FRI-UW-8603
February 1986

EARLY SUCCESSIONAL DEVELOPMENT OF A BENTHIC-EPIBENTHIC COMMUNITY AT A NEWLY CONSTRUCTED BEACH IN SLIP 1, COMMENCEMENT BAY, WASHINGTON:
Initial Observations 1985

by

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Prepared for

The Port of Tacoma

February 1986

Submitted 28 February 1986

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for Robert Francis, Director
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ACKNOWLEDGMENTS

We gratefully acknowledge the financial support of the Port of Tacoma. Gary Kucinski of the Port was particularly helpful. Douglas Milward assisted us in the field. Jenny Hampel processed the periphyton samples in the lab. Carol Sisley kindly typed the final copy of the report.

INTRODUCTION

A significant amount of the wetland habitats (e.g. marshes, mudflats, shallows) in estuaries has been lost to man's activities (e.g., dredging, filling) over the past century. Only recently, through legislation and environmental awareness has this trend slowed. This has occurred, in part, because of research conducted primarily over the past 20-30 years which has drawn attention to the important ecological role of wetland habitats. This research has shown that estuaries typically support high standing stocks of unique assemblages of organisms that perform key ecological functions in food webs which support economically important resources such as fish and waterfowl.

In the Pacific Northwest, particularly in Puget Sound, declines in the areal cover of estuarine marshes and mudflats have been substantial (Bortelson et al. 1980). The estuary we studied (Puyallup River, Figure 1), for example, has undergone almost complete development. Of an original 10 km^2 of marshes and mudflat, virtually none remain. Coincidentally, salmon runs utilizing the Puyallup River and estuary have declined dramatically, and have only recently been sustained or enhanced through hatchery production. The runs have declined in size concommitant with, among other factors, the loss of shallow water feeding habitat in the estuary which is utilized by outmigrating juveniles in spring.

In an effort to partially mitigate for previous losses of shallow water feeding habitat for juvenile salmonids, the Port of Tacoma constructed a beach in the head end of a deep water slip (Slip 1) in Blair Waterway (Figure 1). Local, state and federal resource and regulatory agencies have developed policies regarding development in nearshore habitats. In general, substantial

