FRI-UW-9004
August 1990

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

PHASE IV REPORT: YEAR FOUR MONITORING, JANUARY-DECEMBER 1989

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ANNUAL REPORT
to
PORT OF TACOMA

Approved

Submitted 8-31-90

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ACKNOWLEDGMENTS

Funding for this work was provided by the Port of Tacoma. We sincerely thank Leslie Sacha and Richard Gilmur of the Port of Tacoma for continuing assistance, support and comments on the draft report. Puyallup Indian tribal biologists Russ Ladley, Dennis LaPointe, Bill Coats, Steve Dillon, Herman Dillon, Jr. and Joe Miyamoto helped with the fish sampling. Colin Levings and Timber Whitehouse of Fisheries and Oceans Canada sampled emergent insects from the system in May, and kindly provided us with the data. We sincerely appreciate the interest of the Tahoma Audubon Society in the wetland and for providing bird observations for the wetland. Jon R. Jensen made bird counts at least weekly in the system in 1989. His data sheets were kindly provided to us, along with additional sitings, by Thais Bock of the Society. We are grateful to Marcus Duke (FRI Publications) for manuscript production and editorial suggestions.

EXECUTIVE SUMMARY

In 1989, the monitoring program for the Lincoln Avenue wetland system included sampling of sediment characteristics, vegetation, benthic fauna, fish and birds. Sediment accretion was investigated to provide an indication of sedimentation rates in the system. In addition, a study of fluxes of water properties, plankton and neuston was conducted over a 24 hour period in May to evaluate the wetland as a source and sink for water-born nutrients, organic matter and floating animals and plants. A short-term study of emergent insects in the wetland was conducted in conjunction with the diel study by biologists from the Vancouver Office of Fisheries and Oceans Canada. The findings of the 1989 monitoring program were as follows:

1. Sedimentation continued with considerable deposition occurring between the 1988 and 1989 monitoring activities.
2. Substantial increases in *Carex* shoot density occurred in 1989. Marsh expansion was evident.
3. Densities of mud-dwelling invertebrates increased in 1989.
4. Invertebrate composition continued to change toward an estuarine assemblage.
5. Thirteen bird species were added to the list, for a total of 109 species.
6. The trend toward an increasing presence of estuarine fish species and the corresponding decrease in the prominence of freshwater species continued in 1989.
7. Under equilibrium flux conditions, the wetland is a sink for some organic matter and a source of inorganic matter. This is typical of wetland systems in the Northwest.

We conclude that the system continues to serve the target resources for which it was designed. The system continues to undergo rapid and dramatic physical, chemical, and biological changes.

Diagram of the Lincoln Avenue wetland system.

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. 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. Earlier reports (Thom et al. 1987, 1988, Shreffler et al. 1990) on the project detail the construction and monitoring results through 1988. This monitoring work has shown that transplanted sedge continues to dominate the vegetation in the system and that other species, especially cattails, have vigorously colonized the system. In addition, target resources including juvenile salmonids, shorebirds and waterfowl occupied and 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.

The monitoring work in 1989 included continued systematic sampling of sediments, vegetation, infauna, epibenthic zooplankton, fish and birds. In addition, a diel (24-hour) "flux" study of the import and export of material in and out of the wetland system was carried out. The objective of this sampling exercise was to examine the question of whether the wetland system is, on the average, a net sink or source of nutrients, organic particulate matter, and organisms over the ebb and flood of tidal and riverine waters in and out of the system. The Lincoln Avenue Wetland presented an ideal opportunity to address this question because of the single, simple entrance/exit between the wetland and the river channel, and because of the previous years' data on fish and neuston entering and exiting the system (Thom et al. 1989; Shreffler 1989).

For the first time in the monitoring of the Lincoln Avenue Wetland, the emergence of aquatic insects that are important as prey of juvenile salmon in the Wetland (Thom et al. 1988, 1989) was examined. This study was conducted in collaboration with investigators from the Department of Fisheries and Oceans Canada. These investigators had conducted similar sampling of emergent insects in natural and "developed fish" habitats in British Columbia (Whitehouse et al. 1989) and were equally interested in comparing these data with the Lincoln Avenue Wetland.

STUDY SITES

The wetland system contains an upland area with a grassland, cattail marsh and swamp, and an intertidal area consisting of mudflats and channels (Fig. 2). Sampling in 1989 of vegetation, infauna, epibenthos and fish was carried out in the intertidal area. Birds were sampled in all

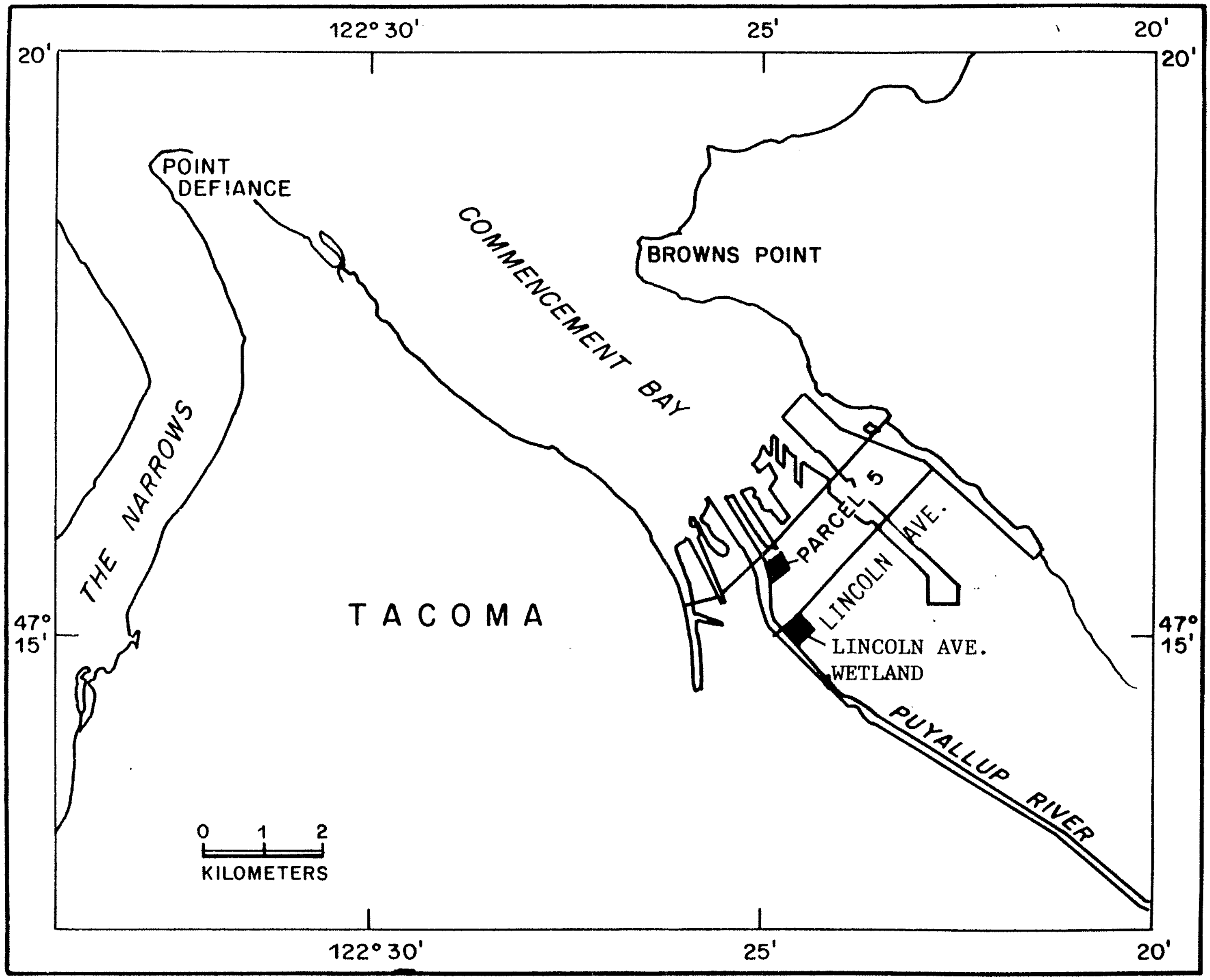

Figure 1. Location of Parcel 5 and the Lincoln Avenue wetland system.

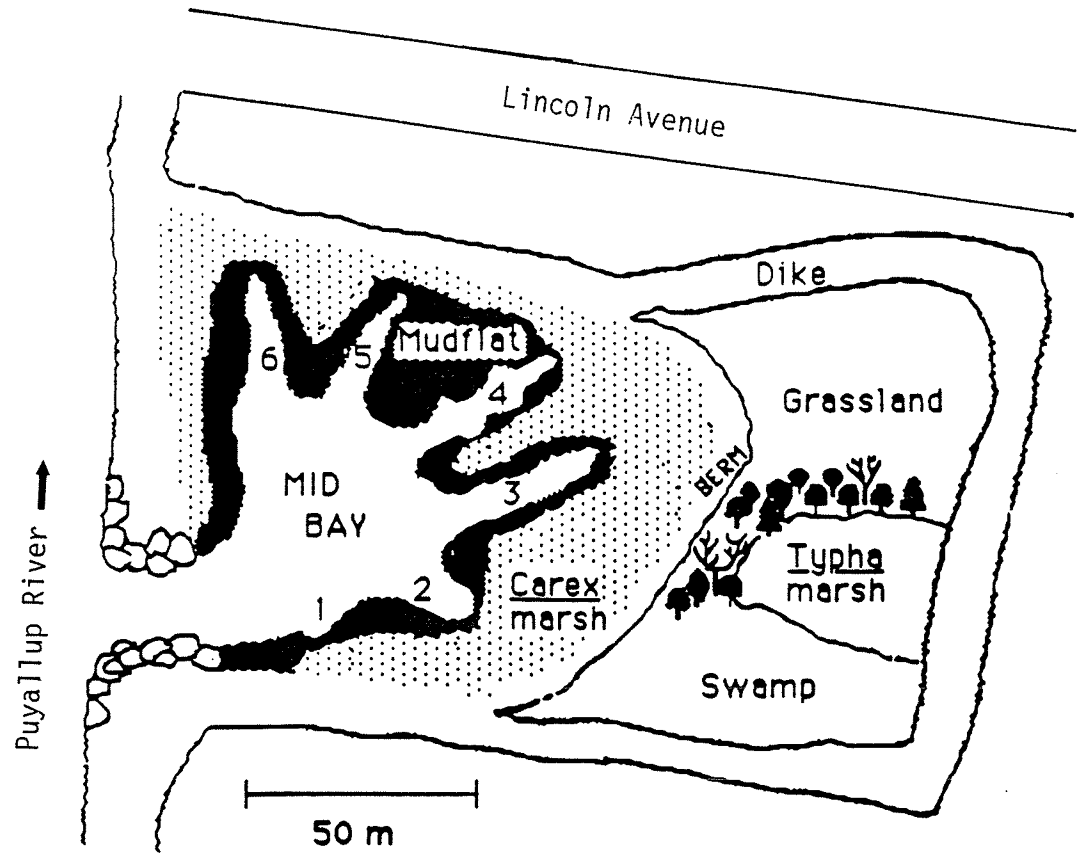

Figure 2. Distribution of various habitat types within the Lincoln Avenue system.

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 in 1986-1987 with *Carex*, and flat 5 served as an unplanted reference area.

An ancillary sedimentation rate experiment was added during the 1989 monitoring period as a verification of the established plot (stake) measurements made since 1986. Sites were located on flats 1-5 within 0.5 m of existing sedimentation stakes.

Emergent insects were sampled during the May 10-11 diel study period in the three most prominent habitats of the estuarine area of the wetland system: (1) unvegetated mudflat; (2) fringing *Carex* marsh; and (3) *Typha* marsh (Figure 2).

