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THE LINCOLN AVENUE WETLAND SYSTEM IN THE PUYALLUP RIVER ESTUARY, WASHINGTON

Phase III Report: Year Three Monitoring, January - December 1988

by

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WETLAND ECOSYSTEM TEAM

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EXECUTIVE SUMMARY

The major objective of our 1988 monitoring program was to evaluate the functional performance of the restored wetland as a temporary residence and foraging area for juvenile salmon (Shreffler 1989). In addition, sediment characteristics, vegetation, infauna, epibenthic plankton, and birds were sampled to evaluate the functional performance of the system relative to target resources (see Figures 1-3). The findings of the 1988 monitoring program were as follows:

1. Twenty-two species (ten families) of oligohaline and euryhaline fish have appeared in the wetland since the dike was breached February 20, 1986--juvenile chum salmon (*O. keta*) and fall chinook salmon (*O. tshawytscha*) were the two most abundant species.
2. Mark/recapture studies indicated that the outmigrating hatchery juvenile chum salmon and the outmigrating hatchery fall chinook salmon accessed the wetland.
3. Estimated individual residence times averaged 2 days and ranged from 1 to 9 days for juvenile chum and averaged between 5 days (volitional) and 38 days (spray-marked) (total range 1 to 43 days) for juvenile fall chinook.
4. Juvenile chum and fall chinook foraged in an apparently selective manner on chironomid insects (midge larvae, pupae, and adults) over all other organisms in the available prey spectrum.
5. There was little overlap between epibenthic prey available (primarily Harpacticoida, Cladocera, and Insecta) and the prey consumed by juvenile chum and fall chinook.
6. Neustonic organisms (drift) which were advected into the wetland from the Puyallup River may have been a major source of prey for juvenile chum and fall chinook foraging in the restored wetland.
7. A detritus-based food chain (detritus-chironomids-juvenile salmon) appears to support a continuously developing emergent wetland community.
8. As in 1987, sediment algae appear to be abundant at times and highly productive, and may be contributing significantly to the food web in the wetland and the river.
9. Carex is doing best at the perimeter on flats 1, 2, 6, 7 and is being outcompeted by Typha on upper flat 4.
10. Sediment accretion in the channels and mid-bay dramatically changed the bathymetry and morphology of the system.
11. Upland vegetated habitats, including the grassland, swamp and cattail (*Typha* spp.) marsh, appeared viable.
12. By December 1988, 92 species of birds had been observed in the system. There was a slight increase in the number of bird species in the system in 1988 as compared to 1987.

We conclude that the system continues to serve the target resources for which it was designed. The system is undergoing rapid and dramatic physical, chemical and biological changes, and is presently in an early stage of development. Continued monitoring of the restored wetland through 1990 will not only increase our understanding of the functional value of this wetland to target resources such as juvenile salmon but should also have a significant bearing on the design and monitoring of future mitigation wetlands of this type. Maintenance recommendations include continued monitoring of sediment accretion, and control of trash and illegal dumping. We also strongly recommend that development of the site as a nature preserve be expedited.

INTRODUCTION

As mitigation for filling a 9.6-acre parcel of land (Parcel 5; Fig. 1) containing wetland and upland habitats, the Port of Tacoma constructed a similarly sized wetland system in the tidally-influenced portion of the Puyallup River. Construction included establishment of a sedge (*Carex lyngbyei*) marsh through initial transplantings. The new wetland system, located at the intersection of the Lincoln Avenue bridge and the Puyallup River (Fig. 1), was connected to the Puyallup River estuary via a breach in the river dike in February 1986. The first report (Thom et al. 1987) on the project details the construction and first-year monitoring results. This initial monitoring work showed that approximately 100% of the transplanted sedge survived through the first growing season. In addition, target resources including juvenile salmonids, shorebirds and waterfowl occupied and apparently utilized the system. On the basis of these findings, it was concluded that the wetland system satisfied ecological performance criteria established as part of the mitigation agreement (Thom et al. 1987). However, the system was in an early stage of development and, similar to any new ecological system, changes were expected in subsequent years.

Our principal focus in 1988 was evaluation of the functional performance of the restored wetland as a temporary residence and foraging area for outmigrating juvenile salmon. Experiments were conducted to estimate juvenile chum and chinook salmon access to, and residence times within, the restored Lincoln Avenue wetland. The role of the wetland as a potential foraging area for outmigrating juvenile salmon was also evaluated. In addition to fish sampling, intensive biological and physical monitoring studies to evaluate the functional performance of the system relative to target resources included sampling of sediment characteristics, vegetation, infauna, epibenthic zooplankton, and birds. Data gathered from these monitoring studies can be used to design a more limited, but ecologically meaningful, future monitoring effort.

STUDY SITES

The wetland system contains an upland area with a grassland, riparian hardwoods, cattail marsh and swamp, and an intertidal area consisting of mudflats and tidal channels (Fig. 2). In 1988, sampling of vegetation, infauna, epibenthos and fish was carried out in the newly constructed intertidal area. Birds were sampled in all habitats. A total of forty sampling sites (30 on the flats, five in channel 4 and five in the mid-bay) were established for sampling (Fig. 3) and were marked with wooden stakes to facilitate relocation during subsequent visits. All flats except flat 5 were planted with *Carex*, and flat 5 served as an unplanted reference area (Thom et al. 1988).

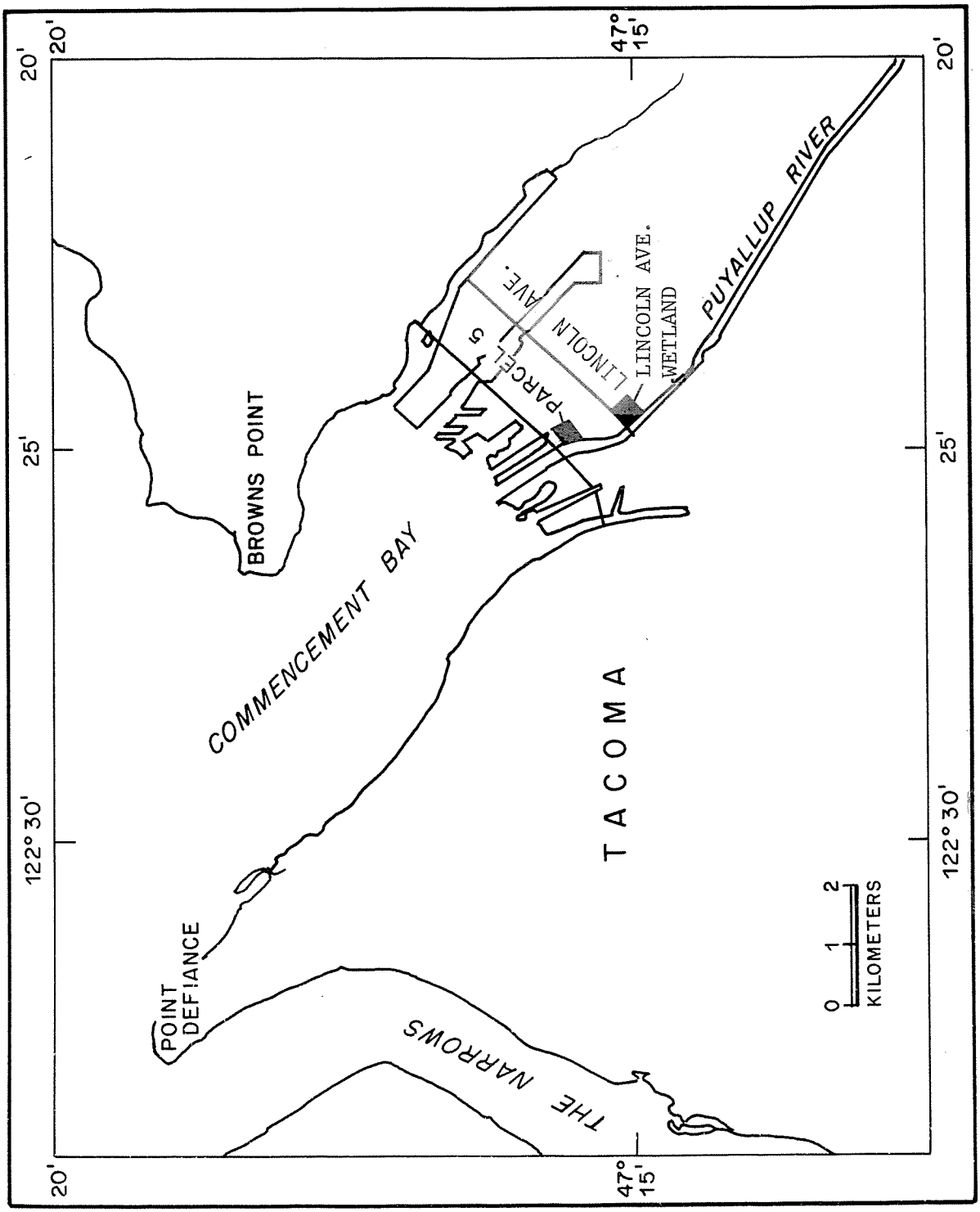


Figure 1. Location of Parcel 5 and the Lincoln Avenue wetland system.

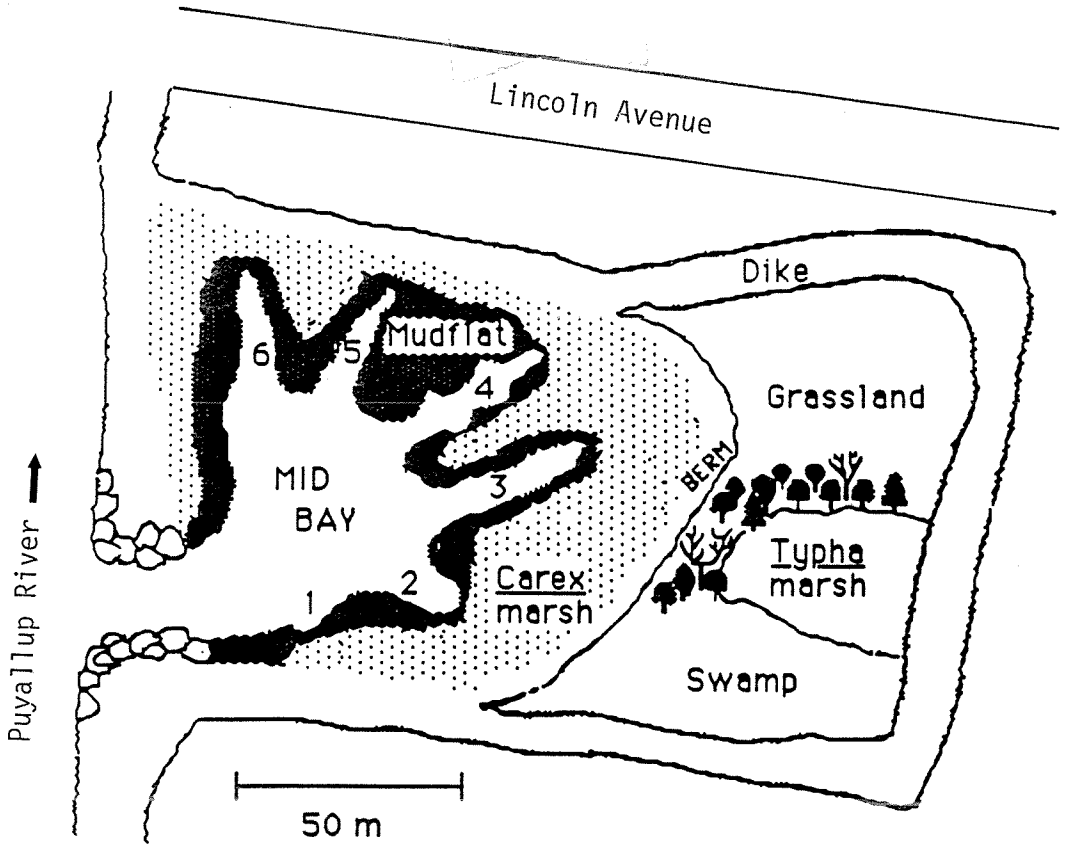


Figure 2. Distribution of the various habitat types within the Lincoln Avenue wetland system.

MATERIALS AND METHODS

SEDIMENT CHARACTERISTICS

Sediment characteristics monitored in 1988 included grain size, volatile solids and surface sediment height. Grain size and volatile solid concentration measure the particle size distribution and organic matter content, respectively, of the sediment. These conditions affect the benthic animal assemblages and help explain changes seen in animal assemblages. Sediment surface height indicates the amount of sedimentation or erosion that has occurred at a particular site. Cores of surface sediments 10-cm deep were collected using the same methods and 20 sampling sites outlined in Thom et al. (1988). In addition, small core (2.1 cm inside diameter x 2 cm deep) samples were taken of sediments at the 20 sites for volatile solids analysis. Grain size was determined using standard sieve and pipette analysis. Volatile solids were measured as the percent loss of weight of a sample of sediment due to ashing at 500°C for 4 hour in a muffle furnace (Thom et al.

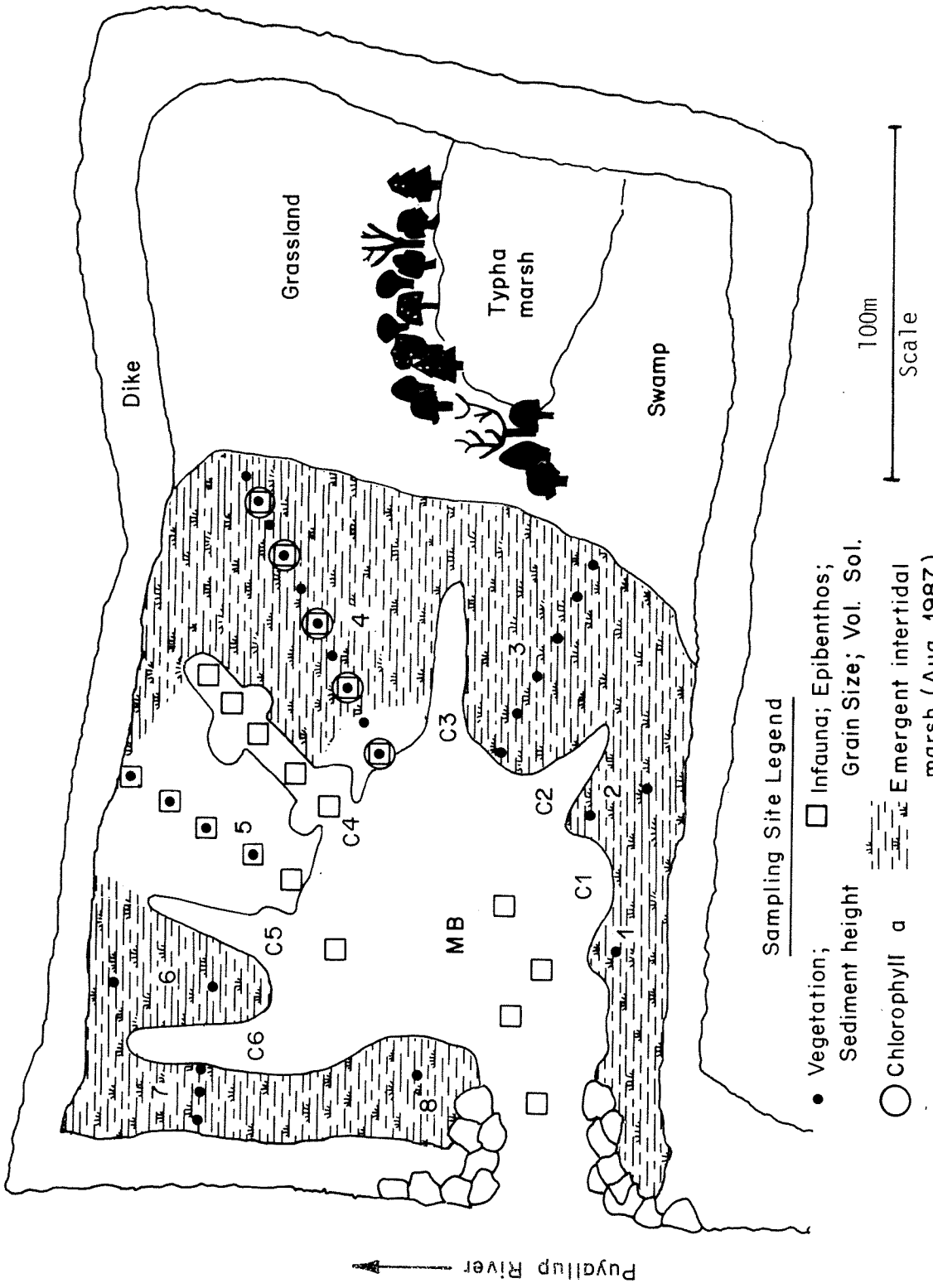


Figure 3. The wetland system showing sampling site on intertidal flats numbered 1-8, channels numbered C1-C6, mid-bay (MB), and adjacent grassland, cattail marsh and swamp habitats.

1987). Grain size and volatile solid sampling was conducted on 21 April in conjunction with infauna sampling.

Sedimentation on the flats was monitored using 29 permanent markers. The markers consisted of wooden stakes driven to a depth such that the top of the stake was 20 cm above the sediment surface. The distance from the top of the stake to the ground surface was recorded on 7 April and 21 September 1988.

VEGETATION

In total, 48,800 shoots of *Carex* with attached roots and rhizomes were transplanted in the Lincoln Avenue wetland system during 1986 and 1987 (Thom et al. 1988). No additional *Carex* was transplanted in 1988.

Chlorophyll *a* and phaeopigment concentrations were determined as a measure of important sediment-associated microalgal biomass from sediment cores (1-cm diameter x 1-cm deep) taken at five sites (12, 28, 44, 60, 76 m) along the flat 4 transect. Samples were collected in April and September of 1988. Sample processing followed the methodology of Thom et al. (1987).

Emergent macrophyte (i.e., rooted plants) percent cover, density and above ground biomass was sampled in April and September at the 29 intertidal sites located on flats 1-8 (Fig. 3); the lowest site on flat 5 was not included. As in 1987 (Thom et al. 1988), macrophyte percent cover was estimated from photographs taken from directly above the center of each 1-m^2 area within a quadrat positioned at each site.

To document the distribution of plants, vertical color aerial photographs were taken from an airplane on 27 July 1988. The negatives were 9 in x 9 in, and the scale for color prints made from the negatives was 1 in = 200 ft. The distribution of major plant assemblages and bottom types was traced from the photographs. These tracings were compared to identical photographs of the system taken on 31 March 1986 and 26 July 1987. All photographs were taken when the predicted tide level was at or below MLLW (U.S.G.S. tidal datum).