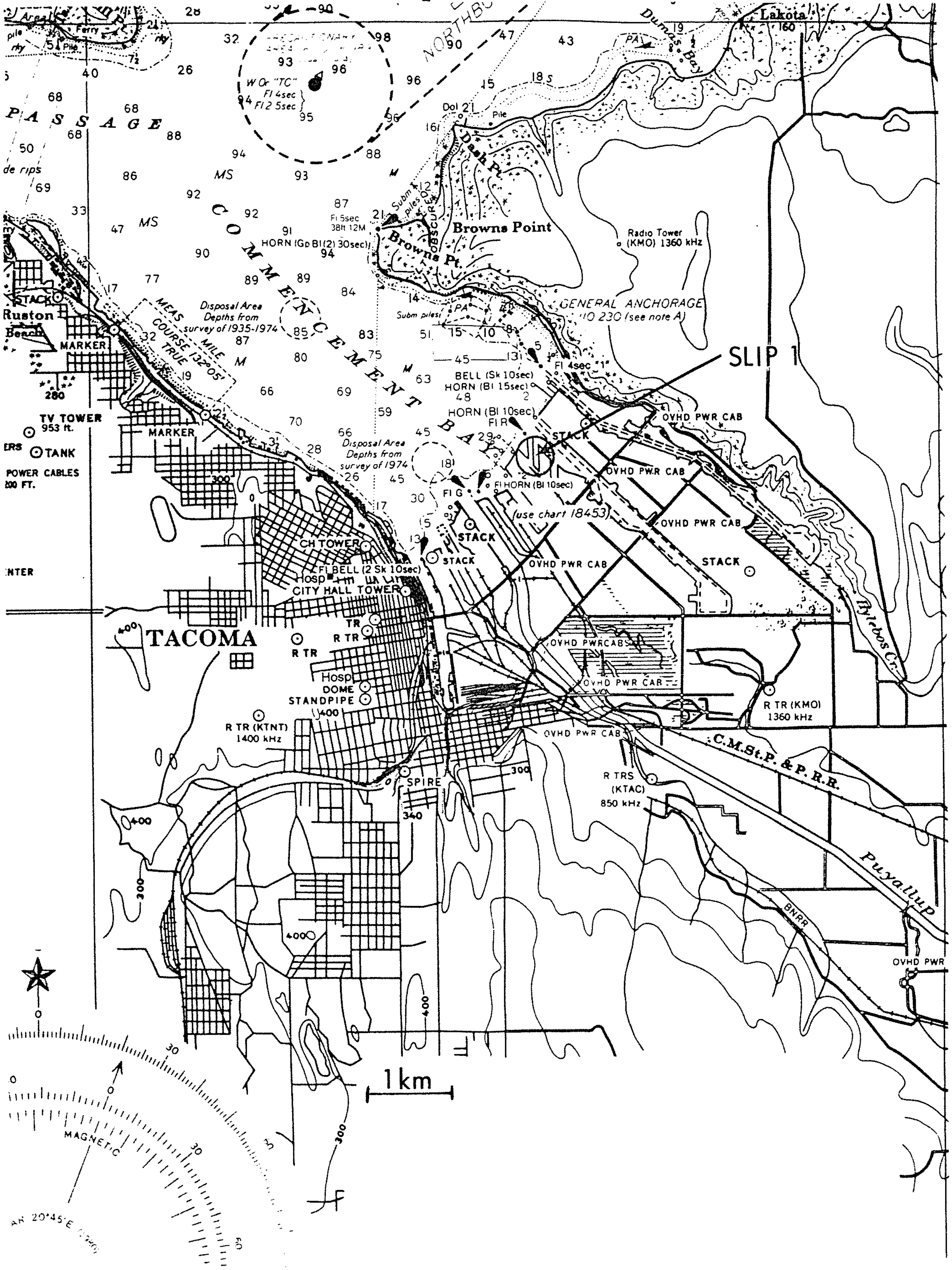

Figure 1. Location of Slip 1.

potential losses of wetland areas due to proposed development must be mitigated by modifying the project to reduce the losses and/or construction or restoration of a similar habitat onsite (nearby). The prevailing policy is one of "no net loss" of wetland habitats. A major drawback is that the technology of creation of wetlands is in its infancy. This is particularly true in the Pacific Northwest where very few projects of this type have been undertaken. A related problem is that the success or failure of habitat construction projects are rarely assessed (Race 1985). The technology of mitigation cannot advance without comprehensive quantitative data on the fate of previous projects. The Slip 1 beach provides a significant opportunity to perform an assessment of beach construction.

One of the principal criteria for evaluation of littoral-shallow water sublittoral beach mitigation projects in the Pacific Northwest is the rating of the productivity of created habitat and its use by juvenile salmonids. A standard is the availability of food organisms preferred by epibenthic-feeding species, such as juvenile pink (Oncorhynchus gorbuscha) and chum salmon (O. keta), (Simenstad et al. 1982). Results from previous investigations of feeding habits of juvenile salmon (Simenstad et al. In Prep.) have suggested that these epibenthic prey resources may not be as available in Commencement Bay as in less urbanized estuaries. Healey 1982 and Simenstad et al. 1982 summarized the feeding habits of juvenile salmon in Pacific Northwest estuaries. One measure of the success of mitigation projects such as the Slip 1 beach, therefore, would be production of the specific epibenthic taxa in the life history stages preferred by juvenile salmon.

The purpose of our work was to document the colonization of the beach by benthic organisms, especially those known to be important prey resources for juvenile salmonids. The beach was constructed in late winter 1985. Our study spanned the season of intense outmigration (April-June 1985). We sampled the biomass and production of the periphyton that attached to the gravel substrata as an indicator of the amount of energy available to the juvenile salmonid prey resources. Productivity is a measure of the rate at which the energy containing compounds are being produced. This has a direct bearing on small animals with high energy requirements, especially during spring. Finally, periphyton form the physical construct for salmonid prey.

STUDY SITE DESCRIPTION

The beach was constructed in deep water at the landward end of Slip 1 (Figure 2). Large riprap boulders were used as the primary fill material, which was overlain with a 10 cm thick layer of 2 cm diameter angular gravel. No attempt was made to smooth the surface gravel, and hence, the beach was characterized by pits and mounds. The beach was constructed between tidal elevations 1.8 m (+6 ft) and -1.8 m (-6 ft) MLLW, and had a slope of approximately 3.5:1 between these depths. The total surface area of the beach was 791 m^2. The tidal elevation range was chosen to cover the range of juvenile salmonid feeding in estuaries.

MATERIALS AND METHODS

Target Parameters

On each of the six sampling trips, we recorded surface water temperature with a hand-held mercury thermometer, and salinity with a refractometer. As an indicator of the structure and function of the benthic community on the beach, we measured the standing stock (dry and ash free dry weight), net productivity, respiration and gross productivity of the periphyton assemblage that attached to the gravel. The density, standing stock (wet weight) and