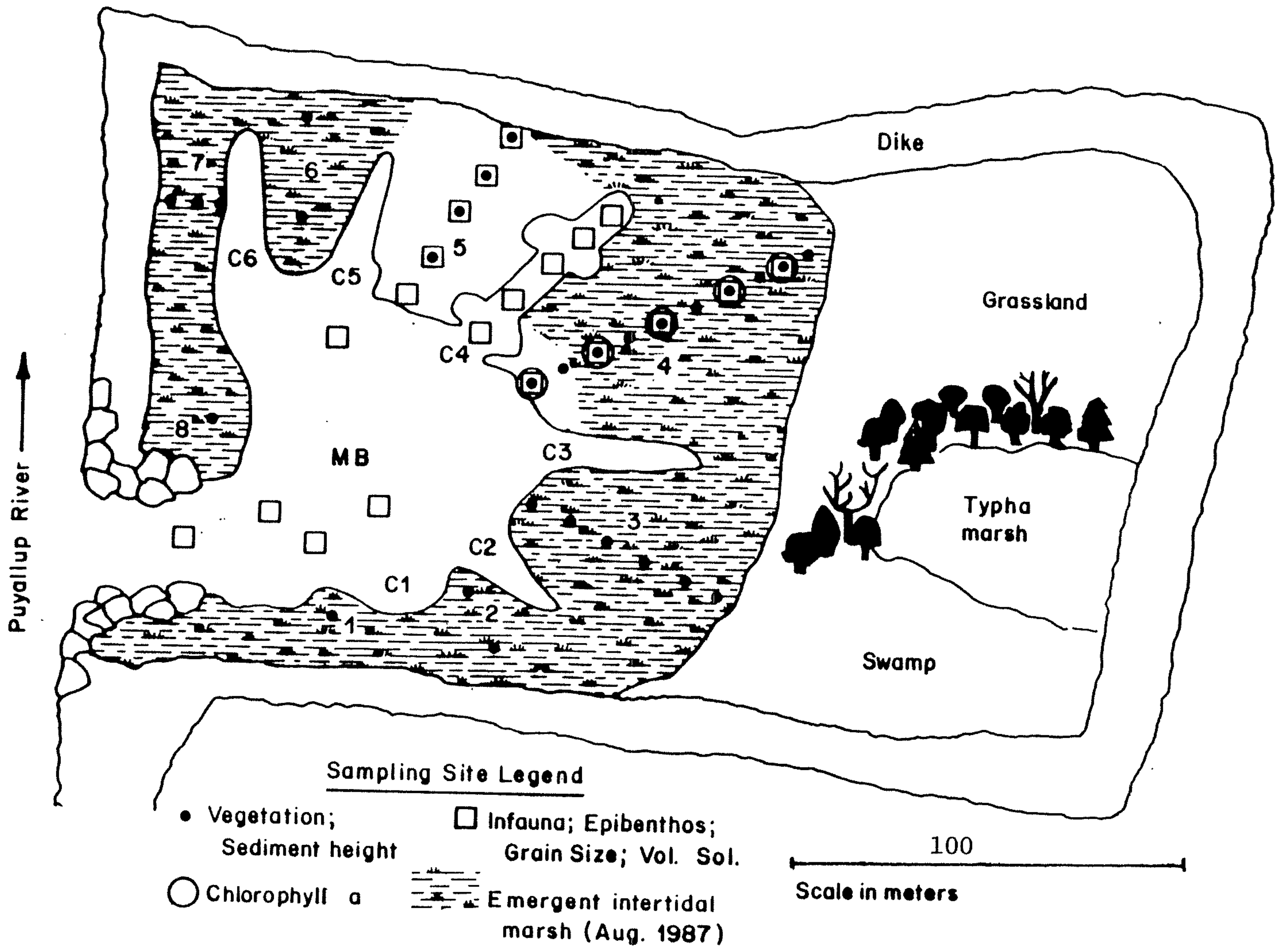

Figure 3. The wetland system showing sampling sites on intertidal flats numbered 1-8, channels numbered C1-C6, mid-bay (MB), and adjacent grassland, cattail marsh and swamp habitats.

MATERIALS AND METHODS

SEDIMENT CHARACTERISTICS

Sediment characteristics monitored in 1989 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 a PVC coring tube with a 5.1 cm inside diameter. The 20 sites sampled were located as follows: 12, 28, 44, 60 and 76 m along the transect on flat 4; 5, 14, 23, 32 and 41 m along the flat 5 transect; 25, 35, 45, 55 and 65 m along the transect in channel 4; and at five sites located between channel 4 and the mouth of the wetland (referred to as the mid-bay sites; Fig. 3). 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 at the percent loss of weight of a sample of sediment due to ashing at 500°C for 4 hours in a muffle furnace (Thom et al. 1987). Sampling was conducted on 11 May 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. On 14 September, the distance from the top of the stake to the ground surface was recorded.

On May 11, artificial horizons were established in small areas adjacent to one of the established plots in the center of the transects that bisect each of the five flats. The locations of these areas were identified for later relocation by precise measurements from the permanent plot marker stakes. These horizons were created by sprinkling gold plastic "glitter" flakes over an approximately 100-cm^2 area of the substrate adjacent to each plot. The glitter was applied uniformly to virtually cover that area.

On September 14, these plots were revisited, the artificial horizon areas relocated, and two 3-cm diameter cores were taken from the center of each area. These cores were capped and returned to the Wetland Ecosystem Team's Seattle laboratory, where they were frozen. When processed at a later date, the cores were removed from the freezer and allowed to thaw just long enough for the sediment cores to become free of the core walls. The sediment cores were then extruded from the core and cut with a bandsaw in 0.5-cm increments. Each increment was placed in a separate petri disk and allowed to thaw completely. After thawing, they were examined under a dissecting microscope and the presence and number of glitter flakes recorded.

VEGETATION

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 on 11 May and 14 September. Sample processing followed the methodology of Thom et al. (1987).

During 1987 and 1988, emergent macrophyte (i.e., rooted plants) percent cover, density and above ground biomass was sampled at the 29 intertidal sites located on flats 1-8 (Fig. 3); the lowest site on flat 5 was not included. 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. The four corners of each 1-m^2 area were permanently marked with wooden stakes to facilitate repositioning of the quadrat during subsequent samplings. The number of shoots of *Carex* and *Typha* occurring within each quadrat was counted in the field. In 1989, we modified the emergent plant sampling method because the cattails were too tall (i.e., over 2 m) to fit within the photographic sampling frame we had used in 1987-88. In addition, the high density of the vegetation prevented the relocation of several of the site markers. Therefore, in 1989 we estimated the cover of each major emergent plant species using aerial photographs and ground truthing.

As was done in all previous years, vertical color aerial photographs were taken (5 July 1989) from an airplane. The negatives were 9 x 9 in, and the scale for color prints made from the negatives was 1 in = 200 ft. During the 14 September visit, the distribution of major plant taxa was outlined on clear plastic sheets which overlayed a photograph. The taxa were relatively easily distinguished by color on the photographs. In the laboratory, a clear plastic sheet containing grid of squares (i.e., pixels) with a scale area of 9.2m^2 was laid over the photograph. The number of pixels in which a plant species covered at least 50% of the area of the pixel was recorded for each species. The number of pixels was multiplied by 9.2 m^2/pixel to yield an estimate of area covered by each emergent plant species. This procedure was repeated for aerial photographs taken in 1986-1988. We felt that the procedure used in 1989 provided a reliable estimate of vegetation cover and that data were of comparable accuracy among years. Information was available for all years on species distribution and cover, and aerial photographs are consistent in scale, season and quality.

Carex shoot density was estimated by tossing a 0.1-m^2 quadrat several times into the area occupied by this species on each flat during the 14 September visit.

INFAUNA

Infauna, as an indicator of biological assemblage development in the sediment, were sampled on 11 May 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 hours, 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

Epibenthos was sampled on one occasion, 17 May, as a representative monitoring date comparable to collections in previous years (Thom et al. 1987, 1988). Sampling design and protocol were identical to prior years (ibid), utilizing an epibenthic suction pump at five sites along transects bisecting a vegetated (#4) and unvegetated (#5) intertidal flat and a tidal channel (#4) (Fig. 3); unlike previous years, the mid-bay of the wetland could not be sampled comparatively because that habitat was now completely dewatered at low tides due to increased sedimentation. The epibenthic suction pump collects animals from within a 0.018 m^2 area, and animals are collected on a 150 μ mesh screen. Samples were preserved in 10% buffered formalin. In the laboratory, the samples were placed in 50% alcohol, identified to species where possible, enumerated, and the wet weight recorded to the nearest 0.1 mg.

EMERGENT INSECTS

Aquatic insect emergence was sampled on May 10-11, during the period of the diel study, using modified Model DAY traps (LeSage and Harrison 1979). These traps are floating pyramidal net structures that cover 0.5 m^2 of the sediment surface. Net mesh size is 0.202 mm. A 500-ml plastic sampling jar was secured in the apex of the sampling net.

Five nets were set haphazardly in the three wetland habitats during low tide. Traps set in *Typha* were located on Flat #4; traps in *Carex* habitat were located on Flat #1; and the traps set in unvegetated habitat were located on Flat #5.

All nets were set at low tide on May 10 between 1015 and 1130 PDT. They were checked at high tide the same day, approximately eight hours later, and reset. They were recovered during mid-ebb tide between 0915 and 1040 on the morning of May 11, resulting in a second set length of 14 to 16 hours.

When the nets were sampled, all insects were killed by placing the net in a 20 liter bucket containing a paper towel dampened with 100% ethyl acetate; the bucket was then tightly sealed for five to ten minutes (LeSage and Harrison 1979). Upon removal from the emergence traps nets, the insect samples were preserved in 100% isopropyl alcohol. Insects were identified to family and enumerated with the aid of dissecting and compound microscopes using appropriate taxonomic keys (Chu 1949; Borror and DeLong 1964; Borror and White 1970; Merritt and Cummins 1978, 1984; Borror et al. 1981).

FISH

Fish residing in the wetland during low tide were sampled in tidal channels, comparable to the previous years' sampling using a 9.7-m two-pole seine with a 6-mm mesh bag (Thom et al. 1988). Sampling occurred on April 12, May 11, May 17, and June 15. Two tidal channels (#3, #4) were sampled on all dates except on June 15, when only channel #4 could be sampled due to extremely low water.

The seine was equipped with a solid core lead line that kept the net on the bottom while the float line kept the top of the net at the surface. Prior to sampling each channel, the surface water temperature, salinity, wind speed and direction, visibility, percent cloud cover, amount of precipitation, air temperature and time of day were recorded. At each channel, the seine was stretched across the width of the channel at the basin end, and then pulled up the the length of the channel to the upland end where the net was drawn completely out of the water. Mud clogging the bag of the seine was washed through the mesh with water before the sample was sorted.

Fish sampling was targeted at estuarine-dependent outmigrating juvenile chum salmon (*Oncorhynchus keta*) and chinook salmon (*O. tshawytscha*), but records were kept on all fish that were captured. Captured fish were then placed in buckets of water, rinsed to remove most of the mud, and sorted to species. Differentiation between the various salmon species was made with the aid of several reference guides (McConnell and Snyder 1972, Trautman 1973, Phillips 1977). Subsamples of at least 10 individuals of each species were placed in labelled 1-qt glass jars and preserved in 70% isopropyl alcohol. Fish that were not part of the subsample were enumerated and released. Large fish which could not be easily preserved were identified in the field, the life history stage and length were noted, and then the fish were released.

In the laboratory, all preserved fish were identified, enumerated, measured (nearest 1-mm fork length or total length), weighed (damp weight to nearest 0.01 g) and checked for reproductive status. Species identifications followed Hart (1973) and Wydoski and Whitney (1979). If necessary, they were verified using the University of Washington synoptic fish collection.

Fish data were recorded on NODC format #100, type 3 (catch summary), type 4 (individual fish examination), and type 5 (stomach analysis) computer forms. These data were then stored on the University of Washington's Cyber mainframe computer and analyzed using the catch summary analysis program (CSRUN) adapted specifically for NODC coded fish data. All fish density and standing stock data were reported as based on the total area estimated for the two channels, i.e., 1,398 m^2 and 1,682 m^2 for channels #3 and #4, respectively (Thom et al. 1987).

BIRDS

Observation of the presence of birds were made at least weekly during 1989 by Jon R. Jensen. The data sheets, kindly supplied by Thais Bock of the Tahoma Audubon Society, included records of species observed in the wetland during each visit.

DIEL FLUXES

The diel "flux" study was conducted from 1230 PDT on May 10 to 1230 PDT on May 11. This involved almost all of a tidal cycle, from just prior to slack low tide to a slack flood at close to midnight, and through a high-low and low-high tidal cycle through the next morning.

Measurements were made or samples collected every two hours at the entrance to the wetland system. Table 1 lists the variables measured, their units and the method used to analyze the sample, if necessary. All concentrations of matter and organisms (e.g., material per unit of volume) were subsequently standardized to a flux rate (e.g., material per unit time) by multiplying by an estimate of the volume and direction of water movement through the mouth of the wetland system. This water flux factor was estimated by using the water elevation with the cross-sectional survey to generate an approximate surface area of the water at the mouth opening at each interval. This surface area was then multiplied by the current velocity to estimated the water flux in (+) and out (-) of the wetland.

Air temperature, current speed, current direction, water level, dissolved oxygen, salinity, water temperature, inorganic nutrient (i.e., nitrate, nitrite, ammonia, phosphate, silicate), total organic carbon, neuston, chlorophyll *a* concentration and zooplankton populations were sampled at the mouth of the system every 2 hours between 12:30 pm (daylight time) on 10 May and 12:30 pm on 11 May. All samples were taken from the center of the mouth by wading or with the aid of a small boat.