INFAUNA

As an indicator of biological assemblage development in the sediment, infauna were sampled on 21 April at the same 20 sites where grain size and volatile solids samples were collected (Fig. 3). The core sampler used for grain size collections was used for infauna sampling. The infauna cores were also 10-cm deep. The samples were placed in labelled plastic jars and preserved in 10% buffered formalin. Following preservation for at least 48 hour, the samples were gently washed on a 0.5-mm mesh sieve, and the animals and other material retained on the screen were

stained with rose bengal and preserved in 70% alcohol. The animals retained on the screen were identified to major taxonomic levels (e.g., nematode, oligochaete, insect larva) and enumerated.

EPIBENTHOS AND NEUSTON

As a measure of biological assemblage development on the sediment surface, and as an indicator of potential fish prey resources, epibenthic animals were sampled using the epibenthic suction pump technique employed in the 1986 monitoring effort (Thom et al. 1987). At the 20 sites used for infauna sampling, epibenthic animals were sampled from within a 0.016 m^2 area and collected on a 150 μm mesh screen (Fig. 4). Epibenthic sampling was conducted on 7 April 1988 during the estimated period of peak juvenile salmon outmigration. Samples were preserved in 5% buffered formalin and later transferred to 50% alcohol in the laboratory. Organisms were identified to species where possible, enumerated, and weighed to the nearest 0.1 mg (wet weight).

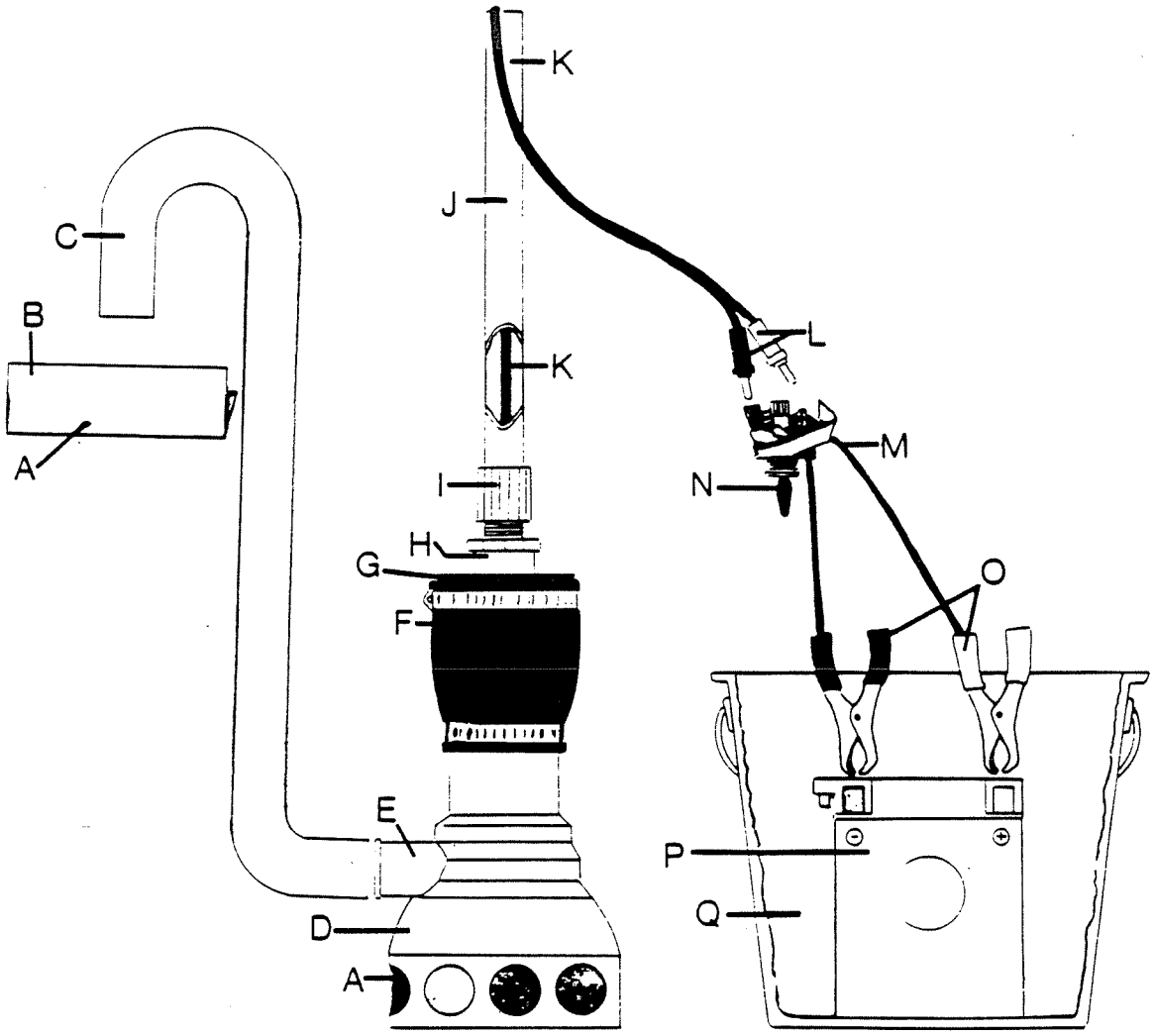
Neustonic (drift) organisms were sampled biweekly (March 30-June 23, 1988) at the mouth of the wetland using a modified neuston net of 253 μm mesh (Fig. 5). The net was positioned in the current for 5 minutes and the volume of water sampled was calculated from a flow meter suspended from the net. The net was monitored and repositioned, if necessary, to prevent clogging with large organic debris, logs, and garbage in the surface drift. In the laboratory, each neustonic sample was filtered directly through a 150 μm mesh sieve and preserved in 5% buffered formalin. All organisms were sorted, identified under a dissecting microscope to the lowest possible taxonomic/life history level, enumerated, and weighed to the nearest mg (wet weight).

FISH

Beach seine sampling in 1986 indicated that juvenile salmon were entering the wetland within 2 months of the breaching of the wetland dike (Thom et al. 1987). The wetland fish assemblage was systematically sampled in 1987 (Thom et al. 1988; Shreffler 1989) and 1988 (Shreffler 1989) and experiments were conducted to determine juvenile chum and fall chinook salmon access to, and residence times within, the restored wetland. Chum and chinook salmon have been the primary salmon species caught in the wetland to date.

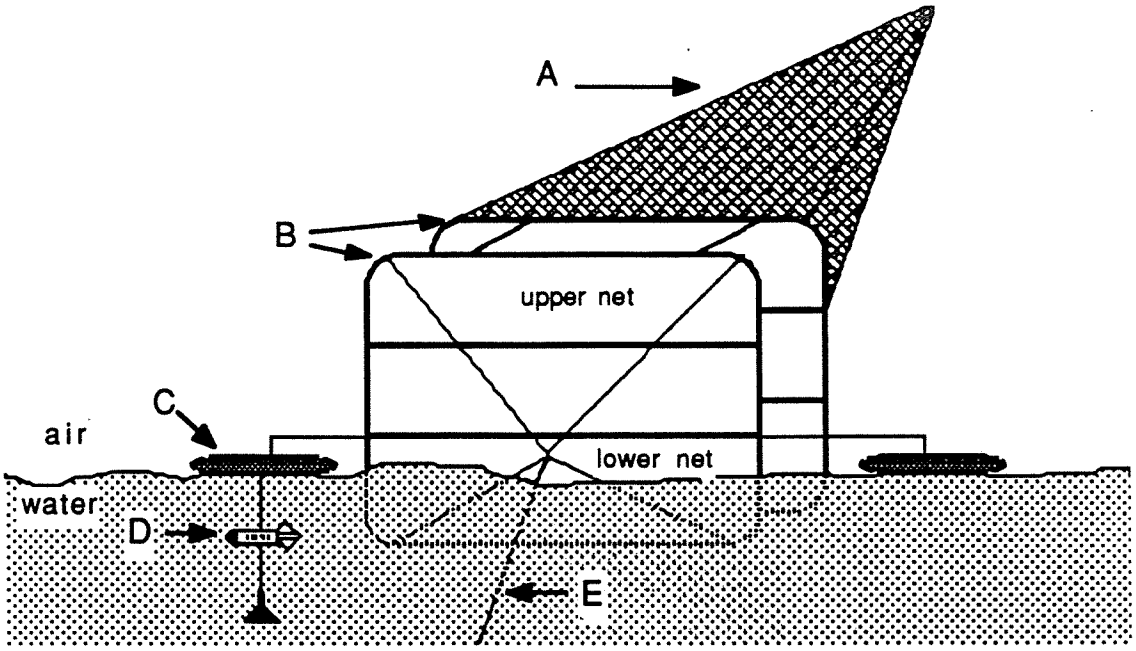
General Sampling Design

The access experiments were conducted to evaluate what proportion of the juvenile salmon outmigrants might be expected to swim into the Lincoln Avenue wetland. The experiments were not designed to strictly evaluate the functional performance of the system, but were intended to provide useful data on the behavior of the outmigrants. Very little information of this type exists elsewhere for comparative purposes. In the access experiments, chum salmon (1987) and fall chinook salmon (1988) were spray-marked and released into Clark's Creek, a tributary of the



A. .25 mm mesh screen
B. pvc collecting sieve
C. clear plastic hose
D. sampling cylinder (height = 10.3 cm, diameter = 14.8 cm)
E. rule 1500©electric bilge pump
F. 3" x 3" nohub
G. 1 1/2" x 3" reducer
H. 1" x 1 1/2" reducer
I. 1" female adaptor
J. 1" pvc handle (elongated or shortened for sampling at various depths)
K. cord
L. connectors
M. duct tape
N. switch
O. battery clips
P. 12 vlt motorcycle battery
Q. holding bucket

Figure 4. Schematic of the epibenthic suction pump used for sampling organisms living at the sediment/water column interface of the Lincoln Avenue wetland; sampling cylinder and screen measurements are in centimeters; all other measurements are in inches as purchasing dictates. (Drawing courtesy of Betsy Peabody, Adopt-a-Beach.)



A. Plankton net: 253-µm mesh, opening 23-cm x 63-cm, 145-cm long narrowing to 8-cm end which attaches to a 253-µm codend: (upper and lower nets were identical, but only lower net was used since the gear was fished passively rather than towed as designed

B. 1.27-cm pvc frames 63-cm x 63-cm; front and back identical and separated by 33-cm pvc crossbars

C. styrofoam float 30-cm wide x 110-cm long x 2.54-cm thick

D. Ocean Dynamics flow meter suspended 23-cm below the float and weighted with a 113 g lead

E. polypropylene tow rope

Figure 5. Schematic of the neuston net used for 1988 sampling of emergent insects and other drift organisms in the Lincoln Avenue wetland.

Puyallup River 4.8 km upstream from the wetland. The spray-marked fish were recaptured and held alive in the inlet net of an inlet/outlet fyke net system constructed at the mouth of the wetland (Fig. 6). The fyke net system was designed and constructed to quantify ingress (fish captured in the inlet fyke net) and egress (fish captured in the outlet fyke net). The inlet and outlet fyke nets were checked daily at low slack tide from May 6 to June 16, 1987 and March 11 to June 30, 1988. Juvenile salmon in the inlet fyke net were transferred to buckets and anesthetized with MS-222. Spray-marked fish were detected using a battery-operated ultraviolet light and preserved immediately in 10% buffered formalin. Unmarked fish were marked with clips on some combination of the ventral, caudal, or anal fins and released into the wetland to evaluate wetland residence times.

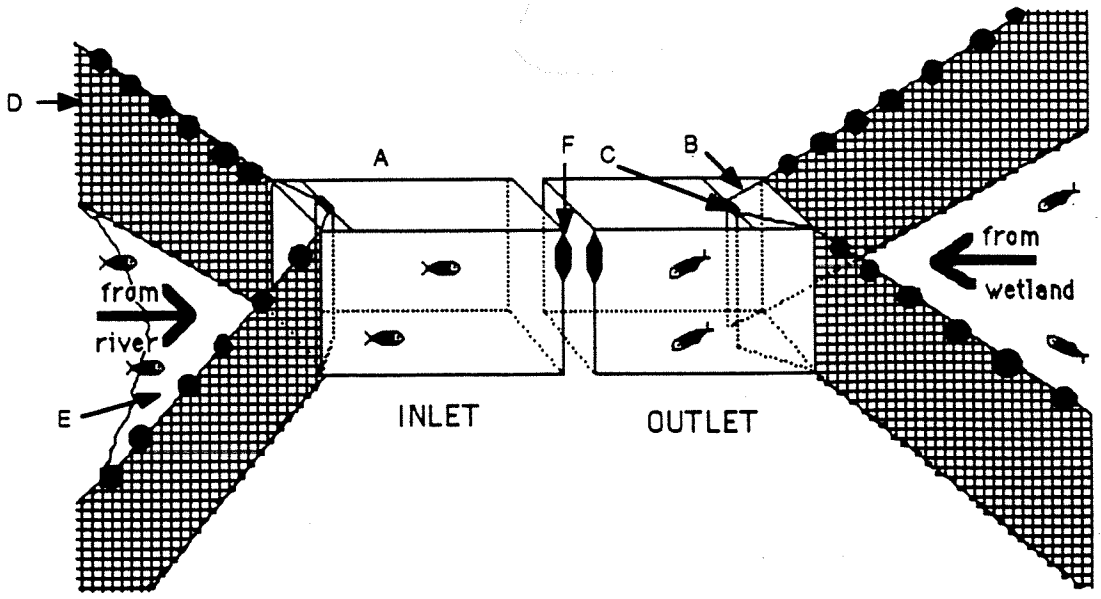
Independent estimates of juvenile salmon wetland residence times were derived from: (1) fish which volitionally migrated downstream, were captured in the inlet fyke net, fin-clipped, released into the wetland and recaptured in the outlet fyke net as they exited the wetland; and (2) marked fish which were transported from the Puyallup Indian Tribe's hatchery, released directly into the wetland, and recaptured in the outlet fyke net.

Using a 9.2-m floating beach seine with a 6-mm mesh bag and a solid core lead line, samples were collected in the tidal channels behind the fyke net system on April 21, May 4, and May 5, 1988 (Fig. 7). Beach seining was minimized, however, because it resulted in high fish mortalities. After beach seine sampling on May 4, the fyke net system was removed from the mouth of the wetland. Four of the six tidal channels were sampled by beach seine on May 5 in order to determine how many fish remained in the wetland despite having free access to the river (i.e., Did the fyke net system artificially increase juvenile salmon residence times by preventing volitional emigration?).

Spray-marking

On May 2, 1987, approximately 10,000 juvenile chum salmon were spray-marked (6,000 red, 4,000 yellow) at the Puyallup Indian Tribe's hatchery with a biologically inert, polystyrene, fine grit, fluorescent pigment using the methodology of Bax (1983). Groups of approximately 300 chum salmon at a time were placed in a plexiglass marking trough, immediately sprayed with pigment for eight seconds using a sandblasting gun connected to a compressed air tank regulated at 125 psi, and then rinsed with a hose into separate net pens. Each experimental group was suspended in a net pen in a concrete raceway. Mortalities were counted the following day and one group of fish was held at the hatchery and checked for mark retention on May 3, June 1, and June 9, 1987.

On March 4, 1988, approximately 20,000 fall chinook salmon (10,000 red, 10,000 yellow) were spray-marked using the same procedure as in 1987, except that the marked fish were held in three separate floating net pens in an earthen pond. The following day, mortalities were removed



A. Net trap: 1.91-cm aluminum pipe frame, 2.46-m x 1.64-m wide x 1.64-m deep fitted with net of 0.64-cm stretch delta mesh knotless nylon

B. Internal wings: begin at forward corners and extend back 0.66-m to form a 15.24-cm wide x 1.64-cm deep opening

C. Spreader bar: 2.54-cm pvc pipe supporting the internal wings

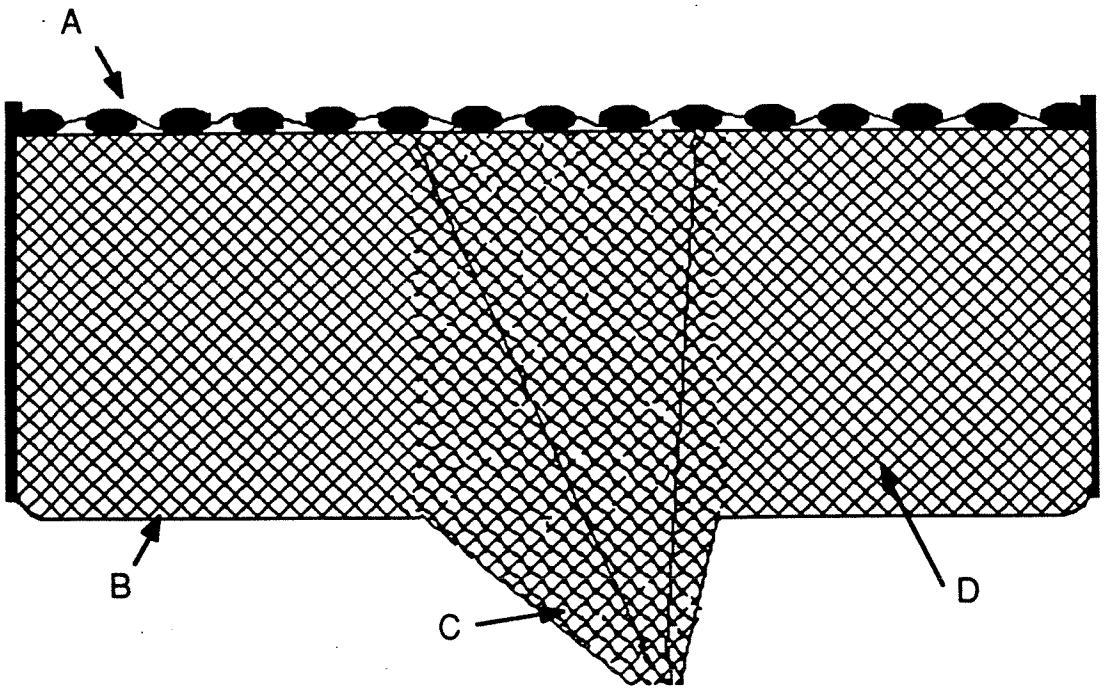
D. External wings: 0.95-cm stretch delta mesh knotless nylon 1.64-m wide x 16.39-m long with a solid core lead line and 0.64-cm SB polypropylene line hung with OS-1 foam floats every 0.66-cm

E. Apron: (on inlet fyke net only) 1.97-m wide x 32.79-m long net of 0.64-cm stretch delta mesh knotless nylon sewn to the bottom of the internal wings

F. Inflatable float: pvc purse seine floats were attached to each of the four corners of both the inlet and outlet traps

* E and F were modifications make in 1988 allowing the system to float up and down with the tides, rather than being anchored as in 1987

Figure 6. Schematic of the inlet/outlet fyke net system positioned at the mouth of the Lincoln Avenue wetland.