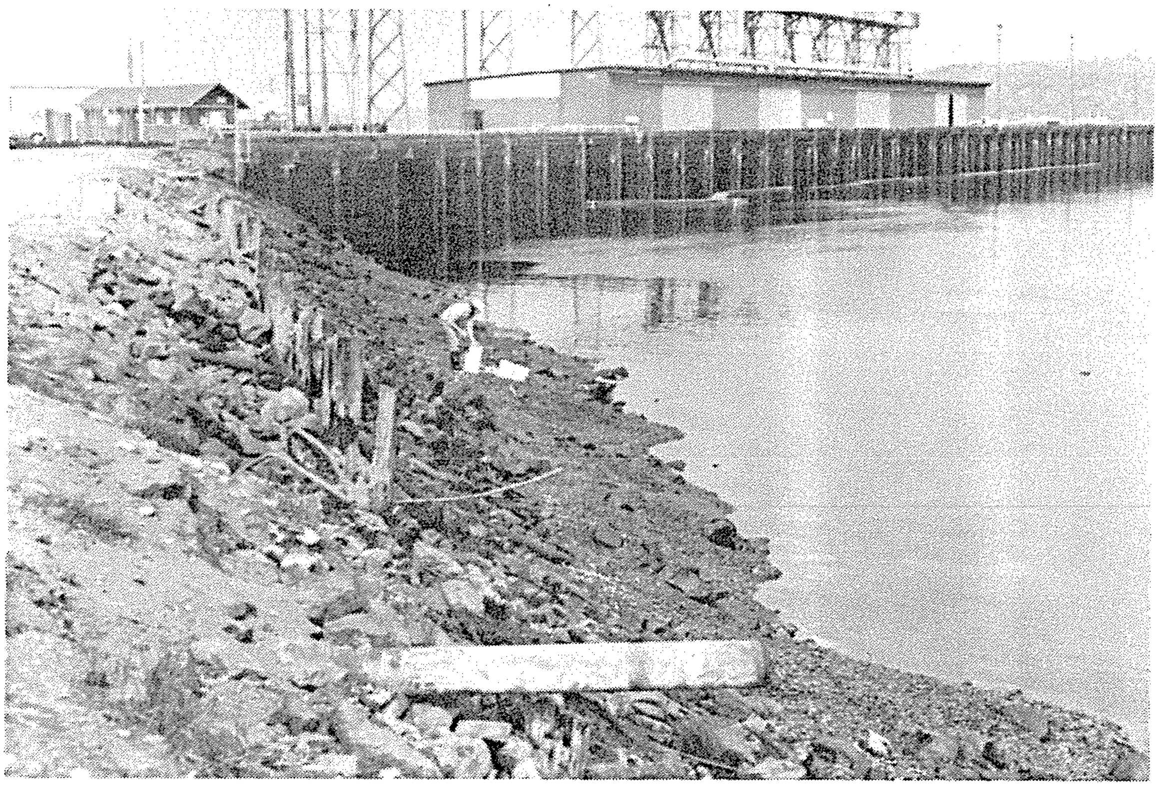

Figure 2. Photograph taken 8 April 1985 of Slip 1 beach looking to west. The tide level is +0.7 m. Note the irregular waterline caused by the pits and peaks of the beach.

taxa abundances of the epibenthic animals associated with the periphyton on the beach were also measured to assess the potential utility of the beach to epibenthically-feeding juvenile salmon.

Sampling Design

We sampled periphyton and epibenthos at four randomly-selected points along three tidal elevation strata: +0.7 m (2 ft), 0 m, and -0.7 m (-2 ft) MLLW, which cover the mid-range of elevations spanned by the beach. A 60-m long baseline was stretched at the upper level (+1.8 m) of the beach, and parallel to the edge of the water. The base line extended essentially the entire length of the beach, but avoided the edges. During each sampling trip, a random number was chosen from a set of 60 random numbers corresponding to each 1 m increment along the base line. Samples were collected at four points spaced at 15-m intervals along the elevation strata; the starting point being determined by the selected random number. A tide gauge attached to a nearby piling aided placement of the sampling stations at the proper elevations. A new random number, which excluded those chosen previously, was drawn for each sampling trip. Samples were collected on 8 and 24 April, 7 and 22 May, and 3 and 18 June 1985; corresponding to the Julian dates (JD) of 98, 114, 127, 142, 154, and 169, respectively. JD's are used in many of the figures below. Sampling was conducted progressively from higher to lower elevations as the tide ebbed. The tides were not low enough on 24 April and 22 May to sample the lowest elevation strata.

Periphyton Sampling

A plexiglass tube 20 cm long, with an inside diameter of 3.7 cm (43 cm^2) was used to take a core of the top 5 cm of gravel. This method usually resulted in the collection of 1-3 pieces of gravel with the attached assemblage in the tube at each point. The bottom end of the tube was sealed with a rubber bung, and the tube was filled with water collected just offshore of the beach. Following an initial settling period of approximately 15 minutes, the dissolved oxygen (DO) of the water in the tube was measured using a YSI digital dissolved oxygen meter. The top tube was then sealed carefully with a rubber bung, and the sample was allowed to incubate in shallow trays containing water at ambient sea temperature. The tubes were gently shaken periodically to mix the water. A second periphyton sample collected at each station was treated in a similar manner, but was incubated in the dark (i.e., the tube was covered with a layer of heavy aluminum foil). Following 0.5-1.5 hrs incubation, the final DO was measured in each tube. The samples were frozen in the tube for later analysis. In the laboratory, the samples were thawed and the periphyton was removed from the gravel by brushing with a denture brush. The periphyton was brushed into a clean tray containing the water from the tube. The entire contents of the tray was filtered through preweighed glass fiber filters. The wet weight was determined to the nearest mg immediately after filtration (the point when no water was visible over the periphyton on the filter). The samples were dryed for at least 24 hrs at 60°C, and reweighed to determine the dry weight. The samples were then ashed in a muffle furnace at 500°C, and weighed to determine the ash free dry weight. A few samples were examined microscopically to identify the most common taxa present. Systematic counts were not made, however.