Light irradiance was sampled hourly during the sample period using a Li-Cor light meter. Temperatures were measured with a hand held mercury thermometer. Current speed was measured using an electrostatic current meter (Montodoro-Whitney PVM 2A). Water samples were obtained from 0.5-m depth using an electric suction pump and filtered through 100 μm mesh sieve at the time of sampling. Subsamples were collected from the bottle and frozen for nutrient and organic carbon analysis. These samples were analyzed at the University of Washington School of Oceanography's routine water chemistry laboratory. Salinity samples were placed in citrate bottles and were analyzed using a conductance salinometer. Chlorophyll *a* concentration was determined from 90% acetone extracts using a Turner fluorometer. The dissolved oxygen concentration in each sample was determined immediately upon collection using a YSI model 58 polarographic oxygen probe. Neuston was sampled with a 0.5-m^2 neuston net held in the prevail

Table 1. Environmental variable and material flux rate measurements made every two hours during diel flux study of Lincoln Avenue Wetland, Commencement Bay, WA, 10-11 May 1989.

Variable/Measurement	Method	Unit	Analysis
1. Water elevation	Direct	ft	Measured on rod located in bottom of channel; later correlated to exact survey of channel mouth
2. Air temperature	Mercury thermometer	°C	
3. Water temperature	Mercury thermometer	°C	
4. Light irradiance	Light meter	$\mu E\ m^{-2}\ s^{-1}$	
5. Current velocity and direction	Electromagnetic current meter	$m\ s^{-1}$	
6. Salinity	Bottle sample	ppt	laboratory salinometer
7. Dissolved oxygen	YSI dissolved oxygen meter	$mg\ L^{-1}$	
8. Nutrients (PO_4, SIO_4, NO_2, NO_3, NH_4)	Bottle sample	$\mu M\ L^{-1}$	sample refrigerated autoanalyzer
9. Total organic carbon	Bottle sample	$mg\ L^{-1}$	sample refrigerated
10. Neuston	Neuston net	no. m^{-3}	taxonomic sorting and weighing
11. Zooplankton sample from mid-depth	Suction pump	no. m^{-3} and weighing	taxonomic sorting and
12. Fish	Fyke net	no. hr^{-1}	taxonomic identification and release alive at time of sampling

ing current 3 to 5 min.; sampling volume was estimated as 0.25-m^2 multiplied by the measured current velocities. Zooplankton was sampled as the organisms retained on the 100-µm sieve at the time of water sampling.

Flux rates for chemical constituents, organic matter and organisms were approximated by integrating the product of the 2-hr measurements of concentration and the water volume flux in and out of the wetland over the sampling period. This integration used a trapezoidal approximation programmed in Quick Basic on a microcomputer.

RESULTS AND DISCUSSION

SEDIMENT CHARACTERISTICS

Since dike breaching in February 1986, sediments from the Puyallup River have been deposited in the wetland, which has resulted in changes in sediment grain size and bottom contours. 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, on average, 1-3 ft of sediment has deposited in the channels and mid-bay. This deposition has occurred largely along the edges of the channels and immediately inside the mouth of the system. Sedimentation that occurred between the 1988 and 1989 monitoring activities was heavy; in particular, the flats received the most sediment recorded (Table 2). We could not locate many of the sediment monitoring stakes and we assumed that some were buried, which indicated deposition of 20 cm or more at these areas. There were several severe rain storms during the winter that probably resulted in very high sediment loads in the river. Sedimentation in the wetland probably occurred during these periods of heaviest runoff. Our observations, along with collections of fish, indicated that adequate water remained in the system during the period of salmonid outmigration in 1989.

Since 1987, the sediments on flat 4 have (1) become coarser (except at the lowest site on flat 4), (2) showed variable changes on flat 5, (3) become finer in channel 4 and (4) become much finer in the mid-bay (Table 3). The changes can be explained by the fact that the mid-bay sediments were coarser initially as compared to those on the flats. Riverine sediments were probably, on average, coarser than those on the flats and finer than those in the deeper mid-bay and channel areas initially exposed by the excavation of the wetland. Sediment percent fines was quite similar among all areas by 1989 (Table 3). Average percent fines were 82.9, 84.1, 96.5 and 73.2, for flat 4, flat 5, channel 4 and mid-bay, respectively. The rate of change in average sediment fines for each area was greatest in the mid-bay between the 1988 and 1989 monitoring activities (Table 4). However, the greatest changes in channel 4 and the mid-bay took place between 1987 and 1988. In terms of modifications in the rate of change of average sediment fines, it appears that the rate of change slowed considerably for the entire system between the 1988 and 1989 monitoring activities.

Table 2. Cumulative sedimentation on flats. Values are increases in sediment surface height relative to stakes placed in the wetland on 20 January 1987. Positive values indicate sediment accretion; negative values indicate scouring. (-- means the stake was not found.)

Flat no.	Site	April 1987	April 1988	May 1989
1	1	+1.4 cm	+3.5 cm	--
2	1	+1.1	+3.5	--
	2	+1.8	+2.5	--
3	1	-1.2	+0.5	--
	2	+2.8	+4.0	+19.0
	3	-0.6	0.0	--
	4	+0.6	+0.5	+17.0
	5	0.0	-1.0	+19.0
	6	+1.3	+1.5	+20.0
4	1	+1.6	--	--
	2	-1.2	+2.0	--
	3	+2.0	+1.0	--
	4	+1.3	+1.0	--
	5	+1.3	+4.0	--
	6	+3.0	+6.0	+20.0
	7	+2.3	--	+20.0
	8	+1.3	+0.5	+20.0
	9	+1.3	-0.5	+20.0
	10	+1.1	-0.5	+20.0
5	1	+2.0	--	--
	2	+0.2	+2.0	+19.0
	3	+1.8	-2.0	+18.0
	4	-0.7	+2.0	+18.0
6	1	+0.7	-3.0	--
	2	+1.8	+1.0	--
7	1	0.0	+1.5	+5.0
	2	+0.4	-1.0	+5.0
	3	+1.5	+2.0	+5.0

Table 3. Percent fines in sediments from 20 sampling sites. (-- = no data.)

Area	Site	Year 1987	 1988	 1989	Change (%) 1987 to 1989
Flat 4	2	92.1%	68.0%	79.7%	-12.4%
	4	73.2	68.9	69.2	-4.0
	6	95.8	93.2	88.2	-7.6
	8	91.5	87.2	83.8	-7.7
	10	10.8	67.8	93.7	+82.7
Flat 5	1	83.3	65.9	86.2	+2.9
	2	91.4	70.2	82.2	-9.2
	3	51.1	80.4	93.3	+42.2
	4	84.0	--	81.7	-2.3
	5	5.0	--	77.1	+72.1
Channel 4	1	56.6	--	96.5	+39.9
	2	61.0	92.5	97.6	+36.6
	3	77.4	93.5	98.9	+21.3
	4	65.6	64.8	91.2	+25.6
	5	35.5	86.2	98.5	+63.0
Mid-Bay	1	3.7	86.7	95.6	+91.9
	2	12.4	--	96.1	+83.7
	3	5.1	72.7	68.4	+63.3
	4	1.9	39.9	83.5	+81.6
	5	--	14.4	22.3	+7.9

Table 4. Rate of change in average percent sediment fines for each area.

Area	1987 to 1988	1988 to 1989
Flat 4	+5.0%/yr	+5.9%/yr
Flat 5	+9.2	+11.9
Channel 4	+25.1	+12.2
Mid-Bay	+47.6	+19.8

The artificial horizon experiment indicated that sedimentation rates could be estimated with this method if the number of cores were increased and the coring method modified. Three of the cores did not contain any horizon flakes (one on Flat #2, both on Flat #4) at all (Table 5). In addition, one of the cores from Flat #3 contained numerous horizon flakes through all increments examined. Discussion with other scientists investigating sedimentation on intertidal flats using this method (D. Reed, LUMCON) indicated that this was typical of deformation and dragging of the horizon deeper into the sediments during the coring process. This usually indicates that the corer walls are too thick and not sharp enough to be used in compacted muds.

Excluding these anomalous cores and assuming the core deformation was not prevalent in the remaining cores from Flats #1, #2, #3, and #5, sedimentation between 1.0 cm and 2.0 cm (average 1.6±0.4 cm) was measured over the 4-month period from May to September (Table 5). If this sedimentation occurs at approximately the same rate over the year, almost 5 cm yr^{-1} occurs on the flats. Confirmation of this method and generation of a precise annual estimate would require

Table 5. Distribution of artificial horizon flakes in two cores recovered 4 months later from intertidal flats, Lincoln Avenue Wetland, Commencement Bay, Tacoma, WA; * indicates the bottom of that core and underlining indicates the deepest occurrence of the artificial horizon.

Flat	1		2		3		4		5	
Core	1	2	1	2	1	2	1	2	1	2
Surface, <0.5	0	0	0	0	1-5	1	0	0	0	0
0.5	7	1-5	0	0	1-5	3	0	0	0	0
1.0	7	5+	0	0	1-5	14	0	0	1	1
1.5	0	0	0	11	1-5	15	0	0	1	7
2.0	3	0	0	0	1-5	0	0	0	0	5
2.5	0	0	0	0	1-5 *	0	0	0	0	0
3.0	0	0	0	0		0	0	0	0	0
3.5	0	0	0	0		0	0	0	0	0
4.0	0	0	0	0		0	0	0	0	0
4.5	0	0	0	0		0	0	0	0	0

modification of the sampling design. This would include: (1) using a thin-walled core to minimize core deformation; (2) applying the artificial horizon glitter in a more dense, uniform layer over a larger surface; (3) sampling with at least five to ten cores per plot; and, (4) sampling every two to three months.

Volatile solids, indicating the organic content of sediments, were greatest in the *Typha* and *Carex* marsh at the upper edge of flat 4 (sites 2 and 4), at the two outermost sites in channel 4 (sites 4 and 5) and the innermost sites in the mid-bay (sites 1 and 2) (Table 6). We encountered plant debris in the bottom of channel 4 during our sampling, which would explain the higher values there. It appears that areas with standing emergent marsh plants and areas which tend to accumu

Table 6. Volatile solids in sediments as a percent of sediment dry weight.

			Year		
Area	Site		1987	1988	1989
Flat 4	2		4.3%	6.3%	7.4%
	4		4.8	6.8	11.3
	6		2.5	3.2	3.4
	8		1.6	2.0	3.1
	10		3.2	2.4	3.3
		Mean	3.3	4.1	5.7
Flat 5	1		3.1	1.9	2.3
	2		2.8	2.6	2.9
	3		3.0	3.7	3.3
	4		3.4	0.6	1.8
	5		1.5	1.9	2.2
		Mean	2.8	2.1	2.5
Channel 4	1		3.2	2.6	2.5
	2		4.4	3.7	3.3
	3		4.4	3.3	1.9
	4		4.8	2.0	4.0
	5		3.4	3.2	5.1
		Mean	4.0	3.0	3.4
Mid-Bay	1		1.2	1.6	4.2
	2		2.5	3.7	3.2
	3		2.8	2.8	2.1
	4		1.9	2.7	1.2
	5		2.0	2.2	1.2
		Mean	2.1	2.6	2.4

late organic debris have higher sediment organic content. This result has generally been seen since 1987. The sediment on flat 4 showed greatest change in average organic content since 1988 (Table 7). The other areas showed very little change since 1988.

VEGETATION

Benthic algae were present and at times abundant in the system. Sediment-associated algal assemblages were present on flat 4 as indicated by sediment chlorophyll samples from May and September (Fig. 4). Mean chlorophyll *a* concentration on flat 4 for both dates was within the range of values seen during 1987 and 1988 samplings. The yellow-green alga *Vaucheria* occurred in patches on all flats. *Vaucheria* is common in tidally influenced estuarine systems in the Northwest.

A total of 48,000 *Carex* shoots were planted in 1986-1987. Total shoot abundance in the system was about 250,000 at the end of the growing season in 1989 (Fig. 5). The increase between 1986 and 1989 is largely due to an increase in shoot density, which went from about 17 m^{-2} in 1986 to 133 m^{-2} in 1989. There was substantial (2.5 fold) increase in shoot density between 1988 and 1989. The decline in total shoot abundance in the system between 1987 and 1988 was related to a decrease in area covered by *Carex* (Fig. 6), which was not offset by an increase in mean shoot density (Fig. 5). Although the area covered by *Carex* decreased between 1988 and 1989, the increased shoot density caused the increase in total shoot abundance in the system. *Carex* continues to occupy the most space among the emergent plants. *Typha* sp. (cattails), which showed a dramatic increase in area covered between 1987 and 1988, showed very little change between 1988 and 1989 (Fig. 5). Many of the cattail plants were robust (up to 3.5 m in height in 1989. Total cover of emergent taxa was slightly less in 1988 as compared to 1987. The 1988 and 1989 vegetation cover was very similar.

A patch of *Scirpus* sp. appeared on flat 3 in 1987. Since then this patch has increased in size to cover approximately 19 m^2. *Eleocharis* sp. cover has remained steady since about 1987 (Fig. 6).

Table 7. Rate of change in average volatile solids as a percent of dry weight of sediment for each area.