A. float line

B. solid core lead line

C. 6-mm mesh collection bag (0.6 m x 2.4 m x 2.3 m)

D. 4 m wings of 3 cm stretch mesh

Figure 7. Schematic of the 9.2-m x 2-m beach seine used for collecting fish in tidal channels of the Lincoln Avenue wetland.

from the pens and a group of fish was held at the hatchery and checked for mark retention on March 6, 11, 20, and April 29.

Access

Approximately 9,000 spray-marked chum salmon ($\bar{x}$ = 44.4 ± 2.87 mm fork length [FL]; $\bar{x}$ = 0.65 ± 0.14 g wet weight; yellow and red marks combined) were released at 1700 h on May 7, 1987 into Clark's Creek and allowed to migrate downstream volitionally .

On March 14, 1988, approximately 17,800 spray-marked fall chinook salmon ($\bar{x}$ = 45.18 ± 3.17 mm FL; $\bar{x}$ = 0.896 ± 0.209 g wet weight; yellow and red marks combined) were released at 15:00 hours into Clark's Creek at the site where chum salmon had been released in 1987.

Access Model

A model was developed to estimate what percentage of the total population of outmigrating hatchery and wild chum and fall chinook salmon (Table 1) might access a wetland in the Puyallup River estuary:

$$\text{Access} = [R \div 1/2(H + W - M)]100$$

where: R = total number of recaptures collected in the wetland (inlet fyke + outlet fyke + beach seines),

H = hatchery production (sum of WDF and Puyallup Tribal Hatchery releases),

W = wild production (based on mean total run sizes for six years 1978-1983), and

M = mortalities (before the outmigrants reached the wetland).

The two major assumptions of the model were that half of the outmigrating chum and chinook salmon travelled along the same side of the river as the wetland and that mortality upstream of the wetland was roughly 10% based on findings for the Nanaimo River estuary (Healey 1980). No data exist on the Puyallup River to evaluate these two assumptions.

Table 1. Summary of 1987-1988 estimates of hatchery and wild juvenile chum and chinook salmon outmigrants for the Puyallup River and recaptures of chum and chinook outmigrants in the inlet-fyke, outlet-fyke and beach seines at the Lincoln Avenue wetland (LAW).

	Outmigrant estimates		Recaptures at the LAW		
	Hatchery*	Wild**	Inlet-fyke	Outlet-fyke	Beach seines
Chum					
1987	9,000	6,000	5	140	44
1988	349,920	6,000	221	74	85
Chinook					
1987	1,556,995	9,000	14	2,441	696
1988	1,719,000	9,000	2,041	332	565

Residence Times

On May 21, 1987, 438 yellow-marked chum salmon ($\bar{x}$ = 52.36 ± 4.21 mm FL; $\bar{x}$ = 1.28 ± 0.30 g wet weight) were released into channel 3 of the wetland on an incoming tide at approximately 15:30 hours. A second group of 447 red-marked chum salmon ($\bar{x}$ = 53.72 ± 3.57 mm FL; $\bar{x}$ = 1.31 ± 0.30 g wet weight) was released at 17::00 hoursours into channel 3 on May 27, 1987 just prior to high tide.

On March 23, 1988, approximately 1,000 red-marked fall chinook salmon ($\bar{x}$ = 48.16 ± 3.97 mm FL; $\bar{x}$ = 1.20 ± 3.88 g wet weight) were released at 16:00 hours into channel 3 during an incoming tide. The yellow-marked group all died at the hatchery due to the failure of an aerator; hence, there was no second release group in 1988.

Foraging

Fish were collected from tidal channels at low slack tide on 12 days between February 17 and June 16, 1987 using a 9.2-m floating beach seine with a 6-mm mesh bag and solid core lead line. In 1988, beach seine samples were collected on April 21, May 4, and May 5. The fyke net system which was constructed at the mouth of the wetland to monitor access and residence times was checked daily (March 11-June 30) for juvenile salmon. Captured fish were sorted and identified; subsamples of at least ten individuals of each different species were preserved immediately in 10% buffered formalin. In the laboratory, all preserved juvenile salmon were identified, counted, measured (nearest 1 mm fork length [FL]) and weighed (wet weight to nearest 0.01 g). For each preserved sample, stomachs were removed from up to ten chum salmon and chinook salmon. Prey items in the stomach contents were identified to the lowest possible taxonomic/life history level and ranked based on modified IRI (Index of Relative Importance) values, where IRI = % frequency of occurrence x [% numerical composition + % gravimetric composition] (Cailliet 1977).

Standardized forage ratios (Manly et al. 1972) were calculated for overlap between potential prey available in the wetland and prey consumed by juvenile chum and chinook salmon. The standardized forage ratio (SFR) relates percentage of the diet contributed by a prey taxon to its percentage of the co-occurring fauna:

$$SFR = P_i/R_i \div \Sigma P_i/R_i$$

where P_i = % prey in the diet

R_i = % prey in the fauna

A prey taxon can be defined as positively selected when its relative abundance among prey in the diet is greater than its relative abundance in the fauna. There are two critical assumptions in using SFR as an index of selectivity: (1) all taxa in the environment have been accurately sampled and

are equally available; and (2) all prey items can be identified and are digested at the same rate (Gabriel 1978).

BIRDS

No bird counts were made by the Wetland Ecosystem Team (WET) in 1988. The only bird data available for 1988 is a list of species observed at the Lincoln Avenue wetland by members of the Tahoma Audobon Society. Thais Bock of the Tahoma Audobon Society graciously provided us with these data sheets. The voluntary efforts of the Tahoma Audobon Society to monitor bird utilization of the restored wetland highlight the commitment of volunteers to the restoration project.

RESULTS AND DISCUSSION

SEDIMENT CHARACTERISTICS

Since the construction in 1985, deposition of sediments from the Puyallup River in the wetland has resulted in changes in sediment grain size and bottom contours. The primary location for sediment build-up continued to be in the mid-bay and channels as previously reported by Thom et al. 1988 (see also Fig. 13). The net result has been to decrease the depth of these areas and reduce the area that contains water during all stages of the tide. Although surveys have not been conducted since dike breaching, we estimate that up to 4 ft of sediment has been deposited in the channels and mid-bay. Our observations in spring (April) of 1988 showed that during high river flows, the water depth in channel 4 and mid-bay averaged approximately 4 ft at a predicted tide level of -0.6 ft MLLW. These observations, along with recent collections (1988) of fish, indicate that adequate water to support many fish species remains in the system during the period of salmonid outmigration.

Grain size of surface sediments showed a clear shift from pre-breach conditions (Table 2). On flat 4, the percent of fine sediments (phi size < 4.0) decreased slightly for sites 1-4, but site 5 showed a surprising, and as yet unexplained, sixfold increase in silt and clay. All of the channel 4 sites had increased percentages of silt and clay in April 1988 relative to August 1987. The largest overall changes in sediment phi size were in the midbay where fine sediments appear to be rapidly accreting. These data contrast the 1987 data which were used to conclude that the sediments in the wetland had become coarser following dike-breaching.

Cumulative changes in sediment height relative to 20-cm sampling stakes were mostly positive indicating that a great deal of sedimentation is taking place on the flats (Table 3). In particular, sedimentation appeared to be heavy on flat 4 sites 5 and 6. Only seven of the twenty-eight sampling sites showed evidence of scouring, and of those seven, flat 5 site 3 and flat 6 site 1 were the

Table 2. Sediment phi size at the 20 sampling sites 1987 vs. 1988. Percent of sediment sample that was silt and clay (phi size >4.0).

Site	Habitat	Distance (m)	Pre-breach	Aug. 1987	April 1988
1	flat 4	12		92.1%	68.0%
2	flat 4	28		73.2	68.9
3	flat 4	44		95.8	93.2
4	flat 4	60	32.0	91.5	87.2
5	flat 4	76		10.9	67.8
6	flat 5	5		83.3	65.9
7	flat 5	14		91.4	70.2
8	flat 5	23		51.1	80.4
9	flat 5	32		84.0	
10	flat 5	41		5.0	
11	chan. 4	25		56.6	
12	chan. 4	35		61.0	92.5
13	chan. 4	45		77.4	93.5
14	chan. 4	55		65.6	64.8
15	chan. 4	65		35.5	86.2
16	midbay 1			3.7	86.7
17	midbay 2			12.4	
18	midbay 3		15.0	5.1	72.8
19	midbay 4		10.0	1.9	39.9
20	midbay 5				14.4

most heavily scoured. The physical processes driving the deposition of sediments and scouring are at this time poorly understood.

As in 1987, volatile solids were greatest in the *Typha* and *Carex* marsh at the upper edge of flat 4 (site serial nos. 1-2) and at the two sites in the middle of channel 4 (site serial nos. 12-13; Table 4). The inner end of the transect on flat 4 (sites 1-2) and the two mid-channel 4 sites (12-13) were relatively enriched in organic content. Plant debris in the bottom of the midbay may explain the high April values for sites 17-19. In general, volatile solids were less in September 1988 than in April for all 20 sampling sites. By September, much of the macroscopic vegetation had died back and may have been exported into the river. The high value (3.7%) for the unvegetated portion of flat 5 (site 8) is puzzling, but may be attributed to sediment microalgae. The 1988 volatile solids data suggest that the sediments in the restored wetland system are enriched in organic content but seasonally variable.

VEGETATION

Benthic algae were present and at times abundant in the system (Fig. 8). Sediment-associated algal assemblages were present on flat 4 as indicated by sediment chlorophyll samples. The highest concentrations occurred in September (800 mg chl *a* m^{-2}). The September bloom was the

Table 3. Cumulative change in sediment height relative to 20 cm sampling stakes (- = scouring; + = sedimentation).

Site	Habitat	13 April 1987	7 April 1988	9 Sept. 1988
1	flat 1	-1.4	-3.5	-3.5
1	flat 2	-1.1	-3.5	-2.5
2	flat 2	-1.8	-2.5	-3.5
1	flat 3	+1.2	-0.5	-3.0
2	flat 3	-2.8	-4.0	-5.0
3	flat 3	+0.6	0	+0.5
4	flat 3	-0.6	-0.5	-0.7
5	flat 3	0	+1.0	+0.5
6	flat 3	-1.3	-1.5	-3.0
1	flat 4	-1.6		
2	flat 4	+1.2	-2.0	
3	flat 4	-2.0	-1.0	-6.0
4	flat 4	-1.3	+1.0	-3.0
5	flat 4	-1.3	-4.0	-5.0
6	flat 4	-3.0	-6.0	-5.0
7	flat 4	-2.3		
8	flat 4	-1.3	-0.5	-2.0
9	flat 4	-1.3	+0.5	-3.5
10	flat 4	-1.1	+0.5	-1.5
1	flat 5	-2.0		
2	flat 5	-0.2	-2.0	-2.5
3	flat 5	-1.8	+2.0	+3.0
4	flat 5	+0.7	-2.0	-4.5
1	flat 6	-0.7	+3.0	+3.0
2	flat 6	-1.8	-1.0	-1.5
1	flat 7	0	-1.5	-3.0
2	flat 7	-0.4	+1.0	0
3	flat 7	-1.5	-2.0	-2.0

most pronounced seen in three years of monitoring sediment chlorophyll. During the 1986-1988 sampling period, phaeopigment concentration was generally less than 300 mg m^{-2} in all samplings with the exception of peaks in May (2312 mg m^{-2}) and June (3715 mg m^{-2}) (Fig. 9). As in 1987, heavy mats of the filamentous green alga *Spirogyra* sp. developed primarily on flats 5, 6 and 7 in May 1988 and lasted through August. The mats were so thick at some sites that they clogged both the epibenthos pump during collections of samples and the bag of the beach seine during fish collections. Bubbles of what was presumably oxygen generated from photosynthesis were trapped below the thick mat. In addition, thick clumps of the alga were floating free in the system and were being exported to the river.

The total area of the flats covered with rooted macrophyte vegetation in September 1988 (4500 m^2) was very similar to the end of the growing season in July 1987 (4736 m^2) (Fig. 10). How

Table 4. Volatile solids (percent) in the sediments at the 20 sampling sites.

Site	Habitat	21 April 1988	9 Sept. 1988
1	flat 4	6.3%	6.8
2	flat 4	6.9	4.0
3	flat 4	3.2	5.3
4	flat 4	2.0	2.2
5	flat 4	2.4	2.2
6	flat 5	1.9	2.4
7	flat 5	2.6	2.3
8	flat 5	3.7	2.4
9	flat 5	0.7	3.1
10	flat 5	1.9	1.9
11	chan. 4	2.6	2.6
12	chan. 4	3.7	2.8
13	chan. 4	3.3	2.8
14	chan. 4	2.0	2.5
15	chan. 4	3.2	2.5
16	midbay	1.6	2.5
17	midbay	3.7	2.2
18	midbay	2.8	2.3
19	midbay	2.7	1.3
20	midbay	2.2	2.0

ever, peak *Carex* cover declined from 3472 m^2 in August 1987 to 2750 m^2 in September 1988. *Carex* abundance in 1988 also declined markedly relative to 1987, but was comparable to the end of the 1986 growing season (Fig. 11). The total standing crop of *Carex* in 1988 mimics the decline in abundance (Fig. 12). All of these data indicate that *Carex* is doing best at the perimeter on flats 1, 2, 6, 7 and is being outcompeted by *Typha* on upper flat 4. At the peak of the growing season in 1988, some of the *Typha* had reached heights of nearly 3-m. Losses of *Carex* cover at the lower elevations of all the flats may be attributed to physical scouring around the base of clumps of plants, grazing by waterfowl on the erect shoots, or changes in the sediment characteristics. As mentioned previously (Thom et al. 1988), loss of marsh habitat area does not necessarily reflect a decline in the ability of the system to support target resources.

Plant density plotted on tracings of the aerial photographs illustrates the spatial changes in vegetation distribution (Fig. 13). In general, the upper portions of the flats had the greatest shoot densities (Fig. 14). Flat 2 site 1 nearly doubled in Carex density between 1987 and 1988. Carex on flat 3 and 4 did not extend as far down the flats toward the midbay in 1988 as in 1987. Flat 5 and flat 8 remain unvegetated after three years. Flat 6 and 7 showed higher Carex densities in 1988 probably because of the 1987 transplanting efforts (Thom et al. 1988).

Physical, biological, and chemical factors continue to actively determine the distribution of plants in the system. For example, we noted evidence of physical scouring around the base of

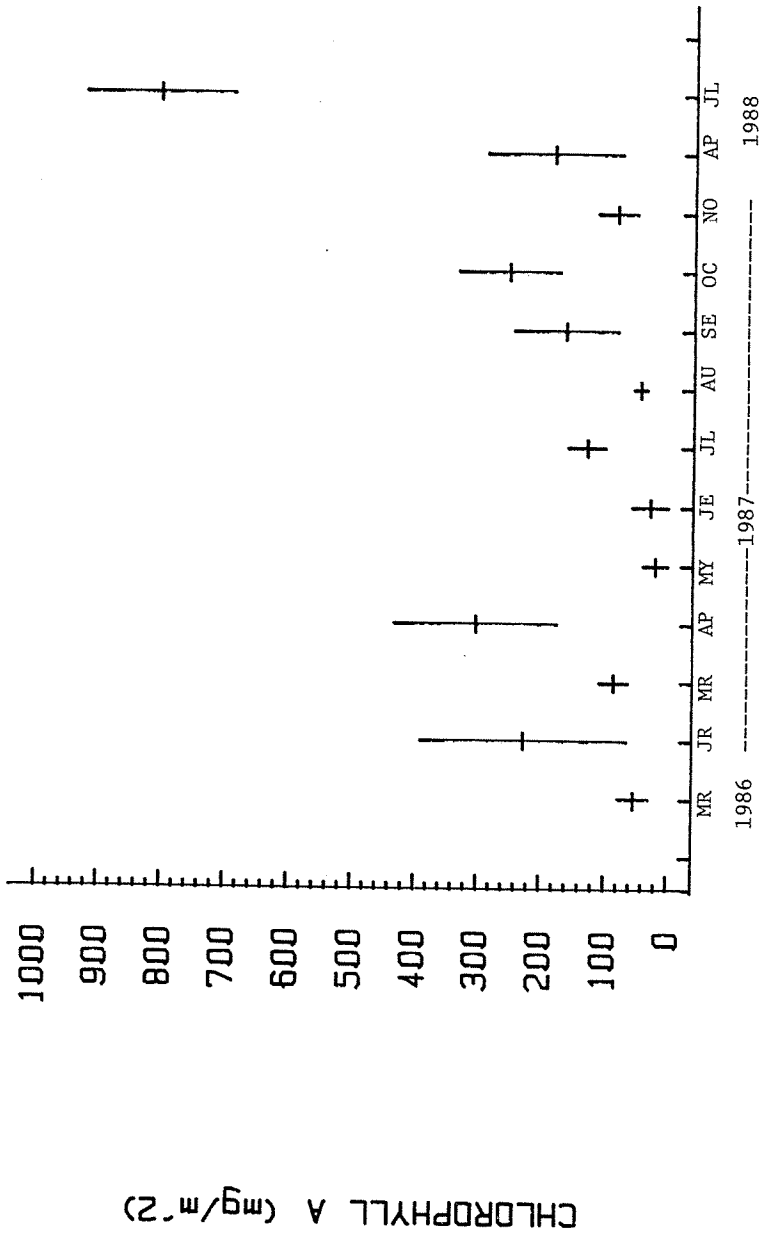


Figure 8. Sediment chlorophyll A concentration (mg/m ^{2}) on flat 4 over time.