Net primary productivity (NPP), respiration (R), and gross primary productivity (GPP) of the periphyton assemblage were calculated based on the changes in oxygen concentration. Rates were standardized separately for surface area sampled, and dry and ash free dry weight data. The formulae in

Strickland (1960), with a PQ=1 and an RQ=1, were used for the calculations.

Epibenthic Zooplankton Sampling

Epibenthic organisms were suctioned from 0.016 m^2 of the gravel substrata by an epibenthic pump modified from the systems utilized in epibenthos studies in the Columbia River estuary (Simenstad 1984), the central Puget Sound shoreline (Thom et al. 1984), and Hood Canal (Simenstad et al. 1980, Simenstad et al. In prep.). The samples were collected during an ebbing tide when approximately 0.25 m of water covered the station. Intake screens were composed of 250-230 m mesh screen, thus limiting contamination by large meiofauna and macrofauna. In the field, each suctioned sample was filtered directly through a 150-230 m sieve and preserved in 5% buffered formalin.

In the laboratory, each sample was sorted under an illuminated dissecting microscope and identified to the lowest taxonomic/life history level possible. They were enumerated and weighed (damp weight) to the nearest 0.1 mg. If necessary, samples were split further by taking 1% incremental subsamples with a Henson-Stempel pipette until sufficient animals (at least 100 of the most common taxa) were obtained.

Fish Stomach Contents Analysis

Although food web linkages were not an objective of our study, three juvenile chum salmon were fortuitously obtained from beach seine collections made by biologists from the Puyallup Indian Tribe at Slip 1 on April 8, coincident with our sampling of the beach. These were preserved immediately in 10% buffered formalin.

Standardized stomach contents analyses were conducted on individual fish stomachs according to procedures described in Simenstad et al. (1980). These analyses describe the stomach (defined as from the esophagus to pyloric sphincter) and its contents quantitatively in terms of fullness (scaled 1 [empty] to 7 [distended]), stage of digestion (scaled 1 [unidentifiable] to 6 [completely undigested]), and taxonomic, numerical, and gravimetric composition.

Data Storage and Analysis

All epibenthos data were entered and stored as files on the University's Cyber mainframe computer in modified National Oceanographic Data Center (NODC) computer formats and codes (including the NODC taxonomic and life history codes). Epibenthos data was recorded in NODC format #410, record type #6, computer format. These files were tabulated and summarized statistically using the FRI computer program SUPERPLANKTON (FR 363), which is specifically designed to address NODC-formatted data. All stomach contents data were recorded onto NODC format No. 100, record Type #5 computer format for tabulation and basic statistical analyses using a FRI computer program package, GUTBUGS, specifically designed for the NODC-format stomach analysis data (Swanson and Simenstad 1984). Subsequent, more detailed analysis of the summary data was performed using the data base management software R:Base 5000 and statistic/graphical software Statgraphics on IBM PC-compatible computers. The entire data set for periphyton was entered and analyzed using Statgraphics.

All densities and standing crops of epibenthic organisms are reported as per unit area (m^2) but may be transformed to volumetric (m^3) data for the epibenthic portion of the water column within 10 to 15 cm of the bottom substrate by multiplying the areal estimates by 8.42 to connect to the 0.0019 m^3 volume of the epibenthic pump sampling cylinder.

The relative importance of prey taxa was assessed using a modification (by using biomass instead of volumetric measurements) of Pinkas et al.'s (1971) dimensionless Index of Relative Importance (IRI). IRI_i = % frequency of occurrence of prey taxon i multiplied by the product of the % numerical and the % gravimetric composition of taxon i (Calliet 1977). This is presented graphically using the three axis prey spectrum plot, with the frequency of occurrence of each prey taxon plotted sequentially (descending) on the horizontal axis and the percentage of total prey abundance and percentage of total prey biomass plotted above and below this axis, respectively. Prey taxa were compared by their proportional contribution to the sum of the IRI values composing the prey spectrum (% Σ IRI); in the case of the IRI spectrum plot, this represents that proportion of the total area of the prey taxa bars represented by each taxon i. The advantage of the IRI approach is that the more representative prey taxa are not completely dominated by large (high biomass) prey which are uncommon or few in number or by numerically abundant or common prey which contribute low biomass to the diet.

