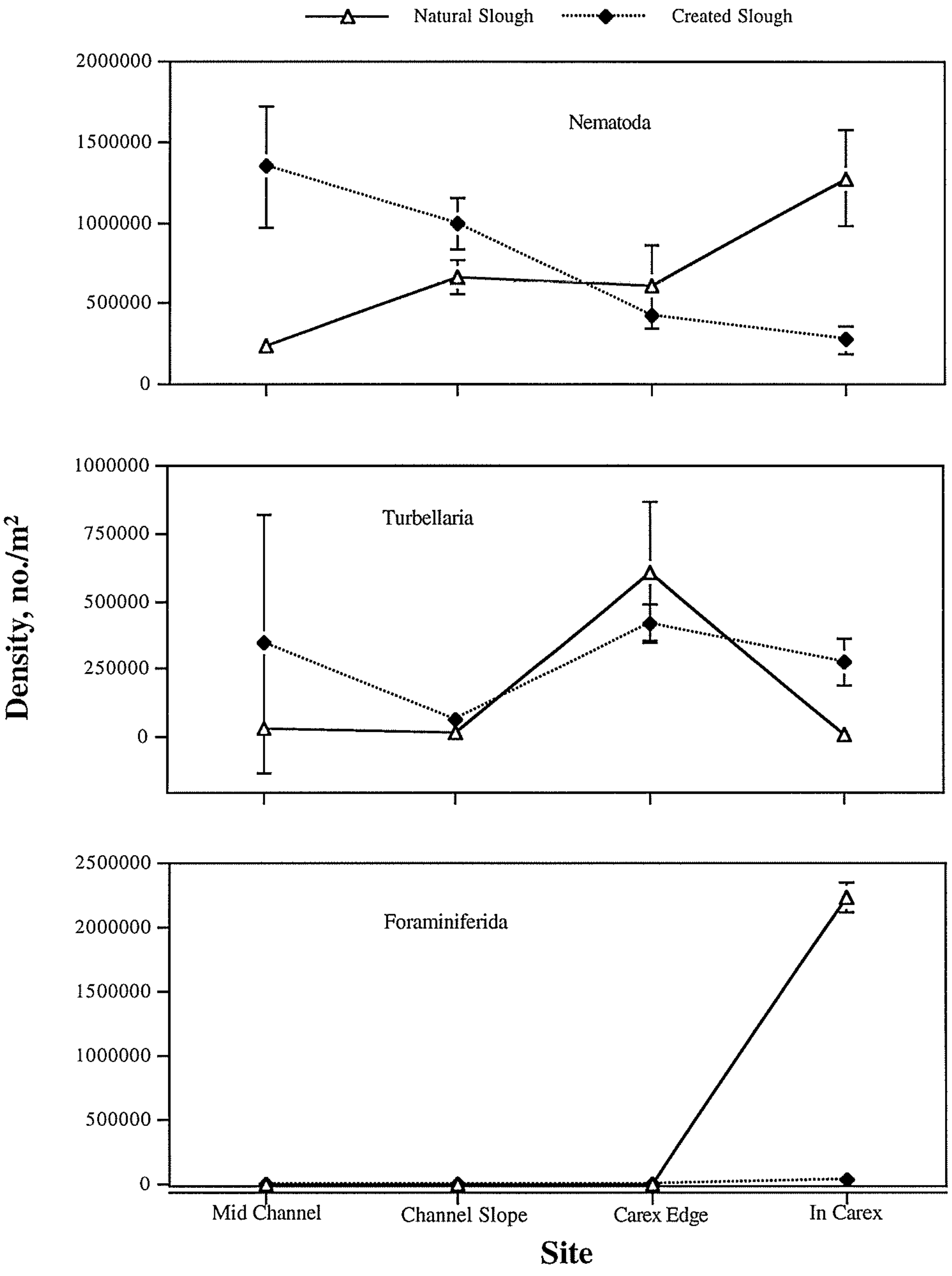

FIGURE 25.—Densities (no./m^2) of non-crustacean meiofauna from different intertidal elevations in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

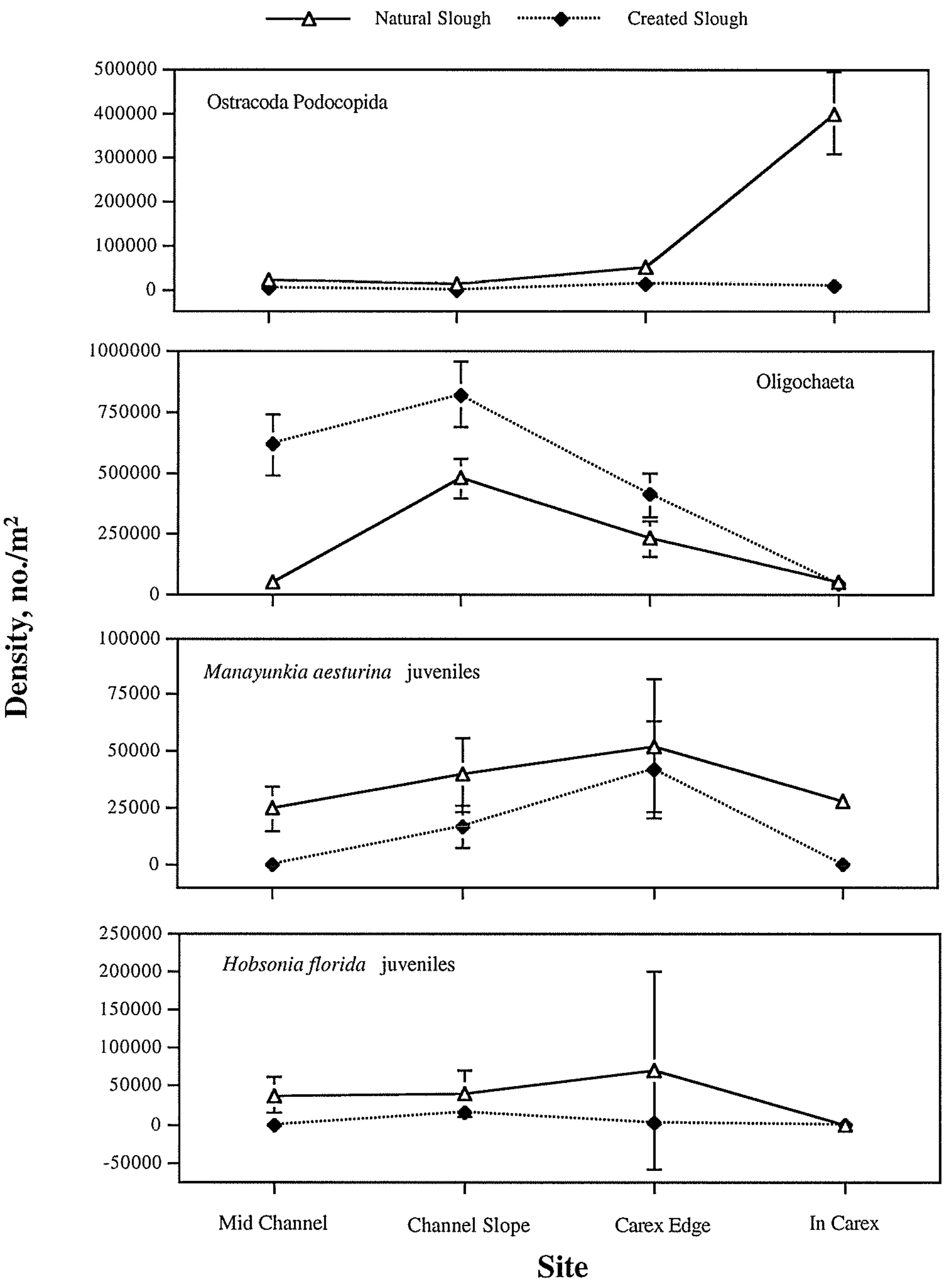

FIGURE 26.—Densities (no./m^2) of benthic meiofaunal annelids and ostracodes from different intertidal elevations in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

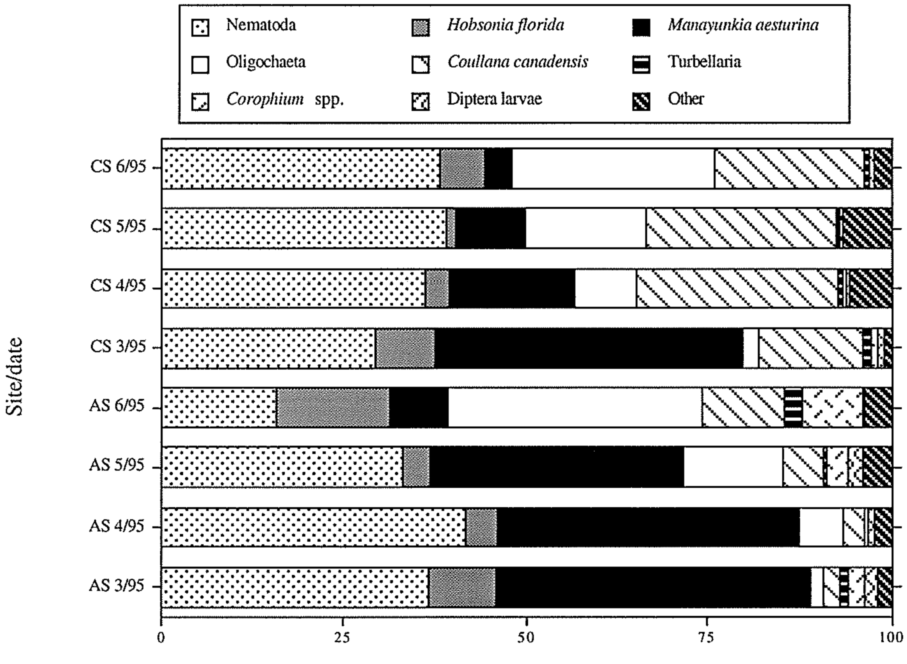

FIGURE 27.—Monthly cumulative numerical composition of benthic macrofauna in created (MS) and Ann's Slough (AS) from March–June, 1995, in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