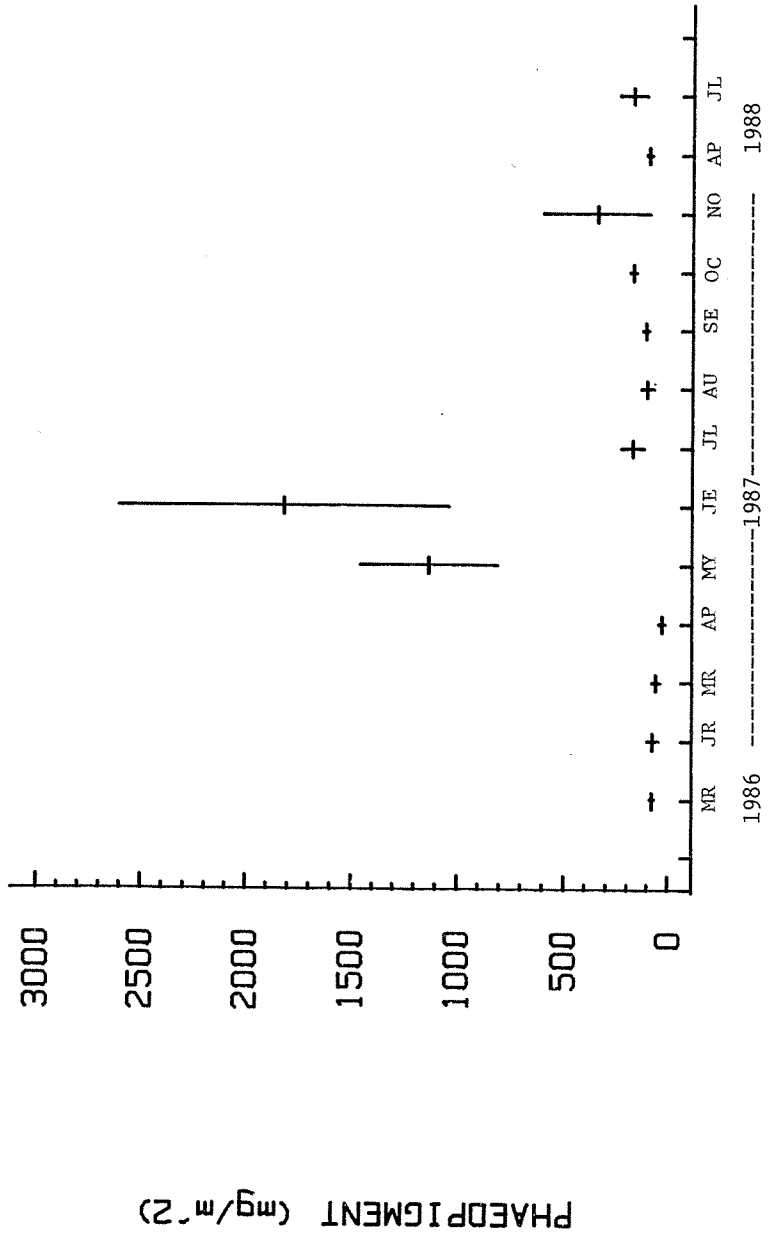


Figure 9. Sediment phaeopigment concentration (mg/m^{-2}) on flat 4 over time.

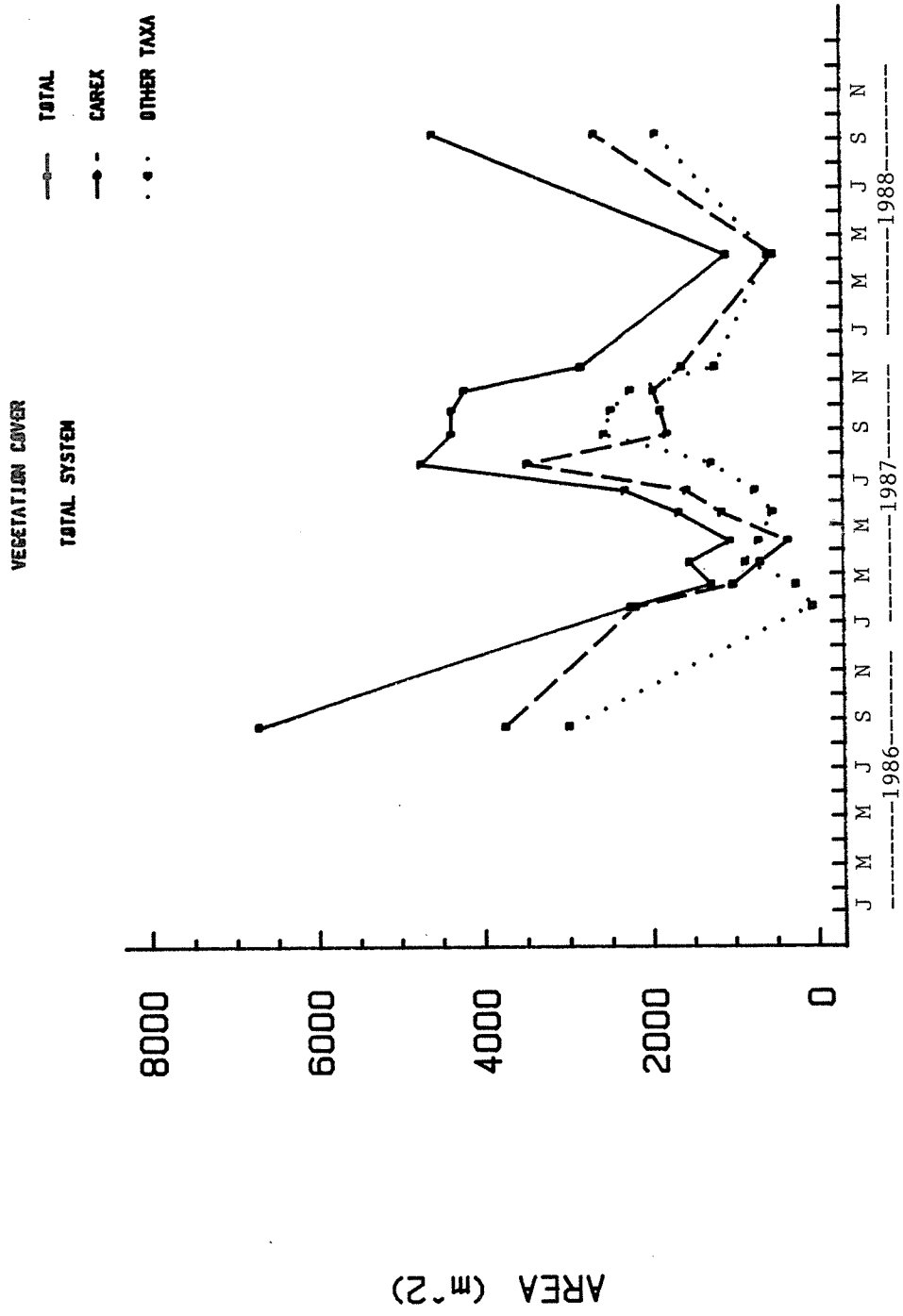


Figure 10. Total vegetation cover (m^{-2}) on the flats versus time.

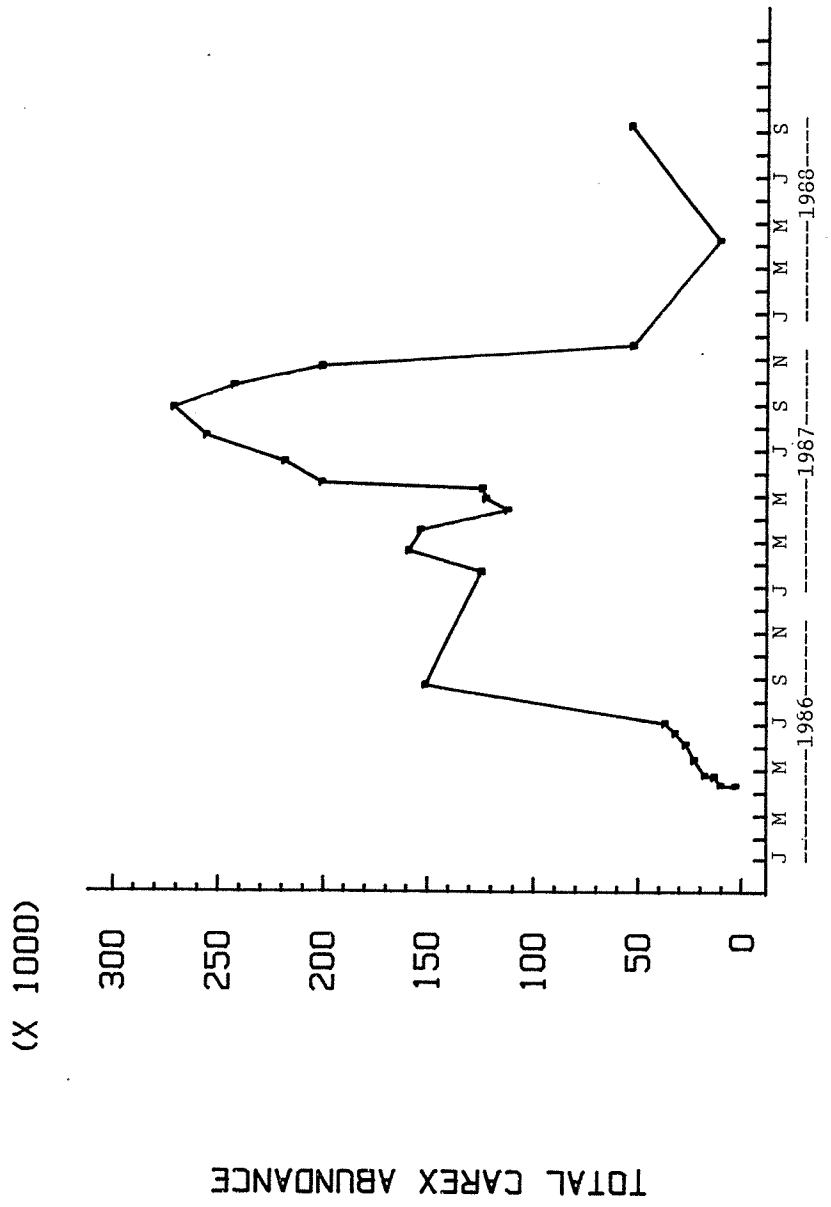


Figure 11. Total *Carex* shoot abundance in the system versus time.

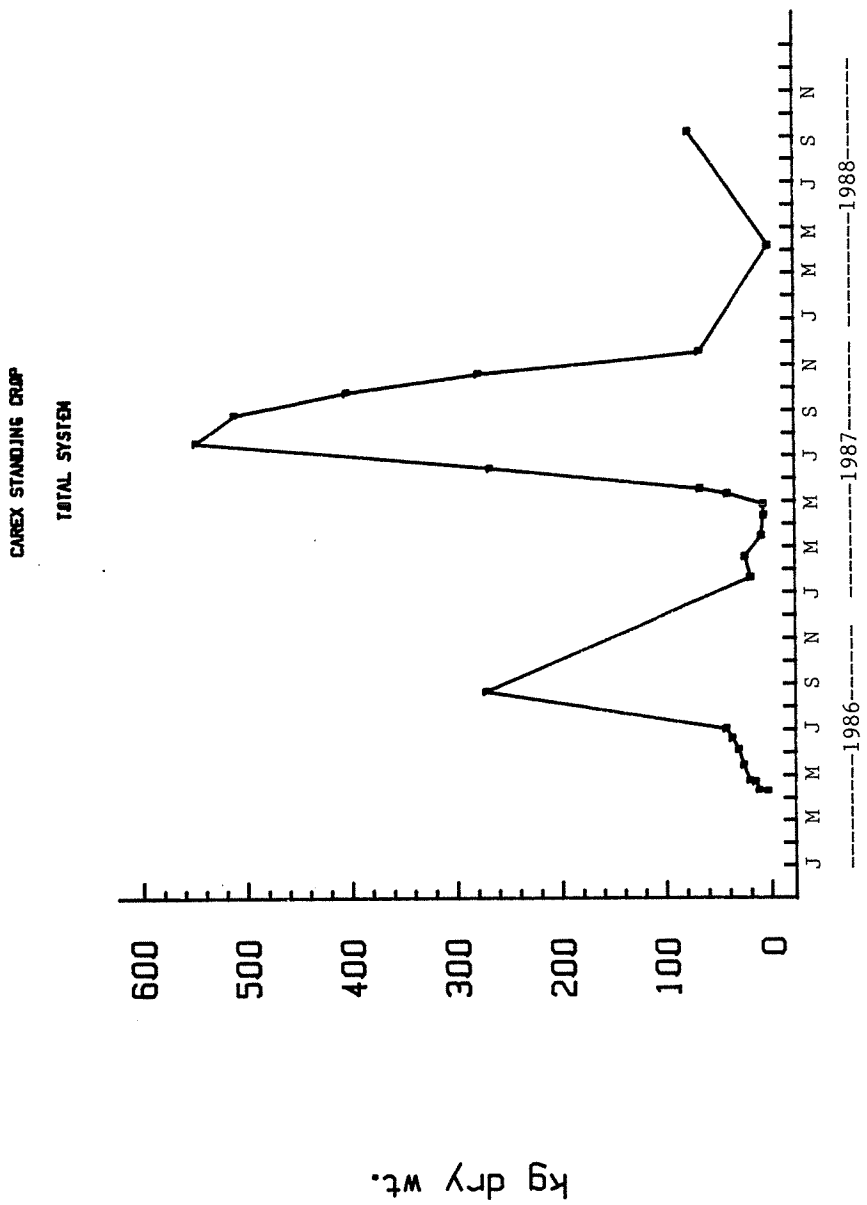


Figure 12. Total *Carex* shoot abundance in the system versus time.

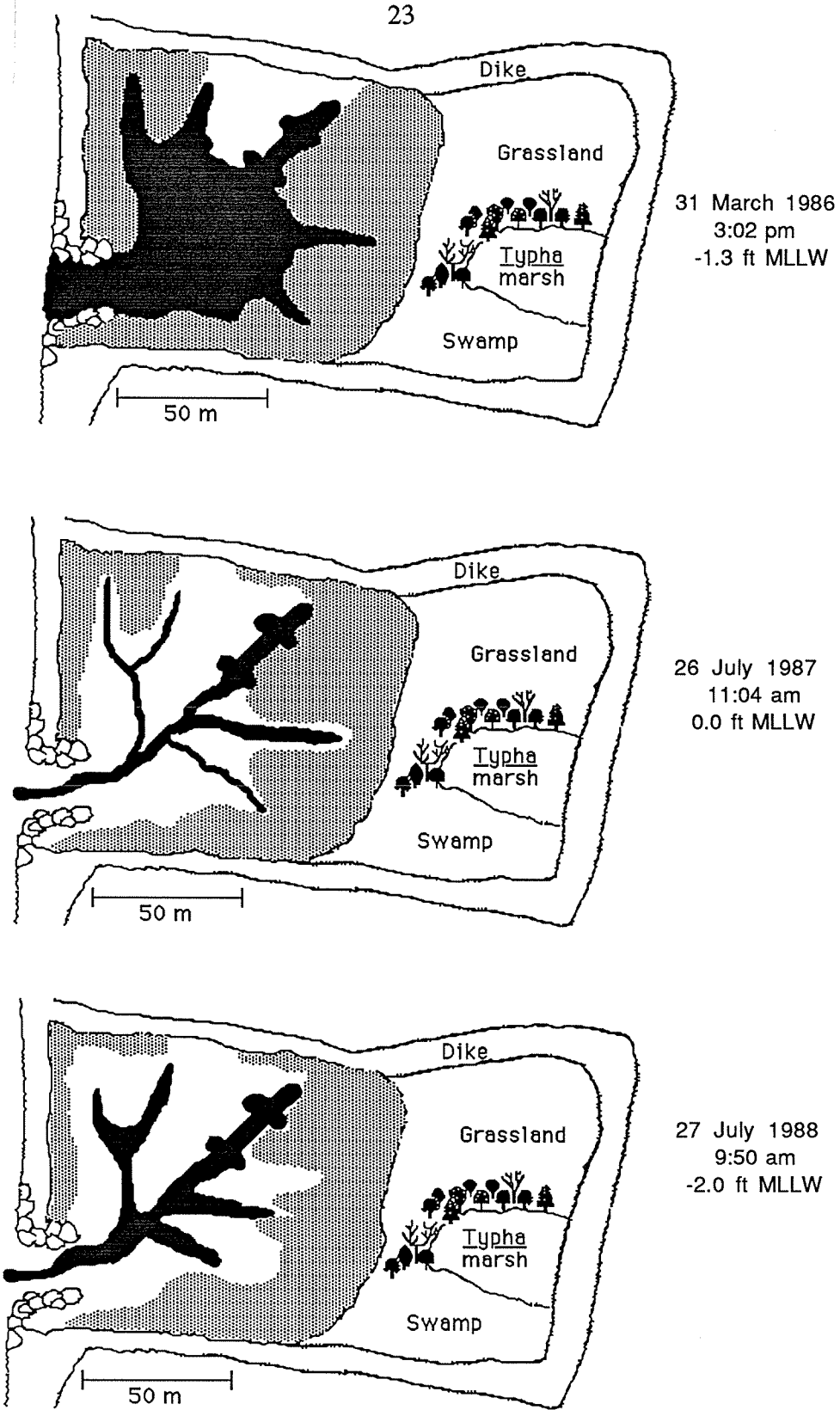


Figure 13. Spatial changes in vegetation (hatched pattern) and water distribution (black), 1986-1988.

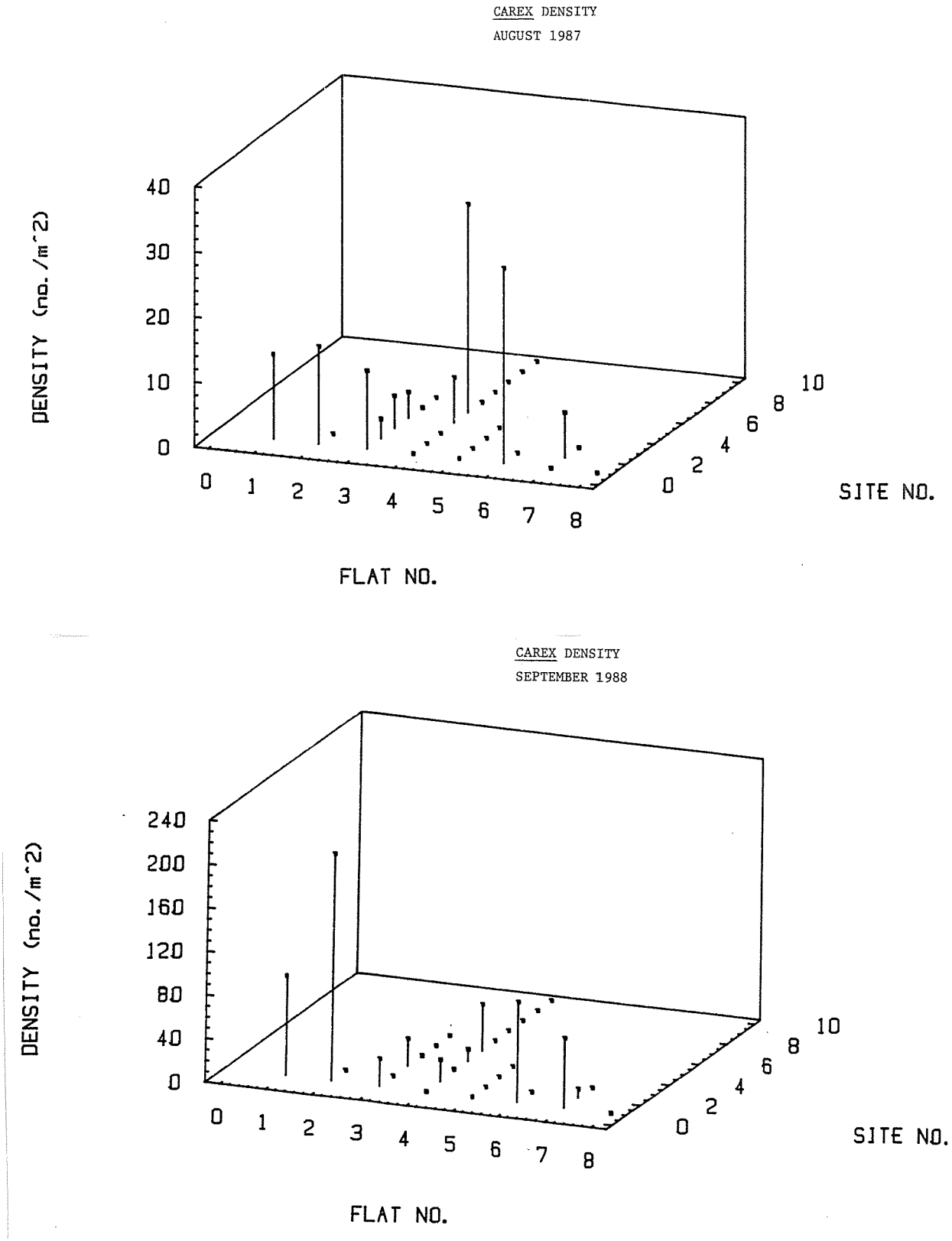


Figure 14. Comparison of *Carex* density and distribution on the flats, September 1987 vs. September 1988.

clumps of plants and grazing by waterfowl, especially Mallards, on the erect shoots. In addition, sediment characteristics are undergoing rapid changes. All of these factors may be influencing the productivity and survival of marsh plants.