RESULTS AND DISCUSSION

Physical and Chemical Factors

Surface water temperature showed a steady increase from a low of 10°C to a high of 16°C between 24 April and 3 June (Figure 3). Salinity was very low (5 ppt) on the first sampling trip, but remained between 17-19 ppt thereafter (Figure 3). Based on our observation of plume excursion during some site visits, the Puyallup River has a significant influence on the water properties in the region of Slip 1. The low salinity on the first trip is probably due to a strong pulse of freshwater from the Puyallup River. Based on the fact that ambient salinities in mid-Puget Sound in this region are 27-29 ppt (Thom

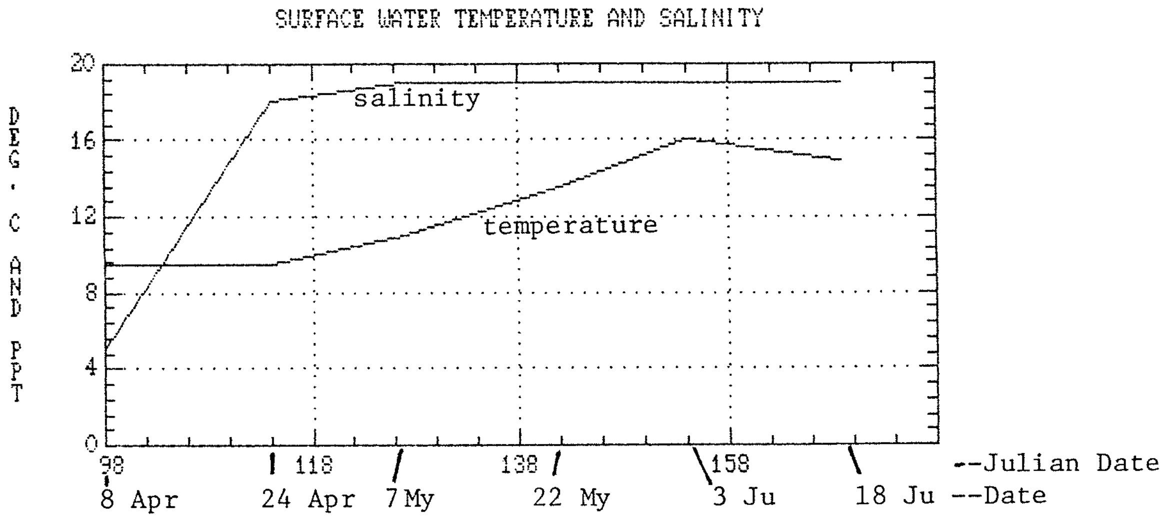

Figure 3. Water temperature and salinity at the mitigation beach.

et al. 1984), it is evident that the river diluted surface water at the beach during the entire sampling period.

The gravel substrata remained unconsolidated throughout the sampling period. We found no evidence of significant sedimentation on the beach.

Periphyton Assemblage

The assemblage consisted primarily of a dense mat of filamentous and tube dwelling diatoms. The most common genera were Navicula (Schizonema), Melosira and Fragilaria. Other benthic genera included Cocconeis, Pleurosigma, and Synedra.

Two peaks in ash-free day weight (AFDW) were evident at +0.7 and 0 m elevations on 8 April and 3 June (Figure 4). AFDW was highest at the lowest elevation on 8 April and 18 June. Using data from all stations together for each sampling, mean AFDW was greatest on 8 April (97.287 g/m^2) and second highest on 3 June (88.140 g/m^2). Periphyton dry weight showed a corresponding pattern. AFDW was, on average, 26% of the dry weight and the two measures showed a strong linear relationship (Figure 5). Spatial patterns for AFDW by transect position at each sampling date indicated a relatively high degree of variation among stations on 3 June and also on 18 June (Figure 6). Our observations suggest that the variations during latter sampling dates were largely due to the heterogeneity in the environment as a result of the peaks and pits in the beach. The pits tended to support a visibly denser accumulation of periphyton than did the peaks. The reason that the differences were most pronounced later in the sampling period is probably due to the effects of warming temperatures and increased desiccation stress on the peaks. The pits had areas that were shaded, may have retained water longer, and thus were subjected to less heat stress.