Area	1987 to 1988	1988 to 1989
Flat 4	+0.8%/yr	+1.6%/yr
Flat 5	-0.7	+0.4
Channel 4	-1.0	+0.4
Mid-Bay	+0.5	-0.2

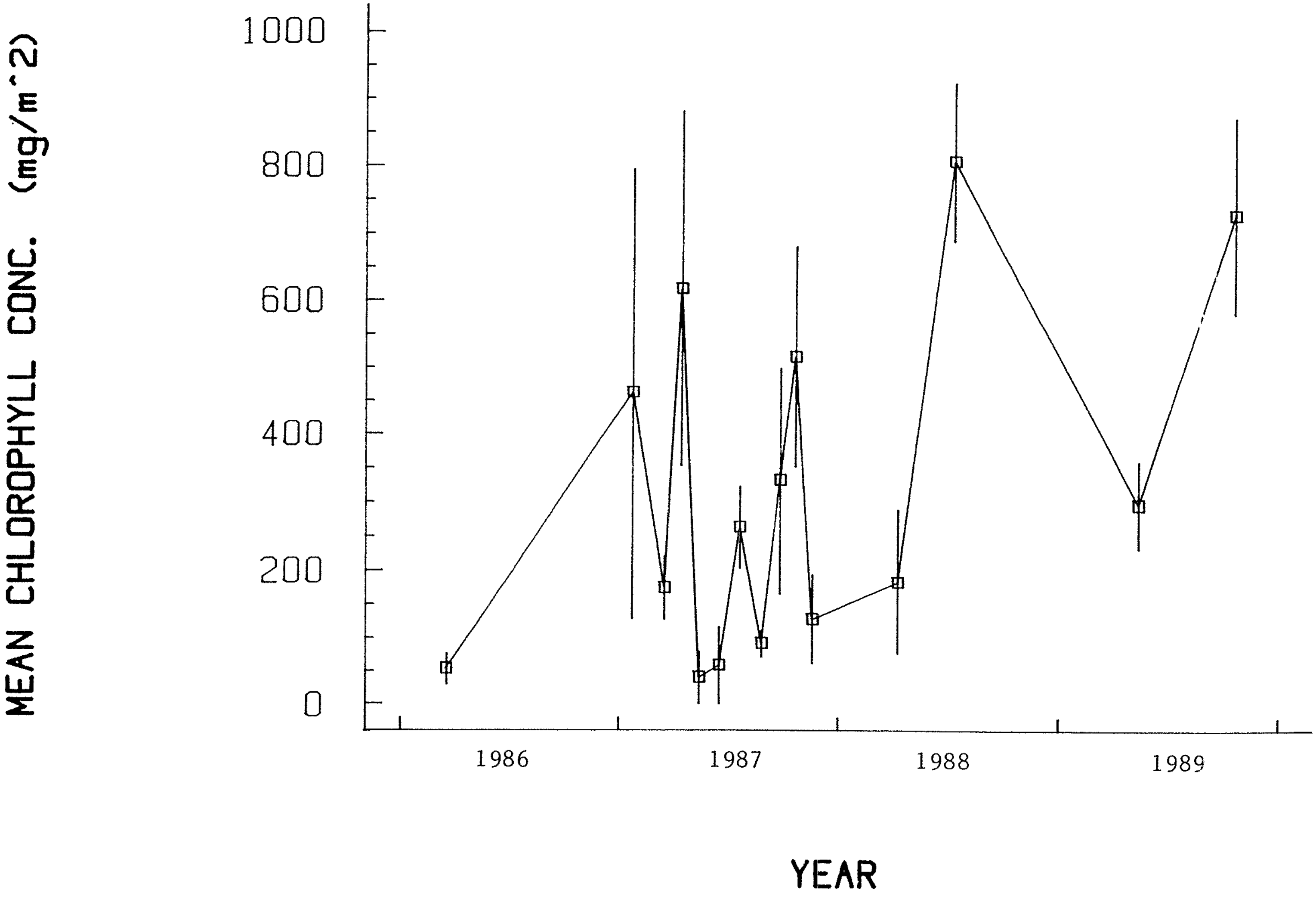

Figure 4. Mean chlorophyll *a* concentration (±SE) in sediments on flats.

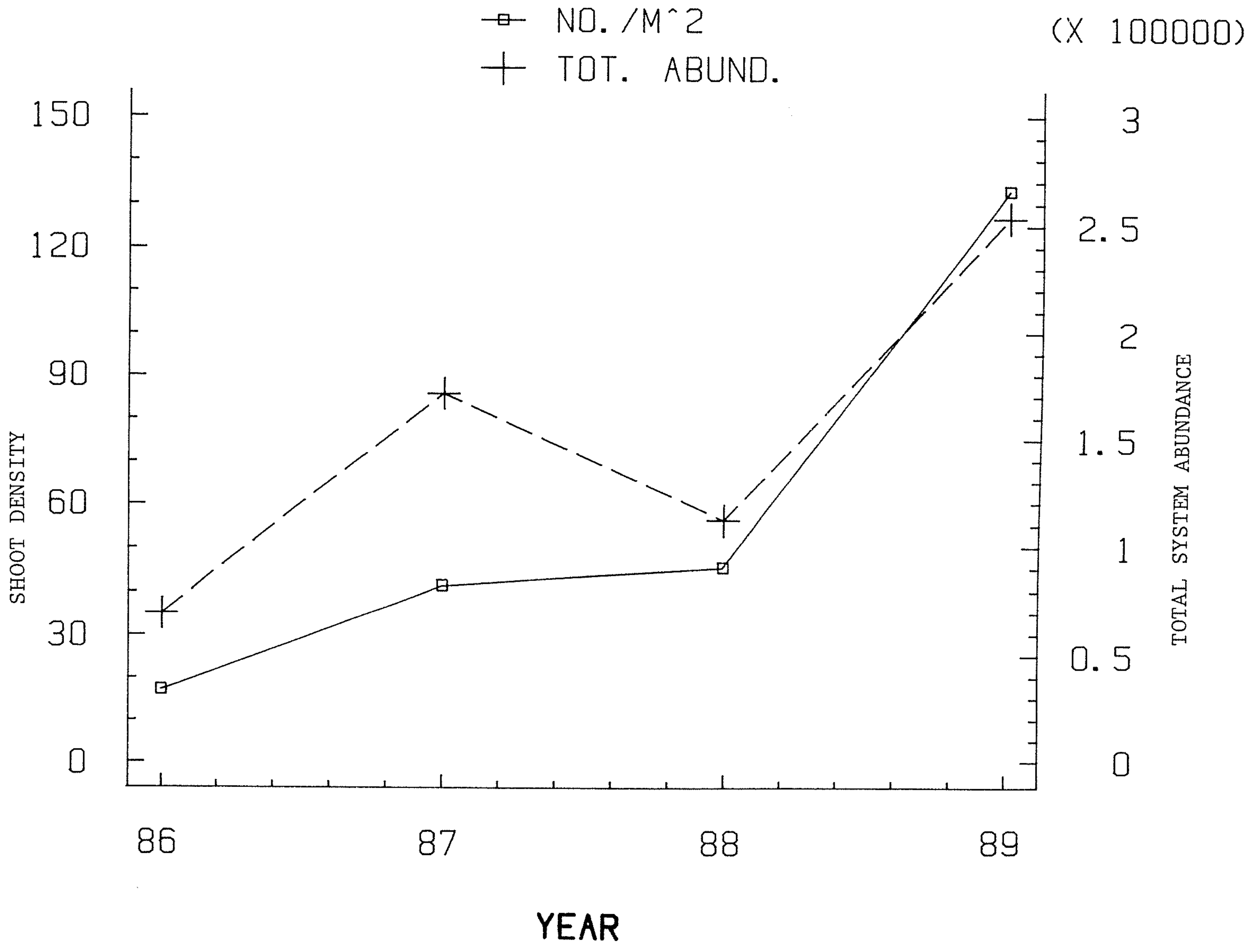

Figure 5. Mean shoot density and total shoot abundance of *Carex lyngbyei* in the tidal portion of the system.

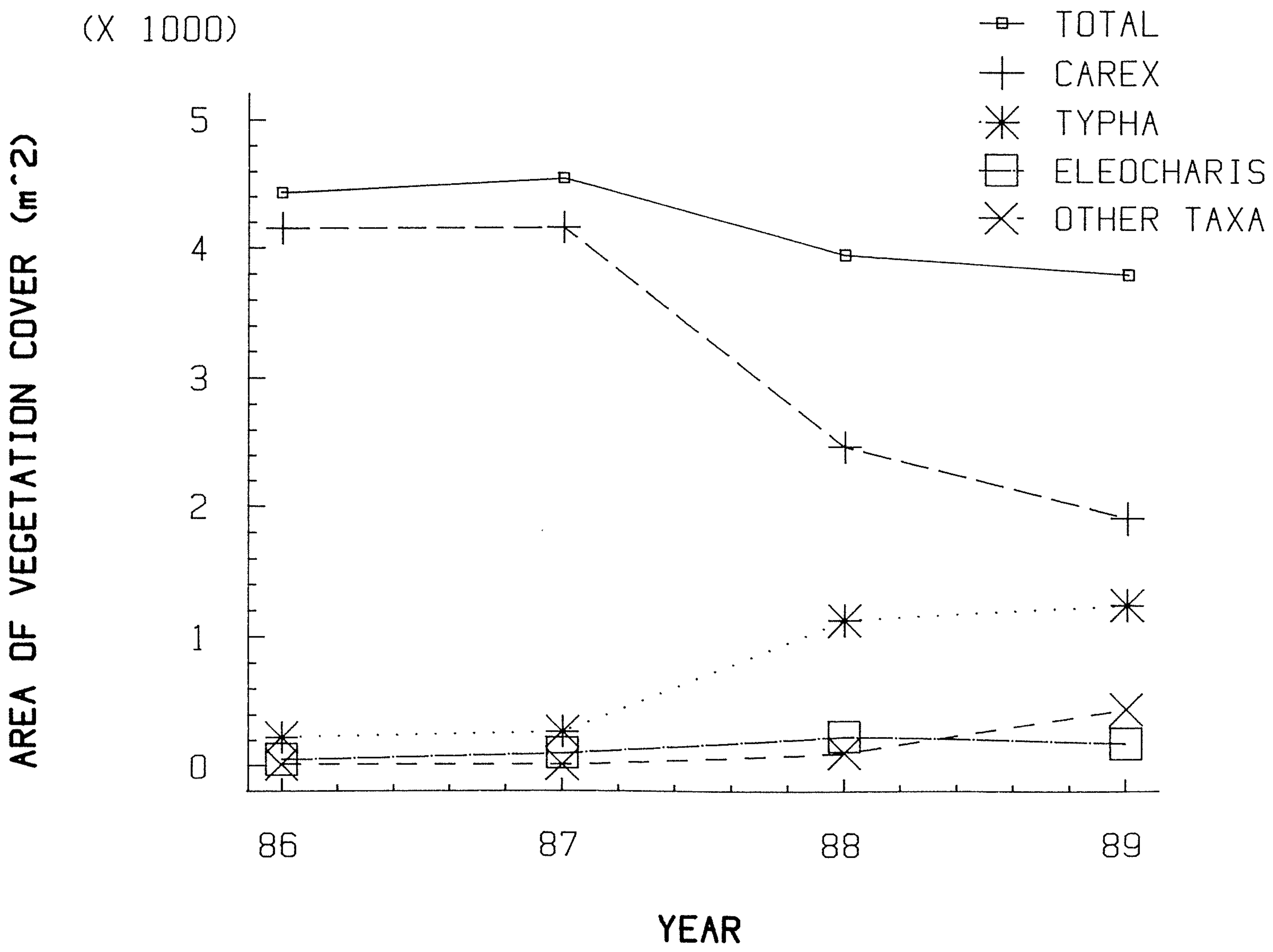

Figure 6. Area covered by major vegetation types in the tidal portion of the system.

There continues to be several low growing ground cover taxa that occur in open patches among the larger emergent marsh taxa. This group of taxa has gone from a cover of about 9 m^2 in 1987 to 446 m^2 in 1989.

As indicated above, considerable amount of sediment has accrued on the flats. During our sampling in September we noted that the marsh plants (particularly *Eleocharis*) appeared to be colonizing areas at the leading edge of the established marsh. This colonization may have been due to increased elevation as a result of sedimentation. Progradation of marshlands is a natural process which involves interactions between sediment processes and biological processes. Progradation of the marsh in the system was predicted prior to construction.

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. Bird data (see below) in particular show that the marsh continues to function as an important bird habitat. Water was present in the marsh throughout the year.

