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Decadal Development of a Created Slough in the Chehalis River Estuary: Year 2000 Results

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Acknowledgements

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Introduction

Creation of wetlands often results in systems that are less than functionally equivalent to natural wetlands, although those designed for specific functions often perform effectively (Hammer 1992; NRC in press.). Whereas wetland creation refers to the conversion of a persistent upland or shallow-water area into a wetland, wetland restoration refers to the return of a wetland from a disturbed or altered condition (Mitsch and Gosselink 2000) or a close approximation of its original condition (NRC 1992).. Creation of freshwater wetlands usually involves modification of hydrologic regimes; both excavation of uplands or filling of deeper waters to intertidal elevations has been used to create estuarine wetlands by the reintroduction of tidal inundation. Often, estuarine wetlands have been created by the deposition of dredged material, with the introduction of planted vegetation (Streever 2000). However, the ecological performance of created estuarine wetlands has sometimes been less than expected compared to natural reference wetlands, but the period of assessment is often too short (e.g., 3-5 yr) to evaluate the long-term trends in performance because complex ecological processes and ecosystems cannot be predictably and instantaneously created (NRC in press). While there is some evidence that "functional trajectories" (*sensu* Simenstad and Thom 1996) of restoring and created wetlands may follow predictable rates and patterns, there is considerable evidence that the typical time allowed to make such a determination (~<3 yr) is grossly insufficient. Furthermore, most monitoring of restoring and created wetlands sample neither ecological processes *per se* nor the likely physical or geochemical mechanisms that strongly influence these processes; yet, modifying and correcting wetland restoration and creation projects that are not meeting ecological expectations requires such a mechanistic understanding.

This report describes the functional performance of a somewhat atypical created estuarine wetland—a slough in a Pacific Northwest tidal floodplain—approximately one decade after its creation. Estuarine sloughs are natural channels in tidal floodplains that are formed and maintained primarily through tidal action and have little freshwater drainage, and are believed to be important wetlands of high biological diversity and importance to fish and wildlife of the region. Prior to this project, there were no documented responses to estuarine slough restoration or creation within the Pacific Northwest, and actually very few studies of juvenile salmon use of estuarine slough habitats.

Since 1990, the University of Washington, School of Aquatic and Fishery Sciences' Wetland Ecosystem Team (WET) and the Battelle Marine Sciences Laboratory (BMSL) have periodically assessed the development and ecological status of a brackish estuarine slough created in the Chehalis River estuary, Grays Harbor, Washington (Simenstad *et al.* 1992, 1993, 1997). As a part of the Grays Harbor Navigation Improvement Project (GHNIP), in 1990 the U.S. Army Corps of Engineers-Seattle District (USACE-SD) constructed an estuarine slough in the Chehalis River tidal floodplain as mitigation for loss of 0.73 ha (~1.8 ac) of shallow subtidal channel which was considered important as habitat for migrating juvenile salmon (Gwill Ging, U.S. Fish & Wildlife Service, Olympia, Washington, unpubl. report). Under conditions of the mitigation plan, the USACE-SD 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 the integrity of the designed slough. As developed in interagency consultation, the created slough was explicitly designed to: (1) provide and maintain ecological functions of natural estuarine sloughs in this region, with particular emphasis on provision of estuarine habitat for juvenile salmonids; (2) provide attributes of estuarine sloughs that were considered to provide optimum rearing conditions, such as subtidal refugia and habitat complexity; and (3) develop conditions comparable to adjacent natural sloughs, including Lyngbye's sedge (*Carex lyngbyei*) habitat that was initially planted in the created slough.

We studied the created slough over the initial ten years of its development to verify that the ecological functions, principally support of fish and wildlife, of the created slough are developing as anticipated. An adjacent natural slough (informally named Reference slough in earlier reports), which was used as an aid to the design of the created slough, serves as a "reference" or control habitat in this evaluation.

In 1990-1992, 1995 and 2000, we compared both structure (geomorphology, vegetation, large woody debris) and ecological function (fish utilization and prey resources) between the two sloughs. Pilot sampling of juvenile salmon and their predators and prey, water quality, and emergent marsh vegetation were initially conducted at the reference slough during spring-summer 1990 to determine the community composition and juvenile salmon utilization of the natural slough conditions, and to develop and test sampling designs and methods. Subsequent monitoring of juvenile salmon and related parameters was conducted in April-September 1991 and repeated in March-September 1992 and 1995. Monitoring of transplanted Lyngbye's sedge (*Carex lyngbyei*) and naturally recruiting emergent marsh plants has occurred four years after transplanting (1991-1994), and coincident with the other monitoring schedule six and ten years after slough construction. Sedimentation, site stability, and LWD are scheduled to be monitored after the first ten years. In addition to this basic ecological assessment of the development of the created slough, in 1991 and 1992 we used this intensive monitoring program as the template to conduct manipulative experiments to evaluate important rate processes (fish short-term residence times and growth rates) (Miller and Simenstad 1994a&b, 1997) and the landscape structure of the created and other tidal channels (Hood 2000, In press). Presently, the two sloughs are also included in a graduate student M.S. thesis research project on the ecological role of large woody debris (LWD) in support of estuarine fishes (Wick 2002).

This report includes: (1) description of monitoring and other assessments conducted in 2000; (2) the results from the monitoring and assessment in 2000 in the context of the decadal time series; and (3) description of the relational database (Estuarine Sloughs Database) that has been assembled to access the existing and subsequent (sampling year 2000) data. Where feasible, we have presented information in time series, from 1990 (reference slough) or 1991 (created slough) through 2000.

Methods and Materials

Study Site

The created slough and Reference 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). The mouth of Reference slough is ~500 m (1640 ft) upriver from the mouth of the created slough.

The created slough is ~366 m (1200 ft) long, averages 30 m to 50 m wide, and encompasses 1.6 ha (~4 ac) of intertidal and shallow subtidal habitat (Fig. 3). Basic habitat components designed for the created slough include a shallow subtidal channel, fringing salt marsh, unvegetated mudflat and channel margins, and a riparian buffer zone; 12 indented "alcoves" are spaced along both shorelines. In addition, Large Woody Debris (LWD) was left or introduced into the slough during construction and *Carex lyngbyei* was transplanted into the constructed slough-wetland in spring 1991 to provide further habitat complexity considered to be beneficial for juvenile salmon. On the basis of a digitized 1991 aerial photograph, the total intertidal area of the created slough is 19,035 m^2. In 1995, the *Carex lyngbyei* sedge habitat occupied approximately 4,920 m^2, and below the sedge was ~11,026 m^2 of open water over a moderate-gradient intertidal mudflat and a subtidal channel. The original subtidal channel covered ~4,554 m^2 but now has since accreted sediments sufficient to raise the thalweg into intertidal elevations and it no longer dewaters during lowest spring tides.

The natural estuarine habitat of Reference slough is shallower, narrower, longer and more sinuous than the created slough (Fig. 4). It 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 small channel, and an additional 4,546 m^2 of sedge "bench" habitat is dominated by *Carex lyngbyei* (more *Carex* bench area was underwater at the time of the aerial photo, and could not be delineated).

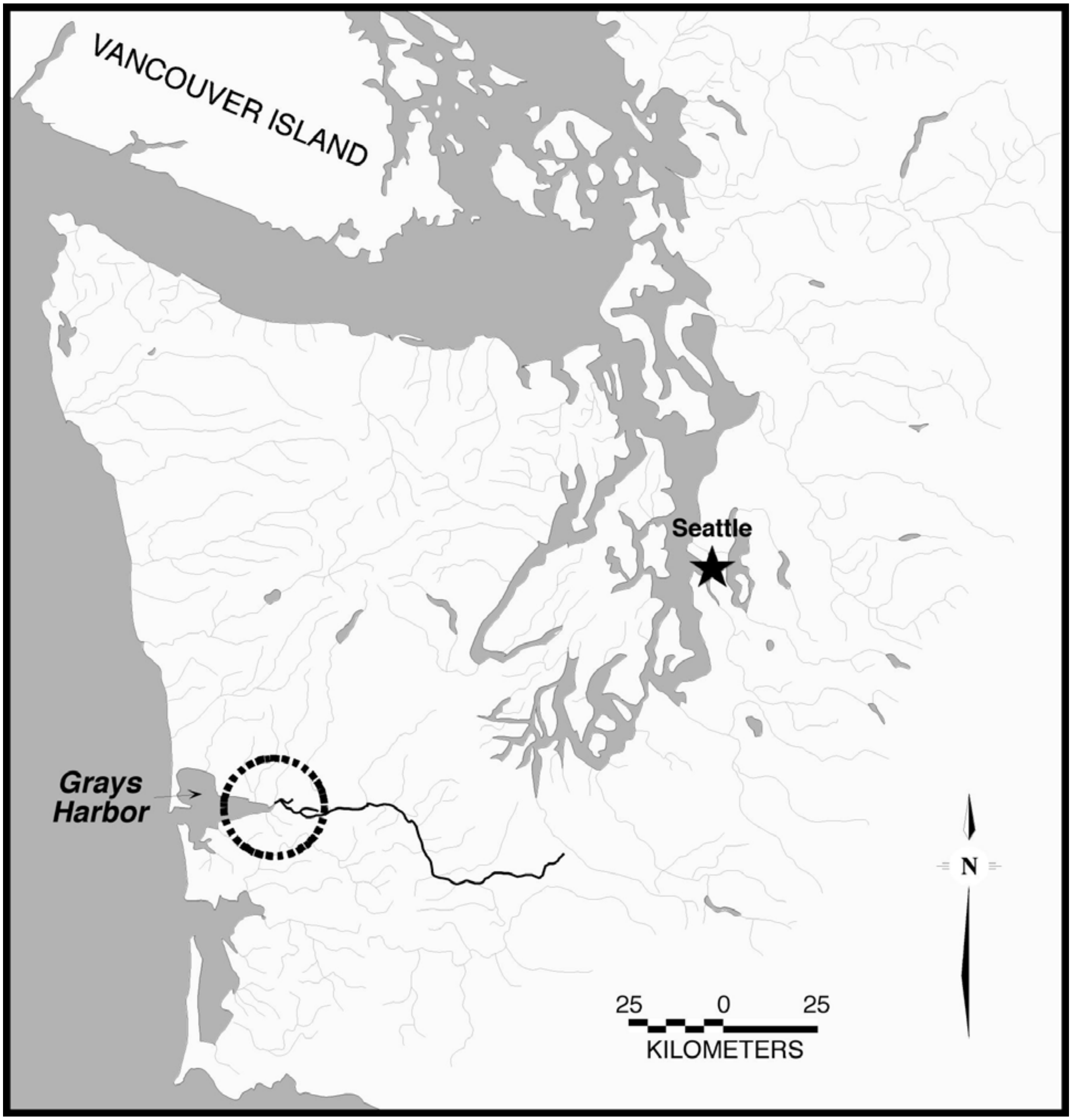

Figure 1. General location of studies evaluating ecological functions of created and natural (reference) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington. The dark line indicates the mainstem Chehalis River and the dark, dashed circle highlights the area shown in Figure 2.

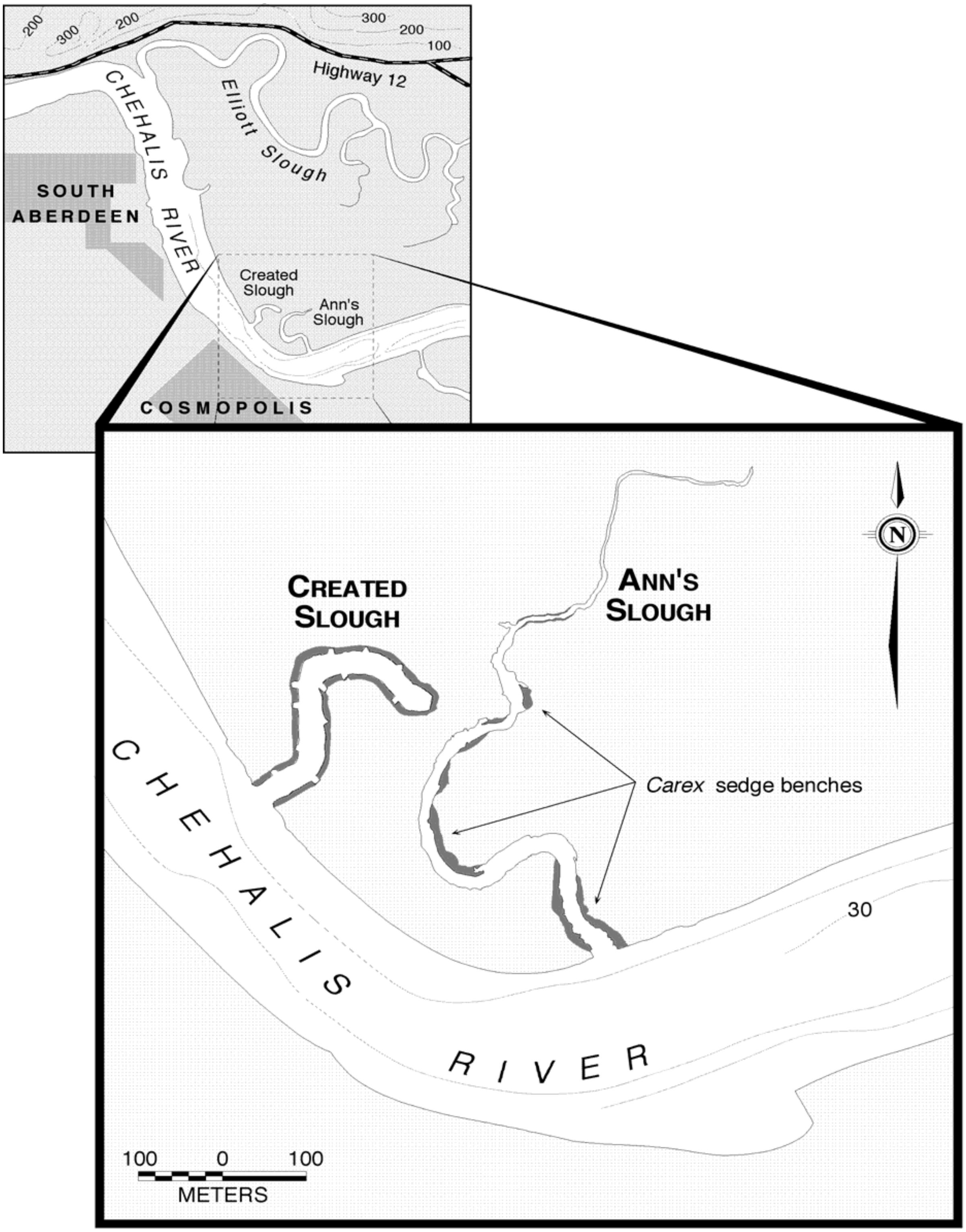

Figure 2. Location of created and natural (reference) slough in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

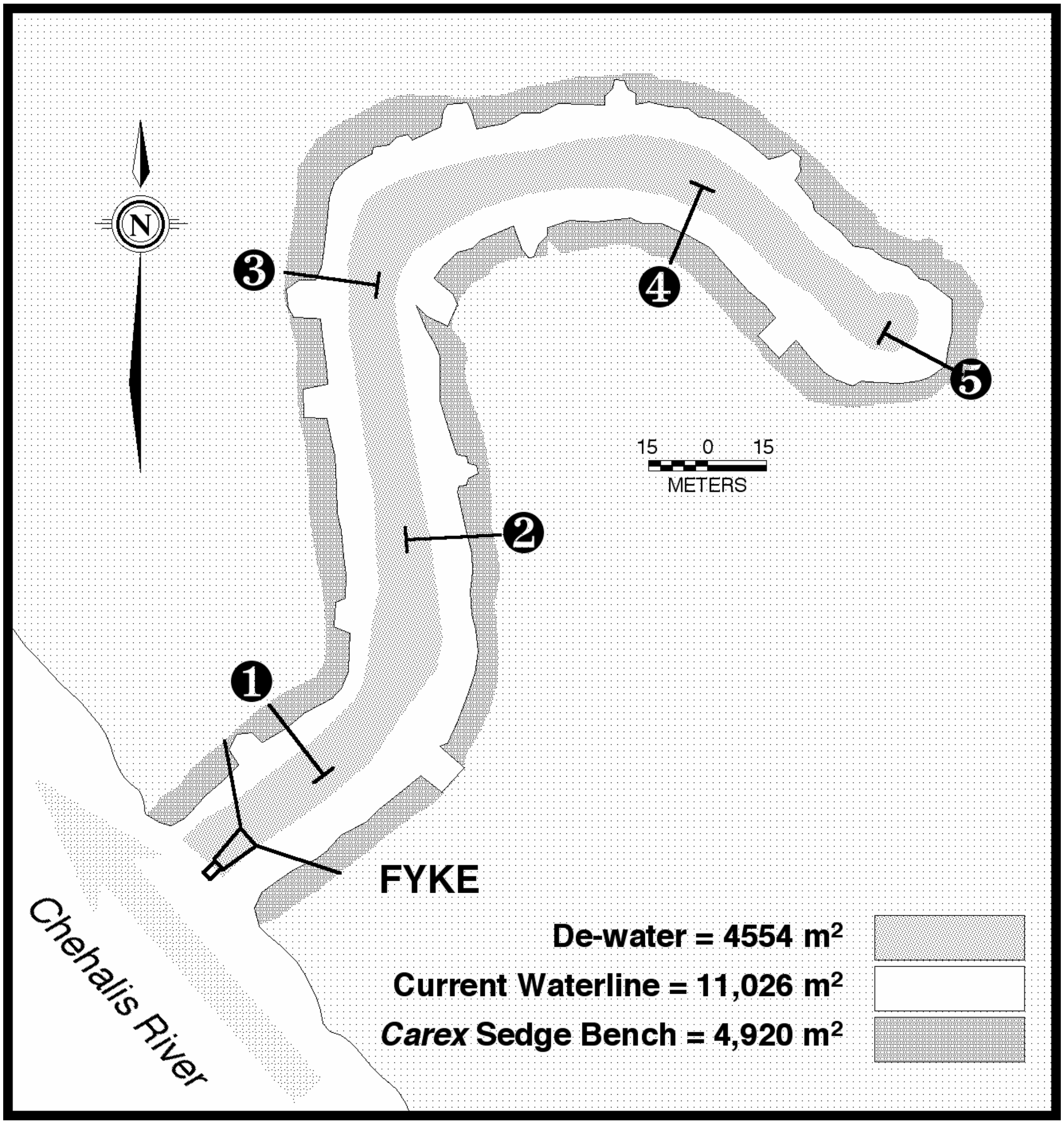

Figure 3. Schematic of created slough in brackish region of Chehalis River estuary, Grays Harbor, Washington, based on digitized image from 1991 aerial photograph; circled numbers refer to sampling stations; position of tidal fyke net indicated at mouth of slough.

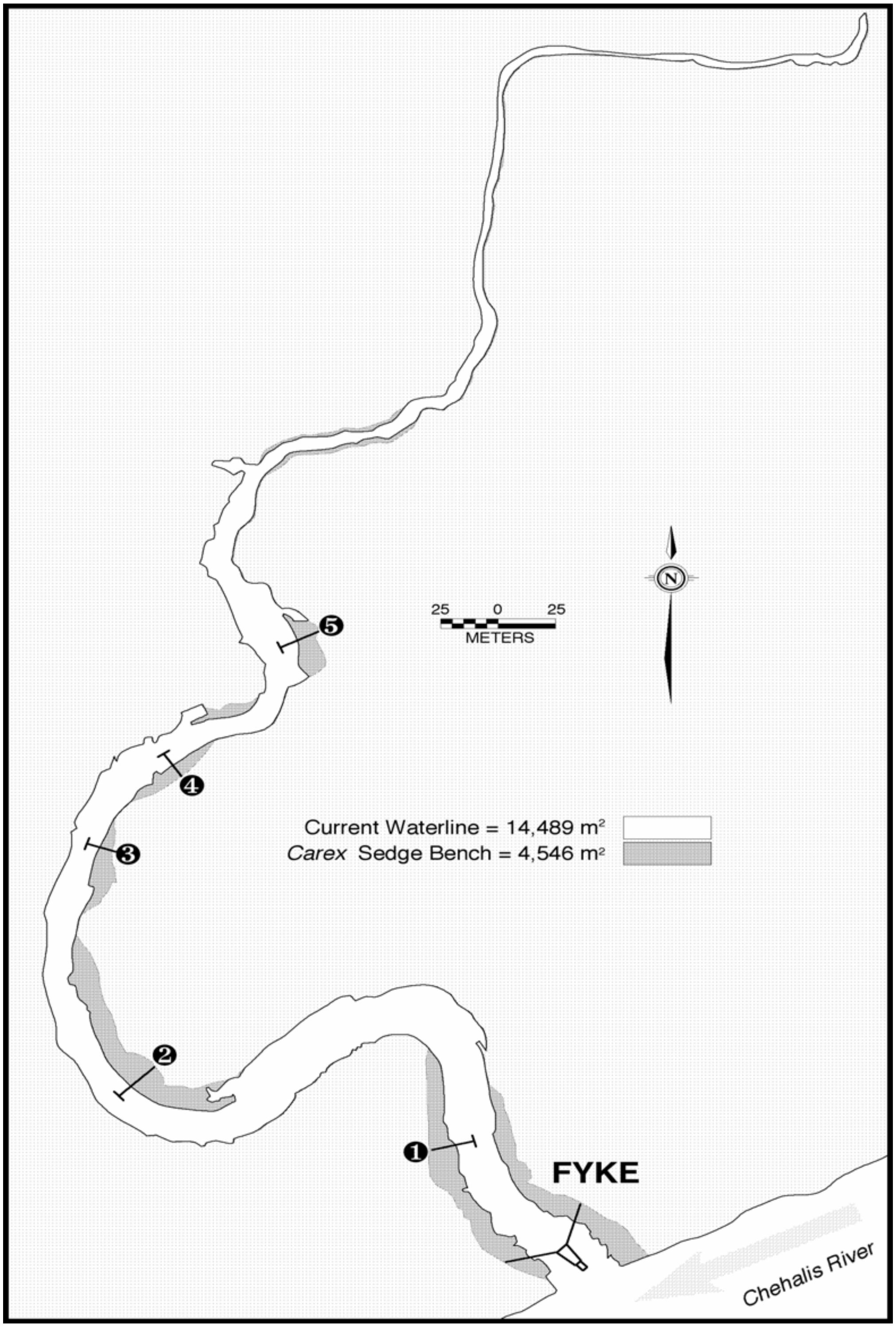

Figure 4. Schematic of reference slough in brackish region of Chehalis River estuary, Grays Harbor, Washington, based on digitized image from 1991 aerial photograph; circled numbers refer to sampling stations; position of tidal fyke net indicated at mouth of slough.