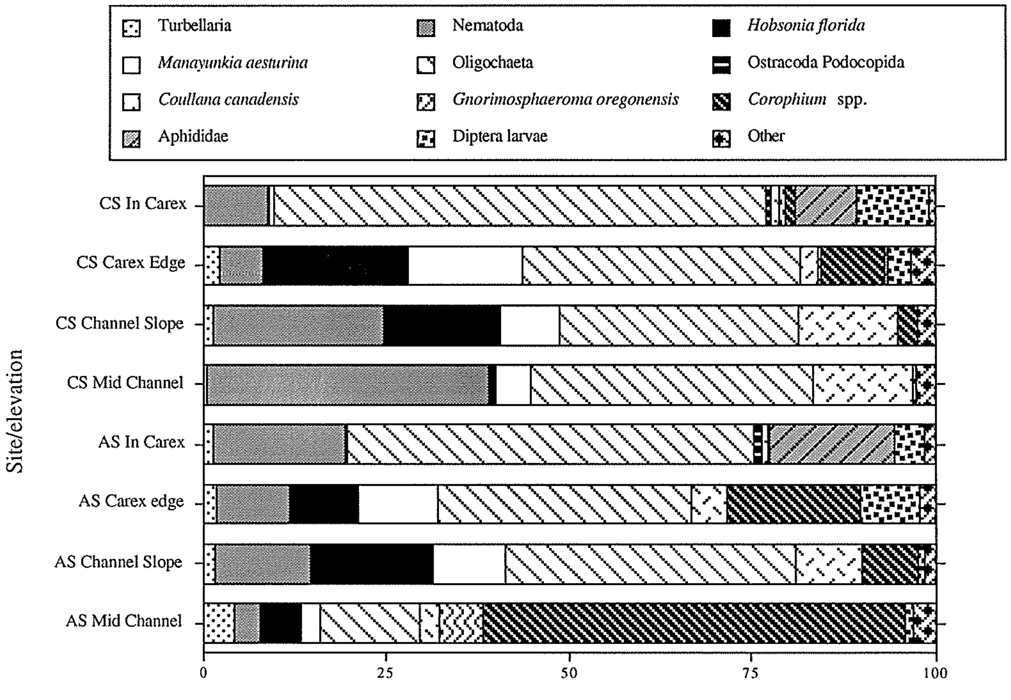

FIGURE 28.—Cumulative numerical composition of benthic macrofauna by intertidal elevation in created (MS) and Ann's Slough (AS) from March–June, 1995, in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

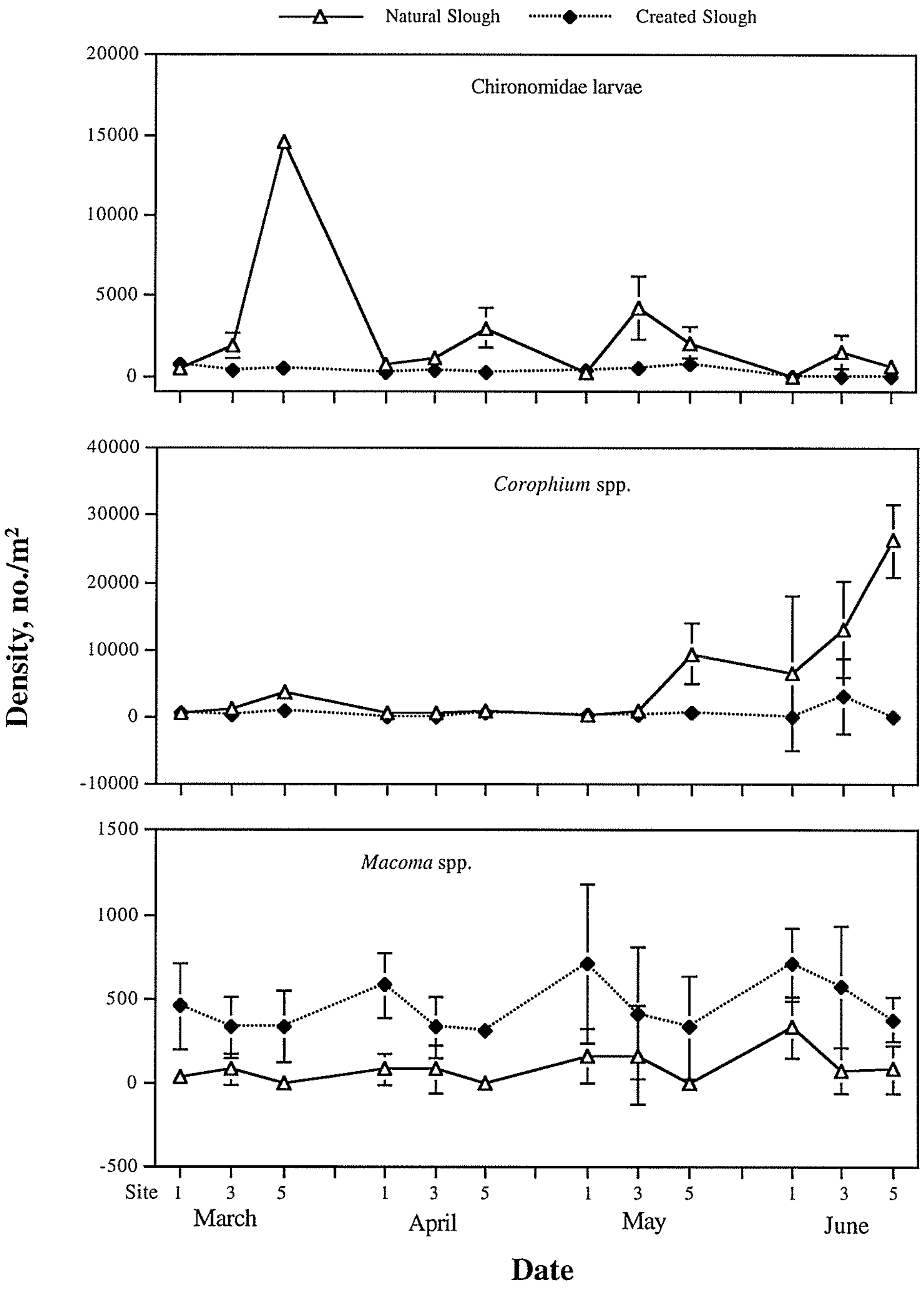

FIGURE 29.—Densities (no./m^2) of prominent benthic macroinvertebrates in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

in abundances of *Corophium* spp. (more dense in mid-channel in Ann's Slough), chironomid larvae (more dense in channel slope and *C. lyngbyei* edge habitats in Ann's Slough) and *Macoma* spp. (more dense in mid-channel habitats in the created slough).

Emergent Insects

The taxonomic composition of insects emerging from the *C. lyngbyei* habitat in the two sloughs (Fig. 33) was generally comparable, but emergent insect biomass and density tended to be higher in the created slough than Ann's Slough in all but a few instances (e.g., ephyrid flies and hymenopteran wasps [Symphyta]). On the basis of biomass, flies in the families Chloropidae, Dolichopodidae, and Cosmopterigidae dominated the identifiable taxa (≥4 mg m^{-2}); numerically, flies from the families Cecidomyiidae,

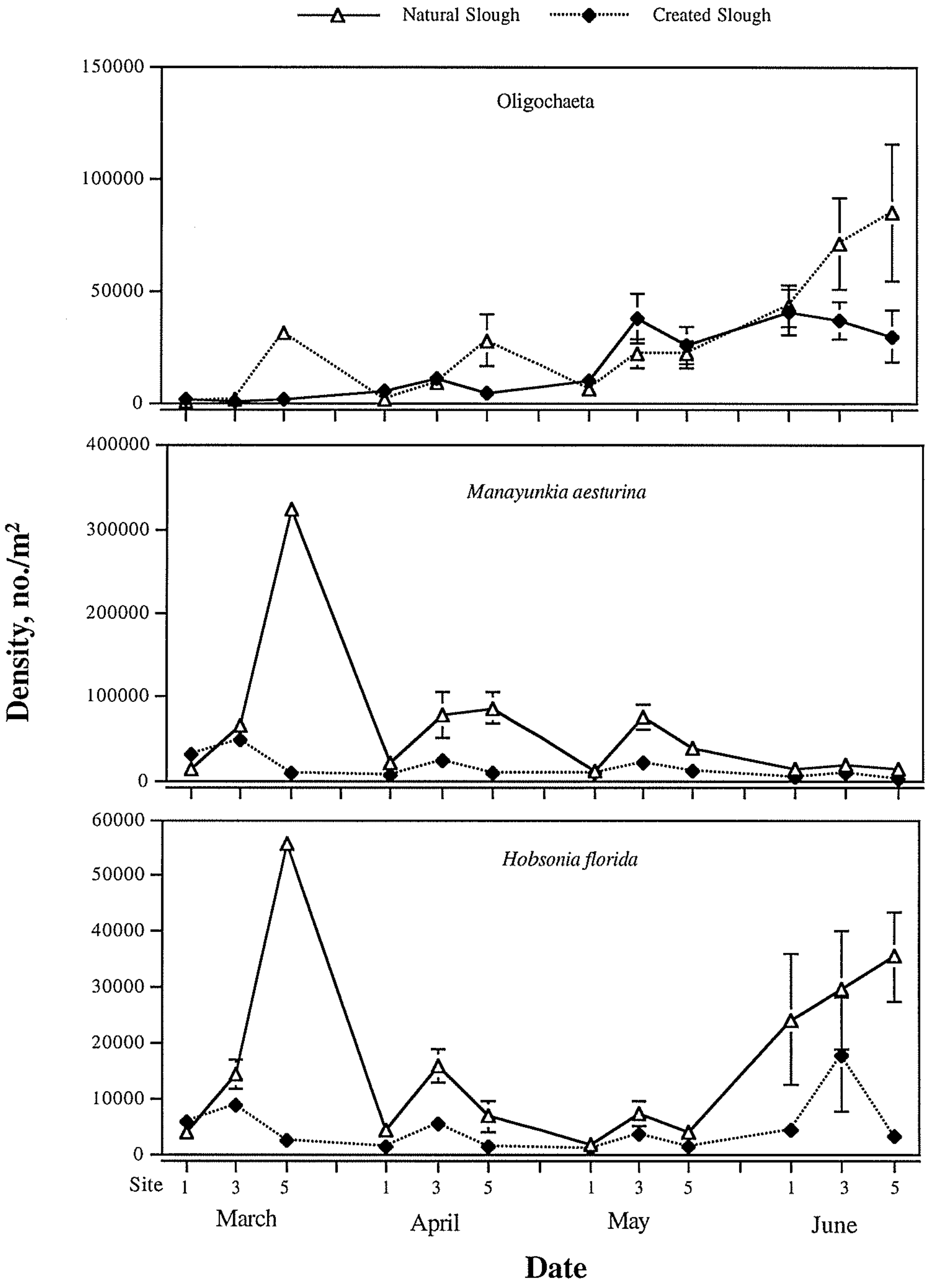

FIGURE 30.—Densities (no./m^2) of prominent benthic Annelida in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

Psychodidae, and Dolichopodidae, wasps (Apocrita and Symphyta hymenopterans) and Cosmopterigidae were most prominent (>30 individuals/m^2). The created slough generated particularly more flies (Psychodidae, Cosmopterigidae) and other insects. Among the taxa that appeared in the diets of juvenile salmon, chironomid flies were only a minor portion of the emerging insect biomass but numbered >15 individuals emerging per m; the created slough had higher densities of emerging chironomids.