The upland habitats, which include the grassland, cattail marsh, and swampy area, showed very little change in the aerial photographs or from observations made on the ground. The increasing annual abundance of fish and bird species suggests that the marsh continues to function as an important habitat for feeding and refuge. Incidental samples of water in the marsh had very high densities of insect larvae and other invertebrates, which suggest a thriving system. Water was present in the marsh throughout the year, but only the two deepest channels (3 and 4) retained water during the drought from June-August.

INFAUNA

Total infauna abundance and density changed dramatically between March 1986 and September 1988 (Table 5). Infauna abundance was 170.9 x 10^6 organisms in March 1986 as compared to 183.8 x 10^6 in September 1988. Total infauna density decreased from 9,085 organisms m^{-2} in March 1986 to 8,438 organisms m^{-2} in September 1988. The largest proportional decrease in infauna abundance and density occurred on the channels, followed by the mid-bay. Relative to March 1986, the flats showed more than a tenfold increase in 1988 both in total abundance (9.4 x 10^6 organisms vs.102.8 x 10^6 organisms) and density (785 organisms m^{-2} vs. 8,586 organisms m^{-2}). Total abundance increased between spring and late summer samplings in 1987, primarily due to a substantial (6.3 x) increase in abundance on the flats. The infaunal abundances in the channels and mid-bay decreased between these two samplings. The relative abundance of taxa groups was for the most part unchanged between spring samplings in 1986 and 1987 (Table 6). As in previous years, oligochaetes represented the dominant taxa in the infauna. All of the other taxa combined represented only 5% of the total abundance. Physical factors, including sediment grain size changes, bottom depth changes and changes in organic matter, are probably interacting in structuring the infaunal assemblage. Although the exact factors causing the variability in infauna abundance and density are presently unknown, these data indicate that major seasonal shifts are occurring in the benthos, and that these shifts must be considered in interpreting the long-term changes in the system.

EPIBENTHOS AND NEUSTON

Significant changes have occurred in the epifaunal assemblage since the March 1986 post-breach sampling. Total epibenthos density and standing stock decreased threefold and fivefold respectively between 1987 and 1988. Although the prey of juvenile salmonids were more common

Table 5. Total system abundance and density (no./m^2) of infauna in the wetland system. Areas of habitats used for calculations were: flats = 11,974 m^2; channels = 6,091 m^2; mid-bay = 3,717 m^2 (Thom et al. 1987).

	March 1986		March 1987		August 1987	
Habitat	Total	No./m^2	Total	No./m^2	Total	No./m^2
Flats	9.4×10^6	785	65.9×10^6	5,504	416.1×10^6	34,667
Channels	103.7×10^6	17,025	232.5×10^6	38,171	165.5×10^6	27,171
Mid-bay	57.8×10^6	15,550	242.8×10^6	65,321	107.5×10^6	28,921
Total	170.9×10^6	9,085	541.2×10^6	24,846	688.1×10^6	31,590

	April 1988		September 1988	
Habitat	Total	No./m^2	Total	No./m^2
Flats	102.6×10^6	8,570	102.8×10^6	8,586
Channels	9.4×10^6	1,549	37.4×10^6	6,145
Mid-bay	45.1×10^6	12,139	43.6×10^6	11,735
Total	157.1×10^6	7,212	183.8×10^6	8,438

Table 6. Relative abundance of taxa collected in infauna samples. Values are the percentage of total number of individuals collected each date.

Taxon	March 1986	March 1987	August 1987	April 1988	Sept. 1988
Insect	78%	1%	<1%	4%	2%
Harpacticoid	9	3	0	<1	0
Oligochaete	8	89	99	92	95
Nematode	4	6	6	<1	1
Ostracod	1	0	0	0	0
Corophium	0	2	0	0	0
Gammarid	0	<1	<1	<1	0
Polychaete (nereid)	0	0	<1	0	<1
Mysid	0	0	<1	0	0
Gastropod (juv.)	0	0	<1	0	0

(see Foraging section below), they still were not a prominent component of the epibenthos (Table 7).

In April 1988, total epibenthic density in all four of the habitats sampled (vegetated flat 4, unvegetated flat 5, tidal channel 4, and the mid-basin) was much lower relative to April 1987 (Fig. 15). The epibenthos densities in April 1988 were highest in the unvegetated flat (231,153 m^{-2}), followed by the vegetated flat (148,989 m^{-2}), tidal channel (24,78 m^{-2}), and mid-basin (7,323 m^{-2})

Table 7. Faunal composition (% numerical, % gravimetric) of epibenthic organisms on flat 4 of the Lincoln Avenue Wetland in 1988 as compared to previous collections (Thom et al. 1987).

	1985-1986		1987		1988	
Taxa	Numerical	Gravimetric	Numerical	Gravimetric	Numerical	Gravimetric
Hydrozoa	0	0	<0.01	<0.01	0	0
Platyhelminthes	0.03	0.10	0.34	1.41	0.33	0.66
Rotifera	2.46	0.82	1.28	1.66	0.03	0.30
Nematoda	0.88	1.35	13.42	3.11	22.22	2.64
Oligochaeta	0.05	0.20	8.21	43.19	6.17	29.99
Acarina	0.03	0.10	0.01	0.05	0	0
Cladocera	4.77	12.17	0.58	1.56	0.54	1.38
Podocopa	0.52	0.88	0.15	0.55	0.06	0.59
Copopoda*	35.92	3.43	4.32	1.36	0	0
Calanoida	0.03	0.13	0.01	<0.01	0	0
Harpacticoida	0.14	0.50	29.72	17.88	12.74	18.62
Cyclopoida	54.13	43.38	0.68	2.41	0.92	1.91
Insecta	1.08	12.12	0.12	1.00	0.15	1.32
Tardigrada	0	0	48.09	25.72	50.01	36.51
Gammarida	0	0	0	0	<0.01	5.57

*Undifferentiated larvae.

respectively; whereas in April 1987, the densities were highest in the tidal channel (775,000 m^{-2}), vegetated flat (466,204 m^{-2}), unvegetated flat (414,735 m^{-2}), and mid-basin (200,000 m^{-2}). The changes in density between April 1987 and April 1988 represent a threefold decrease. Standing crop was also significantly lower in April 1988 for all four of the habitats—roughly a fivefold decrease relative to April 1987. As in 1987, the epibenthos assemblage was numerically dominated by tardigrades, nematodes, and harpacticoids, and gravimetrically dominated by tardigrades, oligochaetes, and harpacticoids (Table 7). The most noteworthy change in fauna was the appearance of harpacticoid taxa including unidentified species of Cletonidae and Canthocamptidae, as well as *Onchyocamptus mohammed* and *Nannopus palustris*. (Table 8) It is unclear at this time whether the variability in epibenthos density and standing crop may accurately reflect the shifts in fauna, or alternatively, whether the variability may be a result of our sampling techniques. In any case, the epibenthos assemblage still appears to be developing and faunal shifts are likely to continue for several more years.

Epibenthos taxa previously categorized as potential juvenile salmon prey included chironomids, mysids, and gammarid amphipods (Thom et al. 1988). Chironomids and gammarid amphipods increased in density and standing stock relative to April 1987, but were still not a prominent component of the epibenthos in April 1988. Mysids did not appear at all in the April 1988 samples.

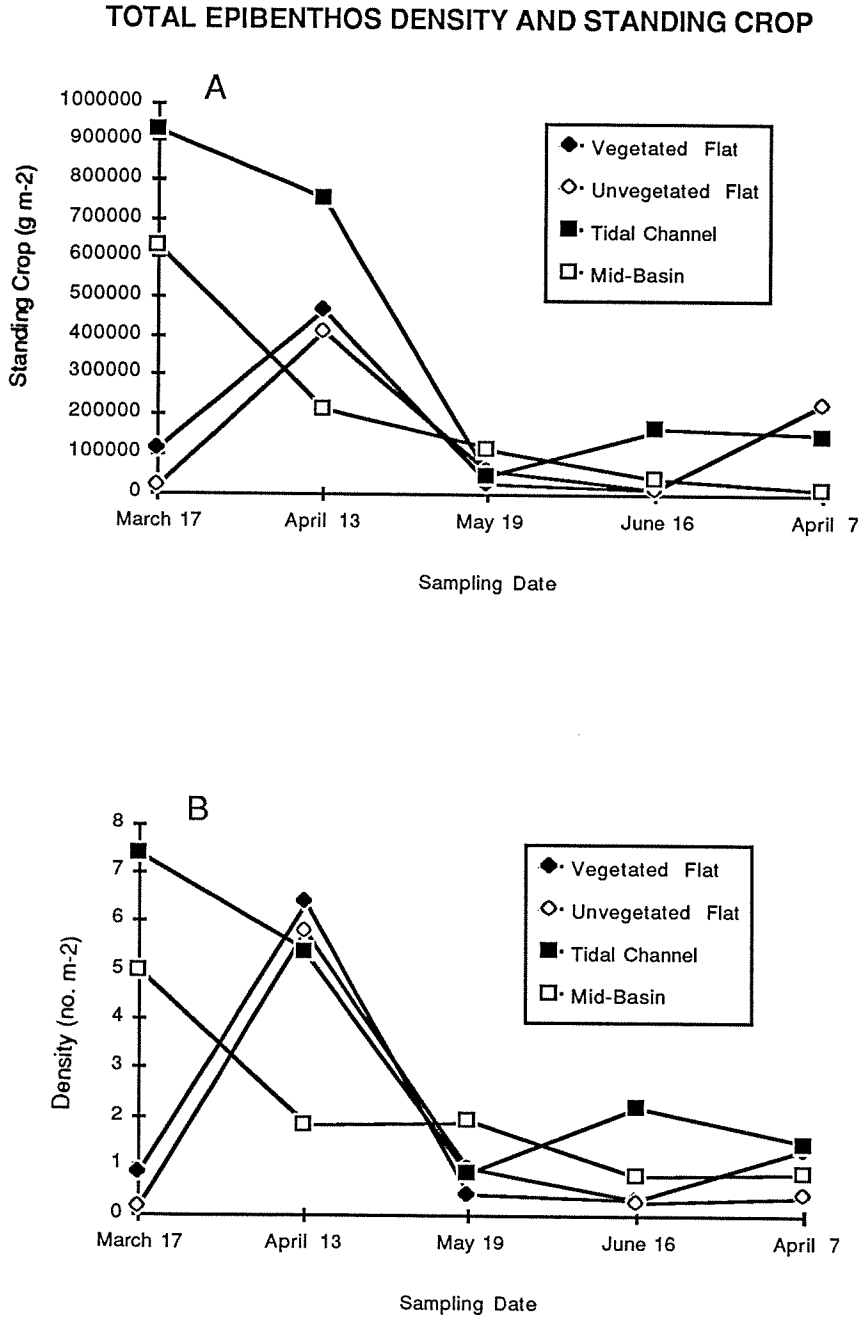


Figure 15. Total density (A) and standing crop (B) of epibenthic fauna for habitats in the wetland system March-June 1987; April 1988.

Table 8. Taxonomic composition and mean density (# m^{-2}) and standing crop (mg wet m^{-2}) of epibenthic organisms sampled in the Lincoln Avenue wetland, 7 April 1988.

Taxa	Life History Stage	Vegetated Flat		Unvegetated Flat		Channel		Mid-Bay	
		#	mg	#	mg	#	mg	#	mg
Turbellaria	J/A	488.9	0.9	222.2	1.8	111.1	1.1		
Rotifera	J/A	44.4	0.4	55.6	0.6			266.7	1.1
Nematoda	J/A	33111.1	3.6	193111.1	8.5	167333.3	14.4	21644.4	2.4
Oligochaeta	A	8311.1	36.0	611.1	2.4	8977.8	64.9	3377.8	26.2
Oligochaeta	J/A	888.9	4.9	333.3	2.2				
Acarina	J/A					133.3	0.9		
Cladocera									
Daphnia sp.						44.4	0.4		
Bosmina longirostris	A					44.4	0.4	44.4	0.2
Chydoridae	A					133.3	1.3	44.4	0.2
Chydorus sphaericus	A	800.0	1.8	1333.3	0.6	1266.7	2.0	533.3	1.6
Copepoda	N			222.2	1.0	155.6	0.7	644.4	2.4
Podocopa	J	44.4	0.4						
Podocopa	J/A	44.4	0.4			44.4	0.4	22.2	0.2
Harpacticoida	A			13.9	0.1	44.4	0.4		
Harpacticoida	C	355.6	1.8	83.3	0.7			133.3	0.9
Ectinosomatidae	A			152.8	1.0	177.8	0.9	266.7	1.3
"	C			55.6	0.3	155.6	0.7	533.3	2.2
Micorarthridion litorale	A	577.8	1.8	5333.3	3.5	18866.7	14.7	20644.4	16.0
"	C	355.6	0.9	2083.3	1.3	3622.2	2.0	15733.3	4.7
"	ECF					44.4	0.4	111.1	1.1
Tachidius discipes	A	1955.6	7.1	5722.2	3.3	11266.7	7.8	9533.3	5.6
"	C	9822.2	2.7	16569.4	5.0	14488.9	4.7	8044.4	3.1
"	ECF	3111.1	3.1	1375.0	1.3	3733.3	3.3	666.7	1.3
"	MP					88.9	0.4	177.8	0.4
Cletonidae	C			83.3	0.3				
Huntemannia jadensis	C			111.1	0.6	44.4	0.4	2600.0	2.7
"	A					222.2	1.8	311.1	0.9
"	ECF					44.4	0.4	400.0	2.2
Onchyocamptus mohammed	A	133.3	0.9						
"	ECF	88.9	0.9						
Nitocra spinipes armata	A	44.4	0.4			88.9	0.4		
Nannopus palustris	A	222.2	1.3	138.9	1.0				
"	ECF			55.6	0.4				
Canthocamptidae	A	133.3	0.9						
Mesochra rapiens	A	1511.1	1.8	458.3	1.3	1000.0	2.0	222.2	5.6
"	C			194.4	0.7	88.9	0.4	111.1	0.2
"	ECF	666.7	1.8	208.3	1.0	222.2	1.3	44.4	0.4
Cyclopidae	A	133.3	0.9	944.4	1.5	800.0	2.0	288.9	0.9
Halicyclops sp.	A	44.4	0.4			177.8	0.9		
"	J/A	1200.0	1.3						
Plecoptera	NY			27.8	0.3				
Eogammarus confervicolus	J	11.1	7.6			44.4	2.7		

Table 8 - cont'd.

Collembolla	J/A					44.4	0.4		
Tricoptera	L					44.4	0.4		
Chironomidae	L	222.2	1.8	194.4	1.3	244.4	1.6	244.4	1.6
Tardigrada	J/A	74577.8	49.8	1680.6	1.5	355.6	0.2		
"	A					13511.1	8.9	577.8	2.4
Total		148988.9	136.4	231152.8	41.3	24777.8	146.7	7333.3	84.7

Life History Codes:

A	=	adults
C	=	copepodids
ECF	=	egg-carying female
J/A	=	juveniles and adults, undifferentiated
J	=	juveniles
L	=	larvae
MP	=	mating pair
N	=	nauplii
NY	=	nymph

Although tardigrades, nematodes, harpacticoids, and oligochaetes continue to dominate the epibenthos, both numerically and gravimetrically, none of these organisms are considered viable prey because of their small size and interstitial occurrence.

The surface drift was expected to be a critical source of prey for juvenile salmon foraging within the wetland. A total of 32 potential prey taxa with a total mean density of 1625 m^{-2} were collected in the 1988 biweekly neuston net samples at the mouth of the Lincoln Avenue wetland. Neustonic organisms (drift) advected into the wetland on the water surface were numerically dominated by *Daphnia* spp. (0.86%), chironomids (midge larvae, pupae, and adults; 7%), and cyclopoid copepods (*Diaptomus* spp.; 2.5%) (Table 9).

FISH

In the three years since the Lincoln Avenue wetland was constructed, twenty-two species of oligohaline and euryhaline fish from ten families have been caught in the new habitat (Table 10). During the initial six months of development, eleven species (six families) occupied the wetland in mean overall densities of up to 3 100 m^{-2} (Thom et al. 1987). Collections in 1987 and 1988 indicated a similar assemblage, but greater dominance by estuarine taxa than in 1986, with total mean densities as high as 7.5 100 m^{-2} (1987) and 20 100 m^{-2} (1988) (Thom et al. 1988). The family Salmonidae was the best represented of the ten families, with eight species (mountain whitefish, pygmy whitefish, pink salmon, chum salmon, coho salmon, chinook salmon, steelhead, and

Table 9. Prey taxa collected in biweekly neuston net samples at the mouth of the Lincoln Avenue wetland (March 30-June 23, 1988).