Sampling Design

In 2000, we assessed six direct and indirect indicators of the fisheries (habitat) function of the created and natural sloughs (Appendix A):

(1) fish species/life history stage occurrence, richness, density and standing stock;

(2) species occurrence, density, standing stock and diets of juvenile salmon and steelhead;

(3) composition and standing stock of insects (fall-out, and sedge enclosure) and benthic invertebrates (macrofauna) that constitute potential prey resources of juvenile salmon and other fishes;

(4) species occurrence of avifauna, with particular emphasis on potential predators on juvenile salmon;

(5) shoot density, and above- and belowground biomass of *Carex lyngbyei* sedge; and,

(6) status and trends in sloughs' physicochemical structure (sedimentation, water quality, LWD).

These parameters were chosen to characterize the created habitat with respect to 1) utilization 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, LWD retention and site stability. These parameters and procedures that form the basis for quantitative comparisons between the created slough and reference slough, and changes in these parameters at the created slough with its development over time, were derived to a large degree from the USEPA's **Estuarine Habitat Assessment Protocol** (Simenstad *et al.* 1991). Simenstad *et al.* (1992) and Table 1 provide more detailed descriptions of the study design parameters and sampling schedule as applied to earlier assessments of the created and reference estuarine sloughs.

Most sampling, except that for motile fishes and neuston, was conducted at five stations distributed approximately equidistantly along each of the two sloughs (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 ($N \geq 3$) tidal fyke net sampling of fishes utilizing the sloughs during flood tide periods; emergence traps, fall out traps and sedge enclosure samples of emergent tidal marsh (*Carex lyngbyei*) insects; benthic macroinvertebrates and meiofauna at different tidal elevations; bird observations; and water quality monitoring.

Less frequent sampling included: sampling of *Carex lyngbyei* once, during peak growing period; Global Positioning System (GPS) measurements of the sloughs' elevations and geomorphology; and digitizing of the large woody debris and other habitat features of the created slough from a georeferenced aerial photograph obtained on July 16, 1995. *Carex lyngbyei* sedge habitats ("benches") and GIS measurement were obtained at both reference slough and the created slough on 24 August 1995. Monitoring of the *Carex lyngbyei* benches, established at the same tidal elevations at each of the five permanent sampling transects at the created slough was continued based on the sites and methods used at reference slough in 1990-1992. Thus, natural *C. lyngbyei* emergent marsh assemblage was represented by the Reference 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).

Table 1 Long-term schedule for monitoring and assessment of Grays Harbor created estuarine slough. Monitoring indicators that were continued or emphasized in 2000 are indicated by bold type.

Study Component/ Target Parameter	Technique	Sampling Period	Sampling Frequency	Years
I. Juvenile Salmon (*Oncorhynchus keta*, *O. tshawytscha, O. kisutch*, *O. mykiss*)				
A. Slough Use				
1. Fish species/life history stage occurrence, density, and standing stock	outlet fyke net maintained for 2-3 days (per slough) per sampling trip;	March-June	monthly	1990-1992, 1995, **2000**
	experimental (multi-ple mesh) gill nets	June	once	
2. Diet, based on IRI	outlet fyke net and 37-m beach seine[1] collections of fish for routine stomach contents analysis; n=10-15 fish per size interval	March-June	monthly	1990-1992, 1995, **2000**
3. Natural Slough Comparisons	opportunistic beach seine sampling of 5-7 sloughs along estuarine gradient	April-May	once	1995
B. Prey Resources				
1. Neuston (Chironomidae, Diptera, Aphid-idae, Araneae, etc.)	neuston boom; n=10, standardized time	March-June	monthly	1995
2. Emergent Insects	$0.5m^2$ emergence traps; n=10	May	monthly	1990-1992
3. Sedge Insect Wash-Off	$1.0m^2$ nets; n=10	March-June	monthly	1995
4. Insect Fall-Out	$0.3m^2$ fall-out traps; n=10	March-June	monthly	1995, **2000**
5. Meio-/Macro-benthos (*Corophium* spp., *Eogammarus* spp., *Neomysis mercedis*, harpacticoids)	$0.0024m^2$ "wet" benthic cores;	March-June; May for once elevation gradient	monthly; for elevation gradient	1995, **2000**

[1] contingent on continuing presence of subtidal refuge in created slough

C. Potential Predators				
1. Fishes (*Cottus* spp., *Leptocottus armatus*, *O. mykiss*, *O. clarki*, *Ptychocheilus oregonensis*)	outlet fyke net 37-m beach seine[1] collections; stomach contents analyses of largest size classes	March-June	monthly	1990-1992
2. Avifauna (*Ardea herodias*, *Mergus* spp.)	observation	March-June	monthly	1991-1992, 1995, **2000**
II. Vegetation				1991-1992, 1995, **2000**
A. *Carex lyngbyei*	0.25m^2 quadrat for stem density; 0.1m^2 core for above- and belowground biomass	August	once	
B. Emergent Plant Assemblages	species occurrence along vertical gradient at standard sampling stations	August	once	
C. Sediment microalgae	1.0cm^2 benthic cores for chlorophyll *a* biomass; n=10	March-June	monthly	
III. Physical Processes/ Environmental Conditions				1990-1992, 1995, **2000**
A. Sedimentation	measurement of microelevation changes by artificial horizon and survey (GPS) measurements	August	once every 5 yr thereafter (except for water quality)	
B. Water Quality	temperature, salinity, dissolved oxygen, pH w/ CTD/water quality monitor	March-June	monthly	
C. LWD Retention	comparison of LWD locations mapped from aerial photographs	July (photo)	once	
D. Site Stability	comparison of slough structure based on aerial photographs and surveys	July (photo)	once	

Sampling Methods

Sampling methods used in the 2000 monitoring were in most cases the same or slightly modified from those employed in 1991, 1992 and 1995, as described in detail in Simenstad *et al.* (1992, 1993, 1997). These and additional or significantly modified protocols are described below.

Fish

Sampling of juvenile salmon and other fishes was conducted using inlet/outlet fyke nets. The inlet/outlet fyke nets were located at the mouths of the sloughs (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

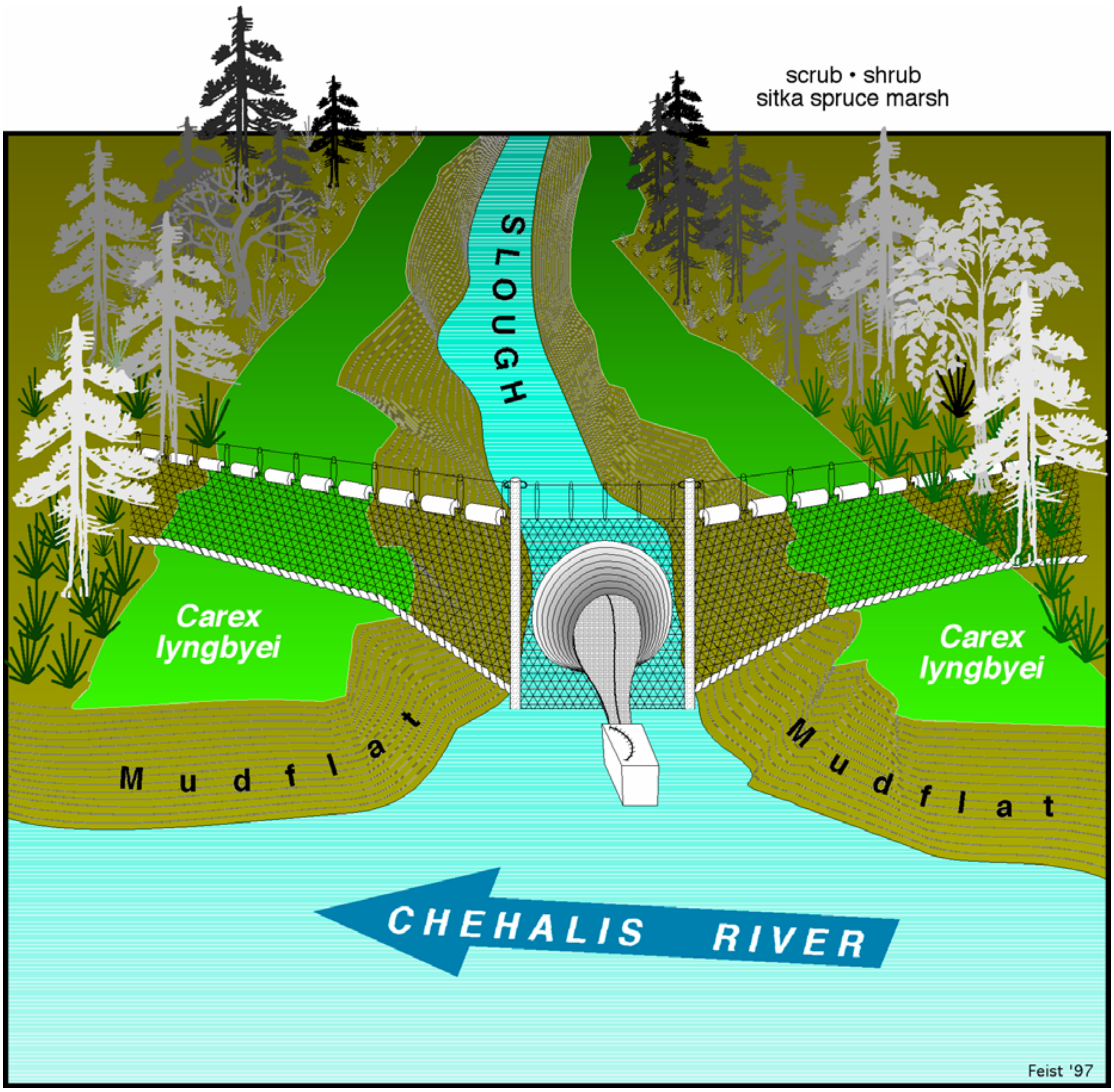

Figure 5. Diagram of inlet/outlet fyke net used to sample juvenile salmon and other fishes using slough habitats in brackish region of upper Chehalis River estuary, Grays Harbor, Washington.

was attached at the end of the fykes, equipped with a narrow opening and panel to prevent fish from escaping back out the fyke. The wings of the nets were constructed of ~13-mm (stretch mesh) nylon netting, and the fykes and live boxes of 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 sampling after the fish had accessed and utilized 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.

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 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.

Juvenile Salmonid Diet Composition

When we had sufficient numbers in our collections, we retained representative subsamples of juvenile salmon for comparison of their diets between the two sloughs. Subsampled juvenile salmon retained for stomach contents analyses were preserved in 10% buffered formalin. In the laboratory, these 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). Prey organisms composing the stomach contents were sorted to lowest taxonomic category possible under an illuminated dissecting microscope, counted, and weighed (blotted wet weight, to nearest 0.001 g).

Fish Prey Resources

Benthic Invertebrates

Comparable to sampling protocols in 1995 (Simenstad *et al.* 1997), benthic macrofauna (organisms retained on a 0.500-mm sieve) were sampled monthly in 2000 at stations 1,3, and 5 in each slough. In 1995 we changed 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 (organisms passing through a 0.500-mm sieve but retained on a 0.125-mm sieve) were sampled with PVC cores of 0.0024 m^2. At each station, 10 replicate samples were taken on mudflats approximately 1 m below the margins of *Carex lyngbyei*. To assess vertical elevation and habitat variability in potential prey, in June 2000 we extracted 10 replicate cores at each of the following strata at station 3 in each slough: 1) mid-channel, 2) at the lower edge of the *C. lyngbyei*, and 3) in the middle of the *C. lyngbyei*.

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 dissection, 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 have been identified or hypothesized as being prey for fishes or birds.

<u>Insects</u>

We used fall-out traps that were 0.25-m^2, rectangular plastic basins to capture insects falling or settling 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 preserved the collected insects. Each month, these traps were set in the *C. 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 are relatively low, they were left to sample over several tidal periods or days. Fall-out trap sampling was conducted monthly from March through June.

Avifauna

Observations were made on bird occurrence, relative abundance and behavior whenever the field team was conducting any other sampling on the sloughs (e.g., 5-6 d [daylight hours] per mo). Species identifications were made with the aid of binoculars when possible, but identifiable birdcalls 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.

Vegetation

Benthic vegetation was sampled at the five sites within the reference slough and the created slough. The parameters used to monitor the development of the created slough are listed in Table 2. Sampling on 21 August 1990 was conducted in the reference slough as a pre-construction baseline for the created slough. Both sloughs were sampled on 4 September 1991, 27 August 1992, 24 August 1995 and 3 August 2000. Field and laboratory methods used in 2000 were the same as those used in 1995 (Simenstad *et al.* 1997).

Table 2 Parameters and sampling dates for sampling emergent vegetation (focused on *Carex lyngbyei*) in the created and natural (reference) sloughs in brackish region of upper Chehalis River estuary, Grays Harbor, Washington, 1990-2000; CS = created slough and AS = reference slough, and — = not sampled.

		Year				
Parameter	Slough	1990	1991	1992	1995	2000
shoot density	CS	—	X	X	X	X
	AS	X	X	X	X	X
aboveground standing stock	CS	—	X	X	X	X
	AS	X	X	X	X	X
live below-ground standing stock	CS	—	—	X	X	X
	AS	X	—	X	X	X
dead below-ground standing stock	CS	—	—	X	X	X
	AS	—	—	X	X	X
total belowground standing stock	CS	—	X	X	X	X
(i.e., live + dead)	AS	—	X	X	X	X
planting success[a]	CS	—	X	—	—	—
stand width	CS	—	—	X	X	X
	AS	—	—	X	X	X

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

Channel Geomorphology

We used high-resolution GPS to conduct cross-sectional profiles of the created slough and natural sloughs in order to compare these to the original created slough design and elevation measurements made in 1992 and 1995 (Simenstad *et al.* 1997). Georeferenced data were collected from the created slough and reference slough on 24 August 1995 using a Trimble Real-Time Differential GPS Survey System. Because long-established benchmarks along the Cosmopolis shoreline of the Chehalis River that were used previously to survey the created slough (e.g., Station "Esteban") had been recently destroyed or buried by the construction of a flood control dike in 1994, in 1995 we occupied a GPS base station at the US Army Corps of Engineers benchmark SALC25.

We again surveyed both sloughs on August 3-4, 2000. For the GPS base station, we occupied Washington State Department of Transportation (WSDOT) survey benchmark GP14101-15 that had recently been resurveyed; the coordinates of this benchmark are latitude 46° 57' 28.20846"N and longitude 123° 46’ 23.52107”E (WSG84) and vertical elevation 4.276 m (14.027 ft) (NAVD88). We used exactly the same GPS measurement protocols as in the 1995 GPS survey, as described in Simenstad *et al.* (1997).

Water Quality

During each monthly sampling period, vertical water column profiles of water quality parameters were acquired in each slough using a Hydrolab Corporation™ MiniSounde 4a® water quality multiprobe. Salinity (practical salinity units, psu[2], ± 0.2 psu), temperature (°C ±0.1°) dissolved oxygen (mg l^{-1}; ±0.2 mg l^{-1}) and depth (m, ± 0.08 m) were recorded continuously (the time required to lower the sensor, i.e., approximately 5 minutes) from the surface to the bottom at each of the five sampling stations.

Large Woody Debris

Aerial photos taken in the years 1995 and 2000 by the US Army Corps of Engineers were used to evaluate the *apparent movement* of large woody debris (LWD) in created slough. One photo taken at low tide in the fall of each year was digitized at 1600 dpi and imported into the graphics program *Canvas® 7.0* (Deneba Systems ™). For 1995, the slough photo was segmented into thirds (slough blind-end, middle, and river-end) and channel margins and visible LWD within each third was highlighted in color graphics on the image. In the 2000 photo, color graphics were added, but the image remained intact. Graphics from the 1995 images were then grouped within each third and superimposed on the 2000 image. The attempt was made to align the 1995 channel margins with the 2000 margins as a guide to placement of the graphics.

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 which 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 utilizes 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 density, the mid-tide surface area of the two sloughs (based on the time and tidal elevation of the digitized aerial photograph from 1991) was used–14,489 m^2 for reference slough and 11, 026 m^2 for the created slough. Because we have no accurate means to estimate area at high tide, when the fish sampling actually occurred, the density estimates should be considered

[2] approximately equivalent to parts per thousand (ppt)

overestimates, although the comparison between the created and reference sloughs should still be directly applicable.

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,

IRI = (%F.O x [%N.C. + %G.C.]),

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

All digital data from the 1990-2000 monitoring of the Chehalis River created and reference sloughs have been organized into the Estuarine Sloughs Database (chehalis.mdb) using Microsoft Access™ (Appendix B).

Results

Fish

Occurrence and Relative Abundance

A total of 12 species were recorded in the created slough, and 15 in the reference slough, in 2000. The most dominant species generally reflected the composition in 1995 (Simenstad *et al.* 1997), e.g., juvenile salmonids (primarily chum and chinook salmon), threespine stickleback, peamouth chub, shiner perch, prickly sculpin, and Pacific staghorn sculpin (Table 3). Two species were captured for the first time, native charr (*Salvelinus* spp.) and juvenile English sole (*Pleuronectes vetulus*), both within the created slough. Rare or infrequent species also captured in 2000 included steelhead and bluegill in the reference slough and surf and longfin smelt and snake prickleback in the created slough.

As demonstrated by fish species richness (Fig. 6), total fish density (Fig. 7), and generally for the prominent juvenile salmon species (Figs. 8-10) and threespine stickleback (Fig. 11), composition and relative abundance fish assemblages were comparable in the created slough (and often exceeded, e.g., species richness) compared to the reference slough soon after the created slough's development. Initial enhanced species richness and fish densities in the created slough were attributed to the deeper tidal channel profile that allowed permanent refuge for larger fish than in the reference slough, although by 1995 sediment accretion in the created slough had eliminated this refuge and the fish catches in the sloughs were more comparable (Simenstad *et al.* 1992, 1993, 1997). By 2000, fish species richness was not detectably different (Fig. 6), although the individual fyke net catches in March (note that the reference slough could not be sampled in March 2000) and April may have been more variable in the created slough than the reference slough.

Table 3 Fish species occurring in reference (R) and created (C) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000; relative occurrence: A = abundant, C = common, I = infrequent (but often abundant when occurring), and R = rare (and not abundant). Asterisks indicate introduced species. LH = life history distribution: an = anadromous, e = estuarine, fw = freshwater, m = marine.

	1990	1991		1992		1995		2000		LH
Species	R	R	C	R	C	R	C	R	C	
American shad, *Alosa sapidissima**			R							an
chum salmon, *Oncorhynchus keta*	R			C	C	A	A	A	A	an
coho salmon, *Oncorhynchus kisutch*	A	A	A	C	A	C	A	A	A	an
chinook salmon *Oncorhynchus tshawytscha*	A	A	A	A	A	A	A	A	A	an
steelhead trout, *Oncorhynchus mykiss*		C				I	I	R		an
native char, *Salvelinus* spp.[3]									R	an?
surf smelt, *Hypomesus pretiosus*	C	C	R			I	R		I	e
longfin smelt, *Spirinchus thaleichthys*		R							I	an
eulachon, *Thaleichthys pacificus*	R					R				an
peamouth chub, *Mylocheilus caurinus*	A	A	A	A	A	A	A	A	A	fw
largescale sucker, *Catostomus macrocheilus*	R	R	C			R	R	C	C	fw
northern pikeminnow (squawfish), *Ptychocheilus oregonensis*	R									fw
redside shiner, *Richardsonius balteatus*	R									fw
threespine stickleback, *Gasterosteus aculeatus*	A	A	A	A	A	A	A	A	A	fw-m
bluegill, *Lepomis macrochirus**		R	R					R		fw
shiner perch, *Cymatogaster aggregata*		A	C	A	C	A	C	A	A	e
yellow perch, *Perca flavescens*	R	R								fw
prickly sculpin, *Cottus asper*	A	A	A	C	I	C	C	C	A	fw-e
Pacific staghorn sculpin *Leptocottus armatus*		A	I	C	I	C	R	A	A	e-m
saddleback gunnel, *Pholis ornata*		R				R				m
snake prickleback, *Lumpenus sagitta*		I		I		R			R	e-m
starry flounder, *Platichthys stellatus*		I	R	I		C	R	I	C	e-m
English sole, *Pleuronectes vetulus*									R	e-m
Total Species Richness	12	20	12	10	8	15	12	12	15	

[3] Because we released this fish, we had no feasible means (e.g., genetic) to determine whether it was Dolly Varden, *Salvelinus malma*, or bull trout, *Salvelinus confluentus*, both of which likely occur in coastal Washington watersheds.