INFAUNA

Mean infauna density, after showing a slight decline between 1987 and 1988, exhibited a substantial (approximately sevenfold) increase between 1988 and 1989 (Fig. 7). The flats showed the least change, and the mid-bay showed the greatest change. Oligochaetes continue to dominate total abundance. Oligochaetes comprised 65.0, 97.9, 97.9 and 99.7% of the infauna abundance on flat 4, flat 5, channel 4 and mid-bay, respectively. The assemblage is characteristic of brackish systems, which are subjected to changing conditions caused by factors such as sediment input or disturbance; the shift may reflect the development of estuarine infauna during the first 13 months following dike breaching in February 1986, as compared to the terrestrial insect fauna, which initially colonized the system. Physical factors, including sediment grain size changes, bottom depth changes and changes in organic matter, are probably interacting in structuring the infaunal assemblage.

EMERGENT INSECTS

The rate of insect emergence was generally higher during the afternoon of May 10 than over the night and early morning of May 10-11, and significantly higher in the *Typha* than the *Carex* habitats, which were both higher than the unvegetated mudflat (Fig. 8). The total emergence rate in the *Typha* habitat in the afternoon of May 10 was 28.39±16.15 organisms m^{-2} hr^{-1}, compared to 6.44±5.36 m^{-2} hr^{-1} at night. In the *Carex* habitat, total emergence was 2.42±1.18 and 0.36±0.13 organisms m^{-2} hr^{-1} in the afternoon and night, respectively. In stark contrast, emergence over the

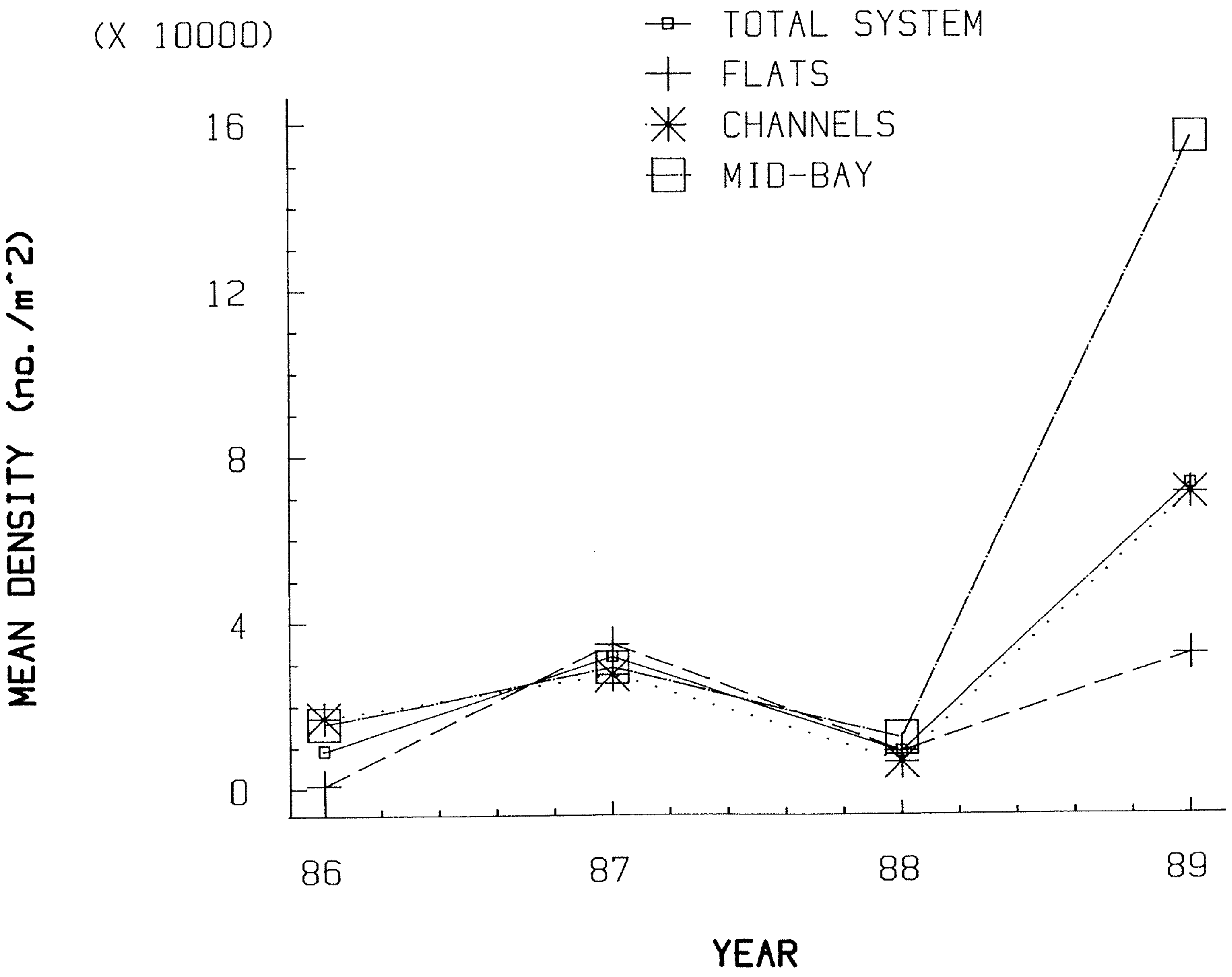

Figure 7. Mean infauna density in the tidal portion of the system.

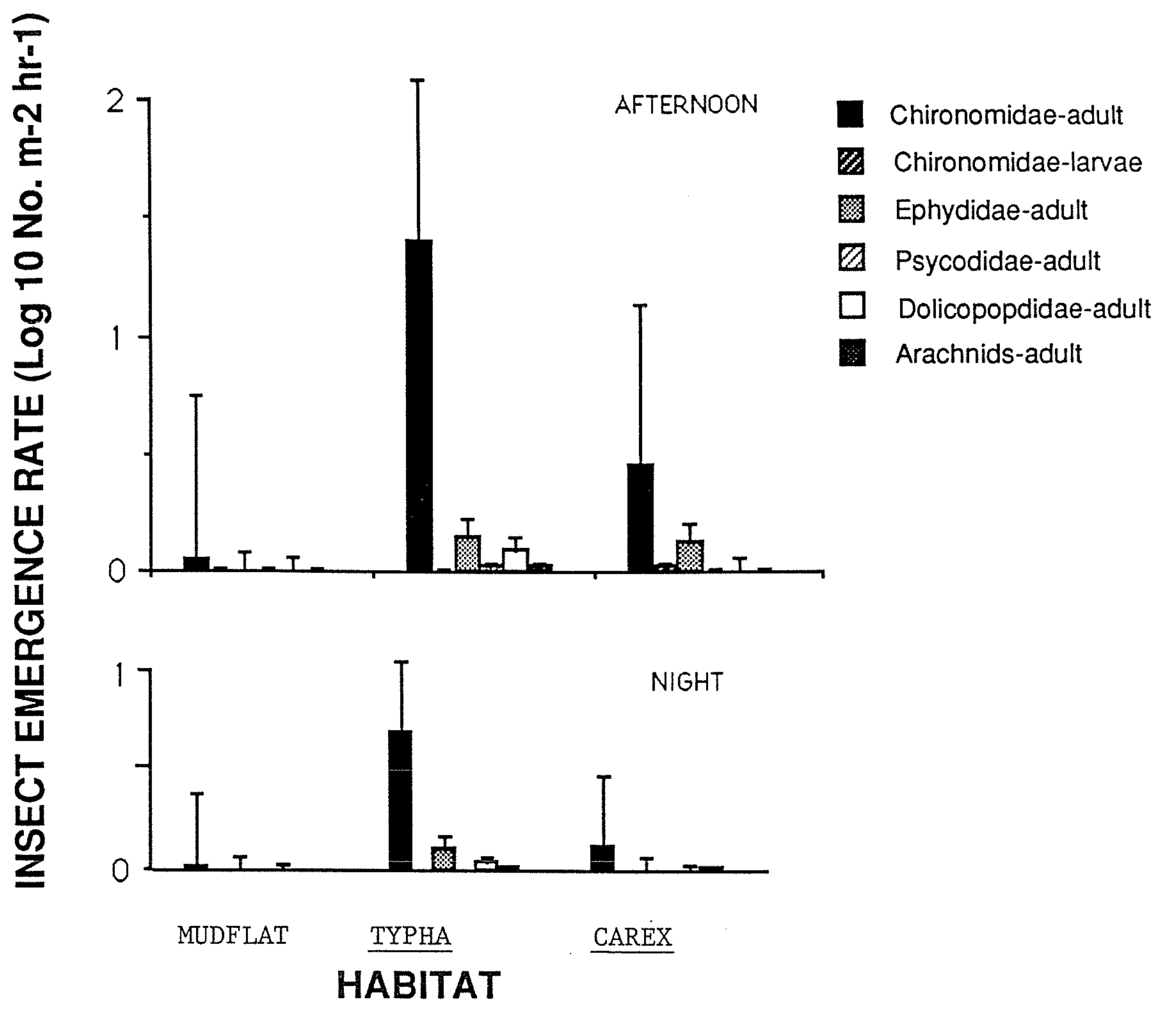

Figure 8. Rate of insect emergence in three habitats in the tidal portion of the system during afternoon (flood tide) of 10 May 1989 and night (ebb—flood—ebb) of 10-11 May 1989. Vertical bars indicate +1SD. Note log scale.

mudflat was extremely low, 0.15±0.33 and 0.05±0.07 organisms m^{-2} hr^{-1} in the afternoon and at night, respectively.

Adult chironomid flies were the most numerous emergents, especially in the *Typha* habitat, where an average of 27.61±15.76 organisms m^{-2} hr^{-1} emerged during the afternoon and 5.83±5.18 m^{-2} hr^{-1} during the night. Emergence of chironomid adults in the *Carex* habitat was an order of magnitude less that of the *Typha* habitat, 1.95±1.07 and 0.34±0.08 organisms m^{-2} hr^{-1} during the afternoon and night respectively. Shore flies (Ephydridae) were the second most numerous emergents, principally during the afternoon in both the *Typha* (1.21±1.57 m^{-2} hr^{-1}) and the *Carex* marsh habitats (0.36±0.29 m^{-2} hr^{-1}). The other taxa, moth and sand flies (Psychodidae), long-legged flies (Dolichopodidae) and spiders (non-emergent arachnids) occurred only sporadically throughout the trap samples.

Comparable estimates of aquatic insect emergence rates from similar marsh habitats in this region are not available in the literature. Raw data reported in a technical report (Whitehouse et al. 1989), describing the results of sampling in the Fraser River and Campbell River estuaries using the same methodology, suggests that the rates we found in the Lincoln Avenue Wetland habitats were comparable, if not higher. Further analyses of both of these datasets is required, however, before direct conclusions and comparisons can be drawn.

EPIBENTHOS

Epibenthic organisms on the littoral flats and in the tidal channels of the wetland system continue to change toward an estuarine assemblage. This is best indicated by the continued shift toward harpacticoid copepods, and the corresponding decline in calanoid copepods, rotifers and tardigrades from previous years' assemblages on flat #4 (Table 8).

Several new estuarine or marine taxa appeared in the epibenthos (Table 9). These included the harpacticoid copepod *Pseudobradya* sp., which occurred in high densities in the tidal channel, and the neritic calanoid copepod *Paracalanus* sp., that was found in low densities in the channel. The presence of egg-carrying female and mating pair *Pseudobradya* suggests that this population is well established in the wetland. Compared to epibenthos collections in mid-May 1987 (Thom et al. 1988) and early April 1988 (Shreffler et al. 1990), the harpacticoid *Microarthridion littorale* was less abundant and *Nannopus palustris* and *Mesochra* (*rapiens*) were both more abundant. The average density of chironomid (Dipteran fly) larvae was also higher (1600 m^2) than we had previously reported on any of the littoral flat transects. It is also noteworthy that these estimates of chironomid larvae at several orders of magnitude higher than the estimates of emerging chironomids derived from the emergence traps.

These relative differences in the relative abundance of epibenthos, however, should not be considered as trends because the sampling intensity is not sufficient to characterize epibenthic organisms that have rapid population turnover rates.

Total epibenthos density and standing crop values were within the range of or higher than from the same period in previous years (Table 9; Thom et al. 1988, Shreffler et al. 1990). In fact, the abundance of epibenthos on the unvegetated flat, ~5 x 105 organisms m^{-2} and 4.4 g m^{-2}, was the highest recorded for either the vegetated or unvegetated flats. The abundance of organisms in the channel, however, was below the previous averages.

Table 8. Faunal composition (top, % numerical; bottom, % gravimetric) of epibenthos organisms on flat 4 of the Lincoln Avenue Wetland in 1989 as compared to previous collections (Thom et al. 1987, 1988, 1990).