Fallout Insects

Densities of insects in the fallout traps increased exponentially from March through June in Ann's Slough but

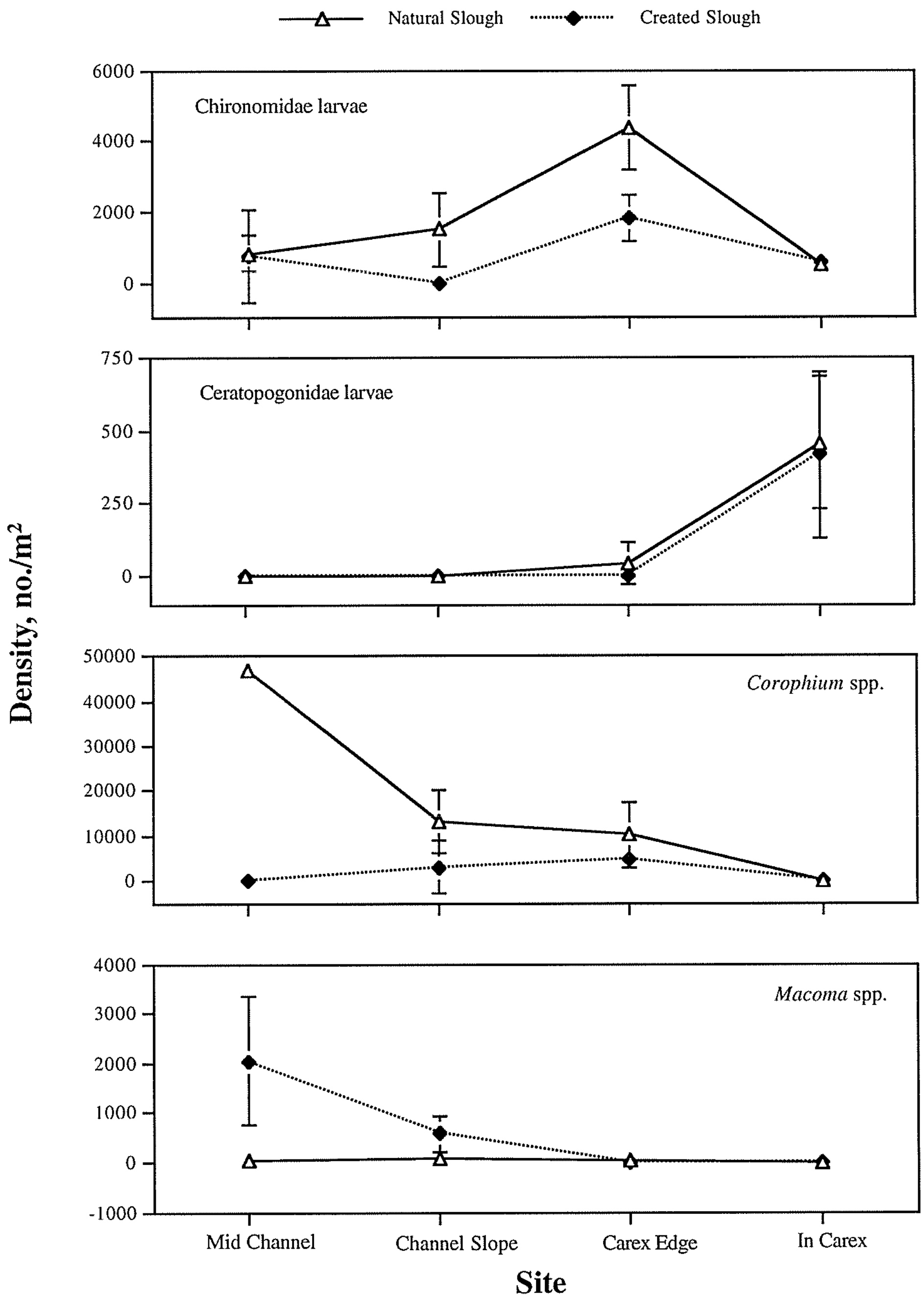

FIGURE 31.—Densities (no./m^2) of other benthic taxa in different intertidal elevations in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

were more variable at the created slough (Fig. 34, top). A variety of taxa, with no predominance by any one taxon, fell into the traps at 5–30/m^2, but flies such as ephydrids (~5–20/m^2), chironomids (~20/m^2), and psychodids (~40/m^2), and aphids (~20–130/m^2) became more dominant in April through June. The psychodid flies predominated only in the created slough in April, and chironomid flies were prominent only in Ann's Slough in May. Aphids, which were important prey of juvenile chinook salmon in both sloughs in May and June, appeared in highest densities in the Ann's Slough fallout traps—uniquely so in May and particularly dense in June. The incidence of spruce needles, which might be considered an index of "non-behavioral" fallout, showed no pattern among months but was consistently

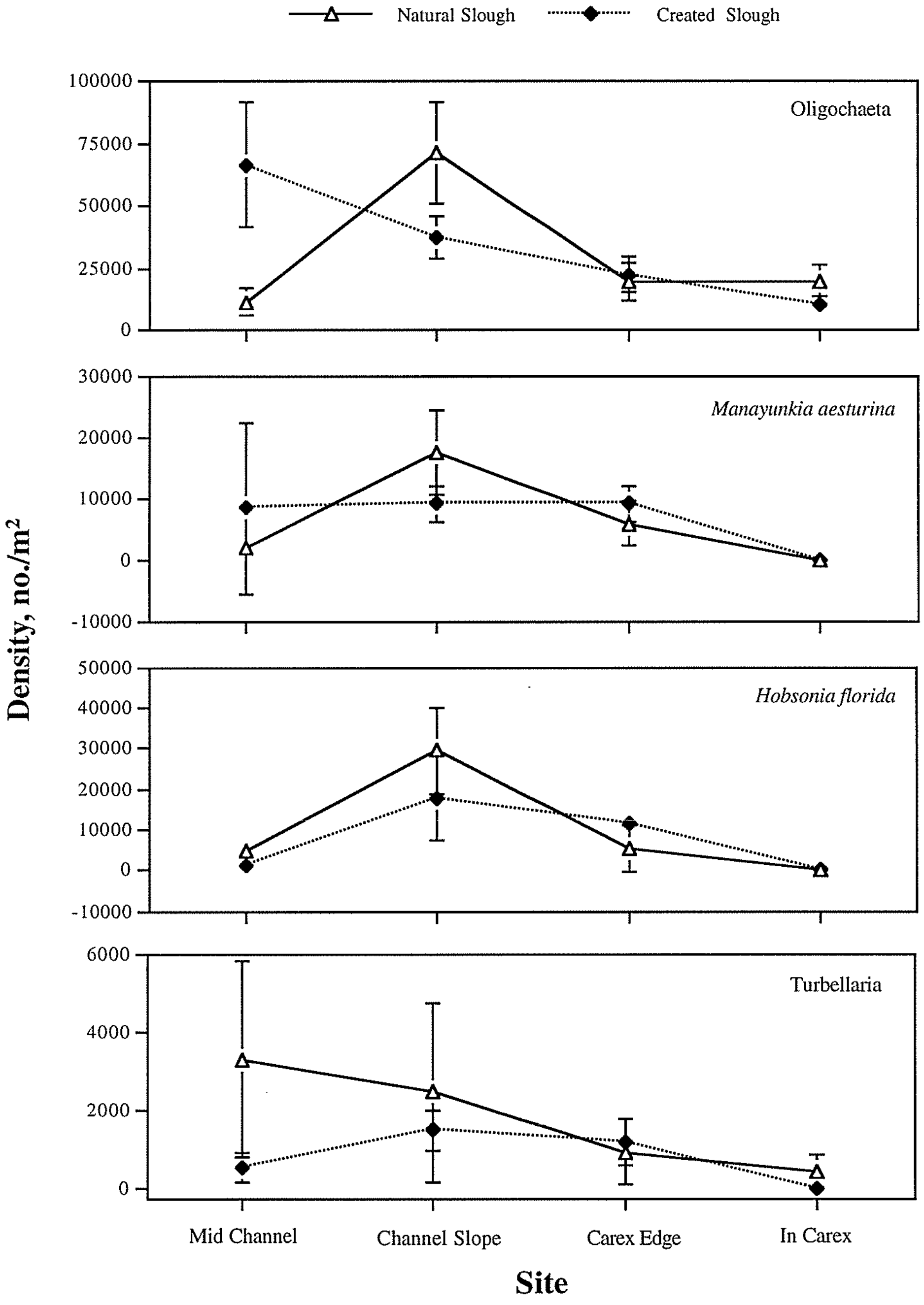

FIGURE 32.—Densities (no./m^2) of benthic Turbellaria and Annelida in different intertidal elevations in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates 90% confidence intervals.

more dense in the traps set in Ann's Slough, possibly in association with the closer proximity and overhang of Sitka spruce along the narrower natural slough.

Sedge Enclosure Insects

Results of the sedge enclosure sampling were similar to those of the fallout traps: insect densities increased from April (<20 insects/m^2) to June (>25/m^2) and, except for April, were more dense in Ann's Slough (Fig. 34, bottom). Aphids dominated the samples in May and June, particularly in Ann's Slough, which had >5X the densities of the created slough in that month; *Clinocera* sp. were present, but less dense, in both sloughs in April and May.

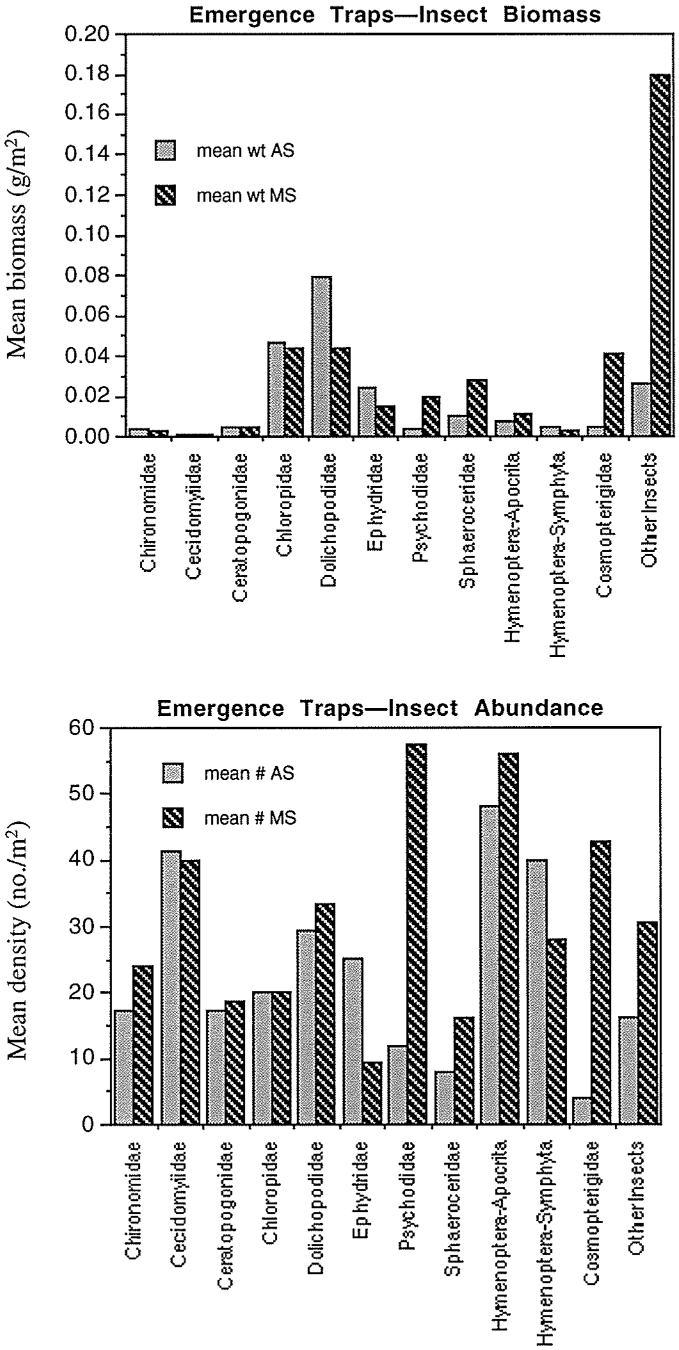

FIGURE 33.—Mean standing stock (biomass/m^2) and density (no./m^2) of emergent insects in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995.