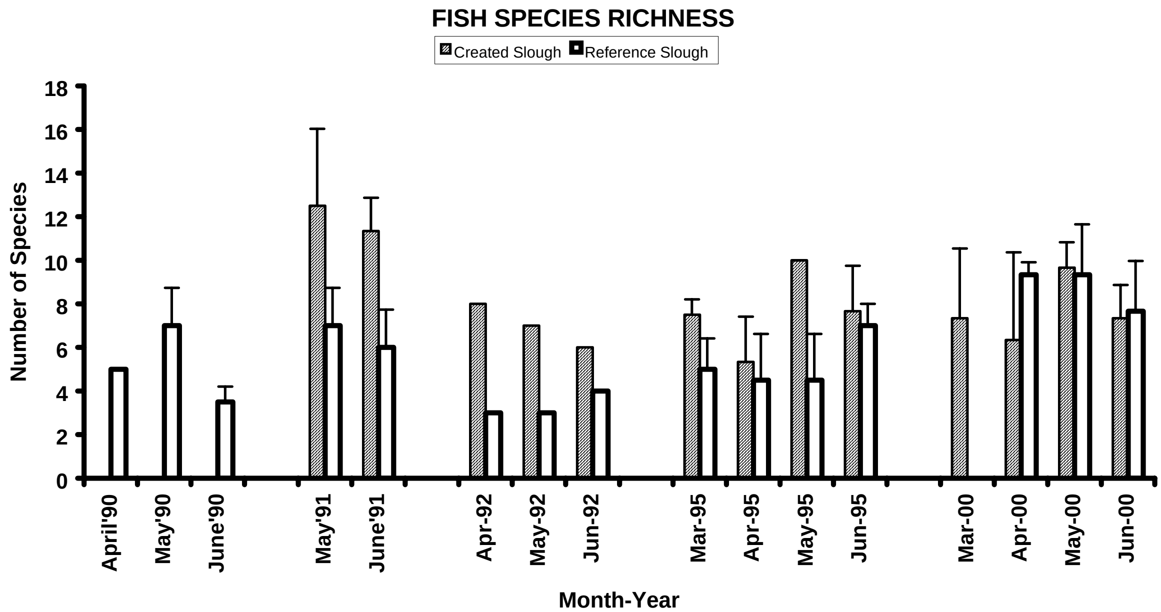

Figure 6 Mean (±1 s.d. error bars) fish species richness in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

Unlike fish species occurrences, the total density of fishes appeared to increase over the decade of fyke net sampling (Fig. 7), where mean total densities were below 300 fish ha^{-1} in 1990, 1991 and 1992 compared to mean densities often >500 fish ha^{-1} in 1995 and 2000. This pattern could reflect a pervasive trend in fish abundance in the estuary or could reflect differences in the sloughs, either in their position along the estuarine gradient or an effect of the created slough. However, the densities of fish in the two sloughs generally tracked each other, suggesting a common influence. This likely reflects variation in the influence of more abundant non-salmonid fishes such threespine stickleback (see below). Under the somewhat higher total fish densities in 1995 and 2000, the high variability in catches (as indicated by the 1 standard deviation error bars) indicated that there were seldom statistically significant differences between the created and reference sloughs, although they did show somewhat different seasonal patterns. In 1995, mean densities in the created slough reached a maximum in April and declined through June, as opposed to densities in the reference slough, which increased consistently from March through June; in 2000, however, mean total densities in both sloughs tended to increase from March (which due to logistic difficulties did not include sampling in the reference slough) to May and then declined between May and June (Fig. 7).

Patterns in total densities of juvenile salmon appeared to substantiate that the catches in the sloughs were tracking similar variability in interannual abundance of fish. Densities of juvenile chum actually increased from being very low in 1990 and 1991 to maxima in 2000 (Fig. 8). Part of this is evidently an effect after 1992 of sampling earlier in the season, when juvenile chum are emigrating from the Chehalis River watershed in February and March. However, even the April

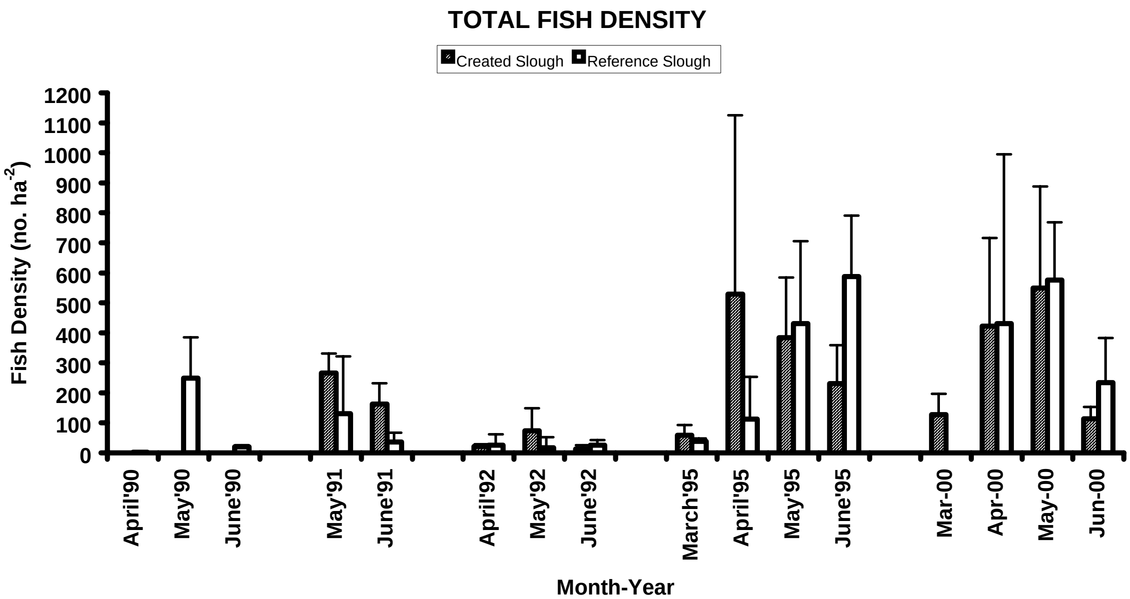

Figure 7 Mean (±1 s.d. error bars) total fish species density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

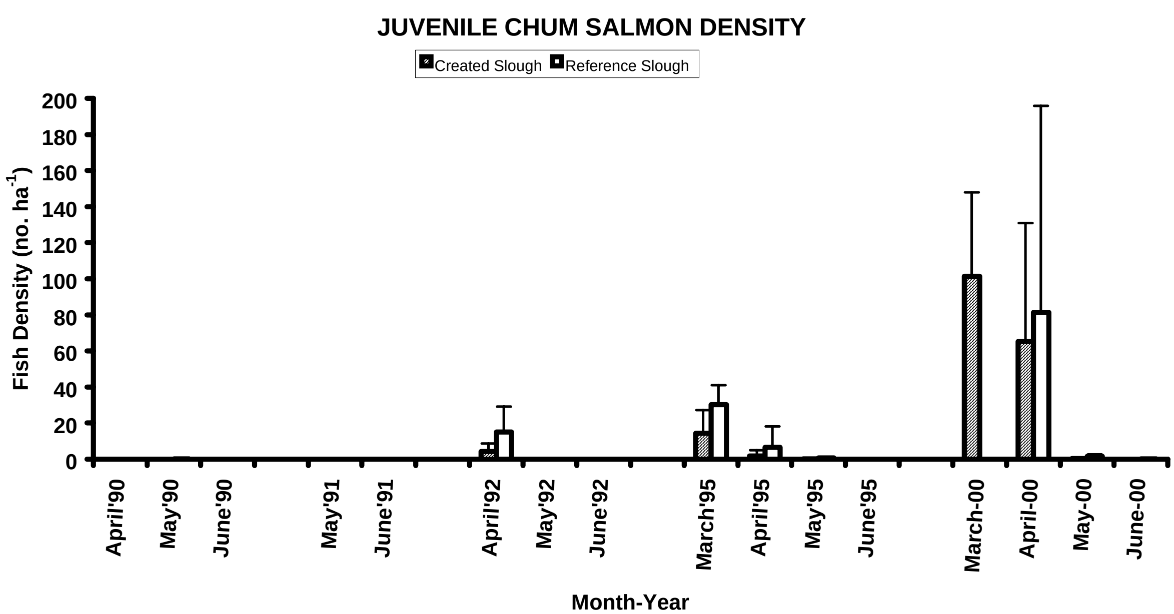

Figure 8 Mean (+1 s.d. error bars) total juvenile chum salmon density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

catches were consistently greater between the earlier and later sampling years. While variability in overall catches can be a function of brood year strength, in all cases the mean densities of juvenile chum salmon tended to be higher in the reference slough than in the created slough, but the difference never exceeded the 1 s.d. error.

Similarly, densities of juvenile chinook (almost exclusively subyearling, "ocean-type" fish) were consistently lower (5-15 fish ha^{-1}) in both sloughs in 1995 and 2000 compared to 1991-1992 (maxima > 20fish ha^{-1}; Fig. 9). While there was some indication of higher mean densities in the reference slough than in the created slough in earlier years (Simenstad *et al.* 1992, 1993), there was no consistent difference between the two sloughs in 1995 and 2000. In all years, juvenile chinook tended to increase in density from March to maxima in May and decline in June.

Juvenile coho (predominantly yearling, "stream-type" fish) appeared in the sloughs less consistently than chum and chinook, especially in 1992 and 1995 (Fig. 10). Subyearling, "ocean-type" coho were caught occasionally, and may be under-represented in our sampling because of their early appearance and small size (Miller and Simenstad 1997). There was no obvious evidence of densities being higher in either slough.

As an index of non-salmonid fish use of the created slough, densities of threespine stickleback demonstrated measurably higher mean densities in 1995 and 2000 (100-500 fish ha^{-1}) compared to the earlier sampling years (<100 fish ha^{-1}; Fig. 11). Stickleback demonstrated slightly different patterns of abundance between 1995 and 2000: in 1995, they reached maximum mean density in April and declined through June, compared to a maximum in May in the reference slough, while in 2000 the maximum density occurred in May in both sloughs.

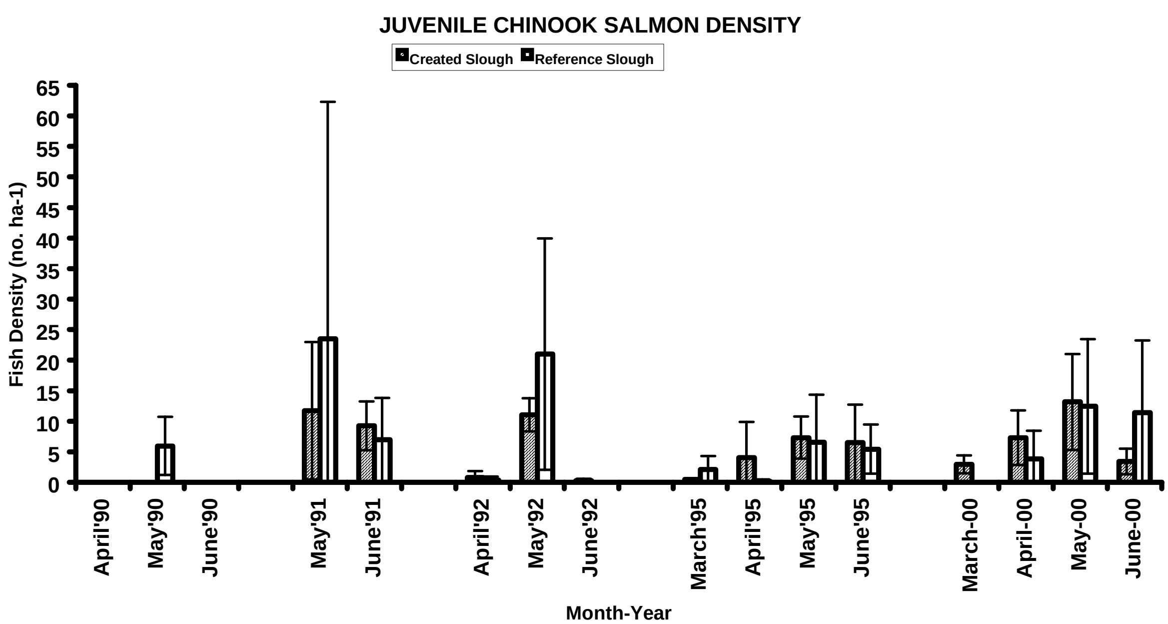

Figure 9 Mean (±1 s.d. error bars) total juvenile chinook salmon density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

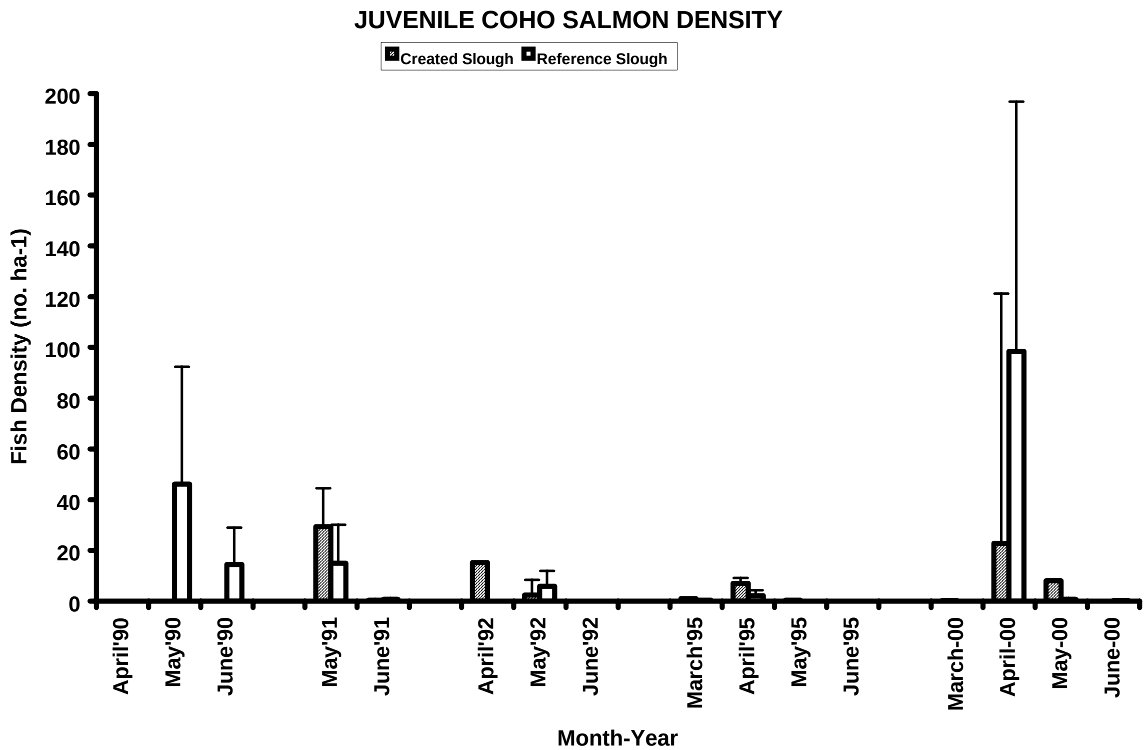

Figure 10 Mean (±1 s.d. error bars) total juvenile coho salmon density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

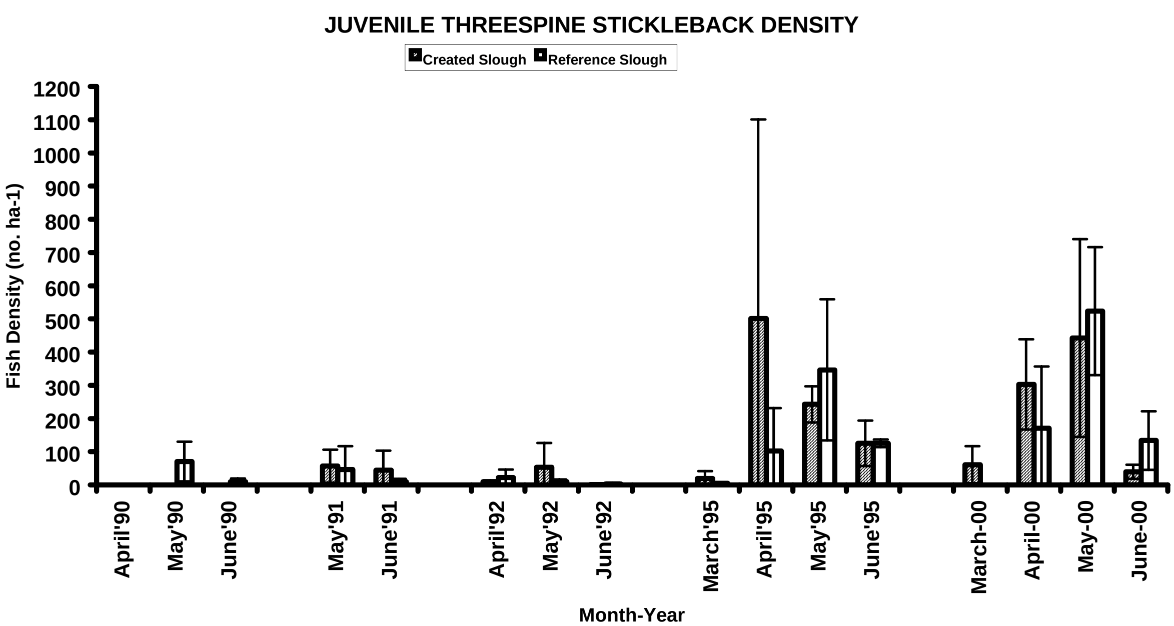

Figure 11 Mean (±1 s.d. error bars) total threespine stickleback density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

Diet

Over the entire sampling period in both sloughs in 2000, the diet of juvenile chum salmon was quite diverse but concentrated on dipteran (Chrinomidae) and other (Collembola, Aphididae, Ceratopogonidae) adult insects, nereid polychaete annelids (which dominated >half the diet biomass), harpacticoid copepods (*Pseudobradya* sp., *Huntemannia jadensis*, *Coullana canadensis*) and gammarid amphipods (primarily *Corophium salmonis*). Based on percent total IRI, adult dipterans accounted for ~42% of the diet composition, compared to ~20% each by *Pseudobradya* sp. and nereid polychaetes (Fig. 12).

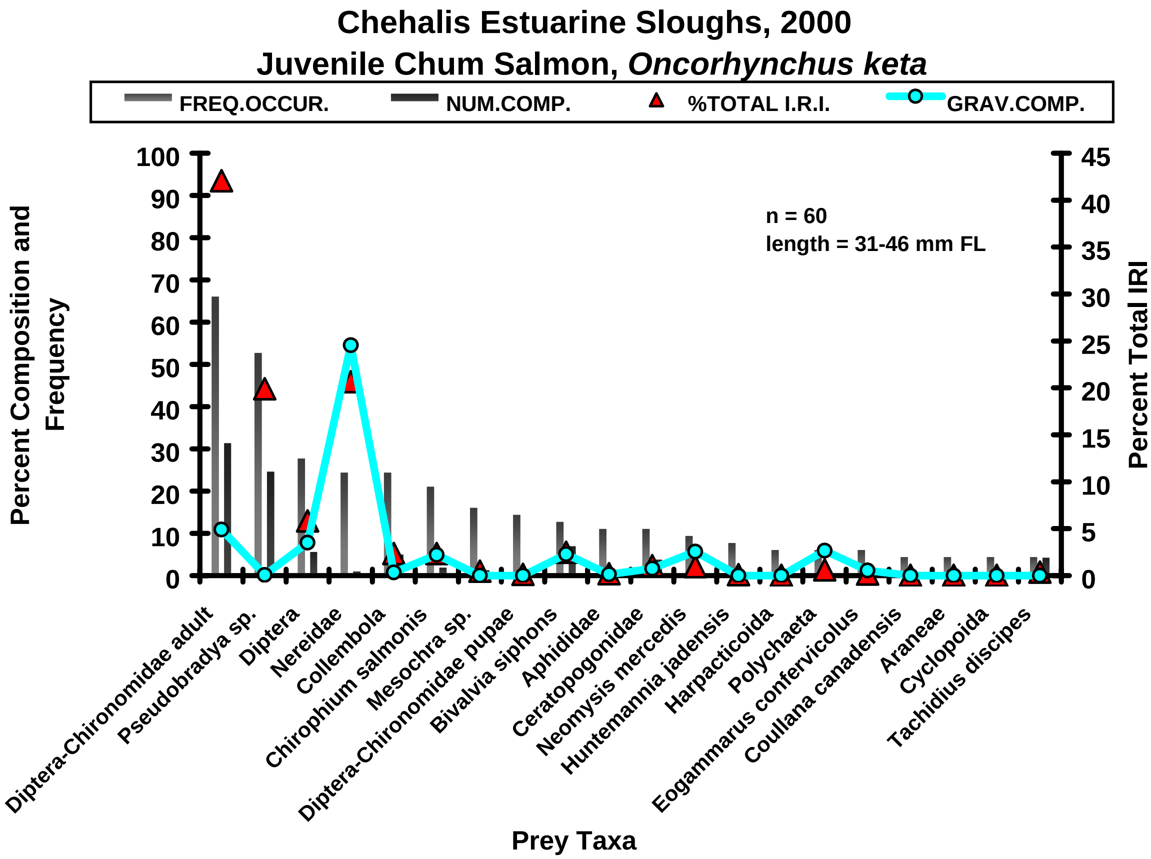

Figure 12 Diet composition (expressed as parameters of Index of Relative Importance, I.R.I) of all juvenile chum salmon, *Oncorhynchus keta*, combined from created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 2000.

The overall diet of juvenile, subyearling chinook (Fig. 13) was similarly dominated by dipteran insects and epibenthic crustaceans, but the dipterans included both adults (38% total IRI) and larvae (16%) and the crustaceans were primarily the tube-dwelling gammarid amphipod, *Corophium salmonis* (25% IRI), and the estuarine mysid, *Neomysis mercedis* (10%). Less prominent prey taxa included other insects (Ceratopogonidae, Coleoptera, Hymenoptera, Aphididae, Psylloida; ~4%), mites (Araneae; ~2%) and nereid polychaetes (2%).