Prey taxa	LH stage	Mean #/m^3	S.D.	% abundance	% biomass
Gastropoda	adult	3.3	10.5	0.20	0.18
Arachnida	adult	0.1	0.4	0.01	0.00
Araneae	adult	0.3	0.8	0.02	0.05
Acarina	adult	0.4	1.2	0.02	0.00
Daphnia sp.	juv/adult	1,398.0	4,102.0	85.89	46.92
Copepoda	copepodid	0.1	0.3	0.02	0.01
Calanoida	juv/adult	1.4	3.2	0.09	0.08
Diaptomus sp.	juv/adult	40.4	103.9	2.48	1.66
Cyclopoida	juv/adult	1.3	2.9	0.08	0.01
Corophium sp.	juv/adult	0.4	0.3	0.01	0.01
Insecta	juv/adult	1.7	5.4	0.11	0.01
Collembola	adult	15.9	24.3	0.98	2.62
Ephemeroptera	adult	0.1	0.3	0.01	0.45
Ephemeroptera	nymph	1.2	2.9	0.07	0.06
Plecoptera	adult	0.2	0.5	0.01	0.13
Plecoptera	nymph	0.1	0.3	0.01	0.04
Psocoptera	adult	1.5	4.0	0.09	0.17
Homoptera	adult	15.6	14.7	0.96	4.88
Aphididae	adult	7.6	14.7	0.47	2.92
Coleoptera	larva	0.1	0.3	0.01	0.00
Col.eoptera	adult	0.6	0.9	0.03	0.80
Coccinellidae	adult	0.9	2.9	0.06	0.05
Neuroptera	adult	0.3	0.7	0.06	0.05
Lepidoptera	adult	0.1	0.3	0.01	1.25
Culikcidae	adult	20.3	37.4	1.25	7.33
Chironomidae	larva	40.5	93.1	2.49	0.35
Chironomidae	pupa	54.7	84.3	3.36	8.81
Chironomidae	adult	14.0	39.8	0.86	3.11
Hymenoptera	adult	3.4	4.2	0.21	2.17
Formicidae	adult	0.3	0.5	0.02	0.73
Apoidea	adult	0.2	0.5	0.01	14.42
Osteichthys	larva	0.2	0.4	0.01	0.01
Total # of prey categories:		32			
Total mean # of prey/m^3:		1625.2			

cutthroat trout). The six species of Pacific salmon are common estuarine residents as juveniles during their migration to the Pacific Ocean. Twelve other species are considered freshwater or oligohaline (brook lamprey, river lamprey, mountain whitefish, pygmy whitefish, longnose dace, redside shiner, brown bullhead, largescale sucker, bluegill sunfish, black crappie, rock bass, and prickly sculpin). Four species are commonly reported to be euryhaline or diadromous (eulachon,

Table 10. Species of fish taken in beach seine samples (+) from the tidal channels and inlet fyke net samples (x) from the mouth of the Lincoln Avenue wetland, 1986-1988.

Family	Species/common name	1986	1987	1988
Petromyzontidae	*Lampetra richardsoni* (brook lamprey)*		x	x
	L. ayresi (river lamprey)*		x	
Salmonidae	*Prosopium williamsoni* (mountain whitefish)	+	+,x	+,x
	P. coulteri (pygmy whitefish)*		+	
	Oncorhynchus gorbuscha (pink salmon)	+		+,x
	O. keta (chum salmon)	+	+,x	+,x
	O. kisutch (coho salmon)	+		
	O. mykiss (steelhead trout)*			x
	O. tshawytscha (chinook salmon)	+	+,x	+,x
	O. clarki (cutthroat trout)*			x
Osmeridae	Thaleichthys pacificus (eulachon)		x	x
Cyprinidae	*Rhinichthys cataractae* (longnose dace)		+,x	+,x
	Richardsonius balteatus (reside shiner)	+	+,x	+,x
Ictaluridae	*Ictalurus nebulosus* (brown bullhead)*		x	x
Catastomidae	*Catostomus macrocheilus* (largescale sucker)	+	+,x	+,x
Gasterosteidae	*Gasterosteus aculeatus* (threespine stickleback)	+	+,x	+,x
Centrarchidae	*Lepomis macrochirus* (bluegill sunfish)*		x	x
	Pomoxis nigromaculatus (black crappie)*			x

Table 10 - cont'd.

Family	Species/common name	1986	1987	1988
Centrarchidae - cont'd.	*Ambloplites rupestris* (rock bass)*			x
Cottidae	*Cottus asper* (prickly sculpin)	+	+,x	+,x
	Leptocottus armatus (Pacific staghorn sculpin)	+	+,x	+,x
Pleuronectidae	*Platichthys stellatus* (starry flounder)	+	+,x	+,x

*Uncommon; fewer than 5 individuals collected.

threespine stickleback, Pacific staghorn sculpin, and starry flounder). Fewer than five individuals of the following species were collected: brook lamprey, river lamprey, pygmy whitefish, steelhead, cutthroat trout, brown bullhead, bluegill, black crappie, and rock bass.

In addition to the twenty-two species of adults utilizing the wetland, larval and juvenile prickly sculpins, larval largescale suckers, juvenile threespine sticklebacks, and juvenile starry flounders were captured in both 1987 and 1988.

The diverse fish assemblage which has entered the Lincoln Avenue wetland since the dike was breached in February, 1986 (Table 10) is remarkably similar, both in terms of abundances and seasonal occurrences, to the one reported by Levy et al. (1979) for tidal channels of the Woodward Island marsh in the lower Fraser River, with the exception of a few anadromous species (Pacific lamprey, sockeye salmon, Dolly Varden, longfin smelt) which have yet to be reported in the Lincoln Avenue wetland. Several species captured in the restored wetland (brook lamprey, pygmy whitefish, and non-native species including brown bullhead, bluegill, black crappie, and rock bass) were never captured in the lower Fraser River. These non-native species were probably flushed into the Puyallup River from lakes or ponds adjacent to the river during periods of high rain and flooding. Access by fish provided indications regarding predictions of use by salmon but is not a criterion of functional performance for the Lincoln Avenue wetland. Parcel 5 wetland, which was filled and is mitigated by Lincoln Avenue, was inaccessible by fish.

Spray Marking Mortality and Mark Retention

Spray marking proved to be a fast and efficient method of short-term marking of large numbers of juvenile salmon. Spray marking mortalities were low: 5.1% in 1987 and 0.05% in 1988, relative to the group of control fish in 1988 which were netted and handled in exactly the same way but

were not sprayed (0.20% mortality). Monitoring of mark retention in 1987 and 1988 indicated that pigment on some of the marked fish released for residence time experiments may have been difficult to detect, and that the pigment may not have been sufficient to last the entire period of the juvenile chum salmon (1987) and fall chinook salmon (1988) outmigrations (Fig. 16). In both years, less than 50% of the marks were evidently after 30 days. Mark retention was better in 1987 than in 1988, but mortalities due to spray marking were higher in 1987.

Access

Five marked chum salmon of 9,000 released were recaptured (0.06%) in the inlet fyke net in 1987 and 105 marked fall chinook salmon of 17,800 released were recaptured (0.59%) in the inlet fyke net in 1988. On the basis of the data in Table 1, the access model estimated that 3.15% (473/15,000) of the total chum outmigrants (1987) and 0.43% (7,430/1,728,000) of the total fall chinook outmigrants (1988) accessed the Lincoln Avenue wetland.

The mark/recapture experiments to determine juvenile chum and fall chinook salmon access to the wetland and the estimates of wetland access from the model indicate that a small percentage of the population of outmigrating salmon access the restored wetland. This may be due to the early stage of development of the system or may be a result of incorrect model assumptions. The system

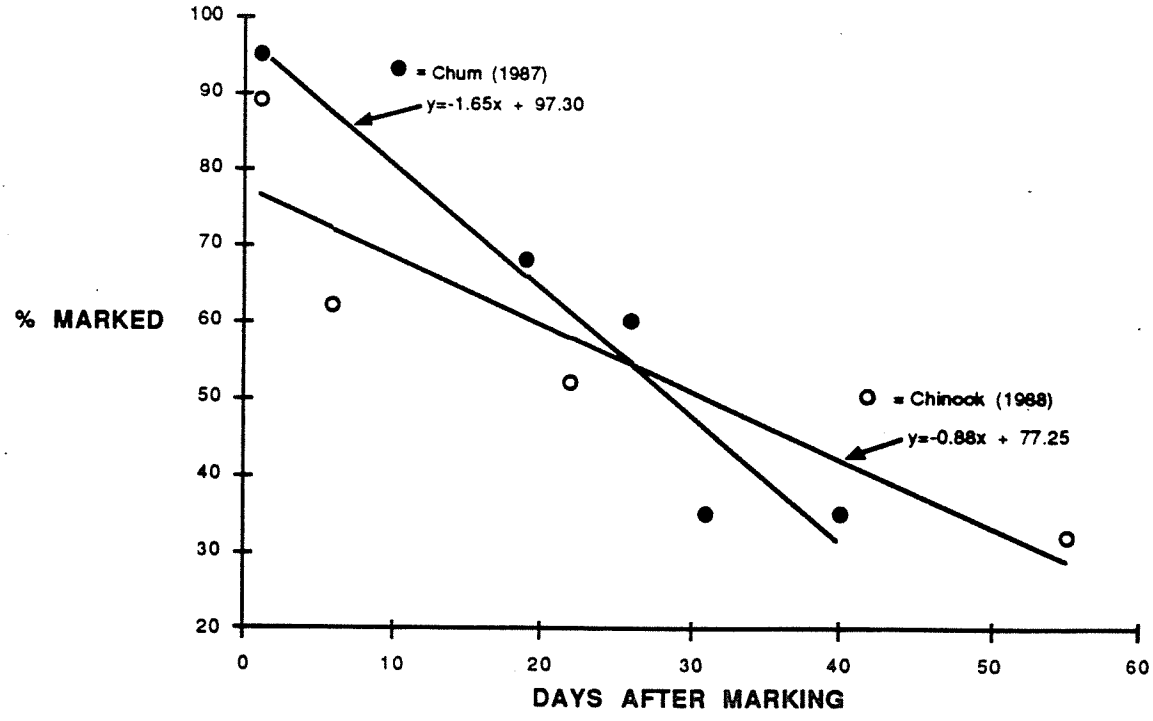


Figure 16. Summary of mark retention for chum salmon (*Oncorhynchus keta*) in 1987 and fall chinook salmon (*O. tshawytscha*) in 1988.

is new and in a state of flux because of: (1) rapid changes in the salinity regime, bathymetry and morphology of the tidal channels due to sedimentation (Thom et al. 1987, 1988); (2) changes in the composition, standing stock, and availability of potential prey resources of juvenile salmon (Shreffler et al. 1988); (3) the size-at-release and timing of hatchery releases; and, (4) tidal effects. In addition, flow patterns of the glacially-fed Puyallup River vary seasonally and annually. Depending upon the swimming behavior and orientation of juvenile salmon with respect to river flow, the proportion of juveniles which access the restored wetland may, in part, be a function of Puyallup River discharge. The model we employed assumed that equal numbers of fish migrate down each bank of the river. In addition, upstream mortality was assumed to be 10%. Data in the Puyallup River are lacking on these two assumptions, and variations from these values could increase or decrease the access values.

Residence Times

Residence times of recaptured chum salmon averaged 1.7 days (range 1 to 9 days) for the yellow-marked release group, and averaged 2.3 days with a range of 2 to 4 days for the red-marked release group (Table 11). Residence times of recaptured chinook salmon averaged 5.1 days (range 1 to 40 days) for fish which migrated downstream and entered the wetland volitionally. Residence times of the red-marked group released directly into the wetland, however, averaged 38.3 days (range 29 to 43 days) (Table 12).

Table 11. Summary of 1988 spray-marked juvenile chum salmon releases, recaptures and individual residence times.

Date	Releases		Recaptures	Residence time
May 21	438 yellow		-	-
May 22	-		39 yellow	1 day
May 23	-		31 yellow	2 day
May 24	-		-	-
May 25	-		-	-
May 26	-		-	-
May 27	447 red		-	-
May 28	-		8 red	1 day
	-		1 red	2 days
May 30	-		1 yellow	9 days
	-		8 red	4 days
May 31	-		1 red	5 days
June 1-10	-		-	-
		Totals	73/438 yellow	$x = 1.73 \pm 1.45$
			38/447 red	$x = 2.29 \pm 1.10$
			111/885	$x = 1.92 \pm 1.37$

Table 12. Summary of 1988 spray-marked juvenile fall chinook salmon releases, recaptures and individual residence times.

Date	Releases*	Recaptures	Residence time
March 12	12 lv	-	-
March 13	17 lv	-	-
March 14	18 rv	-	-
March 15	38 nc	-	-
March 16	18 ad	-	-
March 17	207 lc	10 lc	<1 day
		14 lv	5-6 days
		4 rv	3 days
		2 ad	1 day
March 18	36 uc	10 lc	1 day
		3 uc	6-7 days
March 19-20	-	-	-
March 21	-	1 lc	4 days
March 22	-	-	-
March 23	1,000 red	2 lc	6 days
March 24-29	-	-	-
March 30	37 an	-	-
March 31-April 3	-	-	-
April 4	-	2 an	5 days
April 5-20	-	-	-
April 21	-	1 uc (bs)	34 days
		1 lc (bs)	35 days
		1 lv (bs)	40 days
		6 red (bs)	29 days
April 25-29	-	-	-
April 30-May 3	-	-	-
May 4	-	-	-
May 5	-	12 red (bs)	43 days

Mean residence time (volitional): 5.06 ± 8.09 days
Mean residence time (red release group): 38.33 ± 6.60 days

As of April 20, 1988, none of the red-marked fall chinook released 29 days earlier had been recaptured. On April 21, channels 3 and 4 were sampled by beach seine and six of the original fall chinook red-marked release group were recaptured along with 106 additional unmarked chinook. A total of 94 more unmarked fall chinook were seined from channel 4 on May 4.

The fyke net system was removed from the mouth of the wetland after beach seine sampling on May 4. On May 5, beach seine samples were collected in four of the six tidal channels and twelve red-marked fall chinook salmon and 230 unmarked chinook were collected and preserved. We conclude that the fyke-net system (Fig. 6) probably did not induce overestimates of residence time

because some juvenile salmon remained in the wetland even when given free access to the river. Mean residence times of the fall chinook red release group may have been even longer if it had not been necessary to preserve a significant percentage of the fish on May 5 because of beach seining mortalities. The mark retention-time relationship indicated that less than 50% of the marked chinook had detectable marks by April 21, 1988, and less than 32% by May 4 (Fig. 16). Thus, many chinook salmon which we considered "unmarked" (106 collected on April 21; 94 on May 4; and 230 on May 5) probably had marks that were undetectable.

Chum salmon typically migrate downstream immediately after emergence, primarily at night, close to shore, and near the surface. Although estuarine rearing of chum salmon occurs in some systems (Healey 1979, 1982), extended rearing in brackish water is uncommon (Simenstad et al. 1982). The brief mean residence time documented for chum salmon (<2 days) in the Lincoln Avenue wetland in 1987 suggests that residence in brackish habitats may be naturally abbreviated in the Puyallup River estuary. The rapid seawater acclimation of chum fry relative to chinook fry (Weisbart 1968; Folmar and Dickhoff 1980) may explain the shorter mean residence times of juvenile chum salmon within the brackish wetland. Iwata and Komatsu (1984) found that acclimation to isotonic estuary water for 12 hours was sufficient for efficient adaptation of chum salmon to seawater, whereas 3-4 months were necessary for fall chinook salmon adaptation to seawater (Clarke and Shelbourn 1985).

Like chum salmon, chinook salmon typically exhibit nearshore, nocturnal downstream migrations, but the age, size, and timing of downstream juvenile chinook migrants are highly variable for the different races (fall, winter, and spring). The extended residence times of juvenile fall chinook (up to 43 days) documented in this study are among the longest described for any wetland and the first in a restored wetland. The mean length of twelve recaptured chinook which had a wetland residence time of 43 days increased 15.92 mm (0.37 mm d^{-1}) and their mean weight increased 2.24 g (5 mg d^{-1}). In the Nanaimo River estuary, fall chinook salmon grew about 1.32 mm d^{-1} in length and 5.7 mg d^{-1} in weight (Healey 1980). The shorter residence time estimates for fall chinook which entered the wetland volitionally ($\bar{x} = 5.06 \pm 8.09$ days) relative to the transplanted fish ($\bar{x} = 38.33 \pm 6.60$ days) may have resulted from the following: (1) the fish which entered the wetland from the river may have already begun their physiological adaptation to saltwater; (2) the transplanted fish were never given the opportunity to forage in the river and hence had no way of assessing the foraging value of the wetland relative to the foraging value of the river; (3) river discharge or tidal effects; and (4) fyke-net effects.

A number of factors potentially influence estuarine residence times of juvenile salmon: size of fish (Shepard 1981; Simenstad et al. 1982), risk of predation (Parker 1971; Peterman and Gatto 1978; Fresh et al. 1981, 1982; Magnhagen 1988), availability of prey of the preferred size, type, and quantity (Simenstad and Salo 1980; Healey 1982; Simenstad et al. 1982), physiological

transition (Mason 1974; Simenstad et al. 1982; Iwata and Komatsu 1984), physical factors such as river discharge, turbidity, tidal fluctuations, temperature, and salinity (Shepard 1981), and density dependent interactions among juveniles (Levy and Northcote 1982). Several studies have examined the influence of estuarine residence on subsequent survival (Reimers 1973; Levings et al. 1986; MacDonald et al. 1988), but even the more definitive studies have not determined which habitats or aspects of estuaries promote survival. Whether survival rates of outmigrating juvenile salmon are enhanced by residence in specific estuarine wetland habitats, or whether increased survival of estuarine resident juveniles leads to subsequent increases in the number of returning adult spawners has yet to be clearly determined.

Foraging

Our evaluation of the functional performance of the restored Lincoln Avenue wetland as a foraging area for juvenile Pacific salmon illustrated the following: (1) foraging by juvenile chum and fall chinook salmon was deterministic in both 1987 and 1988 as indicated by the chironomid insects (midge larvae, pupae, and adults) which were selected over all other organisms in the available prey spectrum; (2) there was little overlap between epibenthic prey available and the prey consumed; and, (3) drift fauna which were advected into the wetland from the Puyallup River may have been a major source of prey for juvenile chum and fall chinook salmon temporarily residing and foraging within the restored Lincoln Avenue wetland.

Epibenthic Prey Available and Consumed

1987

Because of their presence at the sediment surface, epibenthic organisms were considered to be potential prey available to foraging juvenile chum and fall chinook salmon. The most abundant taxa among the epibenthos were Nematoda (49.52%), Harpacticoida (36.50%), Tardigrada (2.58%), and Oligochaeta (2.58%) (Fig. 17). However, Nematoda, Tardigrada, and Oligochaeta rarely appear in the stomach contents of naturally foraging fish. Although these taxa were included in Figure 17 as prey "available" for consumption by juvenile salmon, none were found in stomachs removed from juvenile chum or chinook captured in the restored wetland. Harpacticoida, Cladocera, and Insecta are the only prey taxa among those listed as available which have been previously reported in the literature to be consumed by juvenile salmon.