Taxa	Year			
	1985	1987	1988	1989
Hydrozoa	0	<0.01	0	0
	0	<0.01	0	0
Platyhelminthes	0.03	0.34	0.33	0.42
	0.10	1.41	0.66	2.91
Rotifera	2.46	1.28	0.03	0
	0.82	1.66	0.30	0
Nematoda	0.88	13.42	22.22	15.23
	1.35	3.11	2.64	6.34
Oligochaeta	0.05	8.21	6.17	14.81
	0.20	43.19	29.99	24.83
Acarina	0.03	0.01	0	0
	0.10	0.05	0	0
Cladocera	4.77	0.58	0.54	1.91
	12.17	1.56	1.38	7.70
Podocopa	0.52	0.15	0.06	0.10
	0.88	0.55	0.59	0.86
Copopoda*	35.92	4.32	0	0.07
	3.43	1.36	0	0.68
Calanoida	0.03	0.01	0	0
	0.13	<0.01	0	0
Harpacticoida	0.14	29.72	12.74	57.22
	0.50	17.88	18.62	38.50
Cyclopoida	54.13	0.68	0.92	3.35
	43.38	2.41	1.91	10.62
Gammarida	0	0	<0.01	0
	0	0	5.57	0
Insecta	1.08	0.12	0.15	0.61
	12.12	1.00	1.32	4.63
Tardigrada	0	48.09	50.01	6.93
	0	25.72	36.51	2.91

*Undifferentiated larvae.

Table 9. Taxonomic composition and mean density (no. organisms m^{-2}) and standing crop (mg wet m^{-2}) of epibenthic organisms sampled in three habitats of the Lincoln Avenue Wetland, 17 May 1989; » denotes common estuarine prey of juvenile salmon.

Taxa	Life history*	Vegetated flat		Unvegetated flat		Channel	
		#	mg	#	mg	#	mg
Turbellaria	J/A	277.8	19	2177.8	104	1066.7	53
Nematoda	J/A	10055.6	41	84711.1	307	3688.9	27
Oligochaeta	J/A	9777.8	161	65155.5	1778	43466.6	1115
Crustacea							
Cladocera							
Daphnidae							
Daphnia sp.	J/A	133.3	10			88.9	4
D. pulex	J/A	11.1	1	44.4	4	44.4	4
D. galeata	J/A	111.1	10	44.4	4		
Bosminidae							
Bosmina longirostris	A	366.6	18	222.2	22	1922.2	54
Chydoridae							
Chydorus sphaericus	A	633.3	10			88.9	4
Podocopa	J/A	66.7	6	1111.1	56		
Copepoda	N	44.4	4	44.4	4	166.7	1
Calanoida	C			222.2	22		
Paracalanidae							
Paracalanus sp.	A					44.4	4
Acartiidae							
Acartia sp.	C					11.1	1
Harpacticoida	C	144.4	10	4888.9	78	1133.3	46
Ectinosomatidae	A	44.4	4	1422.2	82		
Pseudobradya sp.	A					68511.1	263
"	C					8366.6	81
"	ECF					31766.7	166
"	MP					3577.8	54
Tachidiidae							
Microarthidion littorale	A					3833.3	54
"	C					44.4	4
"	ECF					533.3	49
Tachidius discipes	A	3188.9	20	40488.9	282	23822.2	139
"	C	1500.0	19	51644.4	131	31244.4	86
"	ECF	244.4	14	4355.6	109	4566.7	54
"	MP	533.3	13	3022.2	87		
Laophontidae							
Onychocamptus mohammed	A	177.8	9	133.3	4		
	ECF	44.4	4			277.8	28
Ameiridae							
Nitochra sp.	A	177.8	4				
Cletodidae							
Huntemannia jadensis	A	88.9	9			44.4	4
"	C					311.1	27
"	MP					222.2	22
Nannopus palustris	A	1511.1	13	7066.7	104	311.1	27
"	C	1244.4	13	32355.6	109		

Table 9—cont.

Taxa	Life history*	Vegetated flat #	Vegetated flat mg	Unvegetated flat #	Unvegetated flat mg	Channel #	Channel mg
Harpacticoida—cont.							
Cletodidae—cont.							
Nannopus palustris—cont.d	ECF			3155.6	87		
Canthocamptidae	A	455.6	14	355.6	27	2144.4	54
	ECF					88.9	4
Mesochra sp.	A	20144.4	58	121022.2	422	26688.9	121
"	C	6644.4	23	29600.0	109	15266.7	63
"	ECF	1200.0	19	11022.2	113	2677.8	54
"	MP	22.2	1				
Cyclopoida	C	11.1	1				
Cyclopidae	C	266.7	9	844.4	31	1400.0	32
"	A			266.7	27		
Halicyclops sp.	A	800.0	13	4933.3	82	800.0	27
"	C	100.0	10	1333.3	78	933.3	27
Cyclops sp.	C					133.3	4
C. bicuspidatus	A	266.7	10	88.9	9	1911.1	60
"	C	255.6	14			1555.6	29
Paracyclops fimbriatus	A	255.6	6				
"	C	255.6	6				
Oithonidae							
Oithona similis	A					44.4	4
Insecta							
Diptera							
»Chironomidae	L	388.9	24	1600.0	82	533.3	27
Psocoptera	Ny	11.1	6				
Tardigrada	J/A	4577.8	19	26488.9	109	400.0	27
Totals		66033.33	511	499822.22	4711	283733.33	4756
		±48293.59	±360	±529643.57	±4397	±281492.86	±5391
Diversity Indices							
Shannon-Weiner H'							
numerical	3.47		3.51		3.49		
biomass	4.67		3.80		3.83		

*J/A = juvenile/adult; A = adult; N = nauplii; C = copepodid; ECF= egg-carrying female; MP = mating pair; Hy = nymph; L = larva

FISH

Fish taxa collected during both the routine beach seine sampling and the fyke net sampling during the diel study (see below) appeared to sustain the pattern since 1986 of increasing presence of estuarine species and decreasing prominence of freshwater species (Table 10). Species richness ranged between 8 and 10 species, with the exception of only four species captured in mid-May,

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, 1986-1989.

Family	Species/common name	1986	1987	1988	1989
Petromyzontidae	*Lampetra richardsoni* (brook lamprey)*		x	x	
	L. ayresi (river lamprey)*		x		
Clupeidae	*Alosa sapidissima* (American shad)*				+
Salmonidae	*Prosopium williamson* (mountain whitefish)	+	+,x	+,x	
	P. coulteri (pygmy whitefish)*		+		
	Oncorhynchus gorbuscha (pink salmon)	+		+,x	
	O. keta (chum salmon)	+	+,x	+,x	+,x
	O. kisutch (coho salmon)	+			+
	O. mykiss (steelhead)*			x	
	O. tshawytscha (chinook salmon)	+	+,x	+,x	+,x
	O. clarki (cutthroat trout)*			x	
Osmeridae	*Thaleichthys pacificus* (eulachon)		x	x	
Cyprinidae	*Rhinichthys cataractae* (longnose dace)		+,x	+,x	+
	Richardsonius balteatus (redside shiner)	+	+,x	+,x	+
Ictaluridae	*Ictalurus nebulosus* (brown bullhead)*		x	x	
Catostomidae	*Catostomus macrocheilus* (largescale sucker)	+	+,x	+,x	+
Gasterosteidae	*Gasterosteus aculeatus* (threespine stickleback)	+	+,x	+,x	+,x
Centrarchidae	*Lepomis macrochirus* (bluegill sunfish)*		x	x	
	Pomoxis nigromaculatus (black crappie)*			x	
	Ambloplites rupestris (rock bass)*			x	

Table 10—cont.

Family	Species/common name	1986	1987	1988	1989
Percidae	*Perca flavescens* (yellow perch)*				+
Cottidae	*Cottus asper* (prickly sculpin)	+	+,x	+,x	+,x
	Leptocottus armatus	+	+,x	+,x	+,x
Pleuronectidae	*Platichthys stellatus* (starry flounder)	+	+,x	+,x	+,x

*Uncommon; fewer than five individual collected.

and most species occurred throughout the sampling period. The anadromous American shad (*Alosa sapidissima*) and a freshwater species, yellow perch (*Perca flavescens*), were first reported for the wetland system during this year's sampling. Notably absent from the collections during this year were mountain whitefish, an prominent species in previous years (Table 10), and five other rare freshwater taxa (i.e., pygmy whitefish, brown bullhead, bluegill sunfish, black crappie, rock bass). However, the fish sampling in 1989 was considerably less intensive than in 1987 and 1988, when the fyke net sampling was continuous for several periods during the spring and summer (Thom et al. 1989; Shreffler 1989).

Total fish density averaged between 0.044 and 0.476 fish m^{-2} and standing stock between 0.062 and 2.08 g wet m^{-2} (Table 11). The most prominent species were juvenile chinook salmon and three-spine stickleback, which occurred in densities and standing stocks as high as 0.1-0.2 fish m^{-2} and 0.2-1.5 g wet m^{-2}, respectively.

The continued presence and abundance of juveniles of three species of Pacific salmon indicate use comparable to that noted during the intense studies of juvenile salmon residence and foraging in 1987 and 1988. In particular, the mean density (0.24 fish m^{-2}) and standing crop (1.46 g wet m^{-2}) of juvenile chinook salmon captured during the June 15 collections were the highest recorded during the wetland monitoring and probably indicate the longer residence times for this species documented in the earlier studies (Thom et al. 1990; Shreffler et al. submitted).

BIRDS

Between 1986 and 1989, 109 bird species have been noted in the system (Table 12). Thirteen species were added to the list in 1989. The newly observed species included shorebirds, waterfowl and those that utilize terrestrial habitats. Waterfowl were consistently observed in the intertidal portion of the system. Great Blue Heron were commonly seen foraging along the edge of the

Table 11. Densities (no. m^{-2}) and standing stock (grams wet m^{-2} (boldface)) of fish captured in two tidal channels (except on June 15) in the Lincoln Avenue Wetland on four dates in 1989.

Taxa	Date			
	April 12	May 11	May 17	June 15
Family Clupeidae				
Alosa sapidissima,				0.001
American shad				**0.004**
Family Salmonidae				
Oncorhynchus keta, chum	0.020	0.002	0.001	0.001
salmon	±0.012	±0.001	±<0.001	
	0.013	**0.001**	**0.001**	**0.002**
	±0.011	±<0.001	±0.001	
O. kisutch, coho salmon	0.065	<0.001	0.006	
	±0.035	±0.001		
	0.013	**0.010**		**0.014**
	±0.008	**±0.015**		
O. tshawytscha, chinook	0.004	0.015	0.237	
salmon	±0.004	±0.016		
	0.007	**0.087**		**1.456**
	±0.008	**±0.064**		
Family Cyprinidae				
Rhinichthys cataractae,	0.002	0.002		0.001
longnose dace	±0.001	±0.002		
	0.001	**0.001**		**<0.001**
	±<0.001	**±<0.001**		
Richardsonius balteatus,		<0.001		
redside shiner		±<0.001		
		0.001		
		±<0.001		
Family Catostomidae				
Catostomus macrocheilus,	0.013	0.027		0.061
largescale sucker	±0.015	±0.038		
	0.001	**0.003**		**0.122**
	±<0.001	**±0.004**		
Family Gasterosteidae				
Gasterosteus aculeatus,	0.051	0.043	0.023	0.106
threespine stickleback	±0.059	±0.050	±0.033	
	0.073	**0.076**	**0.023**	**0.188**
	±0.086	**±0.090**	**±0.033**	

Table 11—cont.

Taxa	Date			
	April 12	May 11	May 17	June 15
Family Percidae				
Perca flavescens, Yellow perch	0.001 ±0.001 **0.001** **±<0.001**	0.001 ±<0.001 **0.005** **±0.007**		
Family Cottidae				
Cottus asper, Prickly sculpin	0.001 ±0.001 **<0.001** **±0.001**	0.001 ±0.001 **0.001** **±0.001**	0.004	**0.001**
Leptocottus armatus, Pacific staghorn sculpin	0.001 ±0.001 **0.001** **±<0.001**	0.006 ±<0.001 **0.007** **±<0.001**	0.015 ±0.020 **0.037** **±0.050**	0.030 **0.129**
Family Pleuronectidae				
Platichthys stellatus, Starry flounder	0.001 ±0.001 **<0.001** **±<0.001**	0.003 ±0.004 **0.001** **±0.001**	0.005 ±0.005 **<0.001** **±<0.001**	0.030 **0.164**
Mean species richness	9.5±0.7	8.0±2.8	3.5±0.7	10
Total mean density	0.159	0.101 ±0.095	0.044 ±0.112	0.476 ±0.059
Total mean standing stock	**0.109**	**0.192** **±0.060**	**0.062** **±0.153**	**2.08** **±0.084**

Table 12. Bird species observed in the Lincoln Avenue wetland system, 1986-1989. TA = Tahoma Audubon observations; FRI = Fisheries Research Institute observations.

Common name	TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1987-1989
1. Common Loon		X		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. King-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
42. Pectoral Sandpiper	X				X

Table 12—cont.

Common name	TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1987-1989
43. Common Snipe		X	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	X
51. Thayer's Gull	X				X
52. Glaucous-winged Gull	X				X
53. Morning 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 Waxwing	X				X
73. Northern Shrike	X				X
74. European Starling	X	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
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

Table 12—cont.