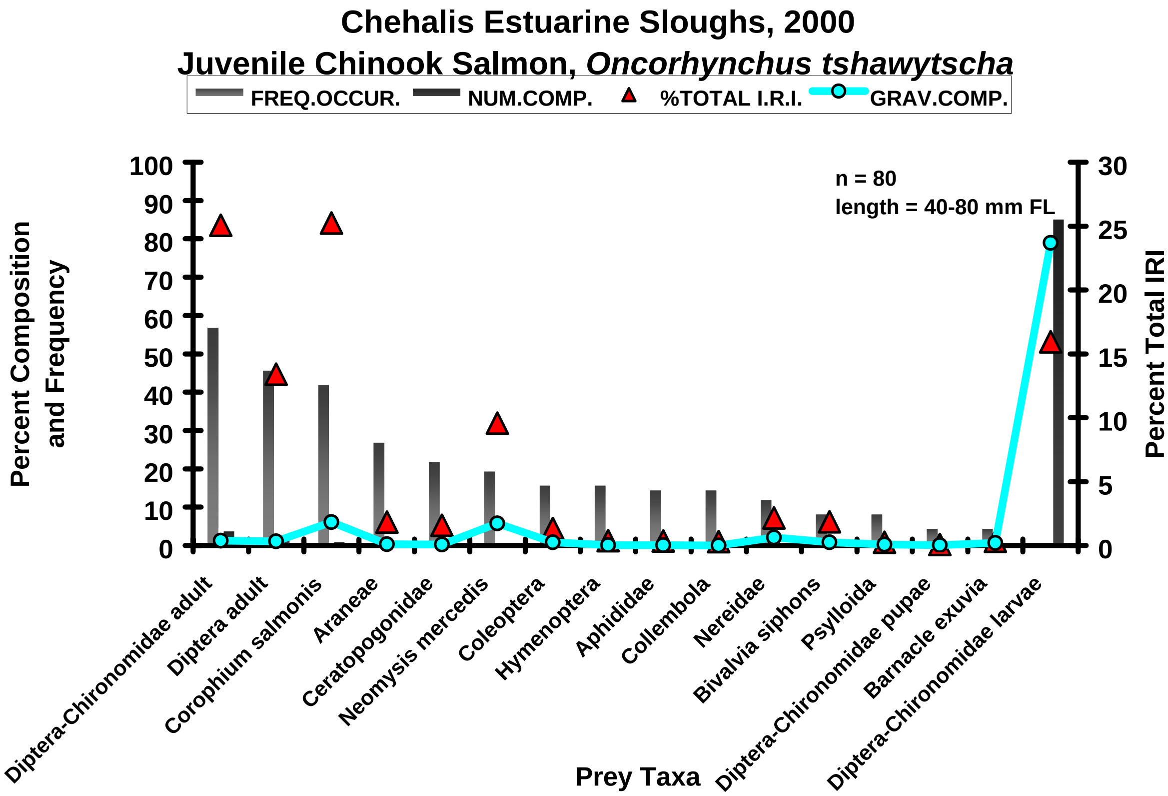

Figure 13 Diet composition (expressed as parameters of Index of Relative Importance, I.R.I) of all juvenile chinook salmon, *Oncorhynchus tshawytscha*, combined from created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 2000.

Compared to subyearling chum and chinook, the overall diet of yearling coho (Fig. 14) was dominated by *Corophium salmonis* (56% total IRI) and *Neomysis mercedis* (~14% total IRI), with incidental contributions by plants and plant parts and nereid polychaetes (both ~9%) and barnacle exuvia (4%). Insects comprised very small contributions (e.g., <1%) to the coho diet spectrum.

Due to the limited overlap of sufficient samples, direct comparison of juvenile salmon diets between the two sloughs was limited to April for chum and April-June for chinook. Based on percent total IRI in April, juvenile chum in the created slough tended to feed predominantly on the harpacticoid *Pseudobradya* sp. (49% total IRI), bivalve siphons (15%) and nereid polychaetes (11%) compared to fish in the reference slough that fed almost exclusively on insects (chironomid adults and pupae, 49%; collembolans, 8%; ceratopogonid pupae, 4%), *Corophium salmonis* (6%) and *Neomysis mercedis* (5%) (Fig. 15). Based on Percent Similarity Index (PSI), overlap of the chum diets in the two sloughs in April was minimal (24.1, where maximum = 100). The corresponding diet composition of juvenile chum in the created slough in March was less diverse and focused more on adult dipterans (40% total

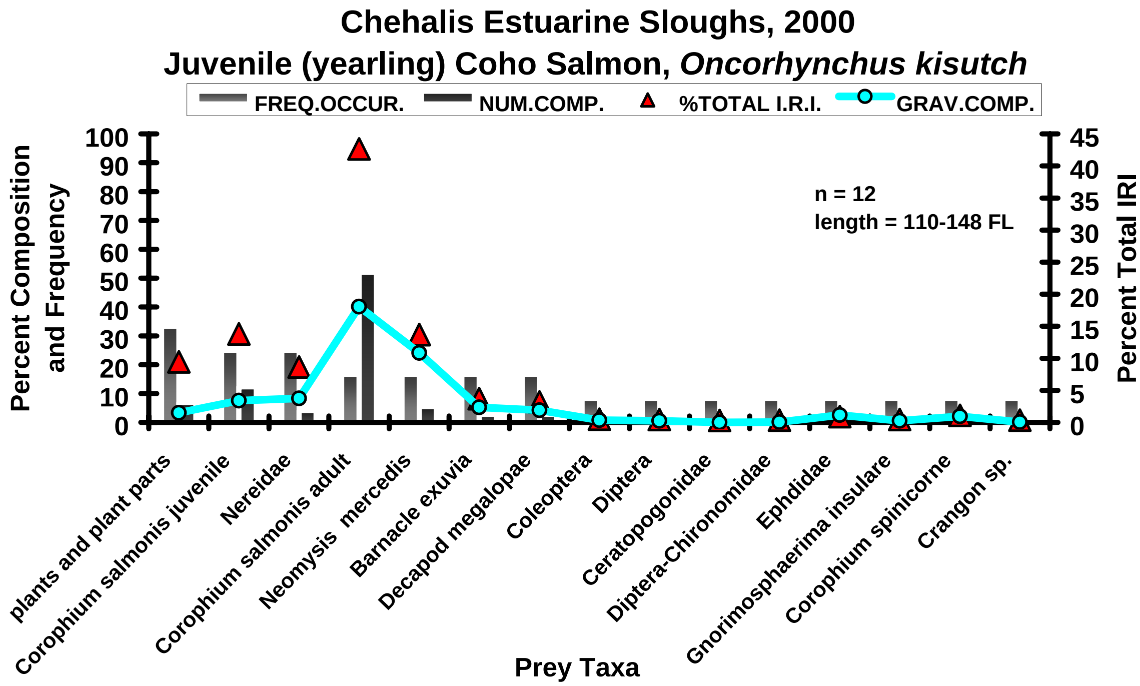

Figure 14 Diet composition (expressed as parameters of Index of Relative Importance, I.R.I) of all juvenile coho salmon, *Oncorhynchus kisutch*, combined from created estuarine slough (insufficient numbers of yearling coho were available from the reference slough) in Chehalis River estuary, Grays Harbor, Washington, 2000.

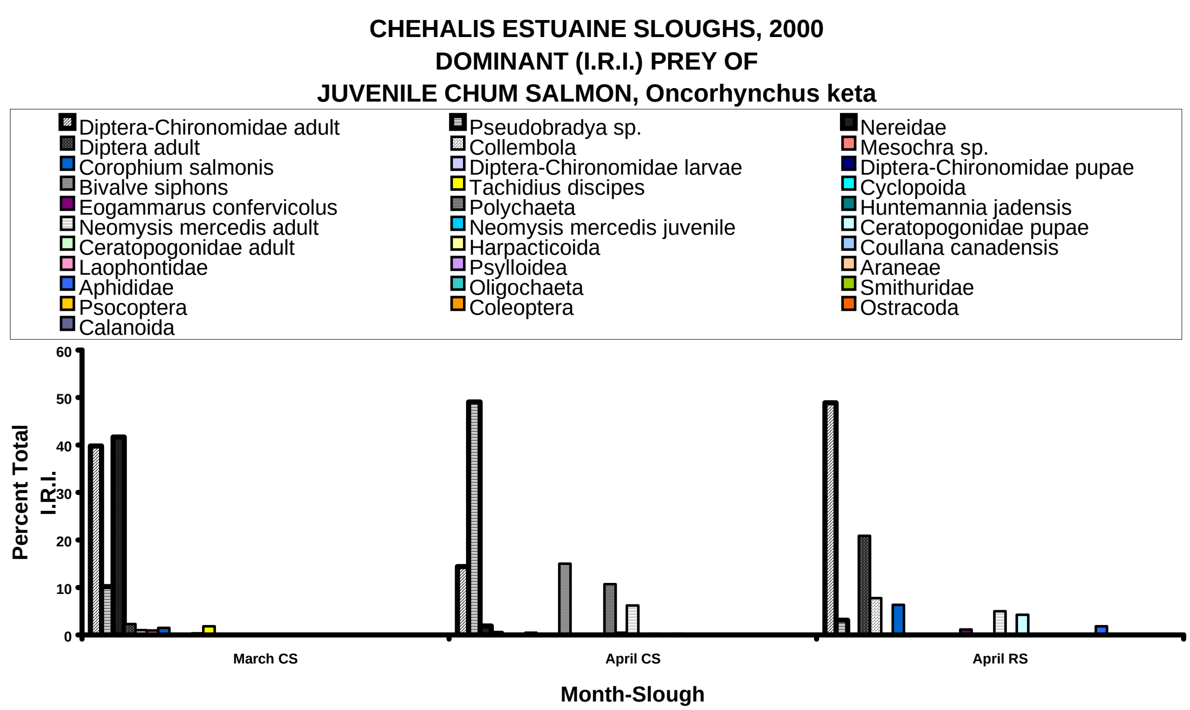

Figure 15 Comparison of diet composition (percent total IRI) of juvenile chum salmon, *Oncorhynchus keta*, from created (CS) and reference (RS) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 2000.

IRI), nereid polychaetes (42%) and *Pseudobryda* sp. (10%); overlap of chum diets from the created slough in March and April was also minor (PSI = 28).

In contrast to juvenile chum salmon diets, composition of juvenile chinook diets was more comparable between the two sloughs in April-June 2000 (Fig. 16). The primary difference was expressed in the contribution by bivalve siphons in the diet of juvenile chinook in the created slough in March (68% total IRI) and April (63%), whereas chinook in the reference slough in April fed predominantly on *Corophium salmonis* (49%) and dipteran (chironomids, ceratopogonids; 26%) and collumbolan insects. Diet overlap between fish captured in the created and reference slough approached PSI = 34 during April. In May, juvenile chinook diet compositions from the two sloughs were more similar (PSI = 45.6), where chironomids and other insects were mutually important and only *Corophium salmonis* and *Neomysis mercedis* were more typically in the diets of fish from the created slough and dipterans were more prevalent in the reference slough. By June, juvenile chinook diet compositions in the created and reference sloughs overlapped by PSI>50 due to the consistent representation of adult chironomids, *Corophium salmonis*, mites (Araneae) and coleopterans.

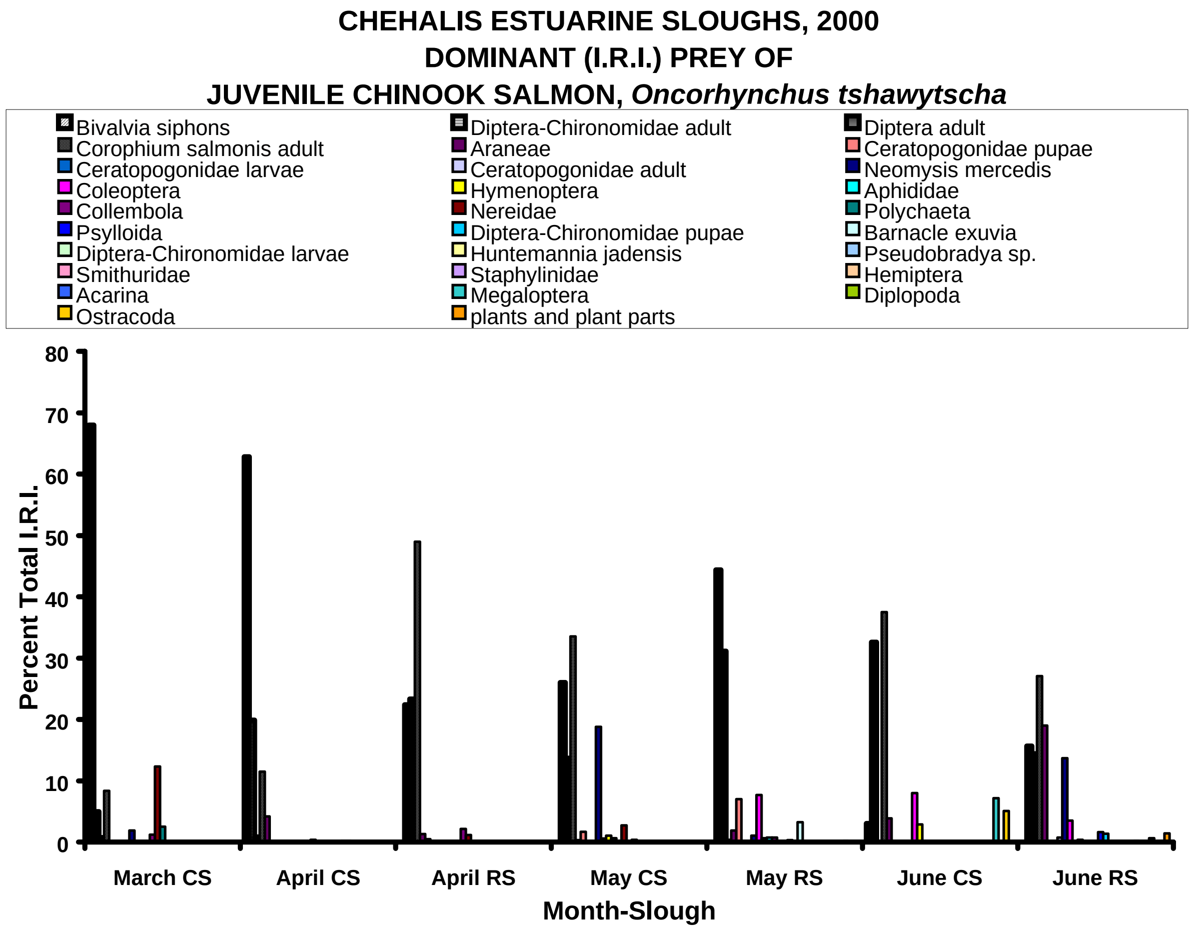

Figure 16 Comparison of diet composition (percent total IRI) of juvenile chinook salmon, *Oncorhynchus tshawytscha*, from created (CS) and reference (RS) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 2000.

Benthic Invertebrates

The mean total density of benthic invertebrates at each of the three transects (1, 3, 5) and overall (Fig. 17) were consistently lower in the created slough (~10,500-27,000 organisms m^{-2}) than the reference slough (~24,000-57,900 organisms m^{-2}). This effect was most evident in May and June, when densities in the reference slough were approximately twice those of the created slough. Numerical composition (Fig. 18) indicated that several taxa likely accounted for some of these differences. Although the nereid polychaete *Manayunkia aestuarina* tended to be more abundant in the created slough (especially in March), nematodes, *Corophium salmonis*, and oligochaetes were consistently more abundant in the reference slough than in the created slough.

This pattern was also evident in the June 2000 sampling of benthic macroinvertebrates at the three tidal elevation habitats (Figs. 19-20). Mean total densities of organisms were similar within the *Carex lyngbyei* bench and in the channel thalweg but higher at the base of the *C. lyngbyei* bench in the reference slough (~48,000 organisms m^{-2}) compared to the created slough (~19,000 organisms $m^{-2)}$. Numerical composition suggested no differences in the *C. lyngbyei* benthos taxa, but higher densities of both nematodes and oligochaetes and greater representation by *Corophium salmonis* at the mid-tidal elevation, below the *C. lyngbyei* bench, in the reference slough. Within the channel thalweg, the created slough fauna was dominated by nematodes, oligochaetes and the introduced cumacean, *Nippoleucon hinumensis,* while *C. salmonis* almost completely dominated the thalweg benthos in the reference slough.

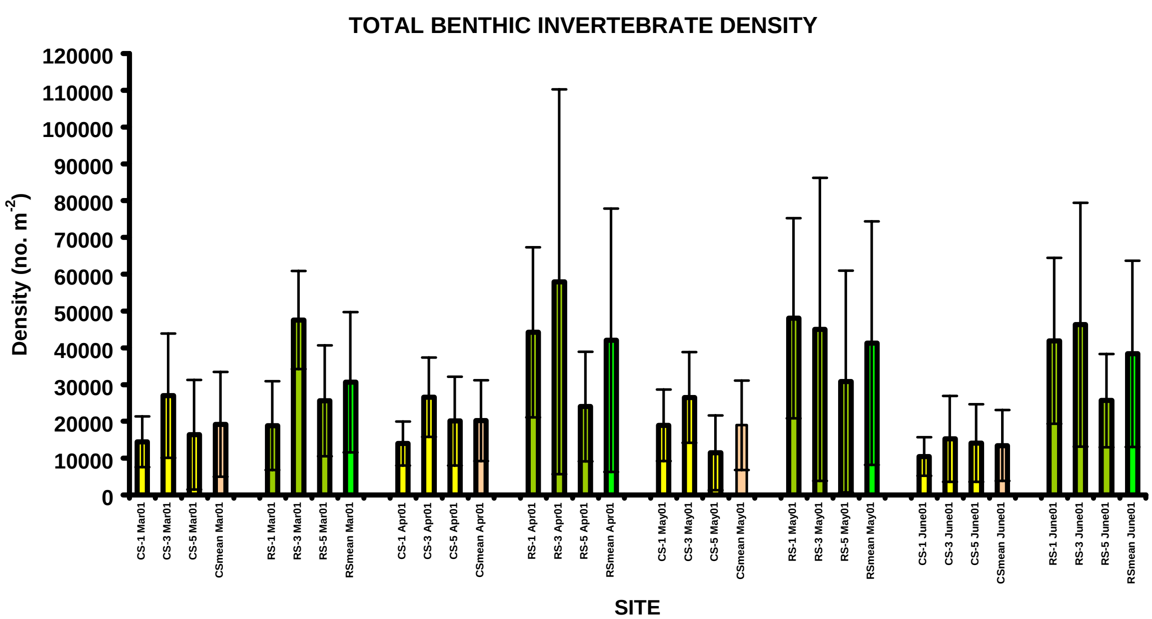

Figure 17 Mean (±1 s.d. error bars) of total benthic macroinvertebrates individual transects and monthly mean in created (yellow and orange, respectively) and reference (dark green and light green, respectively) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, in 2000.

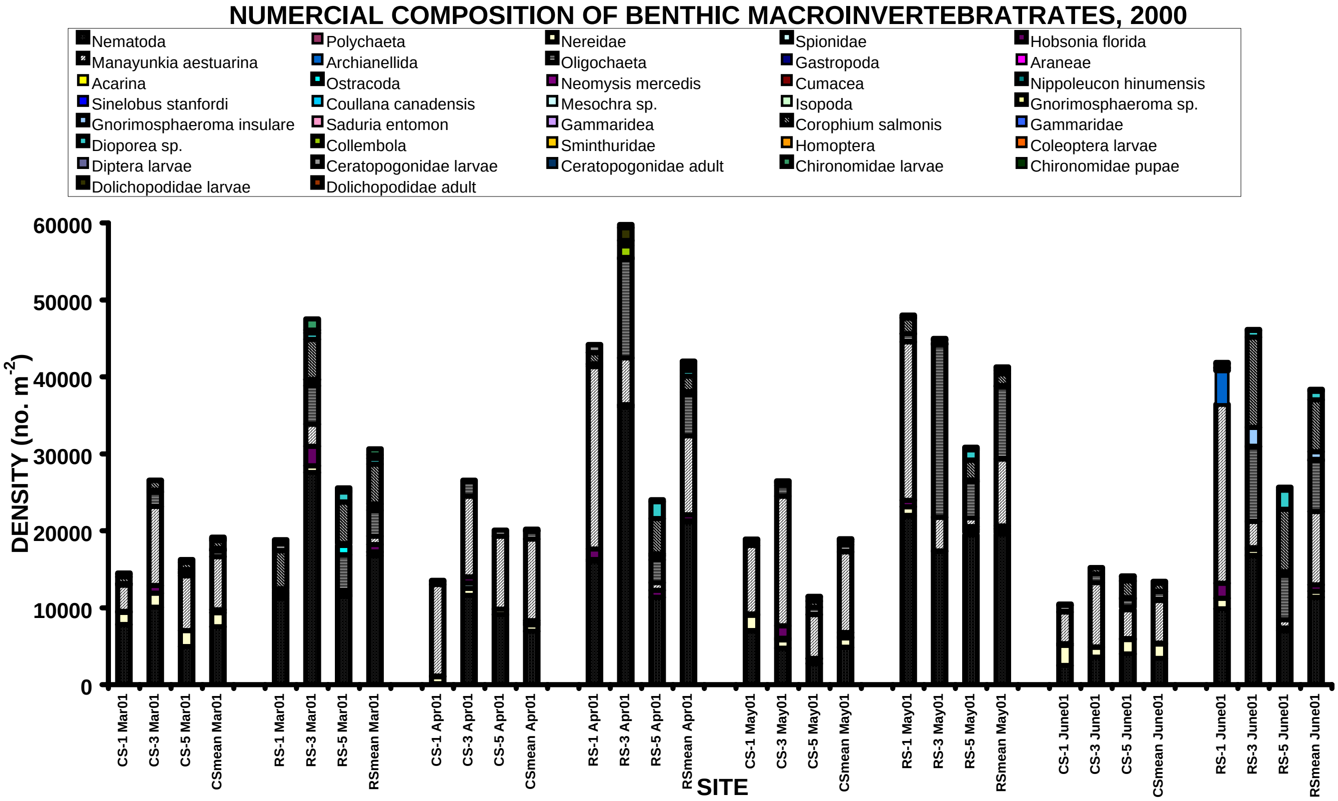

Figure 18 Numerical composition of benthic macroinvertebrates in individual transects and monthly mean in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, in 2000.