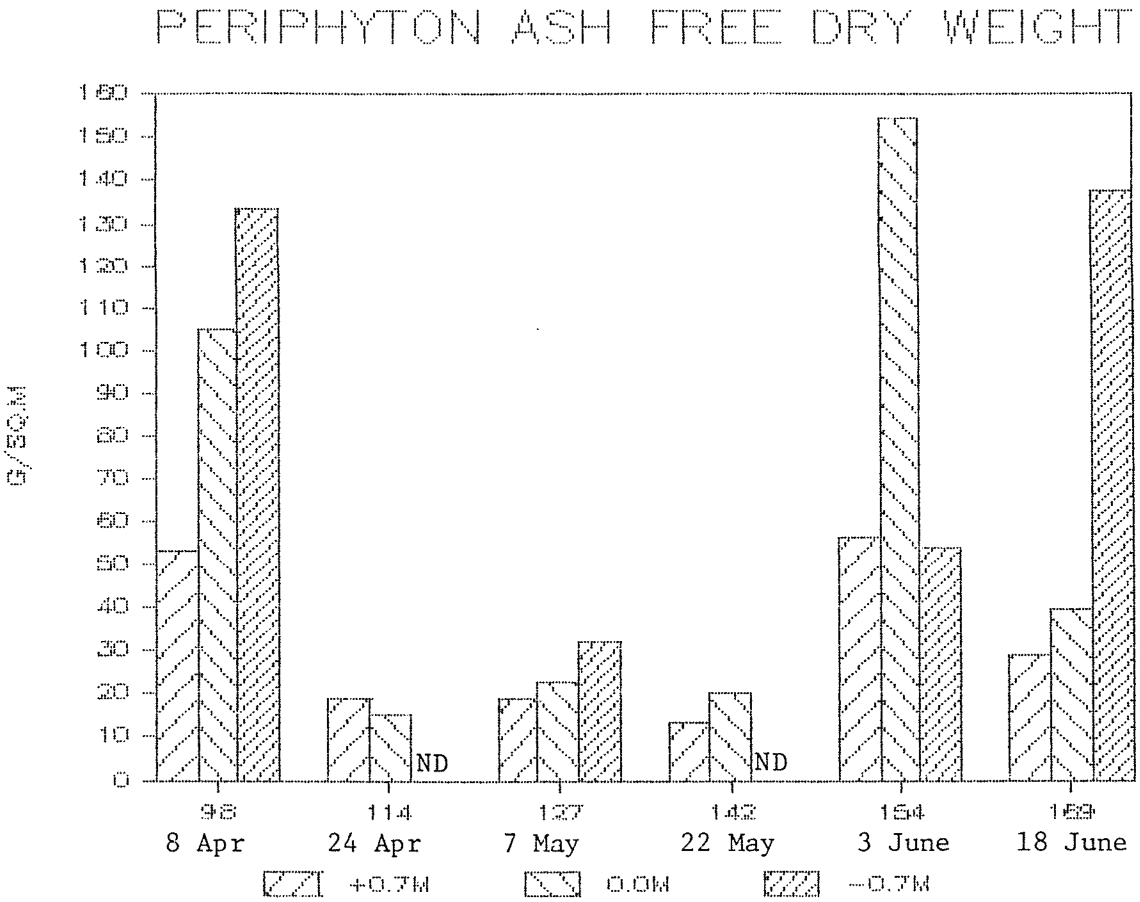

Figure 4. Periphyton mean ash free dry weight by tidal elevation for each sampling.

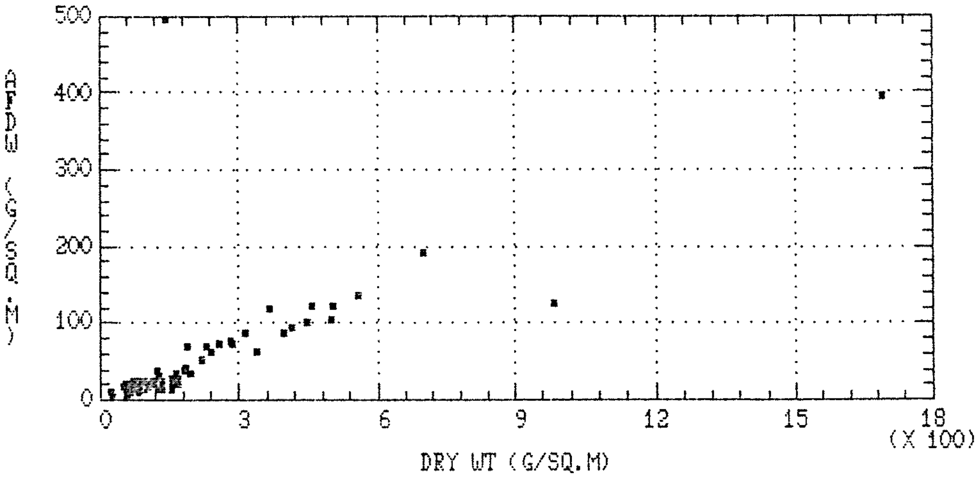

Figure 5. Relationship between periphyton dry weight and ash free dry weight (AFDW).

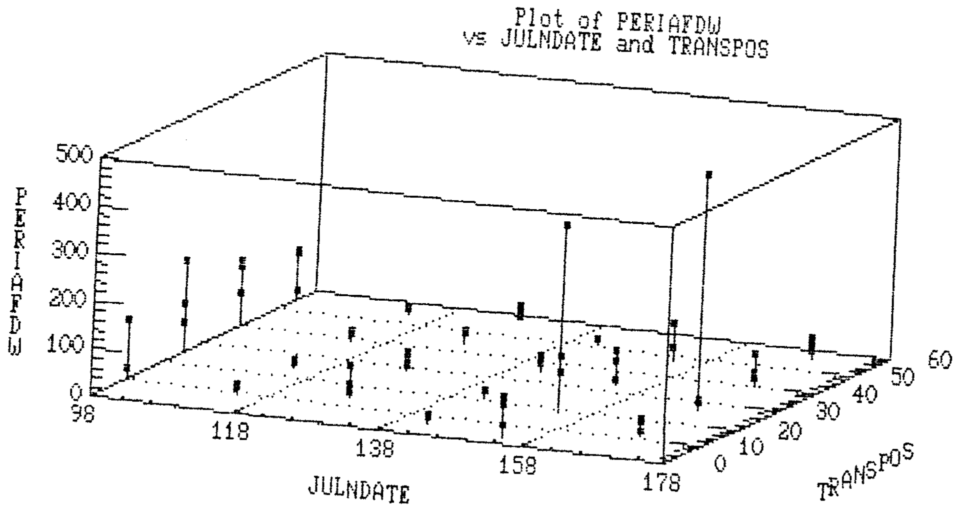

Figure 6. Periphyton ash free dry weight (PERIAFDW) by sampling date (JULNDATE) and position of random transects (TRANSPOS) on the mitigation beach. Individual data points for the three elevations are indicated in the vertical projections above the XY plane.