A variety of prey organisms were consumed by both chum salmon and fall chinook salmon which were captured in the restored wetland, but the dominant prey category overall in both chum and fall chinook salmon stomachs was Chironomidae (midge larvae, pupae, and adults) which represented 42-96% of the total index of relative importance in the diet of the fish (Fig. 18). Stonefly nymphs (Plecoptera), two species of gammarid amphipods (*Corophium* spp.), flies

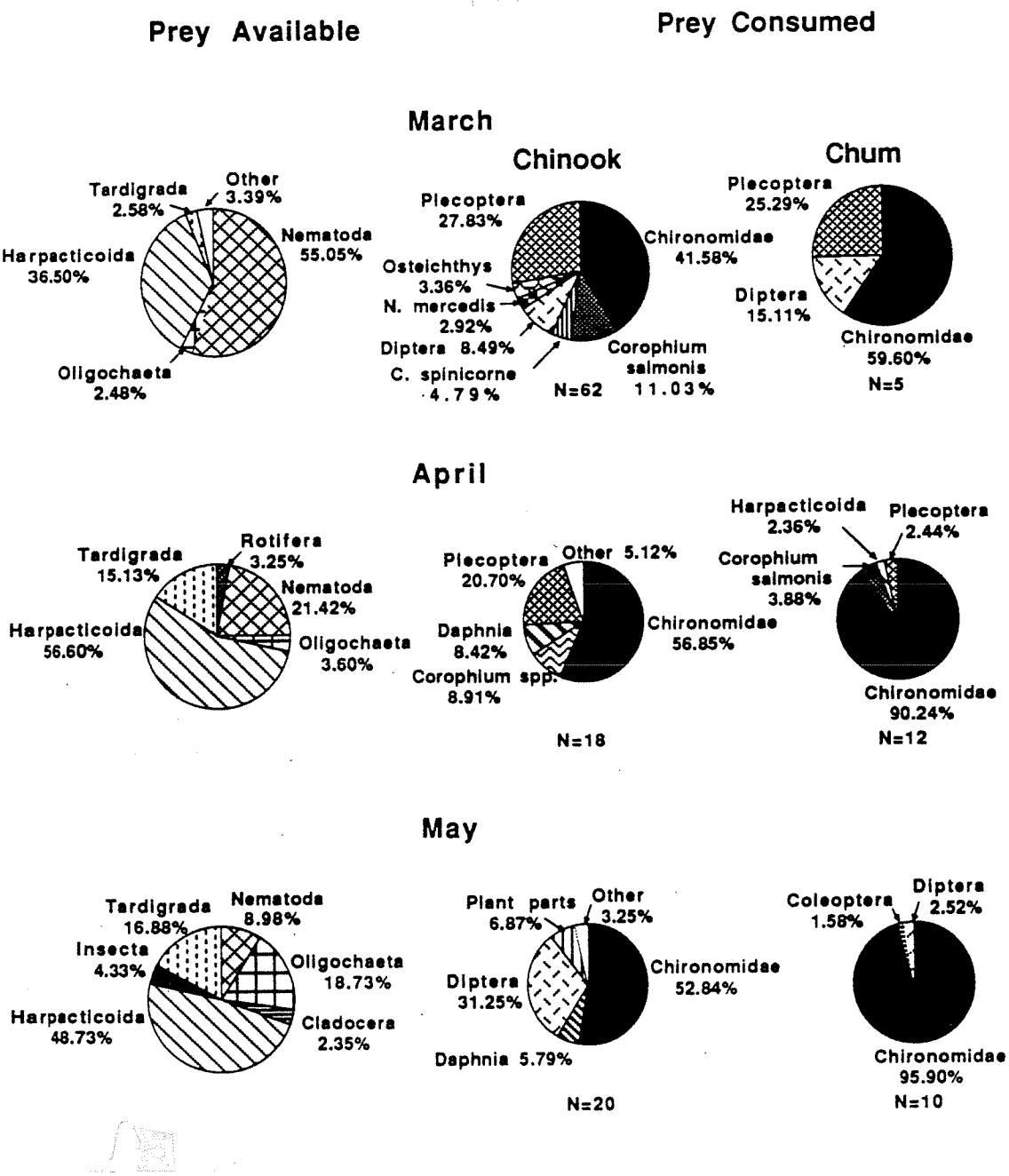


Figure 17. Prey availability (% composition of epibenthos) and rank importance (% total IRI) of items in the stomach contents of juvenile chum (*Oncorhynchus keta*) and fall chinook salmon (*O. tshawytscha*) collected in the Lincoln Avenue wetland beach seine samples, March-May 1987. Prey availability from Thom et al. (1988); sample sizes (n) are indicated below each pie.

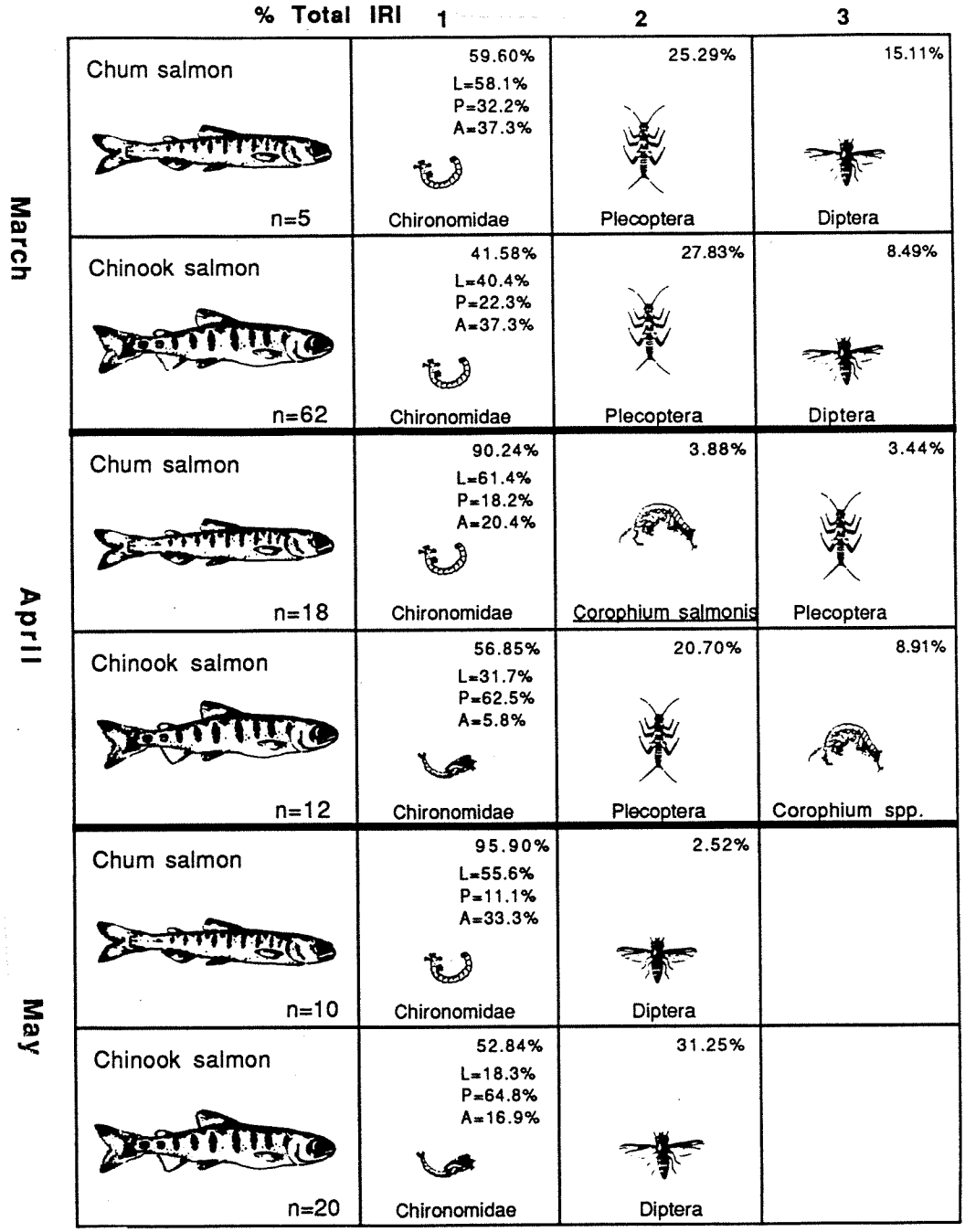


Figure 18. Rank importance of prey items in the stomach contents of juvenile chum (*Oncorhynchus keta*) from the Lincoln Avenue wetland beach seine samples, March-May 1987. Ranking of prey items is based on IRI (% total IRI values; Fig. 8) indicated in the upper right corner of each box. The % chironomids is broken down into life history stages: L=larvae; P=pupae; A=adult.

(Diptera), and cladocerans (*Daphnia* spp.) were among the secondarily important prey found in chum and fall chinook stomachs. A variety of other prey organisms (Arachnida, *Chaoborus*, Coleoptera, Collembolla, *Eogammarus confervicolus*, Harpacticoida, Homoptera, Hymenoptera, unidentified Insecta, *Neomysis mercedis*, Odonata, and Osteichthys) were consumed infrequently or in small numbers. Comparisons of epibenthic prey available and the prey consumed in the Lincoln Avenue wetland during the 1987 outmigration period (Fig. 18) indicated minimum overlap and standardized forage ratios were zero for all prey categories except harpacticoida.

1988

The most abundant taxa among the epibenthos were Nematoda (49.52%), Harpacticoida (30.90%), Tardigrada (13.92%), and Oligochaeta (3.41%); six other taxa comprised the remaining 2.25% (Fig. 19). As in 1987, few of the sampled epibenthic organisms were consumed (Fig. 20) and standardized forage ratios were zero for all epibenthic prey categories.

Neustonic Prey Available and Consumed (1988)

In 1988, neustonic organisms (drift) advected into the wetland on the water surface were numerically dominated by *Daphnia* spp. (0.86%), chironomids (midge larvae, pupae, and adults; 7%), and cyclopoid copepods (*Diaptomus* spp.; 2.5%) (Fig. 19). Comparisons of drift prey available and the prey consumed indicated that *Daphnia* spp. were negatively selected (standard forage ratio ranged from 0.01-0.05), whereas chironomids were positively selected (SFR ranged from 0.82-0.96) by juvenile chum and fall chinook salmon (Fig. 20).

In terms of % total IRI, chironomid larvae, pupae, and adults were the dominant prey consumed by both chum and fall chinook salmon captured in the inlet fyke net, outlet fyke net, and beach seines. Chironomid adults were consumed in higher percentages by chum and fall chinook foraging in the river (inlet fyke net samples), whereas chironomid larvae were selected more often in the wetland (outlet fyke net and beach seine samples). Both chum and fall chinook also consumed stonefly nymphs (Plecoptera), adult flies (Diptera), gammarid amphipods (*Corophium* spp. and *Eogammarus confervicolus*) and *Daphnia* spp.

Fish captured in the inlet fyke net had only riverine prey in their stomachs. Fish captured in the outlet fyke net and beach seines had both riverine and wetland prey in their stomachs because as temporary residents in the wetland these fish had the opportunity to exploit prey produced within the wetland as well as drift advected into the wetland from the river. The input of prey into the wetland from the adjacent upland and riparian habitats was observed but not quantified.

In 1988, none of the beach seine-caught chum or fall chinook salmon had empty stomachs; 0-28% of the fish in the inlet and outlet fyke nets had empty stomachs. Fish which were caught in the fyke nets often were not removed and preserved until 24 h after their entry into the fyke net.

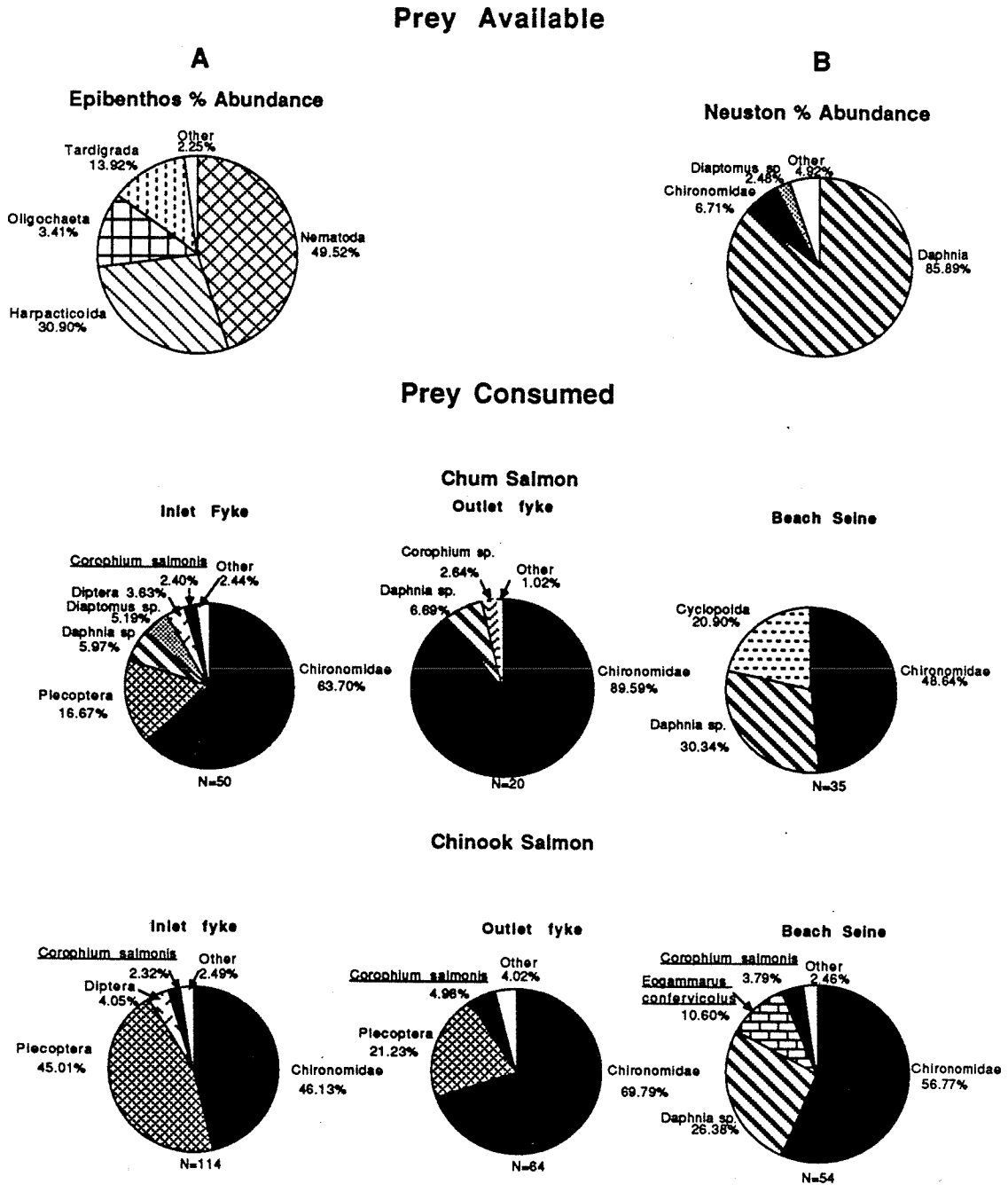


Figure 19. Prey availability: (A) neuston % abundance, (B) epibenthos % abundance, and rank importance (% total IRI) of items in the stomach contents of juvenile chum (*Oncorhynchus keta*) and fall chinook (*O. tshawytscha*) salmon from the Lincoln Avenue wetland inlet fyke net, outlet fyke net, and beach seine samples, March-June 1988. Sample sizes (n) are indicated below each pie.

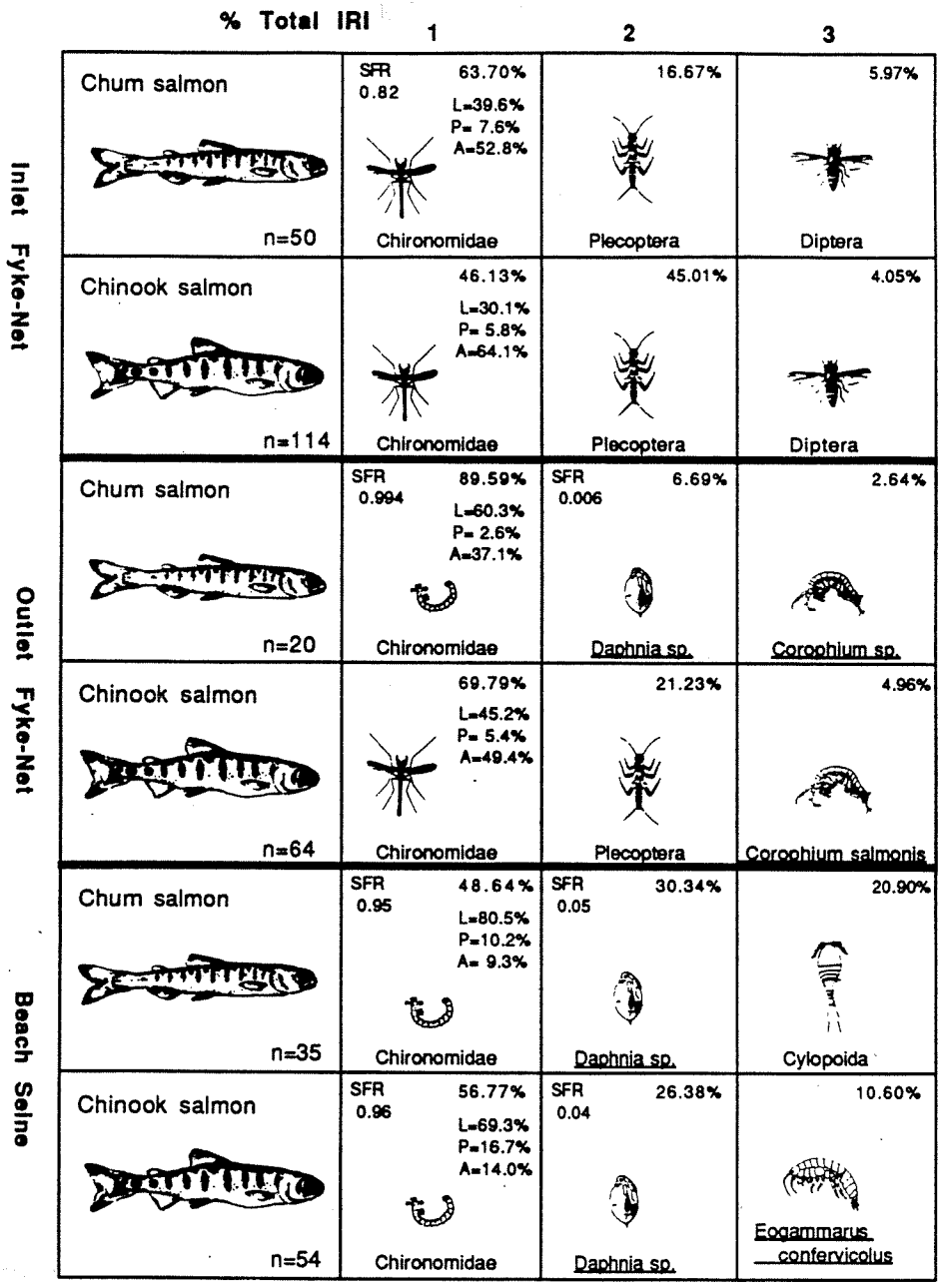


Figure 20. Rank importance of prey items in the stomach contents of juvenile chum (*Oncorhynchus keta*) and fall chinook (*O. tshawytscha*) salmon from the Lincoln Avenue wetland inlet and outlet fyke net, and beach seine samples, March-June 1988. Ranking of prey items is based on IRI (% total IRI values; Fig. 10) indicated in the upper right corner of each box. The % chironomids is broken down into life history stages: L=larvae; P=pupae; A=adult.