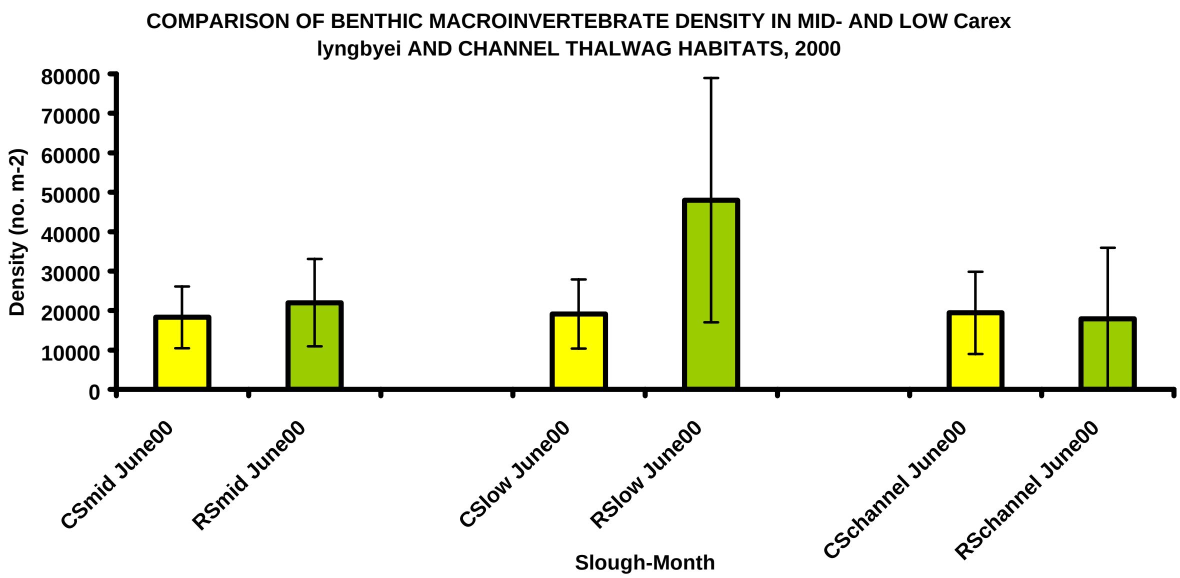

Figure 19 Total density of benthic macroinvertebrates in mid- and low *Carex lyngbyei* and channel thalweg habitats in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, June 2000.

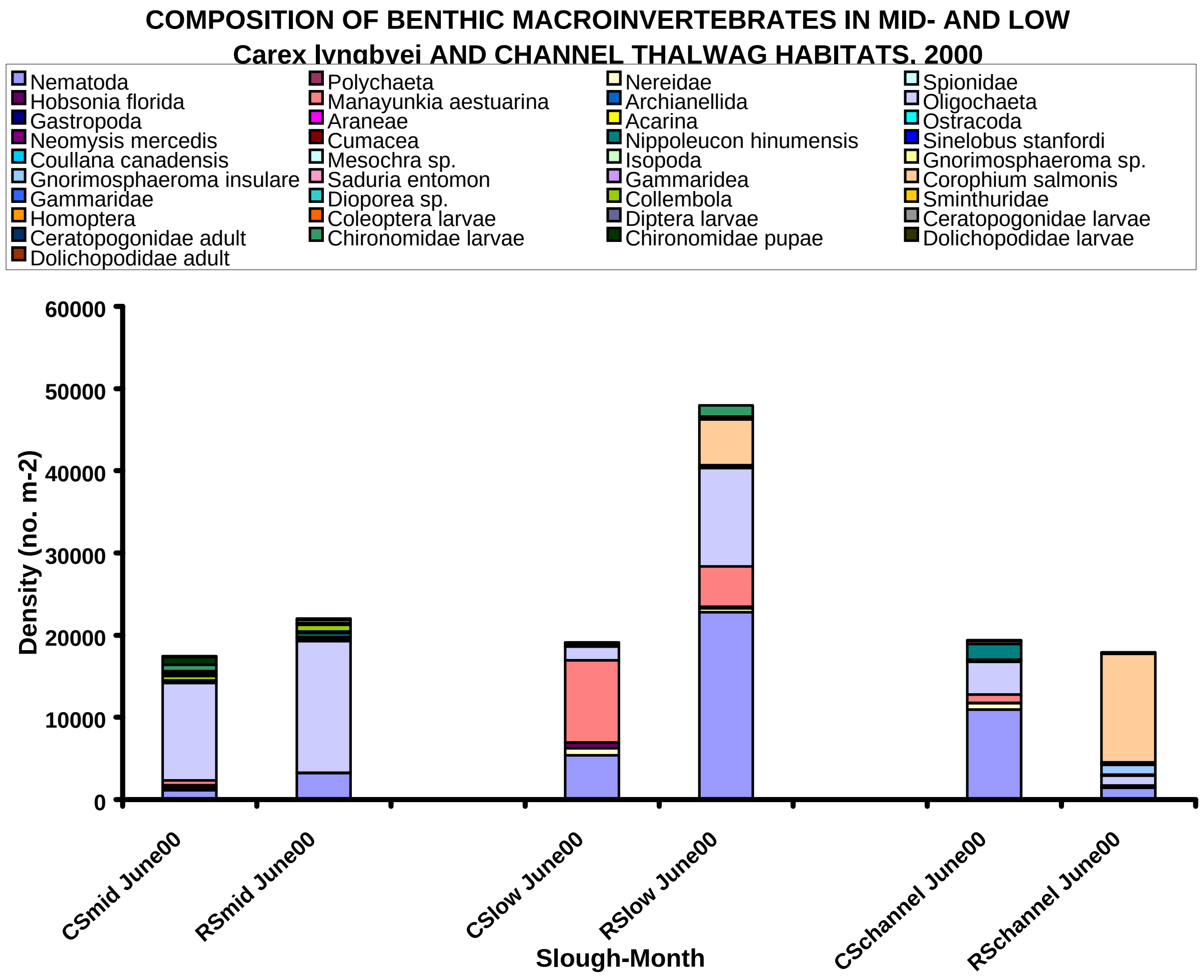

Figure 20 Numerical composition of benthic macroinvertebrates in mid- and low *Carex lyngbyei* and channel thalweg habitats in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, June 2000.

Fallout Insects

Mean total fallout insect densities were relatively consistent, between 300-800 organisms m^{-2}, and generally comparable between the created and reference slough in 2000 (Fig. 21); mean density was higher in the reference slough than in the created slough in all months but May, but inherent variability suggested no statistical significance between them. Differences between sloughs were reflected in some differences in taxa composition (Fig. 22). For instance, psychodids were measurably more abundant in the reference slough from March through May, as were dolichopodids in March and chironomids in April. Conversely, collembolans were consistently more abundant in the created slough in all months. In June, the additional abundance of ephidids and hemipteran nymphs accounted for much of the increased density at the reference slough.

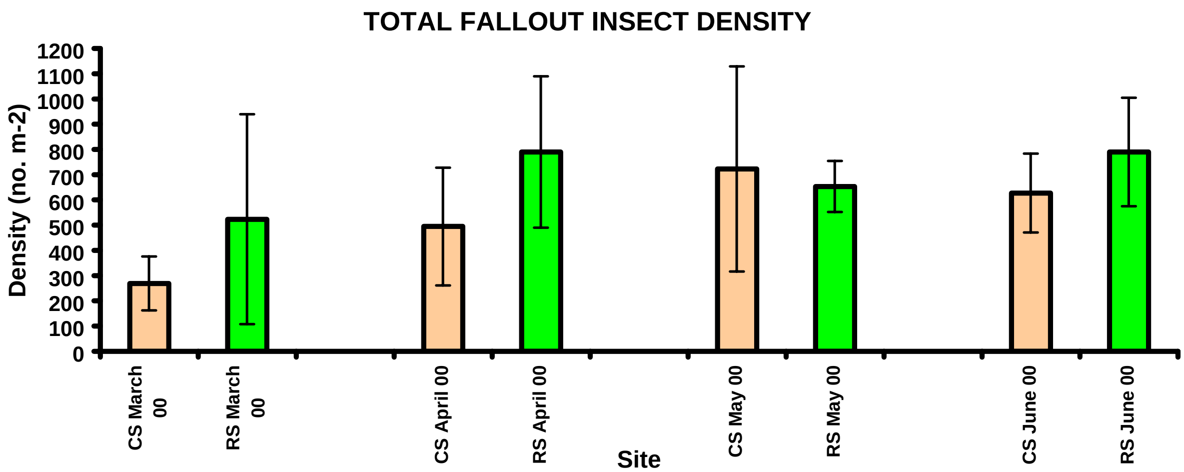

Figure 21 Mean (±1 s.d. error bars) of total fallout insects in created (CS; orange) and reference (RS; light green) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, in 2000.

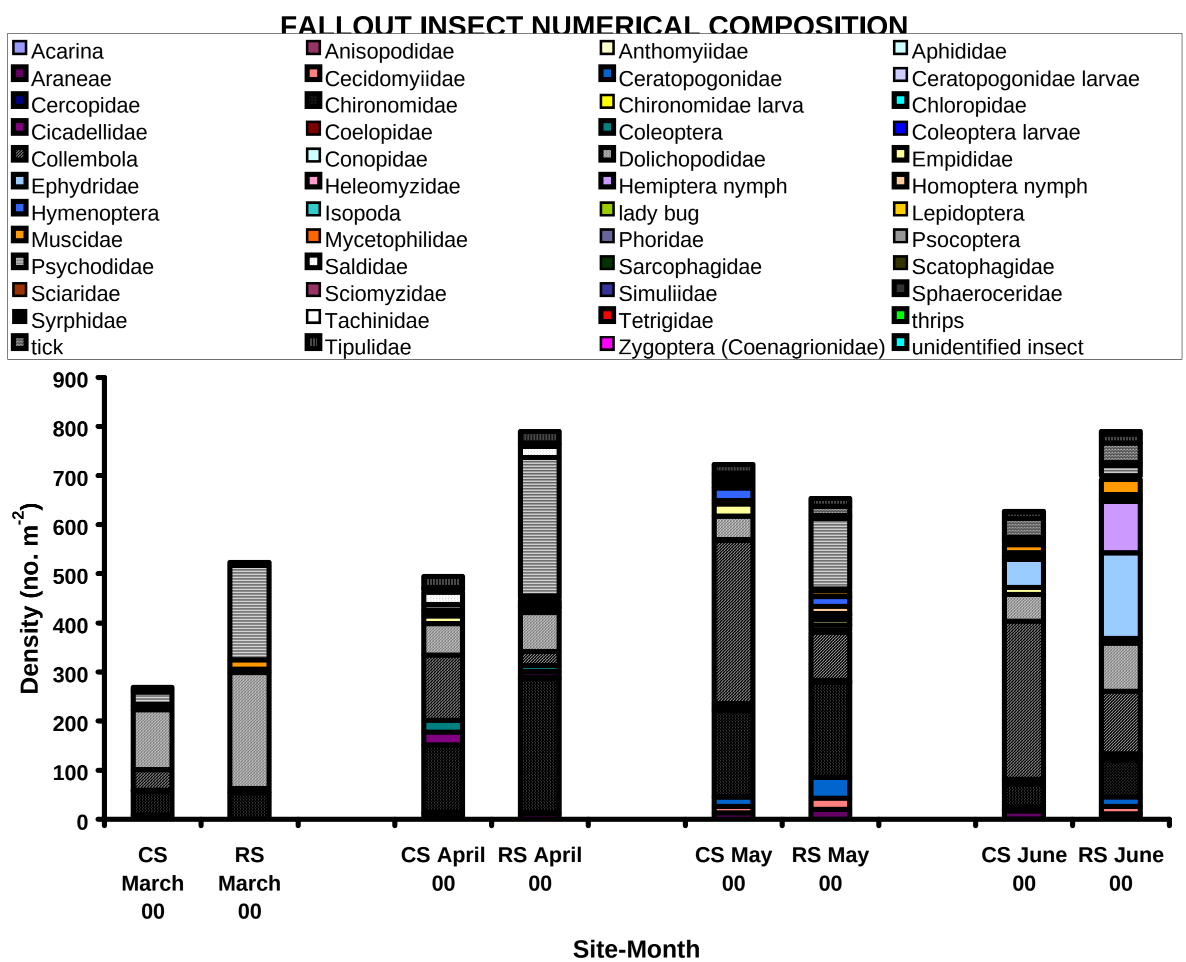

Figure 22 Numerical composition of total fallout insects in created (CS) and reference (RS) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, in 2000.

Avifauna

When feasible, bird observations were noted whenever investigators were working in the sloughs. It should be noted however that other research activities in the sloughs (e.g., involving motorized boat operations) likely constituted a disturbance reducing the probability of observation. In 2000, bird observations were recorded at both sloughs in March-May. The most abundant birds were waterfowl (mallards, *Anas platyrhynchos*, which appeared to be resident with juveniles) sighted on three occasions. Great blue heron (*Ardea herodias*) were commonly observed in both sloughs, but most often in the reference slough. Western sandpiper (*Calidris mauri*) were prominent in both sloughs on several occasions and redtailed hawk (*Buteo jamaicensis*) on one occasion. A belted kingfisher (*Ceryle alcyon*) was common in the created slough. Although not always observed directly, hummingbirds (*Calypte* spp.) were often heard calling and flying. Although these observations were opportunistic, rather than systematic, there was no indication that there was an obvious difference in bird use between the two sloughs. Neither was there any indication that piscivorous birds, such as great blue heron and belted kingfisher, were unusually common or abundant in the created slough compared to the reference slough.

Vegetation

In our survey in 2000, we found 24 plant taxa occurring along the five sampling transects in the created slough (Table 4) as compared to 23 taxa in the created slough in1995 and 23 taxa in the reference slough in 2000. Most species were found primarily at the boundary between the C*arex lyngbyei* stands and the upland.

Mean width of *Carex lyngbyei* stands increased at both the created slough and the natural slough between 1995 and 2000 (Table 5). The greater stand width at the natural slough as compared with created slough is likely indicative of the relatively steeper slope of the sedge benches at the created slough.

Between 1991 and 1992, there was a marked increase in *Carex* shoot density associated with the spread of *Carex* to fill areas between planted patches (Figure 23). On average, two shoots of *Carex* were planted per hole in spring of 1991. By the end of the growing season that year, the average number of shoots per transplanted patch varied between 4 and 11. Shoot density at both the reference and created sloughs showed a marked increase between 1992 and 1994, and essentially was unchanged between 1995 and 2000. This suggests that plant density had reached a maximum amount within the created slough by 1995.

Above-ground biomass followed the trend seen for density (Figure 24). Live and dead below-ground biomass at the created slough in 2000 was generally within the range recorded at the reference slough (Figure 25). However, comparing above-ground to live below-ground biomass between two sloughs (using data from all years at the reference slough, and year 2000 data from the created slough) indicated that the created slough may still have a relatively low amount of live below-ground biomass relative to above ground biomass (Figure 26). This suggests that the below-ground root and rhizome system is still developing even after nine years. However, the relationship for the reference slough may be considerably biased by one extremely high (live below-ground) data point.

Table 4 Vegetation taxa cataloged at five transects in reference and created estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, in 2000; common names according to Sabine (1993).

Slough	**Reference**					**Created**				
Transect	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Alnus rubra, red alder						X				
Cirsium sp., thistle sp.								X		
Gaultheria shallon, salal	X			X	X					
Malus fusca, Pacific crabapple	X				X					
Ribes sp., current sp.			X							
Rosa sp., wild rose sp.	X									
Rubus spectabilis, salmonberry			X	X	X	X	X	X		X
Salix sp., willow		X				X	X	X	X	X
Rumex crispus, curly dock									X	
Juncus balticus (*effusus*?), Baltic (soft?) rush							X	X	X	X
Juncus bufonius, toad rush			X	X						
Scirpus acutus, hard-stem bulrush	X									
Carex lyngbyei, Lyngbye's sedge	X	X	X	X	X	X	X	X	X	X
Aster subspicatus, Douglas' aster		X			X					
Atriplex patula, halberd-leaf saltbush					X					X
Epilobium angustifolium, fireweed							X	X	X	
Equisitum sp., horsetail sp.		X	X	X		X		X		X
Galium aparine, catchweed bedstraw		X			X	X	X	X		X
Heracleum lanatum, cow-parsnip				X				X		
Iris sp., iris sp.									X	
Lemna (?), duckweed			X	X						
Lilaeopsis occidentalis, western lilaeopsis		X			X					X
Lotus corniculatus, birds-foot trefoil		X	X	X	X		X			
Lysichiton americanum, yellow skunk-cabbage										X
Oenanthe sarmentosa, water parsley	X			X	X		X		X	X
Phalaris arundinacea, reed canary grass	X		X	X	X	X		X	X	X
Potentilla anserina, silverweed	X					X	X	X	X	X
Scutellaria lateriflora, blue skullcap						X				
Solanum dulcamara, climbing nightshade		X				X		X		
Typha latifolia, broad-leaf cattail						X	X			
Vicia americana, American purple vetch						X	X			
Athyrium filix-femina, subarctic lady fern			X			X				
Polystichum munitum, sword fern	X	X		X						

Table 5 Mean width (m) of *Carex lyngbyei* stands at the reference and created estuarine slough sampling sites in Chehalis River estuary, Grays Harbor, Washington, 1991-2000.

Year	Reference Slough	Created Slough
1991	15.0	6.2
1992	10.8	5.9
1995	12.4	5.2
2000	13.8	7.6

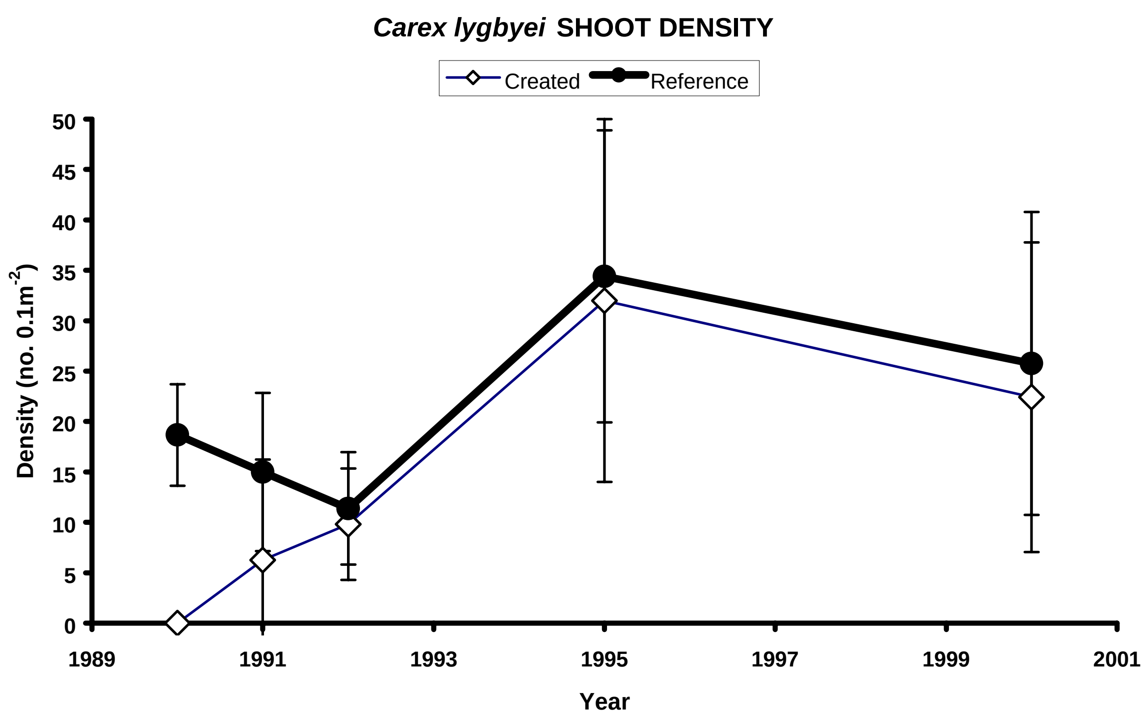

Figure 23 Mean (±1 s.d. error bars) *Carex lyngbyei* shoot density in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

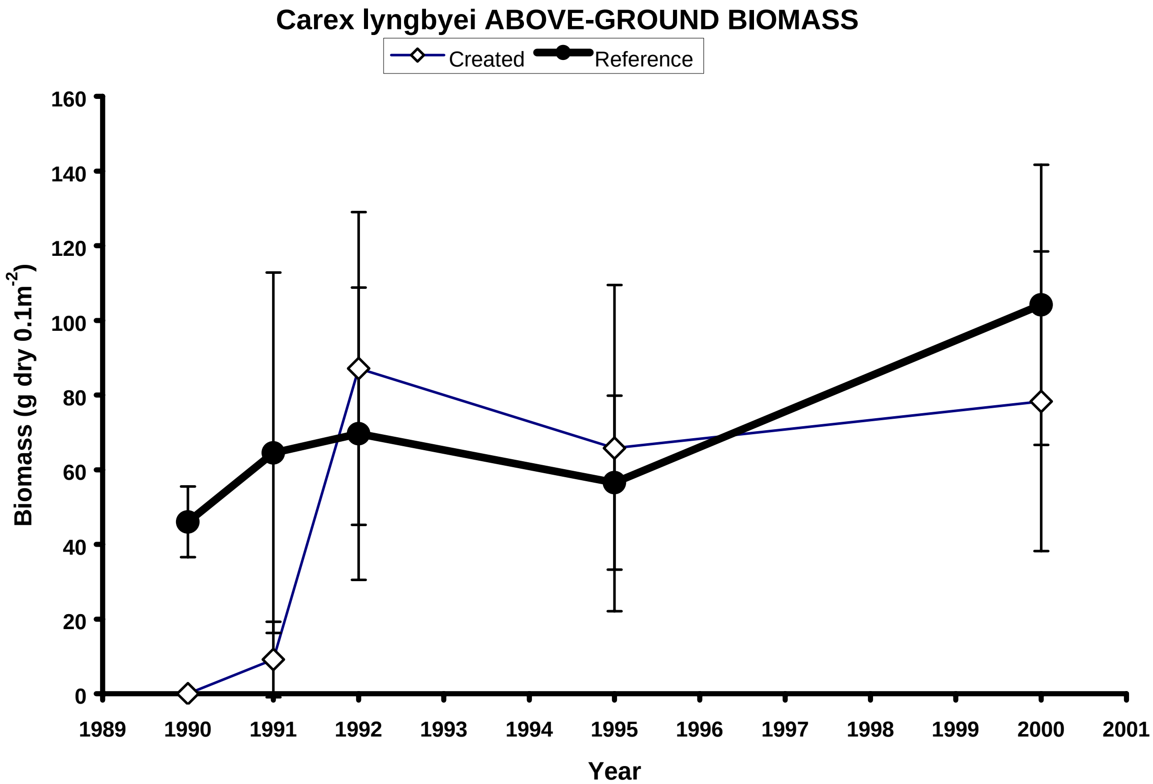

Figure 24 Mean (±1 s.d. error bars) *Carex lyngbyei* above-ground biomass in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1990-2000.