Mean NPP was generally greatest at elevations 0 and 0.7 m MLLW (Figure 7). Peaks in NPP occurred on the same dates as peaks in AFDW (Figures 4 and 7). The relatively high degree of spatial variation in NPP is indicated in Figure 8a. The mean NPP for a pooling of data from all stations for the two highest samplings were 1.743 $gC/m^2/hr$ (s.d.=1.087) and 2.168 $gC/m^2/hr$ (s.d.=1.170) for 8 April and 3 June, respectively.

Respiration (R) was greatest on 8 April, and showed a slight increase on 18 June (Figure 8b). During early spring, the assemblage appears to have a relatively great total metabolic rate, with a large proportion of primary production being respired by rapidly growing plants (and animals). The low NPP, coupled with the slight increase in R, in early summer suggests that the assemblage is also respiring rapidly, perhaps due to a die-off of the ephemeral algae that dominate the beach.

Spatial patterns in GPP (Figure 8c) followed those of NPP (Figure 7). GPP at the +0.7 m elevation declined from a very high value in early April to much lower values later in the season (Figure 9). However, on 8 April and 18 June, R accounted for a greater proportion of GPP than did NPP (Figure 10). The NPP:R ratio was below 1 on these two occasions, which indicated a heterotrophic condition of the assemblage (Figure 11).

A non-linear, extremely variable relationship between periphyton dry weight and GPP was indicated (Figure 12). GPP reached high values at dry weights as low as 100 g/m^2 (= 26 g $AFDW/m^2$). The data do suggest that above about 400 g/m^2 GPP rate did not increase in correspondence to increasing dry weight.

An estimate of total GPP during the spring sampling period was made by assuming that NPP was constant for 6 hrs per day, and R was constant 24 hrs per day. The mean hourly NPP and R for each date was converted to a daily