Hence, fish caught in the fyke nets were confined without food and completely evacuated their guts whereas fish caught in beach seines could have fed until the time they were captured.

Contrary to the findings of Miller and Dunn (1980) that "juvenile fishes in estuaries are trophic generalists," juvenile chum and fall chinook salmon in the Lincoln Avenue wetland foraged selectively on chironomid larvae, pupae, and adults in both 1987 (Fig. 18) and 1988 (Fig. 20) even though other potential prey were available in much greater densities. Several other studies have noted the selection of chironomids as a prey source by juvenile chum and fall chinook salmon foraging in estuarine wetlands (Mason 1974; Dunford 1975; Levy and Northcote 1982). Chironomid pupae and adults comprised gravimetrically 58 to 81% of the diet of juvenile chum salmon foraging in salt marsh channels of the Skagit River delta (Congleton 1978). Chironomid larvae overwhelmingly dominated the diet of all 29 fish species collected in the mainstem of the lower Fraser River (Northcote et al. 1979).

Juvenile salmon residence and foraging in the Lincoln Avenue wetland may be regulated by development of chironomids or other emergent insects. The short life cycles of chironomids (at the most, several weeks) and the large total biomass of the larvae confer ecological and energetic significance on this taxon as consumers and prey (Oliver 1971). The life cycle of chironomids is comprised of four stages—egg, larva, pupa, adult—of which the larva is the critical stage during which all the energy required to complete the life cycle is stored. Chironomid larvae often occur in high densities (up to 50,000 m^{-2}). Due to their wide array of morphological, physiological, and behavioral adaptations, the range of conditions under which chironomids are found is more extensive than that of any other group of aquatic insects (Coffman and Ferrington 1984). In addition, the planktonic behavior of first instar larvae enables chironomids to rapidly exploit new environments and to successfully colonize temporary and intermittent habitats (Davies 1976). Chironomids were among the first colonizers of the restored Lincoln Avenue wetland (Thom et al. 1987).

The chief food source of chironomid larvae is detritus and suspended algae (Oliver 1971; Coffman and Ferrington 1984). While chironomid pupae and adults are ephemeral and, with few exceptions, do not feed, the quantity and quality of detritus available to chironomid larvae in the restored wetland may determine the foraging potential of juvenile chum and fall chinook salmon. A detritus-chironomid-juvenile chum salmon chinook salmon food chain was the dominant pathway reported for the food web structure of several tidal marshes of the lower Fraser River (Northcote et al. 1979). Such a detritus-based food chain also seems probable in the restored Lincoln Avenue wetland and would support previous findings that foraging of juvenile chum and chinook salmon is, in part, a function of the quantity and quality of detritus and detritivorous prey within wetland food webs (Sibert et al. 1977; Healey 1979; Sibert 1979; Naiman and Sibert 1979; Simenstad and Wissmar 1985).

The sources of chironomids for juvenile salmon foraging in the Lincoln Avenue wetland are presently unknown. Densities of larval chironomids in the epibenthos were higher in the mid-bay (67-1889 m^{-2}) than on unvegetated flat 5 (13-889 m^{-2}), channel 4 (111-648 m^{-2}), or vegetated flat 4 (144-288 m^{-2}). Densities on the vegetated flat may have been underestimated due to our inability to quantify the abundances of chironomids attached to, or associated with, the emergent vegetation. No chironomid pupae or adults were found in the epibenthic samples from any of the four habitats in either 1987 or 1988. Chironomid densities in the Puyallup River neuston (larvae 40.5 m^{-3}; pupae 54.7 m^{-3}; adults 14.0 m^{-3}) were low in comparison to epibenthic densities in the wetland, but high relative to neuston densities (1-10 m^{-3}) in the Lower Fraser River (Northcote et al. 1976).

Direct comparison of epibenthic prey available in the wetland with prey found in chum and fall chinook salmon stomachs in 1987 indicated essentially no overlap. Although a number of the epibenthic taxa were only marginally available as prey for foraging salmon (e.g., organisms such as nematodes, tardigrades and oligochaetes which were in the surface sediments or might be difficult for the salmon to see in the naturally turbid waters of the Puyallup River), several of the other taxa should have been available to the fish. On the basis of monthly epibenthic samples from March to June 1987, the potential prey resource in the wetland (excluding Nematoda, Tardigrada, and Oligochaeta) was between 500 and 2,000 organisms m^{-2}. Yet, few of these organisms were fed upon frequently or in abundance by juvenile chum and fall chinook salmon (Fig. 17). On the basis of epibenthic samples taken in April 1988, the potential juvenile salmon prey resource in the wetland (excluding Nematoda, Tardigrada, and Oligochaeta) was between 200 and 1,500 organisms m^{-2}. The 1988 epibenthic fauna may have been locally influenced by organic enrichment due to blooms of microalgae (Thom et al. 1988). Again, few of the epibenthic species were consumed by juvenile chum or fall chinook salmon during 1988 (Fig. 19). We concluded (Shreffler et al. 1988) that among a number of possible explanations for this discrepancy, two were most likely: (1) epibenthos sampling did not accurately assess the availability of the prey selected by the fish, which were predominantly larval, emergent or drift insects; and (2) the selected prey originated outside the wetland and were either consumed in the river before the fry entered the wetland or advected into the wetland as drift.

While numerous studies in estuaries of the Pacific Northwest have noted the importance of harpacticoid copepods as prey for outmigrating chum and chinook salmon fry (Feller and Kaczynski 1975; Sibert et al. 1977; Sibert 1979; Healey 1979; Simenstad and Salo 1980; Simenstad et al. 1982; Levy and Northcote 1982), harpacticoid copepods were comparatively unimportant to the overall prey spectrum of either chum or chinook temporarily residing in the Lincoln Avenue wetland in 1987 or 1988. However, most of the habitats studied have been mudflat and submerged (e.g. eelgrass) wetlands and the same foraging intensity on harpacticoids has not been demonstrated for emergent marsh habitats. The species of harpacticoid copepods

available in the restored wetland, principally *Microarthridion littorale* ($\bar{x}$ = 0.57 mm), *Tachidius discipes* ($\bar{x}$ = 0.60 mm), *Mesochra rapiens* ($\bar{x}$ = 0.65 mm), and *Leimia vaga* ($\bar{x}$ = 0.80 mm) were probably too small either to be seen by the fish or to be of much energy value as compared to the species observed to be selected in other estuarine habitats (i.e., *Harpacticus uniremis*, $\bar{x}$ = 1.2 mm; *Tisbe* spp., $\bar{x}$ >1.0 mm; Cordell 1986).

Sampling of neustonic (drift) fauna during the 1988 spring outmigration indicated that a significant number of prey suitable for juvenile salmon consumption were advected into the wetland from the river (Fig. 17). Although *Daphnia* spp. were the most abundant drift taxon, few were eaten, perhaps because they were more evasive than midges (Chironomidae) or stoneflies (Plecoptera) or they were not visually available; the translucent bodies of *Daphnia* spp. may have been difficult for the juvenile salmon to see in the turbid water of the wetland. The only comparable data on drift fauna as prey for juvenile salmon is for the lower Fraser River (Northcote et al. 1976). Total densities in the Fraser River (1-10 organisms m^{-3}) were lower than those in the lower Puyallup River (up to 2,000 organisms m^{-3}), but diversity was higher—81 taxa in the Fraser compared to 32 taxa in the Puyallup. Northcote et al. (1976) reported a decline in diversity and an increase in density of benthic, epibenthic, and neustonic prey organisms towards the mouth of the Fraser River.

Although some potential prey sources may have been missed by our sampling, a variety of epibenthic and neustonic organisms are available to juvenile salmon temporarily residing and foraging within the restored wetland during the spring outmigration period (Figs. 17, 19). Both chum and chinook salmon fed on epibenthic chironomid larvae and gammarid amphipods, as well as on neustonic chironomid pupae and adults, stonefly nymphs, adult flies, and *Daphnia* spp. There appears to be input of potential juvenile salmon prey into the wetland from both the river and the adjacent upland and riparian habitats. Whether there is any net flux of prey out of the wetland and into the Puyallup river remains unclear.

Recognizing the energetic constraints of juvenile salmon migrating in estuaries (Wissmar and Simenstad 1988), the value of the Lincoln Avenue wetland as a foraging area for juvenile salmon is probably linked to the availability and density of preferred prey organisms. On the basis of the densities of drift fauna being advected into the wetland (1680 m^{-3}) relative to estimates of mean epibenthic densities within the wetland (500-2000 m^{-2}), the restored wetland serves as a prey sink and as a prey source. Although we did not evaluate the bioenergetic value of neustonic prey compared to epibenthic prey, the prevalence of both in the prey spectra of juvenile chum and fall chinook salmon suggests that each may be an important prey resource.

Fall chinook salmon were able to locate adequate prey resources within the wetland sufficient to maintain a growth rate of roughly 5 mg d^{-1} comparable to 5.7 mg d^{-1} reported for the Nanaimo River estuary (Healey 1980).

BIRDS

The wetland system continued to be utilized by a large number of bird species in 1988. A total of 92 species were observed by the Tahoma Audubon Society from January 1988 to December 1988 (Table 13). Eleven new species were observed during this period including Northern Pintail, Blue-winged Teal, Canvasback, Greater Scaup, Stilt Sandpiper, Common Snipe, Yellow-rumped Warbler, Western Tanager, Brown-headed Cowbird, Pine Siskin, and House Sparrow. As in 1987, Mallards, American Widgeons, and Gadwalls were among the most abundant species observed in the system. Red-winged Black Birds were common in the upland cattail marsh. In April-May, Mallard ducklings were abundant in the midbay, channels and mudflats. In May-June, four Green Heron nests were observed in the upland cattail marsh; chicks were observed in two of the nests—one nest had two chicks, the other had three. The nest with three chicks was blown down during heavy winds and all three chicks were killed. The two chicks in the other nest survived and were observed mimicking the mother's flight patterns on two sampling dates in June. Great Blue Herons were commonly observed along the tidal channels and were photographed preying on juvenile salmon on several occasions. Our data on marsh vegetation standing stock, benthic infauna density, epibenthos standing stock and fish abundance suggest that the system is providing food resources to the aquatic food web and resident birds.

CONCLUSIONS

The Lincoln Avenue wetland system continues to serve the target resource groups for which it was designed, including juvenile salmonids, shore birds, waterfowl, raptors and small mammals. The relative ecological importance of the system to the resources appears, based on several quantitative measures, to have increased between 1986 and 1988. At present, the system provides superior ecological support of fish and their prey, as well as greater habitat diversity than Parcel 5. In 1988, the system continued to change dramatically in terms of basin morphometry, sediment characteristics, vegetation, and benthic faunal assemblages. Smaller increases were seen in fish and bird species richness.

The data in 1988 indicate that the system is still in an early developmental stage as highlighted by the presence of a benthic fauna that is indicative of nascent environments. In addition, dramatic changes in vegetation, infauna and epibenthos densities and/or standing stocks indicate that the system is undergoing a colonization process. These types of developmental patterns are typical of "new" environments (e.g., MacArthur and Wilson 1967).

As in 1987, the primary concern regarding the fate of the system is sedimentation. Sedimentation was heavy during the 12 months following dike breaching. Since that time, sedimentation

Table 13. Bird species observed in the Lincoln Avenue wetland system. TA = Tahoma Audubon observations October 1986-December 1988; FRI = Fisheries Research Institute observations.

Common Name	TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1988
1. Common Loon		X		X	
2. Pied-billed Grebe	X	X		X	X
3. Horned Grebe	X	X	X	X	X
4. Western Grebe	X	X		X	X
5. Double-crested Cormorant	X	X	X	X	X
6. Great Blue Heron	X	X	X	X	X
7. Green-backed Heron	X	X	X	X	X
8. Snow Goose	X				X
9. Canada Goose	X	X	X	X	X
10. Wood Duck	X				X
11. Green-winged Teal	X	X	X	X	X
12. Mallard	X	X	X	X	X
13. Cinnamon Teal	X				X
14. Common Teal			X	X	
15. Blue-winged Teal			X	X	X
16. Northern Shovelor	X		X	X	X
17. Gadwall	X	X	X	X	X
18. Eurasian Widgeon	X				X
19. American Widgeon	X	X	X	X	X
20. Common Goldeneye	X				X
21. Barrow's Goldeneye	X				X
22. Bufflehead	X				X
23. Hooded Merganser	X				X
24. Common Merganser	X	X		X	X
25. Red-breasted Merganser	X		X	X	X
26. Cooper's Hawk	X				X
27. Red-tailed Hawk	X	X		X	X
28. American Kestrel	X				X
29. Merlin	X				X
30. Red-necked Pheasant	X		X	X	X
31. California Quail	X	X		X	X
32. Sora	X				X
33. American Coot	X	X	X	X	X
34. Lesser Golden-Plover	X				X
35. Killdeer	X	X	X	X	X
36. Greater Yellowlegs	X		X	X	X
37. Lesser Yellowlegs	X				X
38. Spotted Sandpiper	X				X
39. Bar-tailed Godwit	X				X
40. Western Sandpiper	X	X		X	X
41. Least Sandpiper	X	X	X	X	X

Table 13 - cont'd.

Common Name	TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1988
42. Pectoral Sandpiper	X				X
43. Common Snipe		X	X	X	
44. Long-billed Dowitcher	X		X	X	X
45. Short-billed Dowitcher	X				X
46. Bonaparte's Gull	X	X	X	X	X
47. Mew Gull	X				X
48. California Gull	X				X
49. Western Gull		X	X	X	
50. Herring Gull		X	X	X	
51. Thayer's Gull	X				X
52. Glaucous-winged Gull	X				X
53. Mourning Dove	X				X
54. Rock Dove	X	X	X	X	X
55. Belted Kingfisher	X				X
56. Northern Flicker	X				X
57. Willow Flycatcher	X				X
58. Tree Swallow	X				X
59. Violet-green Swallow	X		X	X	X
60. Cliff Swallow	X	X	X	X	X
61. Barn Swallow	X	X	X	X	X
62. Rough-winged Swallow		X	X		
63. Stellar's Jay	X				X
64. American Crow	X		X	X	X
65. Black-capped Chickadee	X		X	X	X
66. Bushtit	X				X
67. Bewick's Wren	X				X
68. Winter Wren	X				X
69. Marsh Wren	X				X
70. Ruby-crowned Kinglet	X				X
71. American Robin	X	X	X	X	X
72. Cedar Maxwing	X				X
73. Northern Shrike	X				X
74. European Starling	X		X	X	X
75. Orange-crowned Warbler	X				X
76. Common Yellowthroat	X		X	X	X
77. Black-headed Grosbeak	X				X
78. Rufous-sided Towhee	X				X
79. House Sparrow		X		X	X
80. Savannah Sparrow	X	X	X	X	X
81. Fox Sparrow	X				X

Table 13 - cont'd.

Common Name	TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1988
82. Song Sparrow	X		X	X	X
83. Lincoln's Sparrow	X				X
84. Golden-crowned Sparrow	X				X
85. White-crowned Sparrow	X				X
86. Red-winged Blackbird	X	X	X	X	X
87. Brown-headed Cowbird			X	X	X
88. House Finch	X				X
89. American Goldfinch	X	X	X	X	X
90. Northern Pintail					X
91. Canvasback					X
92. Greater Scaup					X
93. Sharp-shinned Hawk					X
94. Yellow-rumped Warbler					X
95. Western Tanager					X
96. Pine Siskin					X
TOTAL NUMBER OF SPECIES	80	33	37	46	92

has resulted in marked changes in the bathymetry and morphology of the tidal channels. The main effects have been to decrease bottom depths in the mid-bay and reduce channel widths. Although these changes did not exclude salmonids from the system in spring because of high river flows, only channels 3 and 4 were deep enough to retain water during the June-August drought—a period of unusually low river levels. Sedimentation was minimal on the flats. We expect that sediment accrual rate will decrease at Lincoln Avenue, and that it is premature at this time to take action to remove sediments or reduce sedimentation.

RECOMMENDATIONS

SYSTEM MAINTENANCE RECOMMENDATIONS

At the present time, we do not recommend sediment removal from the system. However, the spatial patterns and general rate of sedimentation in the system should continue to be monitored using the stakes we established on the flats and new stakes placed by surveyors in the channels and mid-bay.

The single largest maintenance problem at the wetland is trash. Trash that floats in from the river and is dumped from land accumulates in the intertidal and terrestrial habitats. The trash is

The single largest maintenance problem at the wetland is trash. Trash that floats in from the river and is dumped from land accumulates in the intertidal and terrestrial habitats. The trash is unsightly and some materials may be toxic to the organisms. Posting "no-dumping" signs has had little or no effect. Many of the signs which were posted have been torn down and now lay by the side of the dike along with piles of illegally dumped trash. We strongly advise that the Port should hire workers immediately to remove the waste which has already accumulated, and that trash should thereafter be removed monthly at the bare minimum. Furthermore, we strongly encourage developing the area as a nature preserve. This action will enhance the overall habitat quality of the system and may reduce illegal trash dumping.

MONITORING RECOMMENDATIONS

Permit-related monitoring in 1989-1990 should follow the program outlined in the first report on the wetland (Thom et al. 1987). The program includes sediment, vegetation, salmonid prey, fish and bird sampling. The 1989 monitoring effort is presently underway and includes work designed to further evaluate the functional performance of the system as a juvenile salmon rearing habitat. In particular, we are attempting to determine the sources and fates of the chironomids which are the single most important prey taxa for outmigrating juvenile chum and chinook salmon.

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