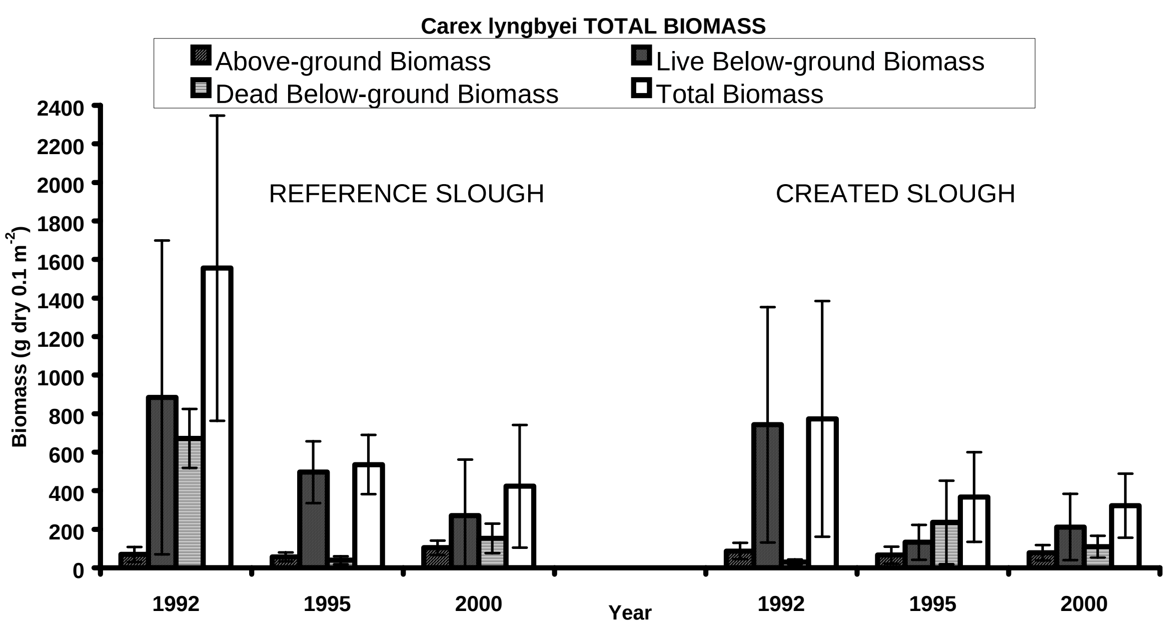

Figure 25 Mean (± 1 s.d.) *Carex lyngbyei* biomass above- and below-ground in created and reference estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1992-2000.

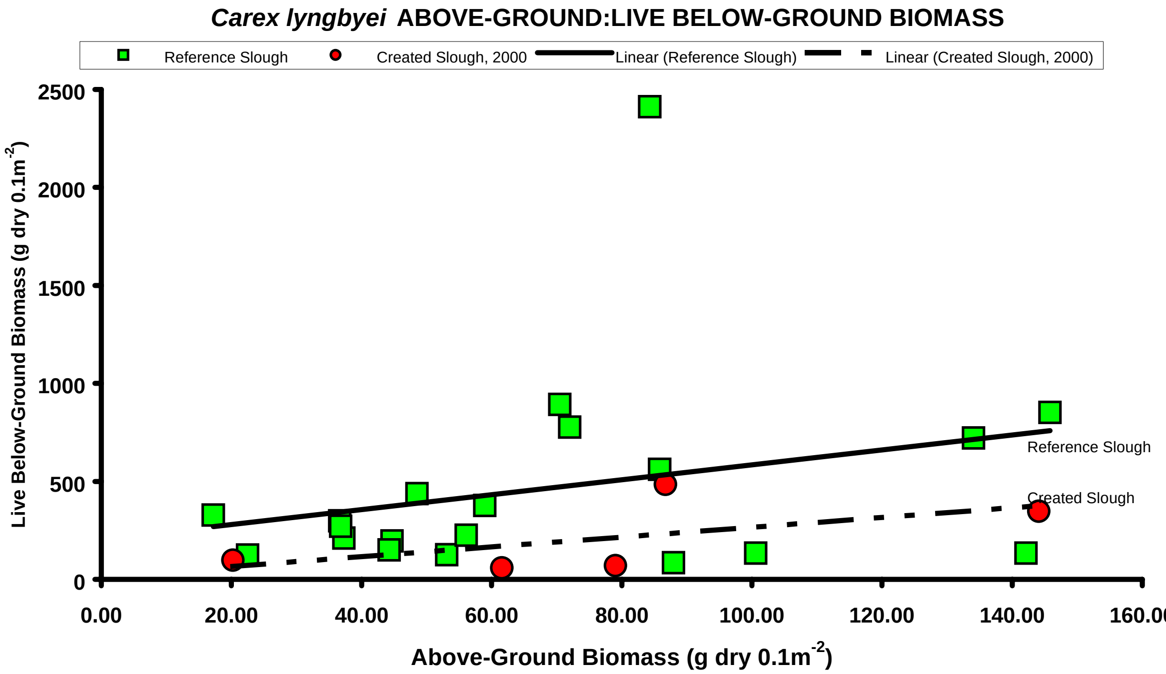

Figure 26 Relationship between above-ground and live below-ground biomass of *Carex lyngbyei* in created (2000 only) and reference (1990-2000) estuarine sloughs in Chehalis River estuary, Grays Harbor, Washington, 1992-2000.

Channel Geomorphology

Resurveying of the cross-sectional profiles of the created and reference sloughs allow relatively precise (± 1 cm horizontal; ± 2 cm vertical) comparison of the two geomorphic structures and any changes since 1995 (when the same survey technique and precision were utilized) and to the original design. An "as-built" survey was never conducted of the created slough post-construction in 1990-1991.

The created slough has a relatively consistent, gradual ~6.2:1 side slope to a minor channel thalweg that varies from ~0.2 m MLLW at the deepest transect (#2) to ~1.2 m MLLW at the end of the slough (Fig. 27). In comparison, the profiles of the reference slough illustrate broader, more variable profile (Fig. 28). As might be expected, the cross-sectional area decrease with increasing distance into the reference slough, such that the profile at transect #5 was only 40-m wide compared to over 120-m wide in the first two transects. The bottom elevation of the channel thalweg decreases from ~0.5 m MLLW at transect #1 to 0.75 m MLLW at transect #5. Distinct channel thalwegs are most evident in the profiles at transects #4 and #5.

Since excavation of the created slough, sediments have accreted in the lower tidal elevations of the slough (Figs. 29-30). At the entrance of the slough (transect T1), erosion has been apparent at tidal elevations above ~1 m MLLW, as much as 0.5 m by 1995, which continued between 1995 and 2000 by as much as ~0.3 m (Fig. 29). Sediment accretion was evident at tidal elevations below 1 m MLLW, and especially in the excavated thalweg channel. By 1995, >1.3 m of sediment had accumulated in the thalweg and up to 0.7 m was evident in some locations (e.g., between 0.25-1.0 MLLW elevations) between 1995 and 2000. This pattern is similar in the

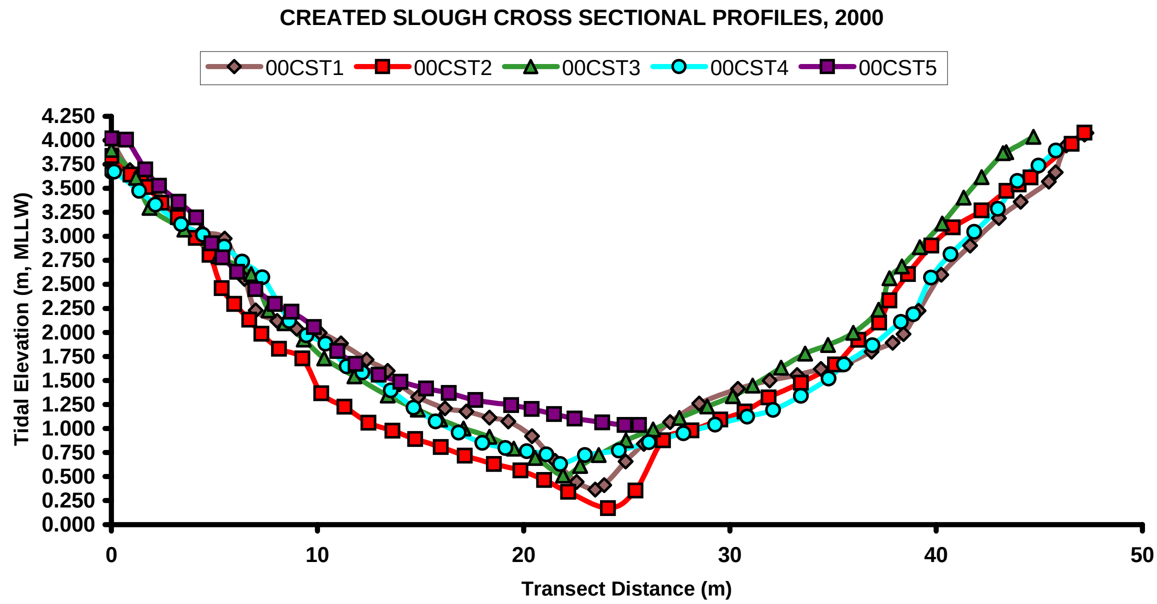

Figure 27 Cross-sectional profiles at five transect locations (00CST1 closest to slough entrance; 00CST5 at greatest distance from entrance) in created estuarine slough in Chehalis River estuary, Grays Harbor, Washington, 2000.

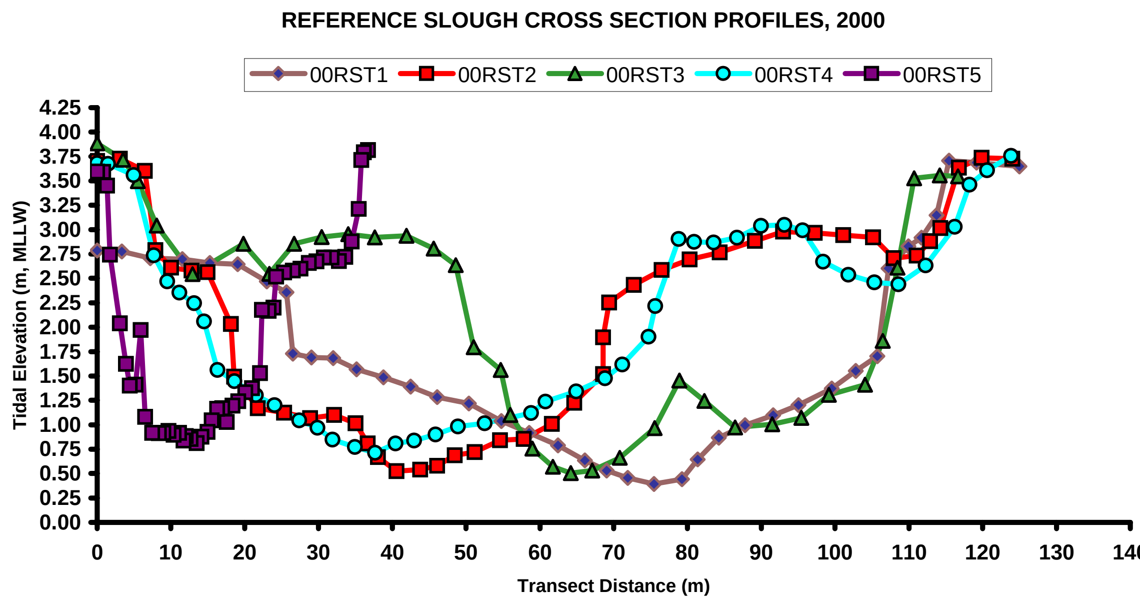

Figure 28 Cross-sectional profiles at five transect locations (00RST1 closest to slough entrance; 00RST5 at greatest distance from entrance) in reference estuarine slough in Chehalis River estuary, Grays Harbor, Washington, 2000.

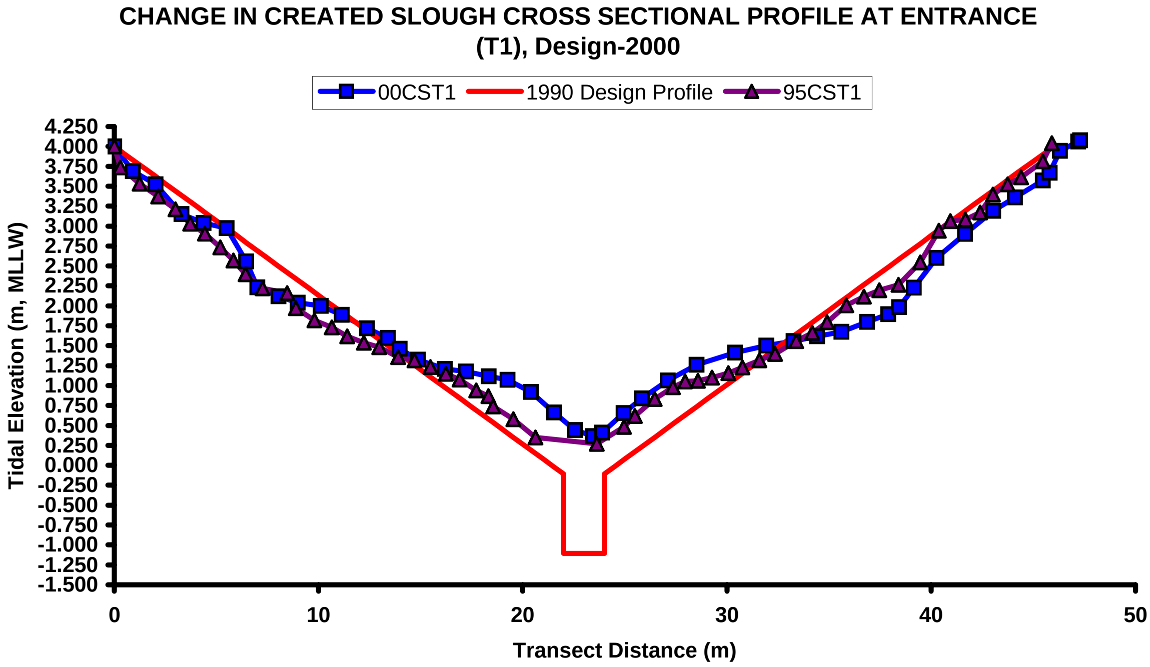

Figure 29 Change in cross-sectional profiles at entrance (transect T1) of created estuarine slough in Chehalis River estuary, Grays Harbor, Washington, 1990 (design) to 2000.

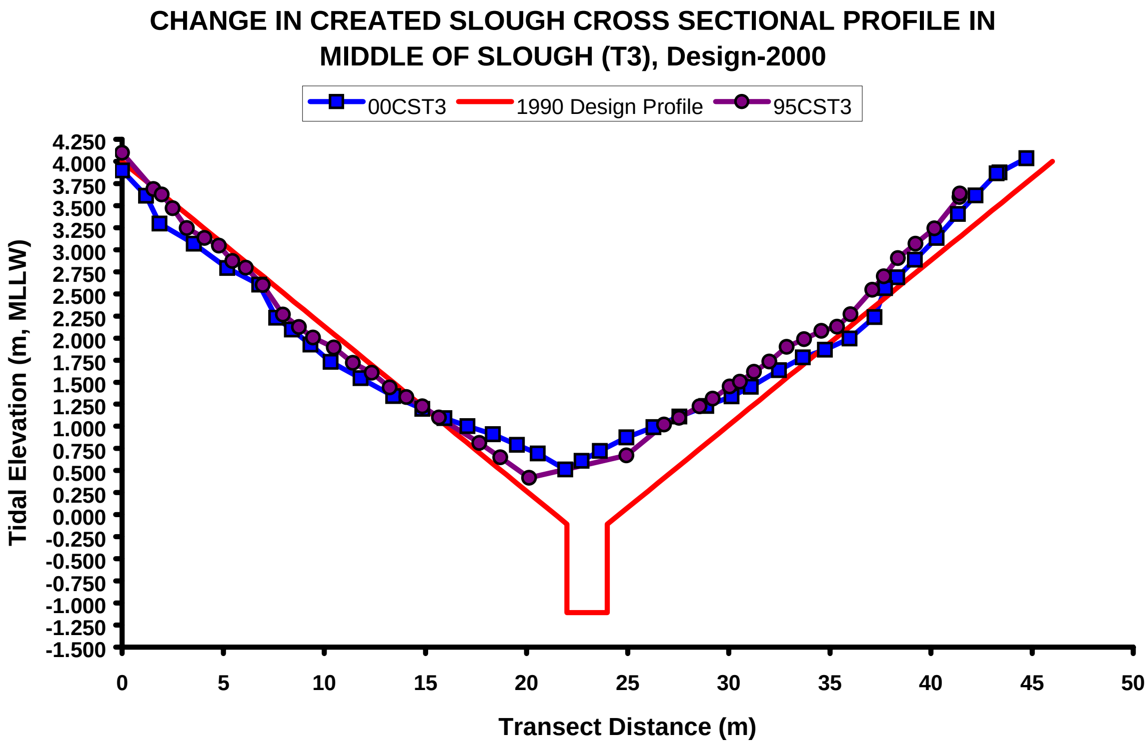

Figure 30 Change in cross-sectional profiles in middle (transect T3) of created estuarine slough in Chehalis River estuary, Grays Harbor, Washington, 1990 (design) to 2000.

middle of the slough, as evidenced in the change in cross-sectional profile at transect T3 (Fig. 30), but with some accretion (~0.25 m) in the higher tidal elevations on the east side of the slough, while erosion on the west side of the slough was similar to that observed at transect T1. However, erosion of <0.2 m occurred on the east shoulder between 1995 and 2000.

Water Quality

As experienced in earlier sampling years (Simenstad *et al.* 1992, 1993, 1997), differences in temperature, salinity and dissolved oxygen between the created and reference sloughs in both the geomorphology and position along the estuarine gradient can often be substantial depending upon river flow. Because the two sloughs are positioned near the upstream end of salinity intrusion, under high river flow salinity intrusion may not reach either. Under extremely low flows it will affect both sloughs and under intermediate flows the upstream (reference) slough may be more saline than the downstream slough.

In March 2000, salinity was evident at all five sampling stations along the lengths of both sloughs. Near the entrance of the created slough, salinity at the bottom approached 6 psu, but declined to <1 psu near-bottom at station 5 (Fig. 31). At the same time, the reference slough indicated salinities of ~4 psu and ~1 psu persisted at the bottom to station 5 (Fig. 32). Both sloughs indicated slight stratification in salinity, but less so in temperature and dissolved oxygen, within 0.2 to 0.5 m of the bottom. In both sloughs, temperatures ranged between 7°C and 8°C and dissolved oxygen between 9 mg l^{-1} and 12 mg l^{-1}.

Water quality characteristics were dramatically different in the two sloughs in April, with salinities ranging 6-12 psu in both the created slough (Fig. 33) the reference slough (Fig. 34) but the degree and complexity of mixing being extremely stratified in the created slough compared to more mixing in the reference slough. Stratification in the created slough involved four distinct strata of ~2 psu (created slough) that persisted to the head of the slough. Some three-layer stratification was evident in the reference slough but did not persist past station 4. This stratification seemed to indicated that several discrete intrusions of saline waters had pulsed into the slough at separate points in the flooding tide.

In May, the created slough had considerably greater salinity intrusion (up to 6 psu at bottom, transect 2) and a complex three-layer stratification (Fig. 34), while the reference slough had almost no salinity and a thoroughly mixed water column (Fig. 35). Similar to the situation in April, stratification in the created slough involved two distinct strata of ~2 psu to 1 psu change at two positions in the water column. Temperature (9°C to 10°C) and dissolved oxygen (~12 mg l-1) were fundamentally the same in to the sloughs, however.