Common name		TA 1986-1987	FRI 1986	FRI 1987	FRI 1986-1987	TA 1987-1989
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
97.	Virginia Rail					X
98.	Semipalmated Plover					X
99.	Dunlin					X
100.	Ring-billed Gull					X
101.	Band-tailed Pigeon					X
102.	Purple Martin					X
103.	American Pipit					X
104.	Yellow Warbler					X
105.	Wilson's Warbler					X
106.	Dark-eyed Junco					X
107.	Bar-headed Goose					X
108.	Black-throated Gray Warbler					X
109.	Stilt Sandpiper					X
	TOTAL NUMBER OF SPECIES	80	33	37	46	105

water. According to Thais Bock (letter dated 22 January 1990, Tahoma Audubon Society, pers. comm.), the system appears to be utilized heavily by many bird species, and the wetland may be attracting species to the Commencement Bay area that would otherwise not be found there because of lack of habitat.

DIEL FLUXES

Environmental Conditions

Air-water temperature

During the diel period, the air temperature declined gradually from 16°C at the time of the first and second sampling interval (1230-1430) until 0430 the next morning (3°C), before it gradually increased to 12°C at the end of the sampling series (Fig. 9a). Water temperature remained relatively

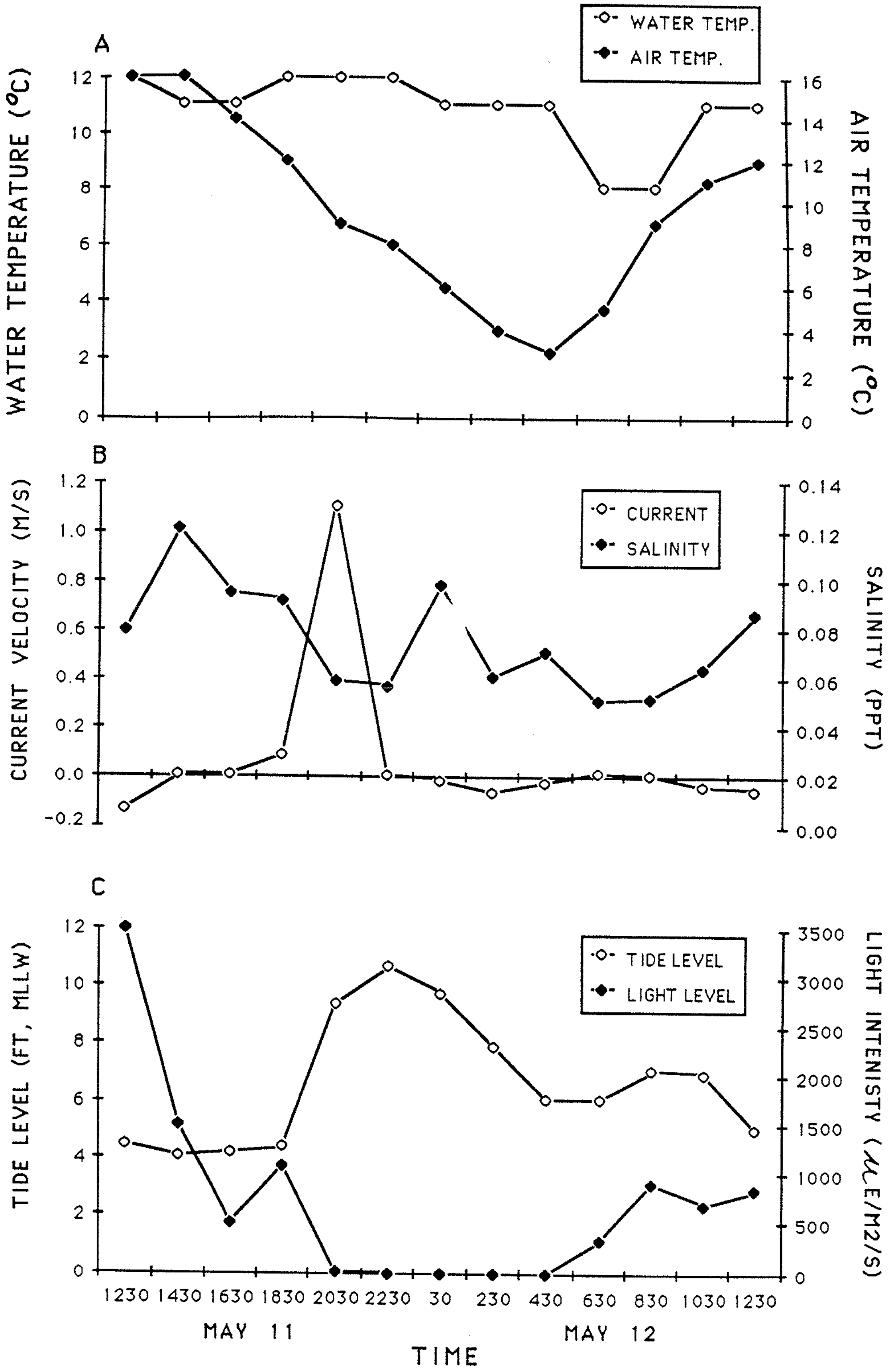

Figure 9. Measurements of environmental variables and material flux rates during diel study on 10-11 May 1989.

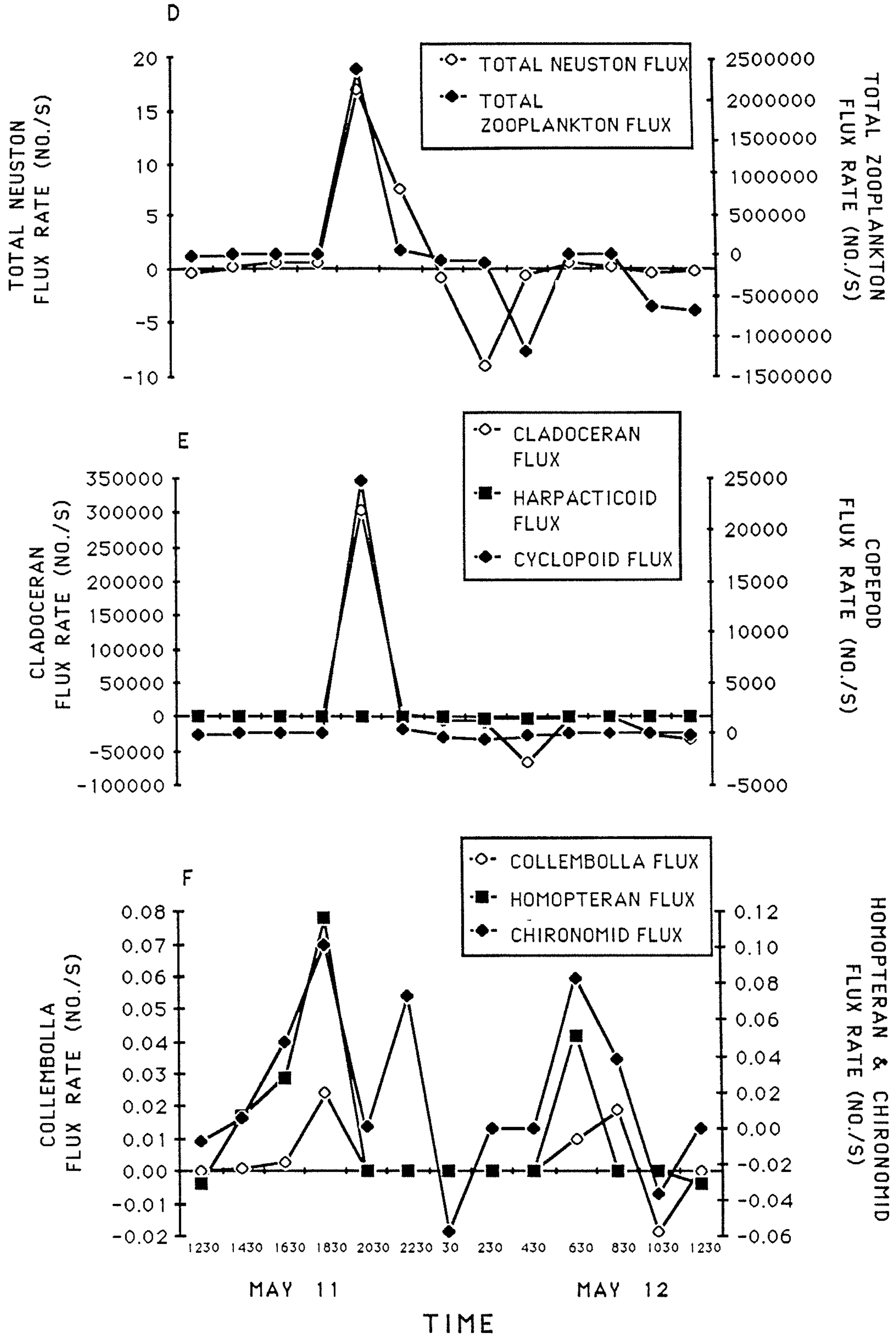
D
TOTAL NEUSTON FLUX RATE (NO./S)
20
15
10
5
0
-5
-10
TOTAL NEUSTON FLUX
TOTAL ZOOPLANKTON FLUX
TOTAL ZOOPLANKTON FLUX RATE (NO./S)
2500000
2000000
1500000
1000000
500000
0
-500000
-1000000
-1500000
E
CLADOCERAN FLUX RATE (NO./S)
350000
300000
250000
200000
150000
100000
50000
0
-50000
-100000
CLADOCERAN FLUX
HARPACTICOID FLUX
CYCLOPOID FLUX
COPEPOD FLUX RATE (NO./S)
25000
20000
15000
10000
5000
0
-5000
F
COLLEMBOLLA FLUX RATE (NO./S)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
COLLEMBOLLA FLUX
HOMOPTERAN FLUX
CHIRONOMID FLUX
HOMOPTERAN & CHIRONOMID FLUX RATE (NO./S)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
1230
1430
1630
1830
2030
2230
30
230
430
630
830
1030
1230
MAY 11
MAY 12
TIME

Fig. 9—cont.

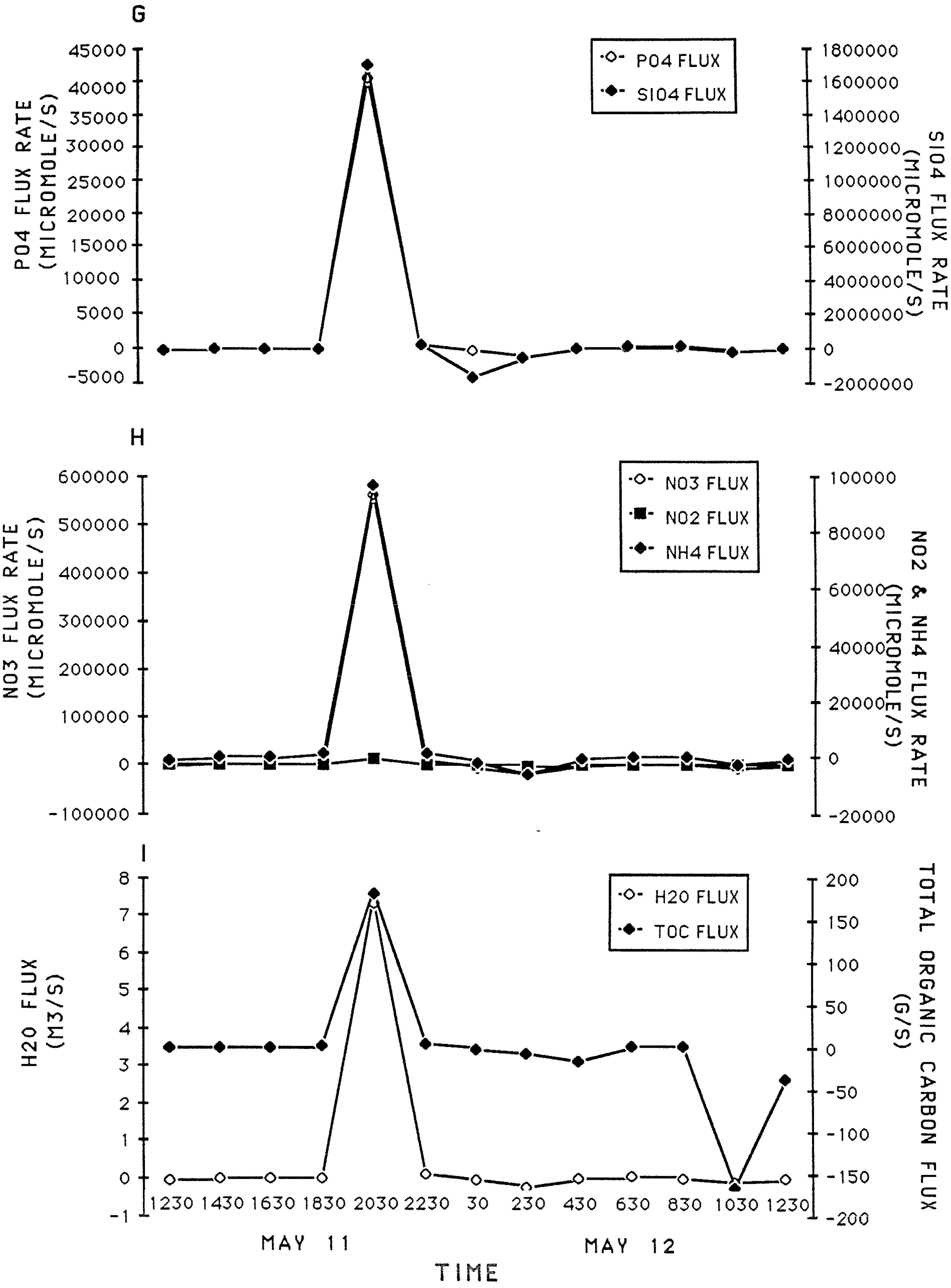
G
PO4 FLUX RATE (MICROMOLE/S)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
PO4 FLUX
SIO4 FLUX
SIO4 FLUX RATE (MICROMOLE/S)
1800000
1600000
1400000
1200000
1000000
8000000
6000000
4000000
2000000
0
-2000000
H
NO3 FLUX RATE (MICROMOLE/S)
600000
500000
400000
300000
200000
100000
0
-100000
NO3 FLUX
NO2 FLUX
NH4 FLUX
NO2 & NH4 FLUX RATE (MICROMOLE/S)
100000
80000
60000
40000
20000
0
-20000
I
H2O FLUX (M3/S)
8
7
6
5
4
3
2
1
0
-1
H2O FLUX
TOC FLUX
TOTAL ORGANIC CARBON FLUX (G/S)
200
150
100
50
0
-50
-100
-150
-200
1230
1430
1630
1830
2030
2230
30
230
430
630
830
1030
1230
MAY 11
MAY 12
TIME