Occurrence and Standing Stock of Fishes

The created slough continues to support equivalent if not more fish species than Ann's Slough (Table 4). Ten to 12 species consistently appear in Ann's Slough but 15–20 may appear in the created slough. As reported previously (Simenstad et al. 1992, 1993), estuarine fishes less tolerant of freshwater conditions are more likely to appear in the somewhat deeper and more saline created slough. For example, in 1995, saddleback gunnel (*Pholis ornata*), snake prickleback (*Lumpenus saggitta*) and eulachon (*Thaleichthys pacificus*) occurred (although rarely) in the created slough but not in Ann's Slough. Similarly, surf smelt (*Hypomesus pretiosus*), Pacific staghorn sculpin (*Leptocottus armatus*) and starry flounder (*Platichthys stellatus*)

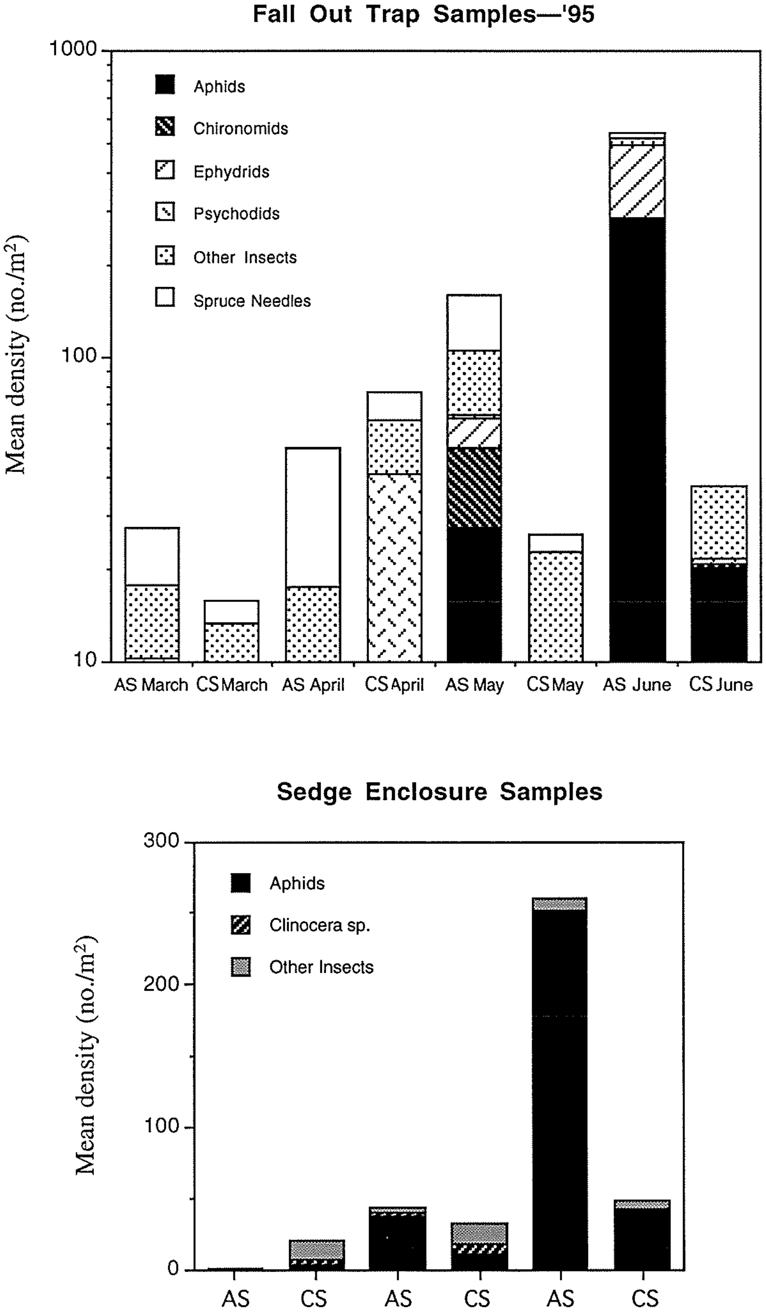

FIGURE 34.—Mean density (no./m^2) of insects captured in fall out traps (top) and sedge enclosure (bottom) samples in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, April–June 1995.

occurred rarely in Ann's Slough but appeared commonly to infrequently in the created slough. Species that were abundant in both sloughs included juvenile chum and chinook salmon, peamouth chub (*Mylocheilus caurinus*), and threespine stickleback (*Gasterosteus aculeatus*).

Although mean total fish density in the created slough was often equivalent to (March, May) or exceeded (April) densities in Ann's Slough, patterns in the total density of fish differed between the two sloughs (Fig. 35). Total fish densities in Ann's Slough increased progressively from March to June while densities in the created slough reached a maximum in April and declined thereafter. High abundances of threespine sticklebacks in the created slough were responsible for the high densities in April while higher

Table 4. Fish species occurrence in created and natural estuarine sloughs, Chehalis River estuary, Washington, 1990–95; A = abundant, C = common, I = infrequent (but often abundant when occurring), and R = rare (and not abundant).

	1990	1991		1992		1995	
Species	Natural	Created	Natural	Created	Natural	Created	Natural
American shad, *Alosa sapidissima*		R					
Chum salmon, *Oncorhynchus keta*	C	I		C	C	A	A
Coho salmon, *O. kisutch*	A	A	A	C	A	A	C
Chinook salmon, *O. tshawytscha*	A	A	A	A	A	A	A
Steelhead trout, *O. mykiss*		C				I	I
Surf smelt, *Hypomesus pretiosus*	C	C	R			I	R
Longfin smelt, *Spirinchus thaleichthys*		R					
Eulachon, *Thaleichthys pacificus*	R					R	
Peamouth chub, *Mylocheilus caurinus*	A	A	A	A	A	A	A
Largescale sucker, *Catostomus macrocheilus*	R	R	C			R	R
Northern squawfish, *Ptychocheilus oregonensis*	R						
Redside shiner, *Richardsonius balteatus*	R						
Threespine stickleback, *Gasterosteus aculeatus*	A	A	A	A	A	A	A
Bluegill, *Lepomis macrochirus*		R	R				
Shiner perch, *Cymatogaster aggregata*		A	C	A	C	A	C
Yellow perch, *Perca flavescens*	R	R					
Prickly sculpin, *Cottus asper*	A	A	A	C	I	C	C
Pacific staghorn sculpin, *Leptocottus armatus*		A	I	C	I	C	R
Saddleback gunnel, *Pholis ornata*		R				R	
Snake prickleback, *Lumpenus saggitta*		I		I		R	
Starry flounder, *Platichthys stellatus*		I	R	I		C	R
Total species richness	12	20	12	10	8	15	12

abundances of peamouth chub and juvenile and adult shiner perch were found in Ann's Slough in June. χ_2 contingency table tests of even distribution of average total fish counts between the two sloughs indicated that the fish use of sloughs was statistically equivalent ($p > 0.50$).

Juvenile chum salmon were extremely abundant in both sloughs in March and April, as were juvenile chinook salmon in May and June (Fig. 36). Although probably not significantly so, based on extensive overlap in variance, the mean density of juvenile chum salmon was consistently higher in Ann's Slough than in the created slough. However, mean densities of juvenile chinook were consistently higher in the created slough; juvenile (subyearling) coho appeared predominantly in March and April and were typically more dense in the created slough. χ_2 contingency table tests of even distribution of chum salmon density between the two sloughs indicated that they were significantly ($p < 0.001$) more abundant in Ann's Slough than in the created slough, while coho salmon were significantly more abundant in the created slough ($p < 0.00003$). Chinook were only slightly more abundant ($p < 0.046$) in the created slough.

Densities of other fishes varied but no consistent differences were evident between the two sloughs. Threespine sticklebacks were abundant in April and generally declined through June, but they occurred in higher mean abundance in the created slough in April and had only slightly higher mean abundance in May (Fig. 37); χ_2 contingency table tests indicated that stickleback density in the created slough was significantly ($p < 0.001$) higher than in Ann's Slough. Peamouth increased in density in May and June (Fig. 36) and tended to be more abundant in Ann's Slough ($p < 0.001$). Prickly sculpin (*Cottus asper*) densities were too low (0.5–4.5 fish/ha) to detect differences between sloughs. Adult shiner perch were abundant at the created slough in May but not at Ann's Slough until June, while juvenile shiner perch did not appear until June (Fig. 38); by June, mean densities of both adult and juvenile shiner perch were considerably higher in Ann's Slough than in the created slough. Pacific staghorn sculpins occurred in low density, and intermittently, from March through June.

Patterns in emigration of fish from the sloughs during the ebbing tide (into the live box of the fyke net) were not consistent among species and months and between sloughs (Figs. 39–42). In March, threespine stickleback and peamouth moved out of the created slough at the beginning and end of the ebbing tide, while others (juvenile chum salmon,

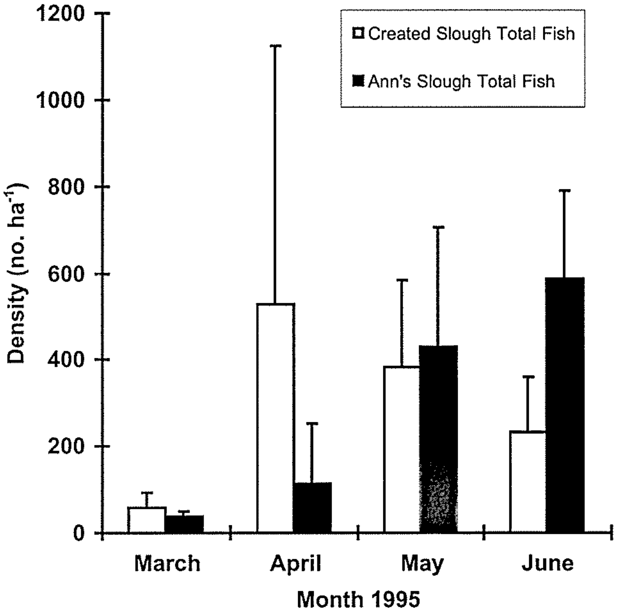

FIGURE 35.—Monthly mean density and variability (no./ha) of total fishes in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates ±1 standard deviation of mean.

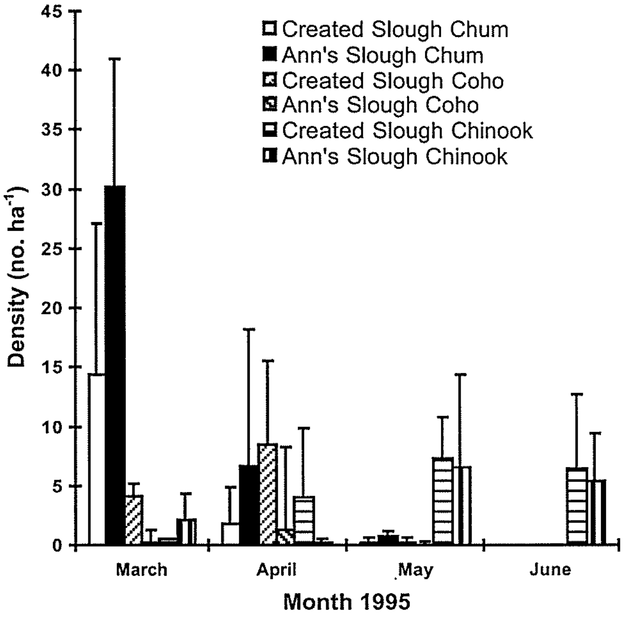

FIGURE 36.—Monthly mean density and variability (no./ha) of juvenile chum (*Oncorhynchus keta*), coho (*O. kisutch*), and chinook salmon (*O. tshawytscha*) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates ±1 standard deviation of mean.