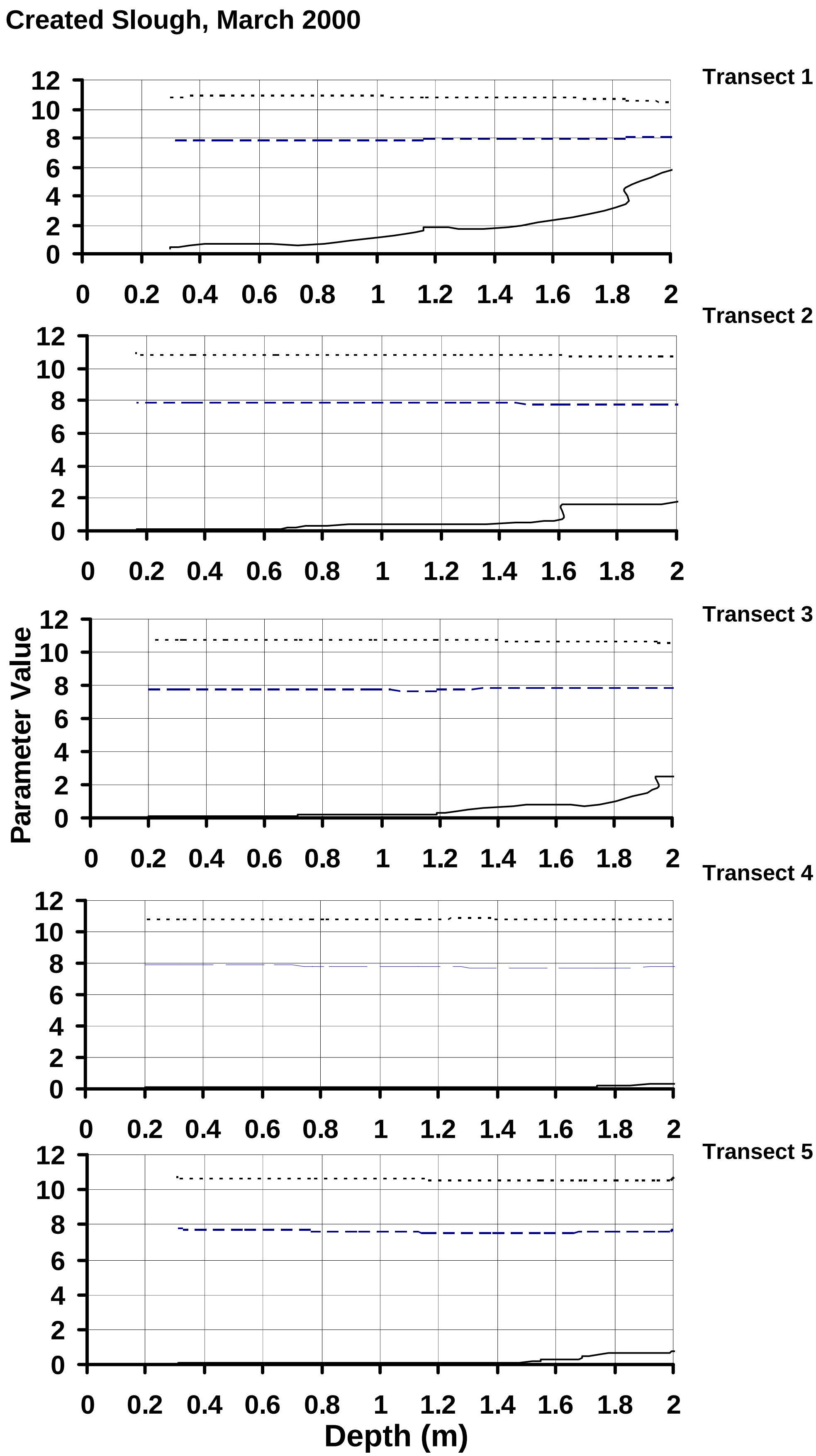

Figure 31 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at created slough, March 2000.

Reference Slough, March 2000

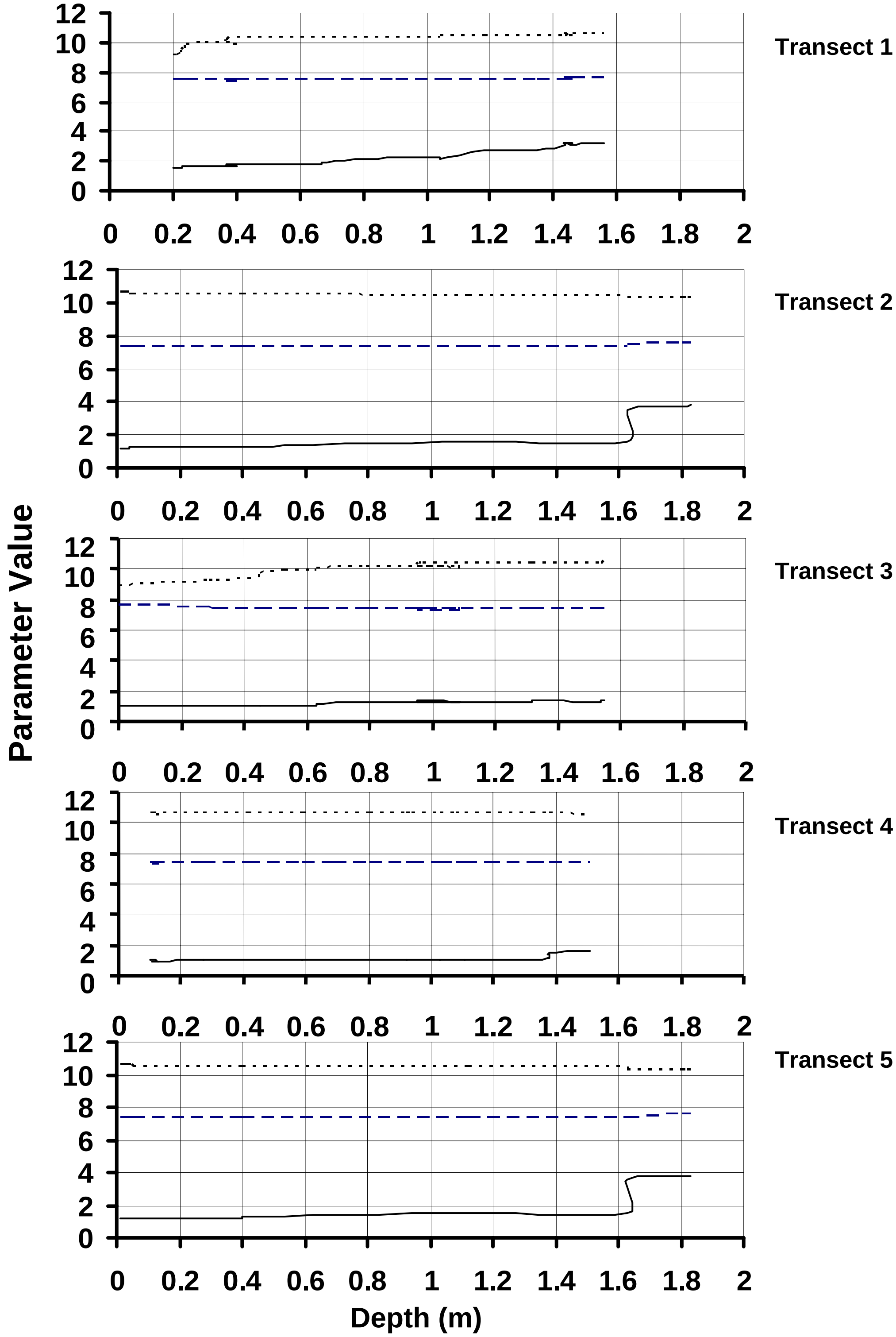

Figure 32 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at reference slough, March 2000.

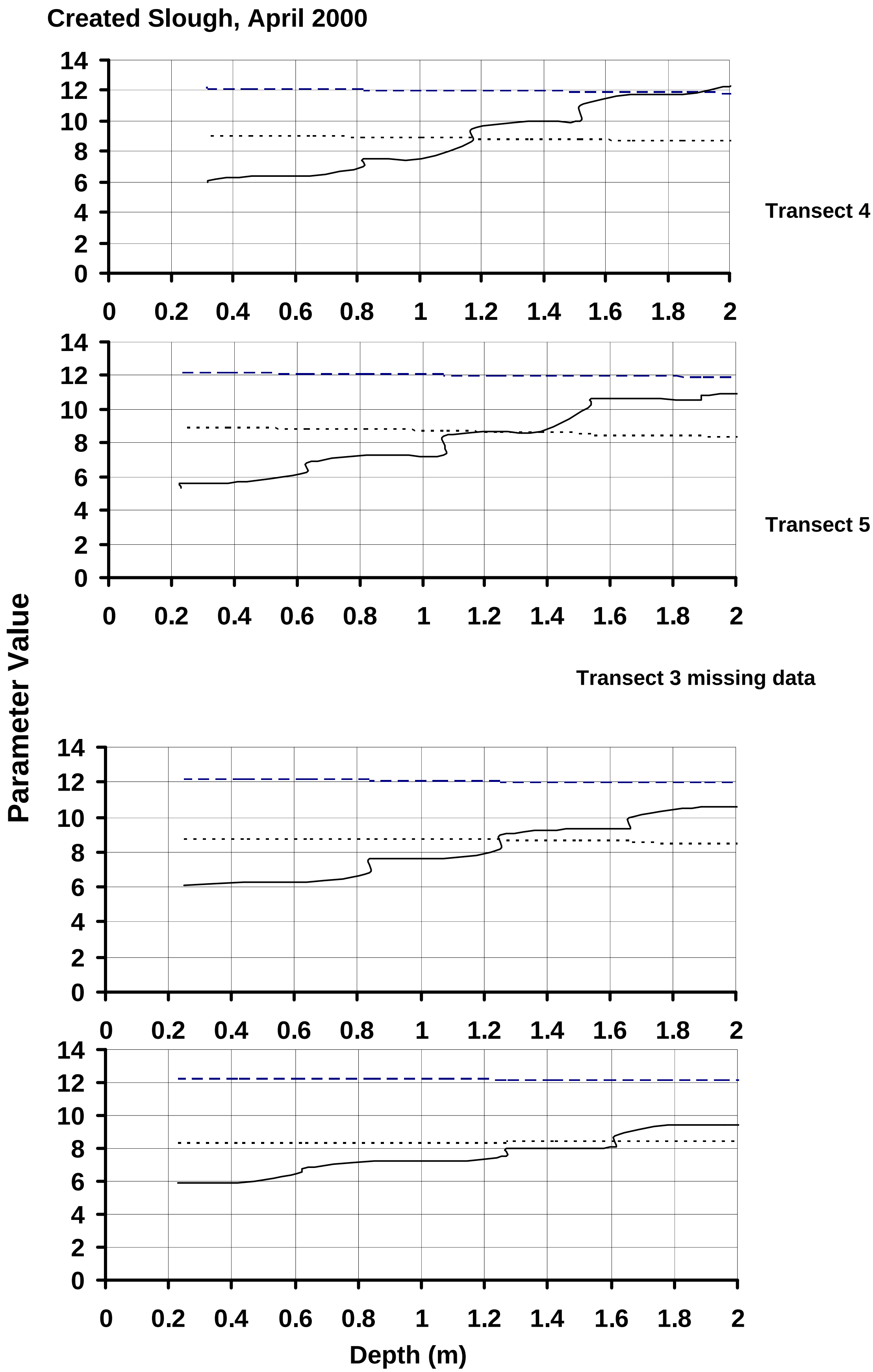

Figure 33 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at created slough, April 2000.

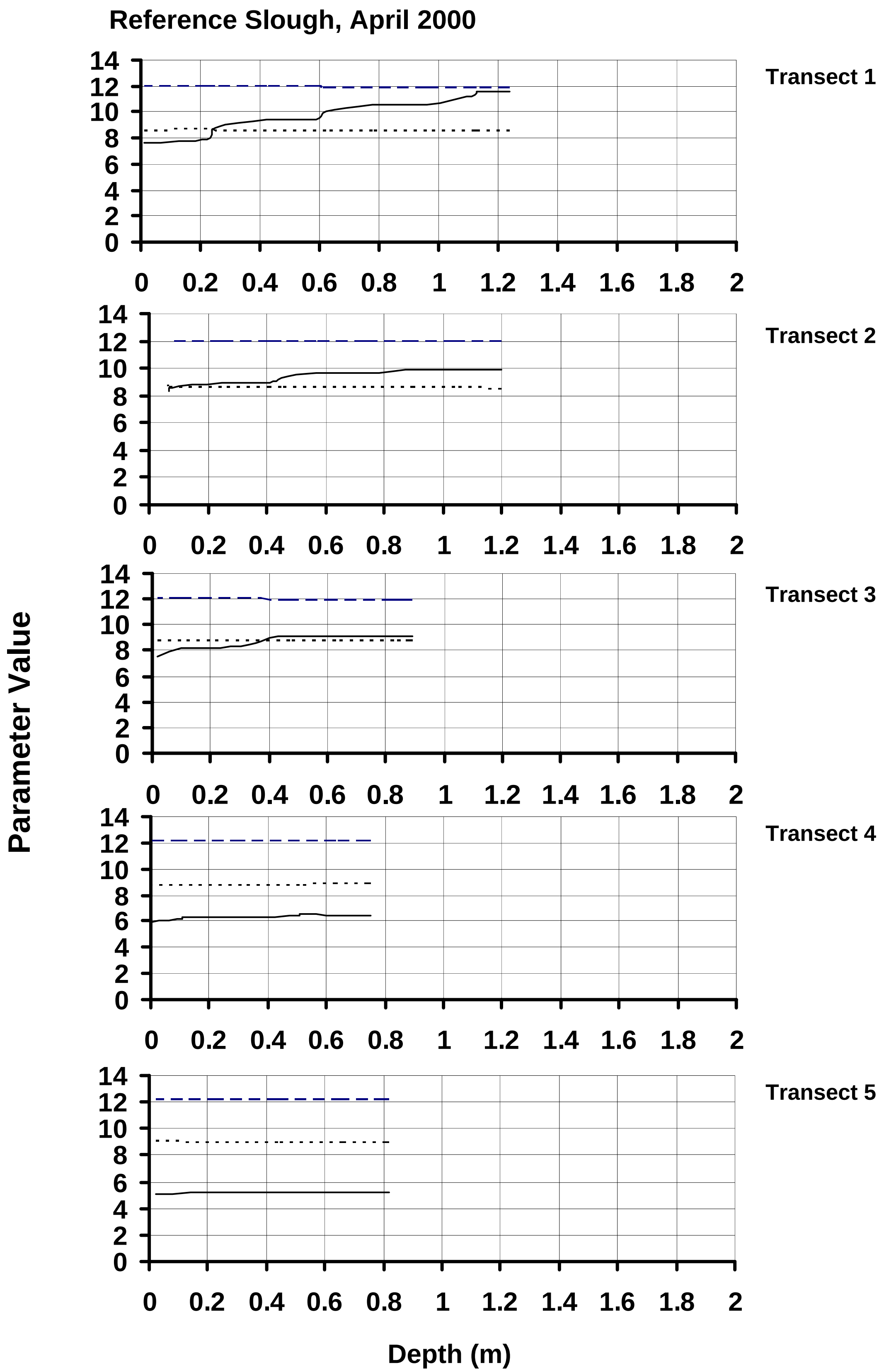

Figure 34 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at reference slough, April 2000.

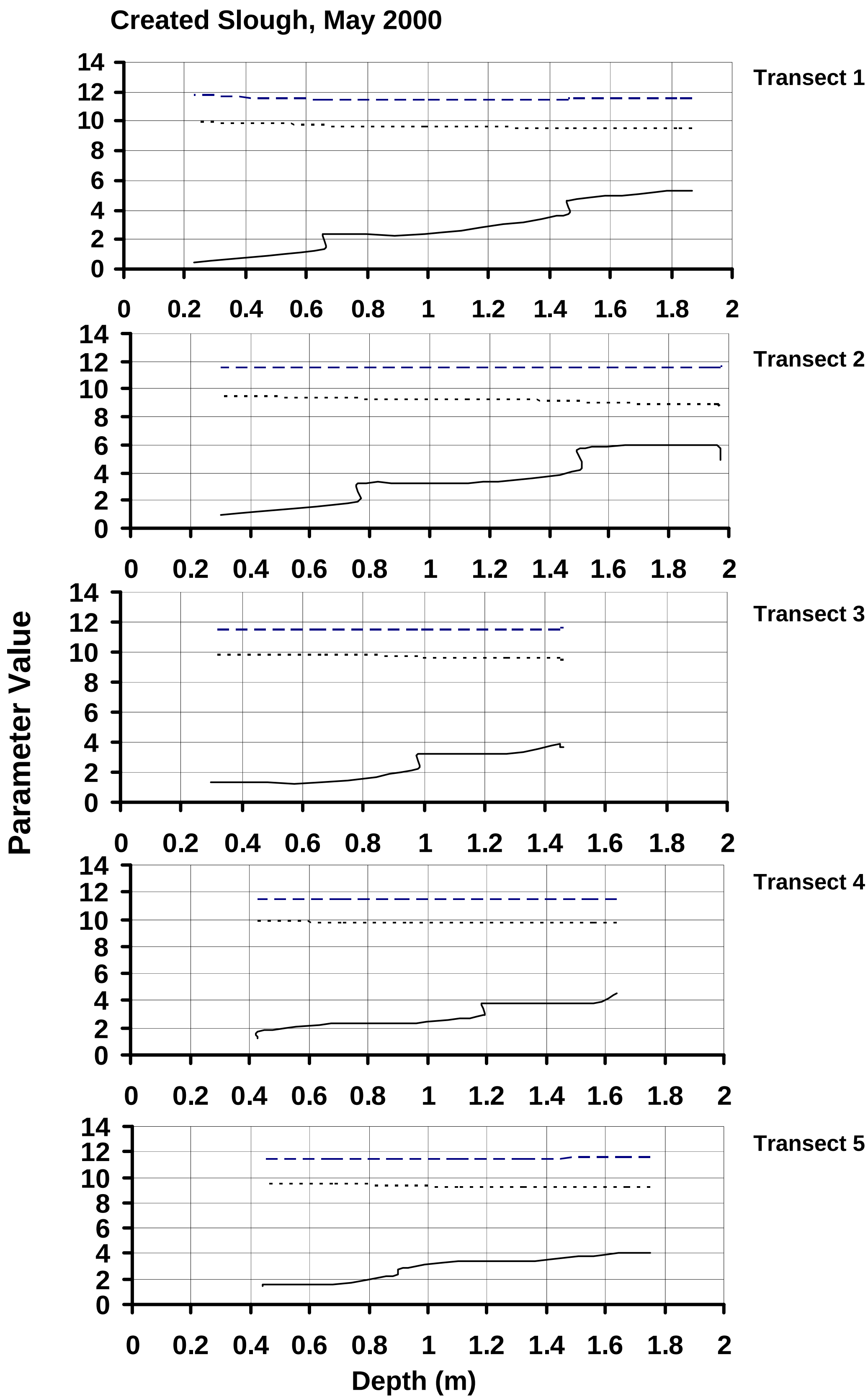

Figure 35 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at created slough, May 2000.

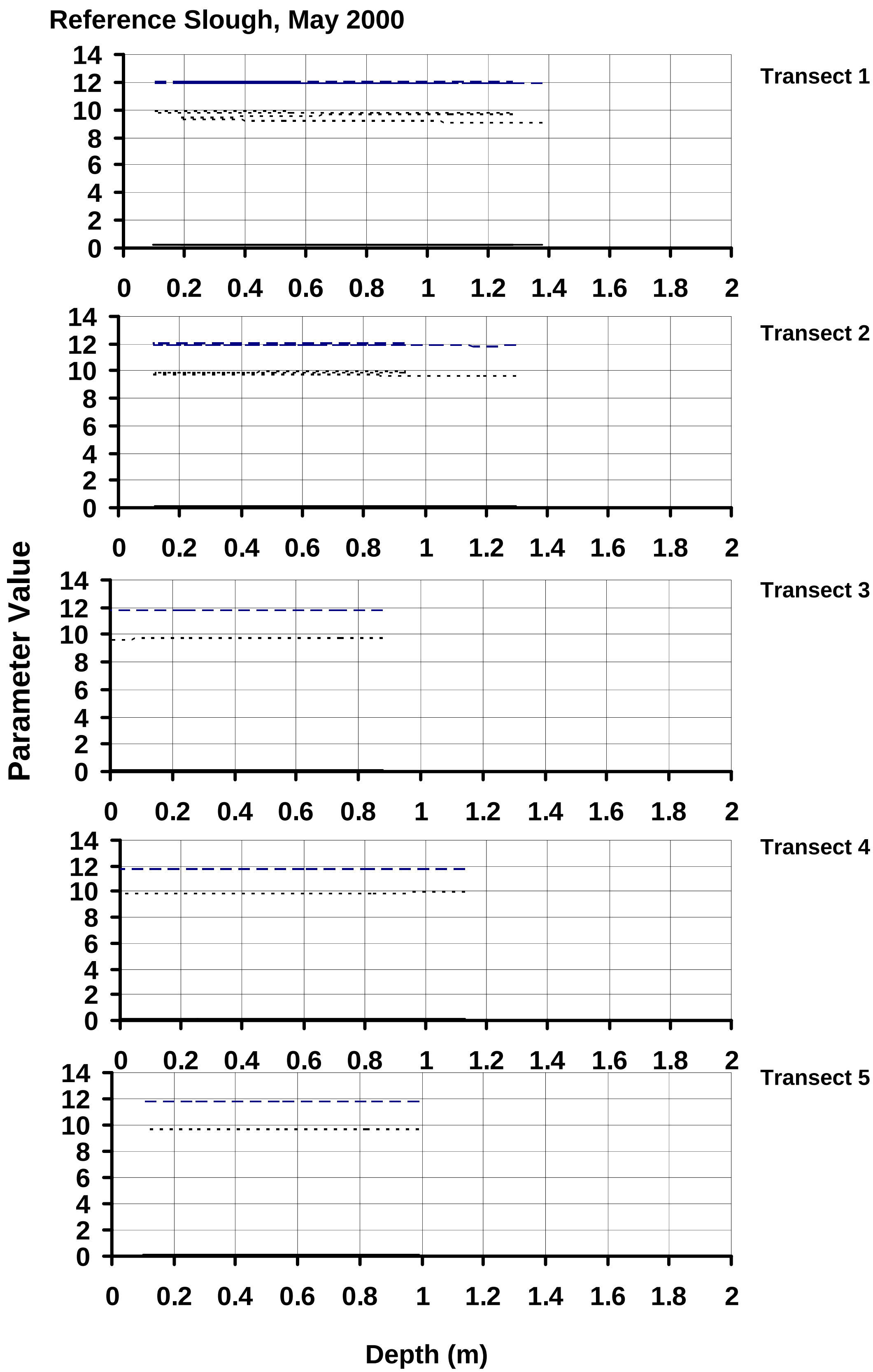

Figure 36 Water column profiles of temperature (long dashed line), dissolved oxygen (fine dashed line) and salinity (solid line) at reference slough, May 2000.

Large Woody Debris

Position of LWD in the created slough in 2000 was documented with respect to *apparent movement*, or whether pieces remained stable, shifted, appeared, disappeared since 1995 (Table 6). Of the 60 visible pieces in the 1995 image, 28 remained in a similar position as in 1995, three shifted, 14 disappeared, and 15 were unclear in the image due to shadows (Fig. 37). Of the 44 pieces visible in the 2000 image, 12 appeared since 1995 (Fig. 38). Subtracting the total number of pieces visible in 2000 (44) from those visible in 1995 (60) results in net loss of 16 pieces; but when the unclear or "shadowed" pieces are taken into account, there is a deficit of only 1 piece. Moreover, in images evaluated in this manner, apparent movement of objects is affected by the subjectivity of interpretation in graphics drawing or superimposition of wood pieces. Thus, minimal LWD movement was detected with reference to the 5-year span of this evaluation.