Fig. 9—cont.

constant, between 11-12°C, through the high-high tide, and decreased to 8°C only during the high-low tide in early morning.

Current velocity/direction and salinity

Current velocities alternated around 0.2 m s^{-1} in and out of the wetland system except for midway through the afternoon flood on the high-high tidal cycle (1830-2030), when it was measured to be as high as 1.1 m s^{-1} (Figure 9b). Salinities actually varied little over the whole period, between 0.12 and 0.05 ppt, showing a general trend of slightly decreasing salinity from 1430 on 10 May to 0830 on the morning of May 11 except for a surge of relatively saline water just after the peak of the high-high tide.

Tide levels

The tide level (water elevation) illustrated the riverflow effect on the tidal flow, with a ~6.6 ft tidal range at the mouth of the wetland over the diel period (Figure 9c) compared to a 12.4 ft tidal range documented by NOAA for Commencement Bay. The range of the high-low and low-high tidal cycles was also appreciably depressed in the wetland during this period.

Material/Organism Flux Rates

Neuston

Total neuston transport into the wetland was relatively low and constant during the early stages of the flood tide and then peaked at ~17 organisms m^{-3} during the maximum current flow into the wetland at 2030 (Figure 9d). Export from the wetland occurred primarily during last stages of the high-low tide (0430), when ~9 organisms m^{-3} were exported with the tide. Import was minor (e.g., <1 organisms m^{-3}) during the succeeding low-high tide cycle. Homopterans and chironomids, and to a lesser extent collembolans, constituted the predominant neuston organisms except during the peak flood tide at 2030, when cladocerans (*Diaptomus* sp.) accounted for the high flux rates (Fig. 9e,f). The peak insect transport actually occurred at 1830, prior to the peak flood velocity, when 0.07-0.08 organisms m^{-3} entered the wetland. The flux of chironomids was also relatively high (0.05-0.06 organisms m^{-3}) during high slack tide (2230) and during the beginning of the early morning (0630) flood tide. The flux of neuston out of the wetland was minor in comparison, i.e., >0.02 organisms m^{-3} during the early stage of the ebb at 0030 and 1030.

Zooplankton

Zooplankton indicated a similar pattern to neuston except for a lag in the flux out of the wetland, which occurred later in the early ebb (0430) and was more prominent in the latter ebb (1030-1230; Figure 9d). Maximum total zooplankton flux was estimated to be 2.4 X 10^6 organisms m^{-3} during the peak water transport into the wetland at 2030. In contrast, the maximum flux out of the wetland was estimated to be 1.2 X 10^6 m^{-3} during the early ebb and 6.5-7.0 X 10^5 m^{-3} during the latter ebb. Cladocerans and cyclopoid copepods comprised the majority of the zooplankton, although harpacticoid copepods were also present (Figure 9e); presumably the normally epibenthic harpacticoids were scoured from the bottom sediments at the mouth of the wetland. All zooplankton taxa followed the same trends in flux in and out of the wetland except for a disproportionately higher flux rate of cladocerans (*Bosmina longirostris*) at the end of the early ebb (0430).

Nutrients

Nutrient concentrations were relatively constant throughout the study period, resulting in nutrient fluxes which were relatively proportional to water flow (Figure 9g,h). PO4 ranged between 0.45 and 0.69 µM, SiO4 between 214.7 and 231.8 µM, NO2 between 0.18 and 0.22 µM, NO3 between 7.8 and 13.4 µM, and NH4 between 1.3 and 8.6 µM. The largest variation, that associated with the highest NH4 concentration, occurred at the very beginning of the first flood tide into the wetland (1830) and also corresponded with a relatively high (11.3 µM) NO3 concentration. High NO3 concentrations (12.1-13.4 µM) at the beginning of the second flood tide into the wetland (0630-0830) were also associated with a decrease in NH4 (2.7 to 1.5 µM). Because the initial stages of the flood tide into the wetland involve primarily freshwater backed up by the incoming tide, these trends suggest that the river is a source of nitrate and ammonium into the wetland and that nitrification or ammonium oxidation may be accounting for conversion of ammonium to nitrate, which through denitrification is made available for uptake (e.g., fixation) by wetland plants.

Total organic carbon

Total organic carbon (TOC) generally varied between 23 and 52 mg l^{-1} but reached almost 800 mg l^{-1} during the final stage of the early morning (high low) ebb tide (0430) and between 1709-1784 mg l^{-1} during the initial stages of the late morning ebb out of the wetland (1030-1230). As a result, the predominant flux of TOC into the wetland corresponded to the high water flow during the evening flood tide and the flux out of the wetland to the relatively minor ebb out the next afternoon (Figure 9i).

Fish

Despite the predominant flux of most materials into the wetland, fish were captured only in the outlet portion of the fyke net (Table 13). These were predominantly chinook fry (19 of the 37 individuals captured). The peak emigration occurred between 0630 and 0830 on 11 May, during the high-low slack tide.

Net Fluxes

The net flux of material and organisms in and out of the wetland system cannot be directly estimated because the final phase of the low-low tidal cycle was not measured at the end of the 24-hr

Table 13. Summary of 24-hr inlet/outlet fyke net monitoring at the mouth of Lincoln Avenue wetland, May 10-11, 1989.

	Inlet		Outlet	
Time	Species	Number	Species	Number*
1630			*O. keta*	2
1830			*O. tshawytscha*	1
0430			*O. tshawytscha*	4
			P. stellatus	2
			G. aculeatus	1
			L. armatus	2
			C. asper	7
0630			*O. tshawytscha*	10
0830			*O. tshawytscha*	1
			P. stellatus	2
			C. asper	1
			L. armatus	1
1030			*O. tshawytscha*	1
1230			*O. tshawytscha*	2

*All fish were released alive; no lengths or weights were recorded.

diel period. This can be approximated, however, by conservatively assuming that an equal volume of water fluxed in and out of the wetland over the tidal-day. Thus, after integration of water transport over the 24-hour period, there is a difference of 5.06 x 10^4 m^3 that would have to be accounted for in the final ebb (Table 14). Given the only 0.2-0.3 ft remaining in water elevation drop, this would appear to require an unreasonably high current velocity. Alternatively, it is more likely that the maximum current velocity measured at over 1 m s^{-1} at 2030 was not sustained for a very long duration of the two-hour interval. In addition, the current velocity was measured only at one point (mid-channel, mid-depth) at the entrance to the wetland system, rather than at several points across the channel's cross-sectional area, which would have provided a more precise estimate of the mean current velocity.

Examination of the uncorrected flux estimates (Table 14) suggests that the wetland is a net sink for all nutrients, neustonic organisms, and pelagic zooplankton, but a source of total organic carbon and of epibenthic harpacticoid copepods that occur in the water column. To obtain a better approximation of the actual flux of material over the whole tidal cycle, we use the last stage of the prior ebb to provide a rough estimate of the flux out of the wetland at the end of the ebb tide on 11 May; this was estimated to be -0.030 m^3 s^{-1} using a velocity of 0.1 m s^{-1} and a cross-sectional area of 0.300 m^2. With the complete tidal cycle accounted for, we then adjusted the potentially anomalous current velocity measurement at 2030 to provide a net balance of water flow in and out of the

Table 14. Estimated net flux of water, nutrients and organisms into (+) and out (-) of Lincoln Avenue Wetland, Commencement Bay, Tacoma, WA, during diel studies, 10-11 May 1989.

Variable	Estimated flux	Adjusted flux
Water	+50,601.6 m^3	0 m^3
Constituent:		
PO_4	+27.81 M	+0.23 M
SiO_4	+11,706.27 M	+101.86 M
NO_3	+389.67 M	+4.48 M
NO_2	+9.08 M	+0.05 M
NH_4	+64.02 M	-2.19 M
Total organic carbon	-181.879 kg	-1.4 kg
Total neuston (total organisms)	+111,636.0	-5,724.0
Chironomids	+1,818.0	+1,818.0
Homopterans	+1,166.4	+1,166.4
Collembolans	+273.6	+273.0
Total zooplankton (total organisms)	+654,340,700	-5,393,335
Cladocerans	+86,367,780	+1,490,148
Cyclopoid copepods	+174,327,200	+4,571,892
Harpacticoid copepods	-15,357,020	-23,070,890

wetland; this results in an adjusted current velocity of 0.055 m s^{-1} compared to the 1.10 m s^{-1} actually measured.

Under these "equilibrium" flux conditions, the wetland would be considered a source of NO_2, total organic carbon, total neuston and total zooplankton, and a net sink for the other variables. In the case of the neuston, it appears that the wetland is actually a sink for the neustonic insects (chironomids, homopterans and collembolans) but a source of cladocerans, which are actually zooplankters that may originate principally from the river. Conversely, the wetland is a net source of zooplankton because the water column contains epibenthic harpacticoids that are scoured and resuspended from surface sediments at the time of peak ebb flow. The difference between nitrate and ammonium fluxes in and out of the wetland suggests that nitrate imported into the wetland is reduced through plant assimilation and remineralized, and/or released from the wetland sediments, to be exported out of the wetland as ammonium.

CONCLUSIONS

The general conclusion is that the Lincoln Avenue wetland system continues to serve the target resource groups for which it was designed. These resource groups include juvenile salmonids, shore birds, waterfowl, raptors, and small mammals. At present, the system provides ecological support of fish, fish prey and greater habitat diversity superior to Parcel 5. The system continued to change dramatically in terms of basin morphometry, sediment characteristics, vegetation, benthic, epibenthic and fish assemblages. The data in 1989 showed that the system is still in an early developmental stage (MacArthur and Wilson 1967).

The primary concerns regarding the system include sedimentation and indiscriminate trash disposal. The main effects of sedimentation have been to decrease bottom depths in the mid-bay and reduce channel widths. These changes did not exclude salmonids from the system in spring because of high river flows. The intertidal portion of the system contained adequate water depths for fish during all stages of the tide in spring. During summer, water remained only in channels 3 and 4 during neap series low tides. This probably excluded all but small hardy fish from the system during summer low tides. At the Lincoln Avenue wetland, sedimentation was expected to be substantial immediately after dike breaching. In natural systems, newly exposed to sediment sources, sedimentation is typically rapid for a period of time, after which the rate of sediment accrual declines. We expect that sediment accrual rate will decrease at the Lincoln Avenue wetland, and that it is premature at this time to conduct remedial action to remove sediments or reduce sedimentation.

RECOMMENDATIONS

SYSTEM MAINTENANCE RECOMMENDATIONS

The spatial patterns and general rate of sedimentation in the system should be monitored using the stakes we established on the flats and new stakes placed by surveyors in the channels and mid-bay. At the present time, we do not recommend sediment removal from the system. 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. We recommend that illegal dumping be controlled by posting no-dumping signs in appropriate locations. Further, periodic clean up by local volunteers or paid workers may be necessary to keep the intertidal habitats free of trash. 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

Permit-related monitoring in 1990 should follow the program outlined in the first report on the wetland (Thom et al. 1987). The program includes sediment, vegetation, fish and bird sampling.

The 1990 monitoring effort is presently underway and includes work designed to evaluate the functional performance of the system.

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