Pacific staghorn sculpin, smelts) showed a more constant rate of emigration or moved out of the slough only at the end of the ebb (coho salmon) (Fig. 39). In contrast, in March most species in Ann's Slough maintained a relatively constant migration rate except for juvenile chum salmon, which emigrated from the slough in a pulse 5 hours into the ebb. In April, limited catches suggested that threespine stickleback moved out of the created slough early in the ebbing tide but out of Ann's Slough in mid- to late tide (Fig. 40). While all other fish demonstrated a constant rate of emigration at low densities in May, threespine stickleback moved out of both sloughs through the latter half of the ebb (Fig. 41). In June, fishes in the created slough either emigrated at a constant rate (juvenile chinook salmon, adult shiner perch, and starry flounder), early in the ebb tide (juvenile shiner perch) or moved out in a pulse at the end of the tide (Fig. 42); in contrast, except for adult shiner perch, which emigrated early, most fish showed only a small, maximum mid-ebb emigration from Ann's Slough.

Our test of whether there was an allometric difference in juvenile salmon that occupied the two sloughs indicated that while juvenile chinook salmon may have different length–weight growth rates (i.e., significantly different regression slopes), the overall allometric relationships of salmon in the two sloughs were indistinguishable (Fig. 43).

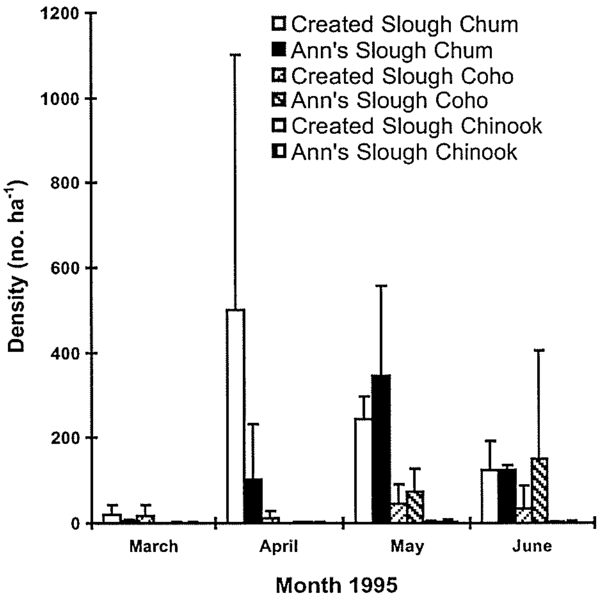

FIGURE 37.—Monthly mean density and variability (no./ha) of threespine stickleback (*Gasterosteus aculeatus*), peamouth chub (*Mylocheilus caurinus*), and prickly sculpin (*Cottus asper*) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates ±1 standard deviation of mean.

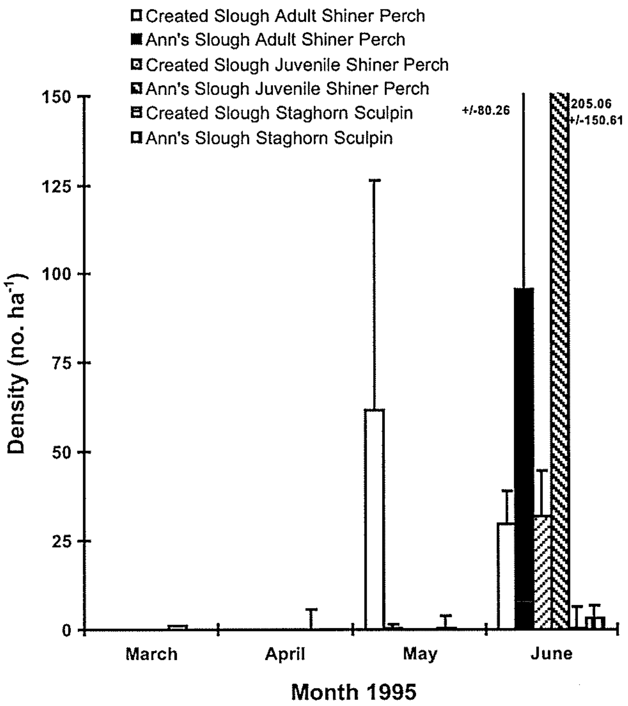

FIGURE 38.—Monthly mean density and variability (no./ha) of adult and juvenile shiner perch (*Cymatogaster aggregata*) and Pacific staghorn sculpin (*Leptocottus armatus*) in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–June 1995; bar at top of column indicates ±1 standard deviation of mean.

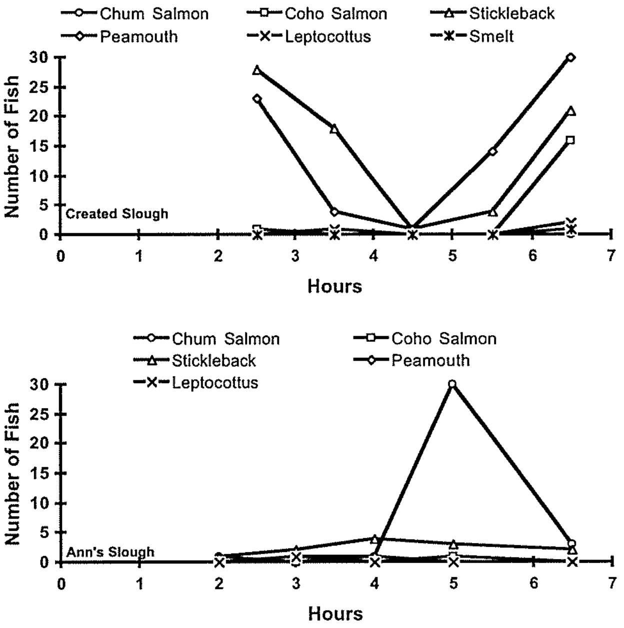

FIGURE 39.—Numbers of most abundant fishes emigrating from created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, during ebb tide on March 23–24, 1996.

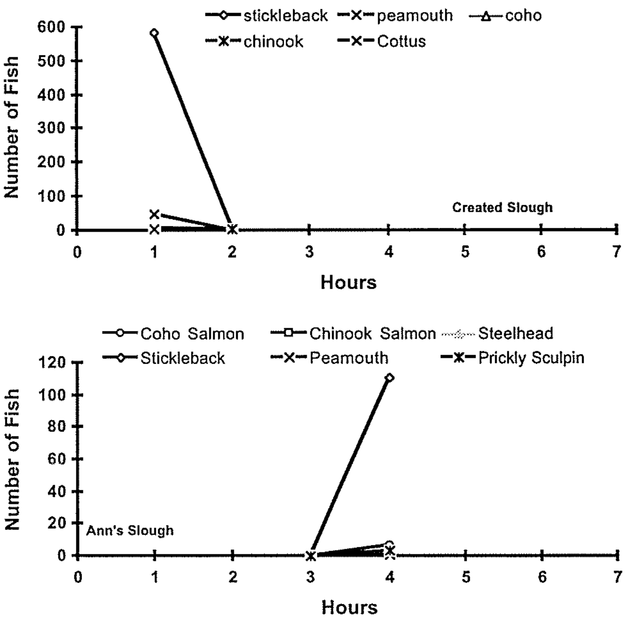

FIGURE 40.—Numbers of most abundant fishes emigrating from created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, during ebb tide on April 20, 1996.

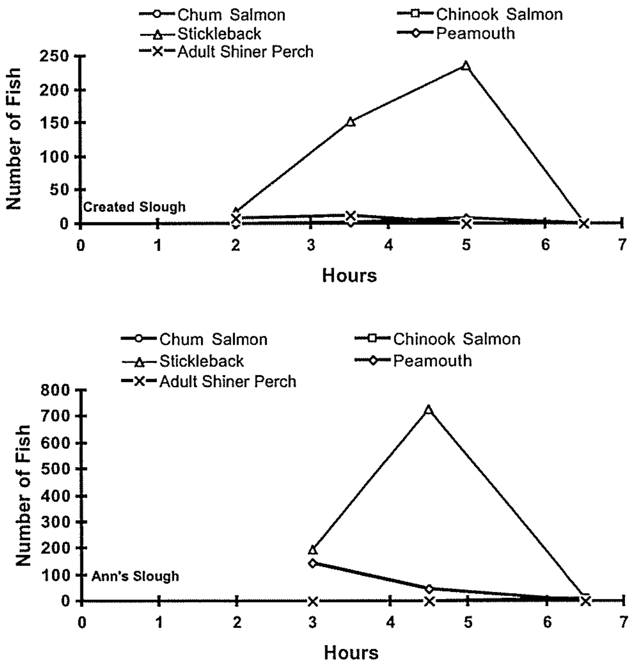

FIGURE 41.—Numbers of most abundant fishes emigrating from created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, during ebb tide on May 19, 1995.

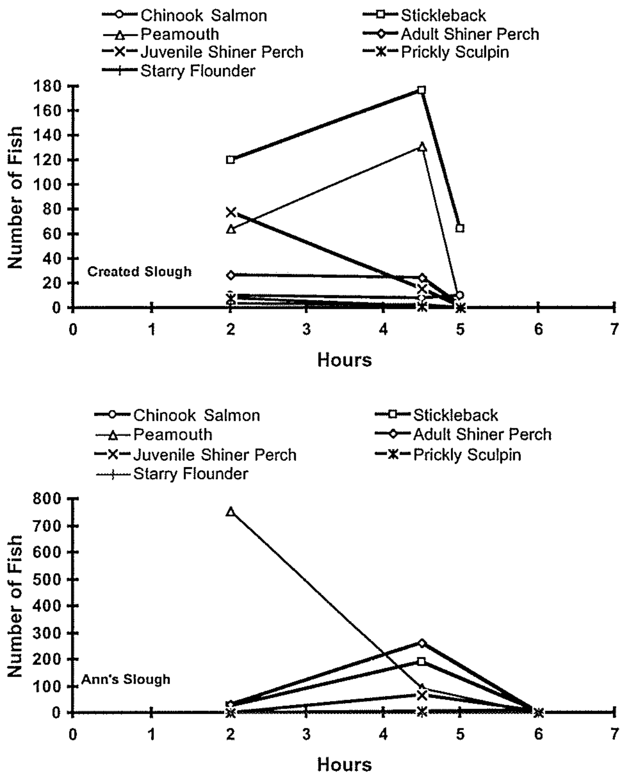

FIGURE 42.—Numbers of most abundant fishes emigrating from created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, during ebb tide on June 19, 1995.