Table 6 LWD attributes and counts from 1995 and 2000 images

Similar position	28
Shifted	3
Appeared	12
Disappeared	14
Unclear (i.e. shadowed)	15
Total 1995	**60**
Total 2000	**44**

Discussion

Ecological conditions of the created estuarine slough in the Chehalis River estuary have matured over the nine years since construction. During our five sampling periods (including 1990, when we conducted pilot studies in the reference slough), we have generally documented, within the constraints of natural and sampling variability, rapid or increasing similarity between the created and reference estuarine sloughs (Simenstad *et al.* 1992, 1993, 1997, this document).

In terms of support of juvenile salmon, the primary design factor and assessment criterion, the ecological status of the created slough can be examined at three assessment levels: *opportunity*, *capacity* and *realized function*, or fish performance (Simenstad and Cordell 2000):

- *Opportunity*—measures of the capability of juvenile salmon to access and benefit from the habitat's capacity
    - fish occurrence and density
    - geomorphology

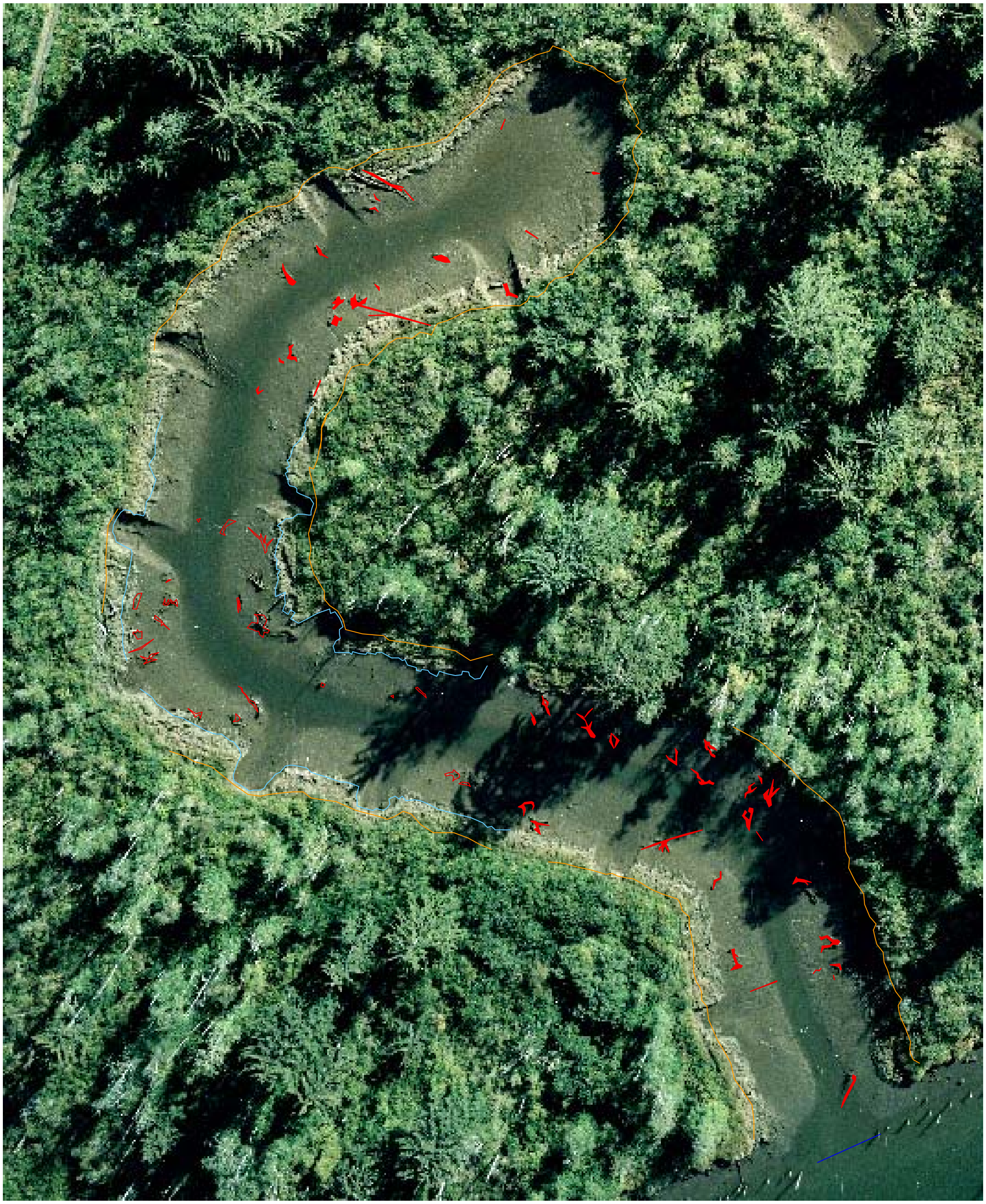

Figure 37 Delineation (red outlines)of large woody debris (LWD) in 1995 in created slough in brackish region of Chehalis River estuary, Grays Harbor, Washington; the orange line delineates the upper edge of the *Carex lyngbyei* sedge zone at the supralittoral transition to upland habitat, and the blue line the lower edge.

Figure 38 Delineation of large woody debris (LWD) from 1995 (red outlines) compared to LWD identified from 2000 aerial photography (yellow outlines) in created slough in brackish region of Chehalis River estuary, Grays Harbor, Washington; the orange line delineates the upper edge of the *Carex lyngbyei* sedge zone, at the supralittoral transition to upland habitat.

- *Capacity*—habitat attributes that promote juvenile salmon production, through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality
    - occurrence and relative abundance of selected fish prey
    - growth of primary producers and habitat-forming vegetation, e.g., *Carex lyngbyei*
    - structure such as large woody debris
    - predation by piscivorous fishes and avifauna
- *Realized function*—direct measures of physiological or behavioral responses that can be attributable to fish occupation of the habitat and which promotes fitness and survival
    - fish diet composition and feeding rate
    - fish residence time and growth

Opportunity of juvenile salmon to access and occupy the created wetland was evident from initial comparative sampling in 1991 (Simenstad *et al.* 1992). By 1995, fish community composition and densities were not qualitatively different between the two sloughs. Although the geomorphic structure of the created slough is still distinctly different, in both cross-sectional profile and plan view, from the reference slough, it appears to be progressing toward a more natural geomorphic form through the process of sediment accretion. However, because the created slough was excavated with an unnaturally deep channel, there has been no impact on accessibility; in fact, absolute accessibility in terms of hours of tidal inundation decreased dramatically during the first three to five years, as the created channel thalweg filled in.

The capacity of the created slough to support juvenile salmon occupying it has also developed rapidly in terms of both emergent vegetation and juvenile salmon prey resources. Although vegetation surveys and *Carex lyngbyei* shoot density and above-ground biomass data would indicate comparability of the created slough to the reference slough vegetation, the below-ground biomass data and experiences from other created marshes in the region (Dawe *et al.* 2000) might still suggest that functional equivalency of the slough vegetation has not necessarily been achieved, or that planting *C. lyngbyei* necessarily accelerated the process.

In general, prey resources of juvenile salmon are comparable between the two sloughs, especially in the case of fallout insects. However, the benthic community still demonstrates somewhat lower total density and different composition in the created slough relative to the reference slough. Some of these differences might be attributable to the differences in levels, timing and stratification of salinity between the two sloughs, although most of the organisms in both sloughs are estuarine species that should be tolerant within these salinity ranges. Some of the more significant differences in density of macroinvertebrates are due to higher abundances of nematodes and oligochaetes in the reference slough. Because these organisms are generally associated with more organic sediments, their lesser contribution to the created slough's benthic community may be indicative of a still-developing benthic environment relative to sediment structure. This is also substantiated by differences in the most notable for the highly-preferred prey of juvenile salmon, the gammarid amphipod *Corophium salmonis*, which is also know to be prominent in organic sediments and is more prevalent in the reference slough.

Capacity for supporting juvenile salmon has also likely increased due to the reduction in potential predation within the slough potential predators such as northern pike minnow, that were able to establish residence in the slough because of the subtidal refuge, were forced out of the slough as it became shallower with rapid sediment accretion. There is no evidence that the created slough is loosing LWD, and may in fact be trapping it through natural processes.

Realized function, or performance, of juvenile salmon is also relatively comparable in the two sloughs. Diet composition was approaching equivalency after five years (Simenstad *et al.* 1997; Miller and Simenstad 1997) and diet overlap of juvenile salmon, especially chinook, was relatively high in 2000. Throughout these changes over the decade of sampling, there were no major differences in juvenile salmon size distributions, or we stratified our diet analyses by fish length, such that fish diet is likely indicative of prey availability rather than predator size. Detailed experiments by Miller and Simenstad (1997) documented no measurable difference in juvenile chinook and coho residence times or growth rates, but there was a tendency for lower stomach fullness in the created slough, after the first two years of comparing the two sloughs.

In summary, it is evident that the structural attributes of the created slough have not reached full equivalency to the reference slough, although the trend does appear to be progressing in that direction as a result of natural sediment accretion and erosion processes continuing to restructure the created slough. Some of these processes may account for the lack of functional equivalency in several indicators, such as benthic macroinvertebrate composition and density. Continued development of these (capacity) attributes, and perhaps continued increase in realized function of the slough for juvenile salmon, will depend upon continuance of the created slough along a trajectory of geomorphic structure toward the reference slough characteristics.

This might reflect influence of variable river flow in the two years, which influences the extent of differential salinity intrusion into the two sloughs. However, daily river discharge (USGS station at Porter) between April and May in 1995 was only slightly different than in 2000. Discharge during that period varied between 2000 cfs and 5000 cfs in 1995 and between 2000 cfs and 4000 cfs in 2000; the only difference was a spring freshet up to 6000 cfs in mid-June (6/11-6/20) in 2000.

In addition to the monitoring and assessment described in the technical reports over the last decade, we have also taken advantage of the USACE support of this assessment to obtain further support (e.g., Washington Sea Grant, National Science Foundation) to support specific graduate student research projects. These have resulted in one M.S. (Miller 1993) and one Ph.D. dissertation (Hood 2000) and resulting publications (Miller and Simenstad 1997). This complementary research is continuing in 2000-2001 with investigations of the role of large woody debris in support of juvenile salmon, using the created and reference sloughs as primary study sites. Much research in riverine systems has documented LWD supporting juvenile salmon through a variety of mechanisms such as modifying fluvial geomorphology and hydrology, increasing habitat complexity, and providing a substrate for primary producers and invertebrates. While there is an extensive history of LWD presence in riverine and estuarine landscapes of the Pacific Northwest, the role of wood in salmon estuarine rearing habitats has not been determined. Assumptions regarding the similarity of the role of estuarine wood relative to riverine wood, as well as knowledge of the past removal and reduction of LWD and its sources from both freshwater and estuarine habitats, provide an impetus to study possible wood/fish relationships in estuarine systems. This research is exploring the relationship between LWD and juvenile salmon in estuarine slough ecosystems while investigating currently unchecked assumptions about the ecological function of estuarine wood. It will also seek to establish a scientific basis and template for future research into the role of LWD in other estuarine ecosystems, such as tidal marshes and mudflats. Finally, the accumulated data will contribute to a more detailed (e.g., microhabitat) understanding and interpretation of the long-term (10-yr) data set already established for both the created and reference sloughs

The extensive background information available from USACE Chehalis River studies is providing a unique opportunity to explore this topic in the River's estuarine sloughs; building on this data and a proposed conceptual model of LWD function for fish habitat, project plans were developed for the following objectives: 1) document fish species and abundance in relation to LWD amount in slough microhabitats, 2) characterize invertebrate assemblages associated with LWD (benthos, epibenthos and LWD-surface), 3) determine short-term deposition amounts for near-LWD and mudflat area slough sediments, and 4) assess spatial and temporal demography of LWD residence in estuarine sloughs. Fish are being sampled by netting areas containing differing amounts of LWD and the relationship of wood-to-fish abundance will be explored, while benthic, epibenthic, and wood-surface invertebrates will be sampled in near- and away-from wood areas to characterize assemblages in LWD habitats. Sediment deposition dishes are being deployed in near- and away- from wood areas for comparisons in short term (1-2 tide cycles) sedimentation amounts. A GIS approach will also be applied to aerial photos supplied by USACE to examine abundance and relative movement of LWD over the 7-year time series for which photos exist.

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References

Cailliet, G.M. 1977. Several approaches to the feeding ecology of fishes. Pages 1-13 *in* C.A. Simenstad and S.J. Lipovsky (eds.), Fish Food Habits Studies. Proc. First Pacific Northwest Technical Workshop, 13-15 October 1976. Wash. Sea Grant Publ. WSG-WO-77-2, Univ. Washington, Seattle. 193 p.

Cordell, J. R., L. M. Tear, C. A. Simenstad, S. M. Wenger, and W. G. Hood. 1994. Duwamish River Coastal America restoration and reference sites: results and recommendations from year one pilot and monitoring studies. FRI-UW-9416, Fish. Res. Inst., Univ. Wash., Seattle, WA.

Dawe, N. K., G. E. Bradfield, W. S. Boyd, D. E. C. Trethewey, and A. N. Zolbrod. 2000. Marsh creation in a northern Pacific estuary: Is thirteen years of monitoring vegetation dynamics enough? Conserv. Ecol. 4: 12. [online, URL:http://www.consecol.org/vol4/iss2/art12]

Hammar, D. A. 1992. **Creating Freshwater Wetlands**. Lewis Publ., Boca Raton, FL. 298 pp.

Hood, W. G. 2000. Landscape allometry of oligohaline tidal channels of the lower Chehalis River, Washington. Ph.D. dissertation. Univ. Washington, Seattle, WA. 166 pp.

Hood, W. G. In press. Application of landscape allometry to restoration of tidal channels. *Restoration Ecol.*

Miller, J. A. 1993. Short-term growth, residence and foraging of juvenile chinook and coho salmonuse of a natural and created estuarine slough on the Chehalis River, WA. M.S. thesis, Univ. Wash., Seattle, WA.

Miller, J. A., and C. A. Simenstad. 1994a. Growth of juvenile coho salmon in natural and created estuarine habitats: A comparative study using otolith microstructure analysis. FRI-UW-9405. Fish. Res. Inst., Univ. Wash., Seattle, WA. 30 pp.

Miller, J. A., and C. A. Simenstad. 1994b. Otolith microstructure preparation, analysis, and interpretation: A potential habitat assessment tool. FRI-UW-9406. Fish. Res. Inst., Univ. Wash., Seattle, WA.

Miller, J. A., and C. A. Simenstad. 1997. A comparative assessment of a natural and created estuarine slough as rearing habitat for juvenile chinook and coho salmon. *Estuaries* **20**:792-806.

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands. 3rd Edition, John Wiley & Sons, Inc., New York, NY. 920 pp.

National Research Council (NRC). 1992. **Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy**. Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, Water Science and Technology Board552 pp., Natl. Res. Council, Natl. Acad. Press, Washington, D.C. 322 pp.

National Research Council (NRC). 2001. **Compensating for Wetland Losses Under the Clean Water Act**. Committee Mitigating Wetland Losses, Board Environ. Studies Toxicol., Natl. Res. Council, Natl. Acad. Press, Washington, D.C. 322 pp.

Pinkas, L., M.S. Oliphant, and I.L.K. Iverson. 1971. Food habits of albacore, bluefine tuna, and bonito in California water. *Calif. Fish Game Fish Bull.* **152**:1-105.

Sabine, B. J. (ed.) 1993. National list of plant species that occur in wetlands, Region 9-northwest. Res. Mgmt. Group, Inc., Grand Haven, MI. 72 pp.

Simenstad, C. A., and J. R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. *Ecol. Engineering* **15**:283-302.

Simenstad, C. A., and R. M. Thom. 1996. Assessing functional equivalency of habitat and food web support in a restored estuarine wetland. *Ecol. Appl.* **6**:38-56.

Simenstad, C. A., J. R. Cordell, W. G. Hood, J. A. Miller and R. M. Thom. 1992. Ecological status of a created estuarine slough in the Chehalis River estuary: Report of monitoring in created and natural estuarine sloughs, January-December 1991. FRI-UW-9206. Fish. Res. Inst., Univ. Wash., Seattle, WA. 49 pp.

Simenstad, C. A., J. R. Cordell, J. A. Miller, W. G. Hood, and R. M. Thom. 1993. Ecological status of a created estuarine slough in the Chehalis River estuary: Assessment of created and natural estuarine sloughs, January-December 1992. FRI-UW-9305. Fish. Res. Inst., Univ. Wash., Seattle, WA. 56 pp.

Simenstad, C. A., J. R. Cordell, W. G. Hood, B. E. Feist, and R. M. Thom. 1997. Ecological status of a created estuarine slough in the Chehalis River estuary: Assessment of created and natural estuarine sloughs, January-December 1995. FRI-UW-9621, Fish. Res. Inst., School Fish., Univ. Wash., Seattle, WA. 47 pp.

Streever, W. J. (ed.). 2000. Salt marshes created from dredged material. Spec. Issue, *Wetl. Ecol. Mgmt.* **8**.

Wick, A. J. 2002. Ecological function and spatial dynamics of large woody debris in oligohaline-brackish estuarine sloughs for juvenile Pacific salmon. M.S. thesis, Univ. Washington, Seattle, WA. 112 pp.

Appendices

A. Study Plan

Year 2000 Study Plan

Taking into account our experiences and adaptive modifications of the basic sampling design since 1990, we adopted a study plan for 2000 that is consistent with the intent of the long-term schedule for monitoring (Table A-2) but provides the best decadal assessment of the status of the created slough. Our criteria for selecting monitoring parameters and sampling design and methodology include:

1. maintain all continuous time series, with emphasis on slough fish (tidal channel fyke trap), vegetation and water quality sampling;
2. enhance sampling on potentially sensitive indicators of created slough development, such as the above- to below-ground *Carex lyngbyei* biomass ratio and fish diet composition and fullness (Miller and Simenstad 1994a, 1997) that are the only indicators showing some delayed convergence;
3. adopt sampling of benthic/epibenthic/neustonic invertebrates that best characterizes fish prey availability;
4. repeat measurements that document changes in slough structure, and would provide evidence for observed differences in biota, e.g., geomorphology and large woody debris; and,
5. gather other information as need to aid in final interpretation of the decade of monitoring results, e.g., large woody debris measurements and tide gauge to assess frequency and duration of flooding at different tidal elevations.

B. Estuarine Sloughs Database

We have organized all digital data from the 1990-2000 monitoring of the Chehalis River created and reference sloughs into the Estuarine Sloughs Database (chehalis.mdb) using Microsoft Access™. More information and assistance regarding Access can be found at the relevant Microsoft websites:

Data Origin

Data was compiled from files in the following formats: Microsoft Excel™, Cricketgraph™ (MAC), ASCII, and entered from hard copy reports to the USACE (available from Publications Office, School of Fisheries, University of Washington). Tables were initially constructed in Excel™ and imported into Access™. Some data, such as the GPS geomorphic measurements and GIS or other graphical layers, which is principally in second- or third-order analytical form will be entered into the database as we convert the virgin data into a transferable format. All data gathered during the Year 2000 monitoring will be input into the database in the same format, for which we will develop Access™ data entry forms, which will enable direct incorporation into the respective data tables.

Database Structure

Tables

Access™ tables were organized for the following categories of monitoring parameters:

- Fish
  - Year
  - Month
  - Slough
  - Fish group (salmon, other, total fish)
  - Species/common name (e.g. chum, coho)
  - Raw Count
  - Mean Raw Count
  - SD Raw Count
  - Density
  - Mean Density
  - SD Density
  - Species Richness (for total fish caught)
  - Mean Species Richness ("   "   )
  - SD Species Richness ("   "   )
- Vegetation (principally *Carex lyngbyei*)
  - Year
  - Slough
  - Mean Shoot Density
  - Mean Above-ground Biomass
  - Mean Below-ground Biomass
  - Ratio of Mean B-G to A-G Biomass
- Water Quality
  - Year
  - Month
  - Day
  - Real time (where applicable)
  - Slough
  - Transect number
  - Depth
  - pH
  - Dissolved Oxygen (DO)
  - Conductivity
  - Salinity

Queries

To facilitate direct and standardized analysis of the monitoring time-series data, we also developed Access™ queries that are designed to perform routine data selections for graphical input to Excel or statistical software packages. Queries were developed for the following retrieval categories and parameters:

- Chinook Density
  - Year
  - Month
  - Slough
  - Fish group (salmon)

- Species/common name (chinook)
- Density
- SD Density

- Coho Density
  - Same as above except for coho
- Chum Density
  - Same as above except for chum
- Other Fish Density
  - Same as above except for all other fish taken as one group
- Fish Species Richness
  - Year
  - Month
  - Slough
  - Fish group (total fish)
  - Species Richness
  - SD Species Richness

- Carex Shoot Density
  - Year
  - Slough
  - Mean Shoot Density
- Carex Above-Ground Biomass
  - Year
  - Slough
  - Mean Above-Ground Biomass
- Carex Belowground Biomass
  - Year
  - Slough
  - Mean Belowground Biomass
- Carex Above-Ground to Below-Ground Biomass Ratio
  - Year
  - Slough
  - Above-ground to Below-ground Ratio
- Salinity all years
  - Year
  - Month
  - Slough
  - Transect number
  - Depth
  - Avg of salinity
- Temps all years
  - Same as Salinity all years, except Avg of temps, not salinity.

Limitations and Anticipated Additions

Data gaps are due to lost/missing data as a result of sampling mechanism failure, inclement weather, or other logistical problems in sampling or data compilation. We anticipated adding the following tables and queries into the database over the next year:

- Prey Resources (Benthos, neuston)
- Stomach contents (prey)
- Geomorphology