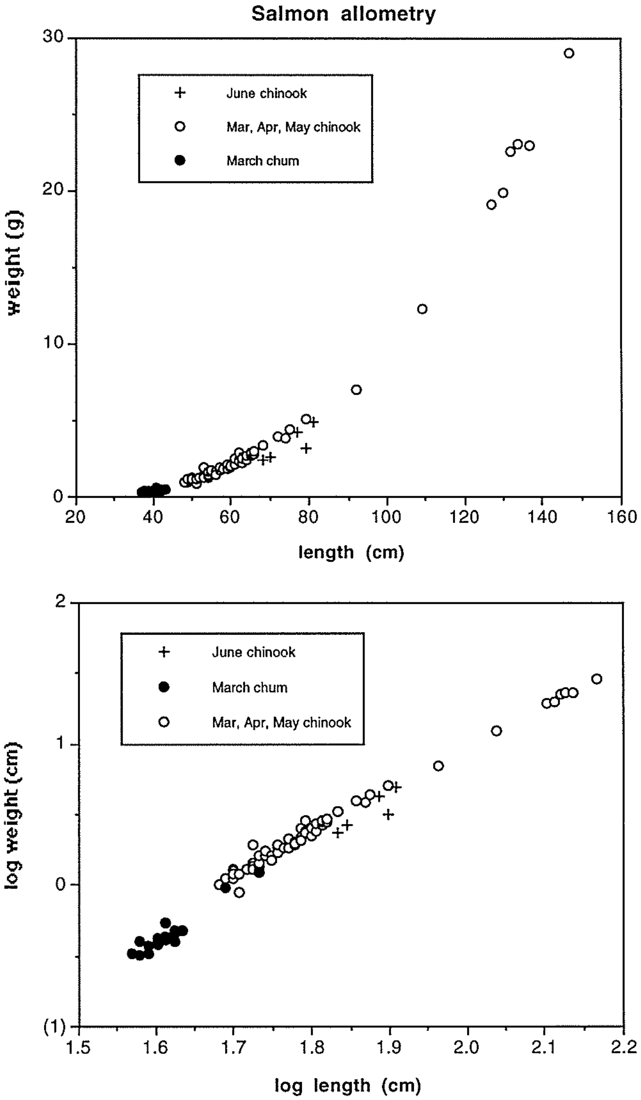

FIGURE 43.—Normal and log-log allometric relationships of chum (*O. keta*) and chinook (*O. tshawytscha*) occupying created and Ann's Slough during March–June 1995 collections in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

Juvenile Salmon Diets

Comparisons of juvenile salmon diet composition in the two sloughs were conducted for chum in March and chinook from March through June (Table 5). There were no substantial differences in the diet composition and feeding indices of juvenile chum salmon in March; subtle, probably insignificant (given the low sample size) differences included the higher representation of the ectinosomatid harpacticoid copepod *Pseudobradya* sp. in the diet of chum in the created slough (25.4% of total IRI) compared with Ann's Slough (12.0%), the unique occurrence of psychodid flies in chum from the created slough, and the greater representation of sminthurid collembolans (springtails) in Ann's Slough (16.7%) compared with the created slough (4.3%).

Samples sizes were sufficient to compare the diet of different sizes of juvenile chinook in the created slough from April through June, and to compare juvenile chinook diets between the created and Ann's sloughs in May. Diet composition of chinook in the created slough shifted from dominance (96.35% total IRI) of bivalve siphons in April to more diverse foraging on insects (adult chironomid flies, occurring as high as 30.3%; aphids, 4.7–49.7%) and the mysid *Neomysis mercedis* (12.6–31.1%). Bivalve siphons also constituted 8.2% of the total IRI of chinook in the created slough in June. While the vast majority of these prey are typical of juvenile chinook salmon prey reported previously, predation by juvenile salmon on bivalve siphons, especially to this degree, is exceedingly rare in any of our previous studies of these sloughs (Simenstad et al. 1992, 1993; Miller and Simenstad submitted) and other estuarine habitats in the Pacific Northwest (Simenstad et al. 1979, Simenstad and Eggers 1981, Simenstad et al. 1982, Simenstad and Fresh in prep.). However, we have recently such prey in chum and chinook diets in the Duwamish River estuary (J. Cordell, unpubl. data).

Table 5. Relative importance (% total Index of Relative Importance, IRI) of prey taxa of juvenile salmon in created and natural estuarine sloughs, Chehalis River estuary, Washington, March–June 1996; LH = life history.

Juvenile chum salmon, *Oncorhynchus keta*

Date		3-23-95	3-25-95
Slough		Created	Ann's
Sample size (w/ stomach contents)		5	5
Mean fish length (mm FL)		40.4	40.0
Mean fish weight (g damp)		0.51	0.49
Mean stomach condition factor (1–7; 1=empty, 7=distended)		3.4	3.8
Mean contents digestion factor (1–6; 1=complete, 6=none)		6.0	6.0
Mean total contents abundance (no. individual prey)		9.8	12.6
Mean total contents weight (g)		0.002	0.001
PREY TAXA	LH STAGE		
Podocopa	adult	0.39	0.57
Ectinosomidae	adult	25.42	11.95
Collembola	adult		0.31
Sminthuridae	adult	4.32	16.73
Diptera	adult	1.15	1.86
Psychodidae	adult	9.48	
Chironomidae	larvae & adult	58.85	68.57
Total Number Prey Categories		6	7
Mean prey diversity (no, prey taxa per fish)		3.4	2.4
Shannon-Weiner diversity—numerical		1.80	1.99
Shannon-Weiner diversity—gravimetric		1.45	1.54
Shannon-Weiner diversity—IRI		1.35	1.61
Percent dominance index—IRI		0.51	0.42
Evenness index—IRI		0.52	0.57
Instantaneous ration (% stomach/contents weight)		0.43	0.20

Juvenile chinook salmon, *O. tshawytscha*

Date		3-26-95	4-21-95	5-17-95	5-20-95	5-20-95	6-18-95
Slough		Ann's	Created	Created	Ann's	Created	Created
Sample Size (w/ stomach contents)		5	5	5	9	9	4
Mean fish length (mm FL)		57.2	74.4	56.4	61.3	57.8	78.0
Mean fish weight (g damp)		1.67	3.90	1.59	2.05	1.73	4.66
Mean stomach condition factor (1–7; 1=empty, 7=distended)		6.0	4.6	4.8	4.9	5.1	3.5
Mean contents digestion factor (1–6; 1=complete, 6=none)		6.0	6.0	4.3	4.6	3.7	5.5
Mean total contents abundance (no. Individual prey)		12.2	85.6	13.3	62.7	33.3	13.0
Mean total contents weight (g)		0.094	0.74	0.23	0.48	0.018	0.016
PREY TAXA	LH STAGE						
Bivalvia	siphons		96.35				8.18
Araneae	juvenile & adult			2.35	0.60	0.52	4.74
Daphnia sp.	adult	7.79					
Neomysis sp.	adult	85.26		31.13	6.40		12.64
Gnorisphaeroma sp.	adult						6.05
Corophium sp.	adult	2.26	0.17	2.01	1.39	7.30	
Sminthuridae	adult				0.06		
Psocoptera	adult				2.24	0.05	
Hemiptera	adult				0.11	0.63	
Cicadellidae	adult				0.04		
Cercopidae	adult				0.06	0.36	2.55
Aphididae	adult			4.67	27.5	49.65	37.7
Dytiscidae	adult			0.43			
Corylophidae	adult			0.49			
Coleoptera	larvae		0.18		0.68		
Dermestidae	adult				0.03		
Staphylinidae	adult					0.27	
Insecta	adult				2.48	0.17	
Diptera	pupae & adult			27.60	5.01	9.82	13.99
Tipulidae	adult	0.67			0.06	4.23	
Psychodidae	larvae					0.15	
Psychodidae	adult			0.49	0.30	0.25	

Table 5—cont.

Juvenile chinook salmon, *O. tshawytscha*—cont.							
Date		3-26-95	4-21-95	5-17-95	5-20-95	5-20-95	6-18-95
Slough		Ann's	Created	Created	Ann's	Created	Created
PREY TAXA	LH STAGE						
Ceratopogonidae	larvae & adult				0.42	5.87	
Chironomidae	larvae				0.02		
Chironomidae	pupae		0.11				
Chironomidae	adult		0.15	30.25	51.88	24.36	14.14
Sciaridae	adult						
Empididae	adult				0.10		
Clinocera sp.	adult				0.21		
Ephyridae	adult					0.07	
Plecoptera	larvae	3.60					
Dolichopodidae	adult				0.06		
Symphyta	adult				0.02		
Apocrita	adult			0.57	0.02	0.29	
Phoridae	adult	0.42					
Telostei	larvae		3.04				
Total number prey categories	6	6	10	26	18	8	
Mean prey diversity (no. prey taxa per fish)	2.2	2.0	4.5	7.9	6.3	3.5	
Shannon-Weiner diversity—numerical	1.80	0.44	2.50	2.30	2.36	2.52	
Shannon-Weiner diversity—gravimetric	0.86	0.84	1.51	3.00	3.12	2.51	
Shannon-Weiner diversity—IRI	0.86	0.26	2.16	2.11	2.23	2.59	
Percent Dominance index—IRI	0.73	0.93	0.27	0.35	0.32	0.21	
Evenness index—IRI	0.33	0.10	0.65	0.45	0.54	0.86	
Instantaneous ration (% stomach contents/fish weight)		6.12	1.87	1.36	2.28	0.95	0.39

Comparison of chinook of comparable length intervals (and equal sample size) in the two sloughs in May illustrated several interesting contrasts: (1) almost twice as many (62.7 vs. 33.3) average number of prey in the fish occupying Ann's Slough than those in the created slough, and over twice the instantaneous ration (2.3% vs. 1.0%); (2) considerably higher diversity of prey taxa in the diets of fish in Ann's Slough compared with the created slough (total number of prey categories, 26 vs. 18; mean prey diversity, 7.9 vs. 6.3); (3) more than double the relative importance of adult chironomid flies (51.9% vs. 24.4% total IRI) in Ann's Slough fish; (4) much greater foraging on aphids (49.7% vs. 27.5%) and *Corophium* sp. amphipods (7.3% vs. 1.4%) by fish in the created slough; and (5) *Neomysis mercedis* occurred (6.4%) only in fish from Ann's Slough.

Insect taxa accounted for much difference in diversity of the diet spectra, accounting for 20 separate taxa in the diets of fish from Ann's Slough compared with 14 taxa in fish captured in the created slough. Psychodid flies, which as emergents were extremely dense in the created slough, had contributed 9.5% of the Total IRI of juvenile chum salmon in that slough. Ceratopogonid flies, also dense emergents but in both sloughs, constituted almost 6% of the total IRI of juvenile chinook salmon in the created slough in May. And, although both types of wasps (Apocrita and Symphyta hymenopterans) appeared in the stomach contents of juvenile chinook salmon, their contributions to the total IRI were extremely small (<1.0%).

Avifauna

Avifauna observations over the sampling periods in the two sloughs in 1995 indicated that the created slough tended to have two to five more bird observations than Ann's slough (Fig. 44). Prominent species in both sloughs were song sparrows (*Melospiza melodia*) and hummingbirds (predominantly Rufous, *Selasporus rufus*, but may also have included Ana's, *Calypte anna*), while bufflehead (*Bucephala albeola*, unique to the created slough and occurring only in March), mallards (*Anas platyrhynchos*), belted kingfisher (*Ceryle alcyon*), osprey (*Pandion haliaetus*, only in the created slough in April), western grebe (*Aechomphorus occidentalis*), great blue heron (*Ardea herodias*), and common merganser (*Mergus merganser*) were less commonly observed. Many of these species were observed only at the created slough in March. After March, many of these species are likely moving from overwintering in these slough habitats into their breeding habitats in more inland, freshwater habitats. The kingfisher, heron, and merganser represent potential predators on juvenile salmonids. But the only notable difference between the two sloughs was

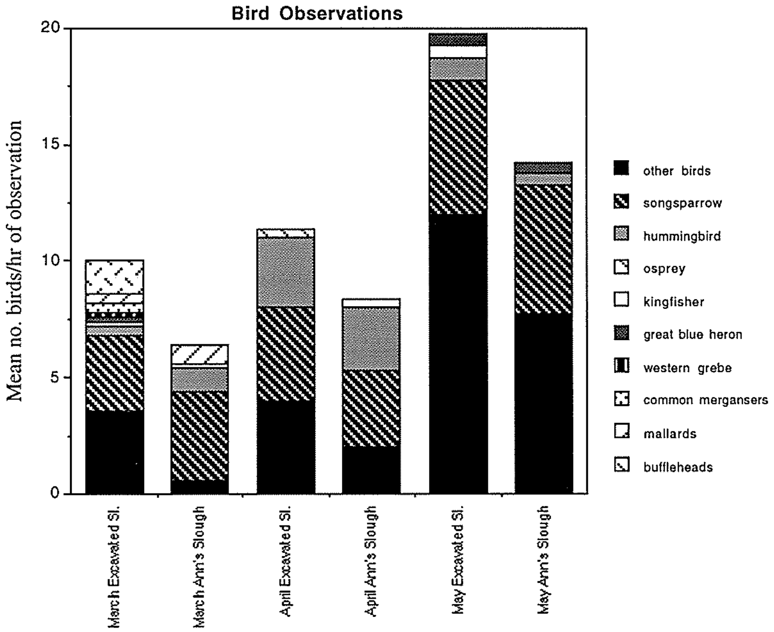

FIGURE 44.—Mean incidence (no. individuals/hr of observation) of birds in created and natural (Ann's Slough) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, March–May 1995.

in the greater occurrence of merganser in the created slough. No bird predation on fish was observed.

DISCUSSION

Slough Geomorphology and LOD Distribution

We have considerably increased the precision and resolution of measurements of changes in slough geomorphology in the created and reference sloughs by implementing the GPS survey technique. Because there was no post-construction survey, we can only interpolate changes in depth and cross-sectional profile by assuming that the construction specifications represent the post-construction form of the created slough. Our suspicions, however, are that the drawings or actual excavation differ (i.e., are lower) by approximately 0.25–0.3 m (Fig. 10).

Qualitative comparison with our results from 1993 and 1995 indicates the narrow subtidal channel that was constructed down the middle of the slough has completely filled in with sediment, as all transects now show the bottom of the channel at an elevation of $\geq$0.0 ft MLLW. Although this is still >1 m deeper than the natural channel profile of Ann's Slough, our observations show that the created slough now completely dewaters during spring low ("minus") tides. With installation of our georeferenced benchmarks and use of a GPS (which makes reestablishment of a benchmark relatively easy), repeated surveys of the sloughs can now be conducted with sufficient precision to accurately measure future geomorphic changes in the created slough and natural variation in Ann's Slough.

Further accretion of sediments in the main basin of the created slough, with continued maintenance or recruitment of LOD, should also promote a more natural channel structure that will increase habitat value for both fishes and their prey organisms (e.g., mysids). At this time, a small, sinuous channel is developing in the fine sediments that have accreted in the center of the slough. We anticipate that this channel will continue to develop a natural geomorphology and increase the slough's structural diversity beyond that designed into its construction.

Large organic debris appears to be quite stable in the created slough, and many of the documented "losses" of LOD pieces may be attributed to sediment accretion. The 15 pieces that were recruited to the slough suggest that LOD should at least for some time be increasing, offset only slightly by loss of LOD due to continuing sediment accretion. With further shallowing of the slough system overall, we would predict a gradual decrease in LOD import, accompanied by lower "loss" due to sediment accretion, and likely stabilization of the LOD environment in the created slough.

Water Quality

The structure of the water quality in the created slough was often different from Ann's Slough, especially in the first half of the sampling period when spring freshet flows in the river may have regulated salinity intrusion between the two sloughs. But, other than slightly elevated salinities (by ~1.5 psu) and temperatures (by 0.25–1.3°C), these differences were principally qualitative (vertical mixing) rather than quantitative differences in water quality per se. By the later sampling periods, qualitative and quantitative characteristics in both sloughs had converged. These differences should not have been large enough to affect behavior of juvenile salmon.

Sampling of water characteristics and quality was not systematic (i.e., it occurred only during our sampling periods, rather than throughout the tidal month), and most of our measurements took place during the spring tidal cycles each month. Subsequently, the results illustrate extreme mixing but not necessarily extreme salinity intrusion because stratification (if it occurs in the estuary) is more likely to be stronger and salinity intrusion up-estuary highest on neap series. As a result, differences observed between the created slough and Ann's Slough likely represent a combination of geomorphic and location factors. We expect geomorphology to be important because the deeper and more consistent cross-sectional profile of the created slough would promote greater stratification and less turbulent mixing with tidal intrusion; Ann's Slough, with its shallower, sinuous, and more rugose channel bathymetry, is more likely to experience mixing of tidal waters with freshwater through the water column. Location relative to salinity intrusion is a factor because in the first half of our sampling period, river flow may have kept salinity intrusion in the vicinity of the river between the two sloughs. Thus, the higher and more pronounced influence of salinity in the created slough compared with Ann's Slough should be mediated to some degree by further shallowing and diversification of the created slough's geomorphology, but there will always be a location effect to some degree.

Emergent Marsh Vegetation

On the basis of several monitoring parameters, the transplanted *C. lyngbyei* habitat in the created slough has rapidly converged with the natural sedge bench in Ann's Slough. Shoot density and aboveground biomass for the created slough are within the bounds of natural variation documented in Ann's Slough; aboveground biomass in the created slough had actually reached this reference level in 1992 (Simenstad et al. 1993; Fig. 31). However, belowground live biomass was considerably below (by 3.8X for mean belowground live biomass) the reference levels and bounds of variation documented for Ann's Slough. Because belowground biomass constitutes a large proportion of total biomass (Fig. 30), the total *C. lyngbyei* standing stock in three of the five samples continues to lag behind the range in total standing stock observed in Ann's Slough (i.e., 1.5X difference in mean total standing stock between the two sloughs). As a result, the ratio of aboveground to belowground live biomass (AG:BLG = 0.11 in the created slough vs. 0.50 in Ann's Slough, Table 5) indicates a potentially important difference between the transplanted *C. lyngbyei* and natural sedge benches. These differences could reflect both the generation of belowground biomass as well as the decomposition rate, but we cannot separate these factors in our sampling. The fact that these differences were not apparent in 1992 (Table 5) suggests either sampling biases (which should not have changed from year to year) or large natural variability, and further documentation would be required to establish the utility of indices of functional equivalency based on belowground biomass.

Important processes such as nutrient cycling, water retention, and establishment of the redox gradient, production of infaunal and epibenthic animal populations depend upon the buildup and degradation of the belowground live and dead material in emergent marshes. In addition, the resilience of the *C. lyngbyei* population to large-scale, intense disturbance is very likely linked to the availability of energy reserves in belowground live root and rhizome biomass. The degree of difference between the reference and created system in belowground, and consequently, total standing stock production parameters implies that these processes are not yet functionally equivalent in the created slough. This long development rate is not unusual for created systems and has been noted to lag even after 7 to 8 years (e.g., the Gog-Le-Hi-Te wetland system in Commencement Bay; Thom et al. 1988a, b, 1989; Simenstad and Thom 1996). Total and belowground standing stock of *C. lyngbyei* will be important parameters indicative of the functional equivalency of the created slough to Ann's Slough.

The geomorphic structure of the created slough may also be a constraining factor on *C. lyngbyei* growth and production. The present elevational range of *C. lyngbyei* distribution remains stable, but it is confined by the steep 5:1 slope of the channel sides. In the absence of the extensive, flat intertidal benches, it may be difficult for *C. lyngbyei* to develop a natural peat base that promotes water retention, nutrient cycling, and geochemical conditions favoring full development of the vegetation community. Naturally dense vegetation, which had been achieved in the created slough by 1992, should continue to promote sedimentation, and we predict *C. lyngbyei* benches will develop naturally between +7 and +10 ft MLLW through mineral and organic matter accumulation.

Benthic Invertebrate Community and Insect Composition

The 1995 benthic invertebrate sampling was the most comprehensive to date in terms of periodicity (four consecutive months) and habitats (four habitat and elevation strata sampled in 1 month). Another difference from previous years is that this sampling used cores instead of epibenthic suction pumps. The results show that this technique is equivalent to previous years' methods and may be more appropriate for oligohaline communities: the assemblage sampled is virtually the same as that sampled in 1991–92 and is similar to intertidal assemblages from other Pacific Northwest oligohaline estuaries (Cordell et al. 1994, 1996). The only taxa not represented in the benthic core samples that had occurred in previous years are truly planktonic organisms such as the calanoid copepods *Acartia* and *Eurytemora* spp., which occurred incidentally in the epibenthic samples.

There are two large and/or consistent differences in benthic macro- and meiofauna populations, indicating that the created slough may not yet be equivalent to a natural slough in invertebrate assemblage structure and densities. First, there is a remarkably consistent difference in taxa richness; although average differences are not large in magnitude, with only one exception the created slough has had consistently lower numbers of taxa categories. One reason for these differences may be the more regular intrusion of high salinity water on the bottom of the created slough; this may explain why the largest differences between the sloughs in taxa richness are in the mid-channel and channel slope samples. There may be several species in these created slough habitats that cannot maintain their populations in fluctuating salinities. An alternative explanation is that Ann's Slough sediments contain higher proportions of organic matter and more developed nutrient cycling and trophic linkages that result in higher invertebrate diversity.

Second, densities of several important habitat attribute prey species—the polychaete worms *Manayunkia aestuarina* and *Hobsonia florida*, the amphipods *Corophium* spp., and chironomid fly larvae—are consistently and often dramatically more abundant in Ann's Slough compared with the created slough. Salinity is probably not the reason for these differences because these taxa are well adapted to fluctuating salinities. Instead, the second explanation above—higher organic matter and more complex linkages in Ann's Slough—may more likely explain these differences.

Although they are not prey attribute taxa, foraminiferans are also much more abundant in sediments among the *C. lyngbyei* sedges at Ann's slough than they are in this habitat at the created slough. This may also be an indication that the transplanted habitat is still on a developmental trajectory in the created slough. It is also interesting that foraminiferans occurr almost exclusively in the vegetated areas. This result is similar to that found in Willapa Bay mudflats with invasive cordgrass, *Spartina alterniflora*, where foraminiferans are restricted mainly to the interior of *Spartina alterniflora* patches (Zipperer 1996; J. Cordell, unpubl. data). The reasons for this distribution are unknown, but may be because the vegetation ameliorates temperature extremes and decreases sediment surface desiccation or because competition from benthic diatoms is decreased owing to sediment shading. Monitoring foraminiferan densities may be useful in the future to measure vegetated habitat function.

The two invertebrates that have had consistently higher densities at the created slough may also be indicators of the hydrological and developmental differences between the sloughs. The large harpacticoid copepod *Coullana canadensis* is an epibenthic species and is a prominent member of brackish water faunas throughout the Pacific Northwest (Cordell and Morrison 1996); in the Columbia River estuary, this species appears to move passively with high-turbidity water masses (Simenstad et al. 1994, Morgan et al. in press). If this is also the case in the Chehalis River estuary, *C. canadensis* is probably regularly introduced into the created slough, which is deeper and has a larger cross-sectional dimension than does Ann's Slough. The benthic bivalve *Macoma* may be consistently more dense in the created slough because there is very little LOD in the sediment at this site. Conversely, at Ann's Slough, LOD in the form of sticks, logs, and bark is so dense that it is difficult to obtain sediment core samples. There may be so little space between the tightly packed LOD that even if juvenile *Macoma* recruit there, they cannot attain a large size or a reproducing population. Instead, smaller infaunal species (such as *Corophium* spp.) that can live in the interstices between the LOD are more numerous in Ann's Slough.

Juvenile Salmon and Other Fish Use

On the basis of both density and size, juvenile salmon use of the created slough is not detectibly different than their use of Ann's Slough. While there are biases associated with sampling with the fyke trap nets (e.g., escapement of small salmon fry around or through the coarser-meshed wings of the net), we feel confident that these biases are relatively constant at both sloughs, so the comparison remains valid as the primary test of equivalency. In addition, irrespective of the biases or inefficiencies of the fyke trap net sampling, we also believe that Ann's Slough density estimates are conservative because we have observed fry (e.g., chum or coho) hiding in the very small pools behind LOD and other debris in the channel of Ann's Slough after tidal exposure. As these microhabitats are not (yet) available to fish in the created slough, our density estimates for Ann's Slough are likely underestimated. Our estimates of fish density at the created slough are also underestimated under conditions when the slough does not dewater (more so in previous years, however); however, tide series were selected in 1995 to minimize such occurrences.

Fish community structure is to some degree correlated with the characteristics of water masses inundating both sloughs. On the basis of differences in the salinity and temperature alone, many of our fish occurrence and abundance results are predictable purely from the standpoint of higher salinities and more water column stratification in the created slough versus Ann's Slough. This is particularly evident with the occurrence of shiner perch that appear initially (May) abundant in the created slough and then appear later (June) in both sloughs as river flow decreases and salinity intrusion increases. While this effect may decrease if the created slough, as we suspect, continues to accrete sediment to some degree, a "location effect" will still likely remain, relative to when salinity fully intrudes into each slough during the winter–summer flow cycle.

Our characterization of fish emigration from the sloughs with ebbing tide is quite ambiguous. It is difficult to determine whether the variation contributing to this ambiguity is real, and emigration is quite random between sloughs and among months, or whether fish movement patterns are regulated by complex factors such as weather and real or perceived predator occurrence. The only concrete information about emigration illustrated by these data is that some species tend to leave the sloughs in pulses (i.e., stickleback, peamouth chub) while others display rather constant emigration (Figs. 10–13).

Juvenile Salmon Diets

Diet compositions (based on the IRI) of juvenile salmon are generally comparable between the two sloughs. In both sloughs, chironomid flies, harpacticoid copepods (*Pseudobrayda* sp.), and several other taxa of insects typically constitute the diet of juvenile chum salmon, while chironomids, mysids, aphids and several other taxa of dipteran flies are common to juvenile chinook diets. Differences in juvenile salmon diet compositions are evident principally in the greater diversity of insect taxa consumed by juvenile chinook in Ann's Slough (in May). Although not contributing to the diet composition materially, the occurrence of a number of these other insect taxa (e.g., Sminttheridae, Cicadellidae, Coleoptera, Dermestidae, Empididae, *Clinocera* sp., Symphyta and Apocrita hymenopterans; Table 2) suggests that the natural slough provides a greater diversity of prey resources, probably through increased fallout from the dense, overhanging riparian vegetation and the more extensive *C. lyngbyei* habitats. Samples from the insect fallout traps and sedge enclosure sampling indicate potentially higher numbers and diversity of insects at Ann's Slough; but the emergence trap samples suggested the opposite (i.e., the *C. lyngbyei* habitat at the created slough provided a higher abundance and diversity of insects). Apparently, foraging by juvenile salmon may be occurring more in the neuston layer (measured by fallout traps) or directly on the sedge vegetation (measured by sedge enclosure sampling) than on the emergent insects within the sedge habitat. More discrete microhabitat sampling of both juvenile salmon and prey would be necessary to test these differences.

While the sample sizes do not allow conclusive interpretation, the one obvious difference in juvenile salmon foraging is associated with the quantity of prey consumed. As documented in previous years' sampling and experimentation (Miller 1993, Miller and Simenstad in press), there have been a number of comparisons over the past several sampling years when the prey abundance, biomass, and the ration of stomach contents to fish weight ("instantaneous ration") have been higher for fish captured in Ann's Slough than those captured in the created slough. In 1995, we documented this for juvenile chinook in May. This may be attributed to either more organisms consumed or consumption of larger organisms. In this case, the juvenile chinook in Ann's Slough had both consumed by almost twofold the average number of organisms as well as included some large organisms (i.e., mysids, *Neomysis mercedis*; 38.1% of total prey biomass and 6.4% total IRI) although the fish captured in the created slough had also consumed large amphipods (i.e., *Corophium* sp.; 27.5% of total prey biomass and 7.3% total IRI). Aphids and chironomids appear to be almost interchangeable in the diets of the fish in the two sloughs. Whether this difference is inherent to structural differences in the two sloughs, and in particular the developmental stage of the created slough, cannot be answered without more focused sampling around this specific question.

Potential Fish and Avifauna Predators

No species or sizes of non-salmonid fishes captured in the created slough are potential predators of juvenile salmon. Steelhead (*Oncorhynchus mykiss*) and Pacific staghorn sculpin are the only fishes that represent potential predators among the documented species inhabiting the created slough in 1995, and these juveniles are too small to be effective predators on salmon fry, fingerlings or smolts. Other potential predators, such as northern squawfish (*Ptychocheilus oregonensis*) and yellow perch (*Perca flavescens*), have not been captured in either slough since 1990–91. It is very probable that rapid sedimentation of the created slough in the first several years after construction, and consequential loss of subtidal refugia during spring tide periods (when we conduct sampling), has reduced to intermediate tide cycles the use of the created slough by large fish that would potentially present significant predation pressure. However, larger fish could occupy the created slough during lesser spring tide series, when natural sloughs like Ann's Slough completely dewater below a +4 MLLW tide but the created slough would still retain water. Our sampling design will not be effective if deployed during these tide series and other sampling, such as beach seining (largely infeasible owing to LOD) or gill-netting would have to be used during in these cases.

Compared with reference observations in Ann's Slough, piscivorous avifauna using the created slough do not appear to present an unusual predation pressure. Common mergansers and western grebes are present in the created slough in small numbers only in March, and kingfishers occurred more often in Ann's Slough than the created slough (only in March) (Fig. 33). Great blue herons are also present in the created slough in March, but their only other occurrence was in May, when they were also observed in Ann's Slough. We should also note that it is not possible to standardize avifauna observations by slough area. Thus, comparisons between sloughs may be conservative in favor of the created slough because more birds are visible. The created slough is wider and riparian vegetation more open; sight distances for bird observation are consequently considerably longer than in the more sinuous Ann's Slough with its extensive, overhanging riparian vegetation. Alternatively, the more open nature of the created slough may cause many birds to be frightened away by observers. An additional consideration is that the deeper, wider structure of the created slough may also promote more use by swimming water birds such as bufflehead.

SUMMARY AND RECOMMENDATIONS

Repeated monitoring since 1991 of an array of indicators of created slough function for fish and wildlife continues to show either comparability or convergence with the reference site, Ann's Slough. Many monitoring parameters suggest that, 4 years after construction, the created slough is functionally equivalent to Ann's Slough in the following: (a) densities of common fishes, especially juvenile salmon, (b) shoot density and aboveground biomass of the transplanted *Carex lyngbyei*, and (c) general avifauna composition and occurrence. However, various other monitoring parameters show lower equivalency, most notably of *C. lyngbyei* belowground standing stock, juvenile salmon prey consumption, and benthic invertebrate composition.

Bearing in mind these mixed results, we suggest that the following nine recommendations be considered before implementing the next phase of the long-term schedule (e.g., 1998–99) for monitoring and assessment of the Grays Harbor created estuarine slough:

1. Continue basic components of the monitoring design, especially considering the long-term dataset from the fyke net, *C. lyngbyei* habitat, water quality sampling, and analysis of aerial photographs for geomorphic and LOD structure.
2. While the fyke net sampling has provided reliable samples under many conditions, we have observed some inherent differences in the sampling efficiency that the nets may exhibit in the two sloughs (e.g., differences in extent of dewatering, fish avoidance patterns). We believe some of these differences are becoming less apparent with the convergence of the created slough to Ann's Slough geomorphology; as the created slough continues to accrete sediment, the more likely it will dewater during low tides. However, we recommend that experimental gillnet sampling be adopted to supplement the fyke-net collections. This will achieve several objectives: (a) provide an independent estimate of relative differences between the two sloughs, (b) enable sampling of discrete habitats (e.g., *C. lyngbyei* marsh, channel bottom) within the sloughs, and (c) contribute further information on the vertical distribution and movement patterns of fish (on the basis of position and orientation in the gillnet).

3. Consider focused sampling for certain parameters in which some of our sampling methods (e.g., emergent insect traps) appear to have inherently high variability across both sloughs. For instance, our sampling using insect fallout traps in other estuaries in the region has found insect fallout traps to be comparatively unbiased, and we recommend concentrating sampling of emergent insects using this method.
4. Initiate supplemental sampling (including brief pilot experiments) to evaluate the distribution and abundance of preferred prey of juvenile salmon that we might not be adequately assessing under the present design (e.g., mysids).
5. Conduct focused sampling and experimentation to determine whether juvenile salmon stomach fullness and instantaneous ration is an appropriate and dependable index to detect differences in habitat quality between the two sloughs.
6. Devote additional sampling effort to compare statistically the extent of overlap between available prey resources and juvenile salmon diet composition in the two sloughs.
7. Develop the measure of total *C. lyngbyei* standing stock, including belowground biomass, as a comprehensive index of functional equivalency.
8. Further define the import and export of LOD by combining analysis of aerial photographs with tagging the population of LOD pieces for long-term measurement of LOD flux.
9. Install and maintain for at least 1 year inexpensive tide gauges at the two sloughs to assess differences in tidal flooding frequency and duration relative to specific slough habitats (e.g., *C. lyngbyei*); these gauges would have to be surveyed into the local GPS grid we have established at the two sloughs.

Continuation of other measurements, such as repeating GPS surveys of both sloughs, should also be seriously considered but could be delayed because of the slow rate of change in the sloughs' geomorphology. Establishment of the tide gauges, however, would require establishing the local datum at the gauge sites using GPS survey-grade measurements.

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