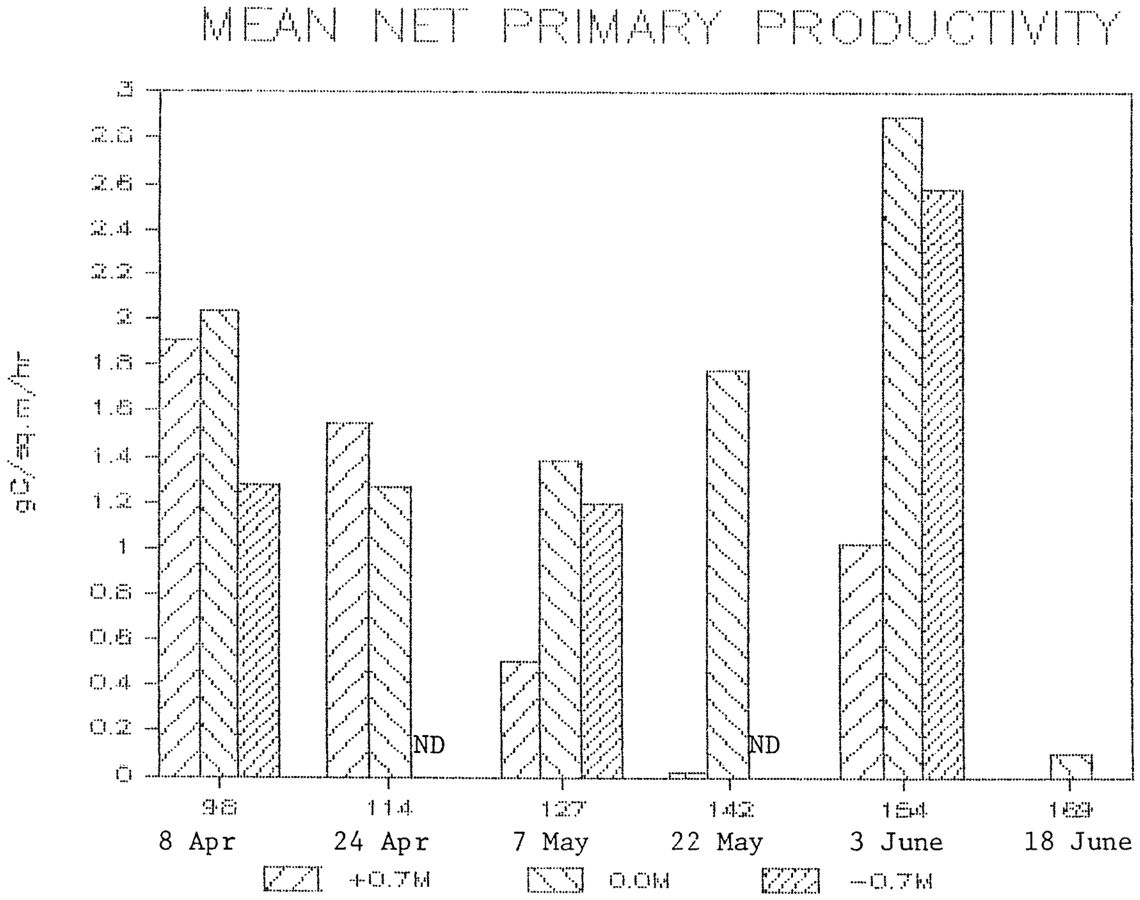

Figure 7. Mean net community primary productivity by tidal elevation for each sampling.

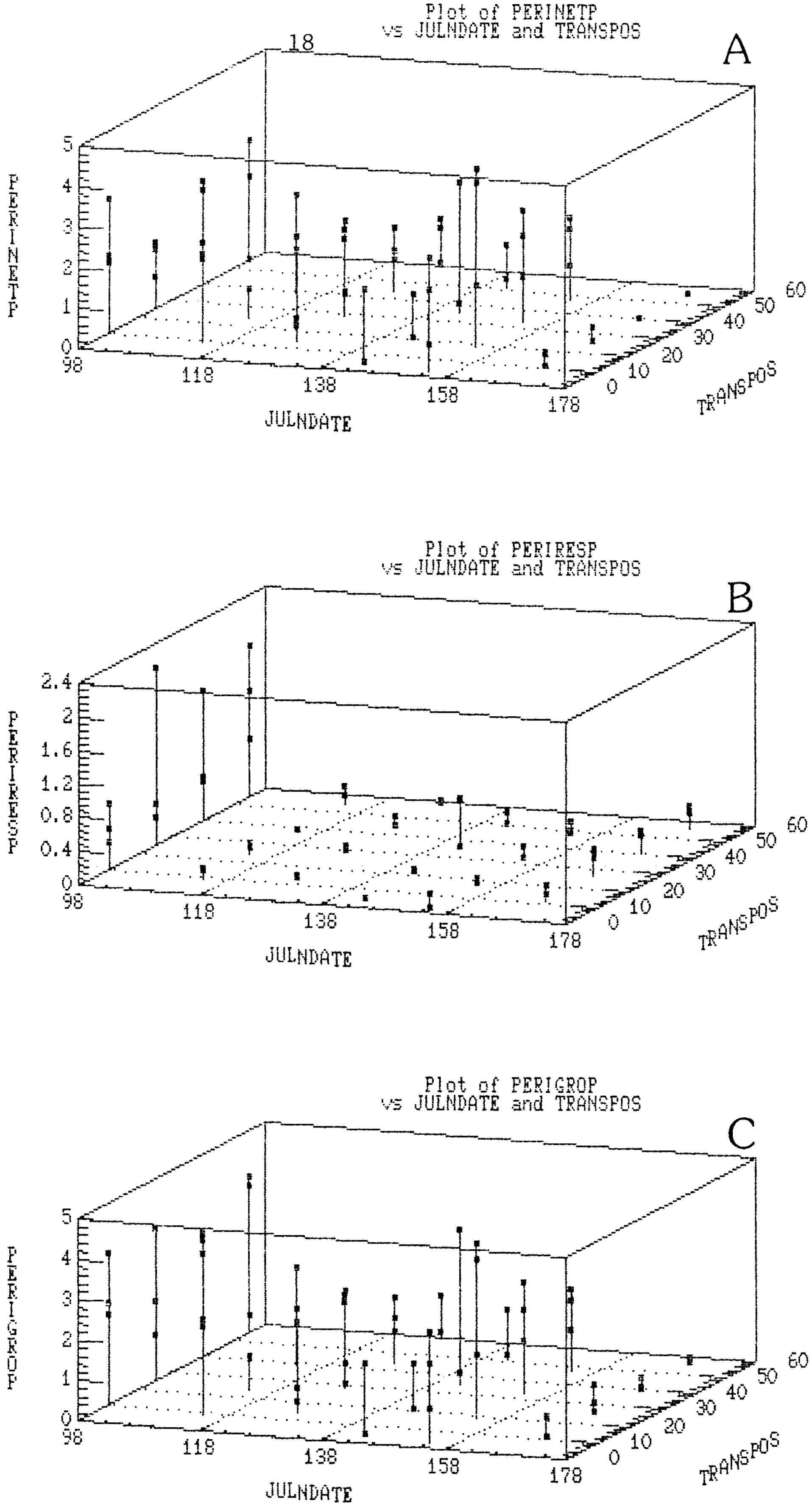

Figure 8. Periphyton net primary productivity (PERINETP) (A), respiration (PERIRESP) (B), and gross productivity (PERIGROP) (C) by sampling date (JULNDATE) and position of random transects (TRANSPOS) on the beach. Individual data points for the three elevations are indicated in the vertical projections above the XY plane.

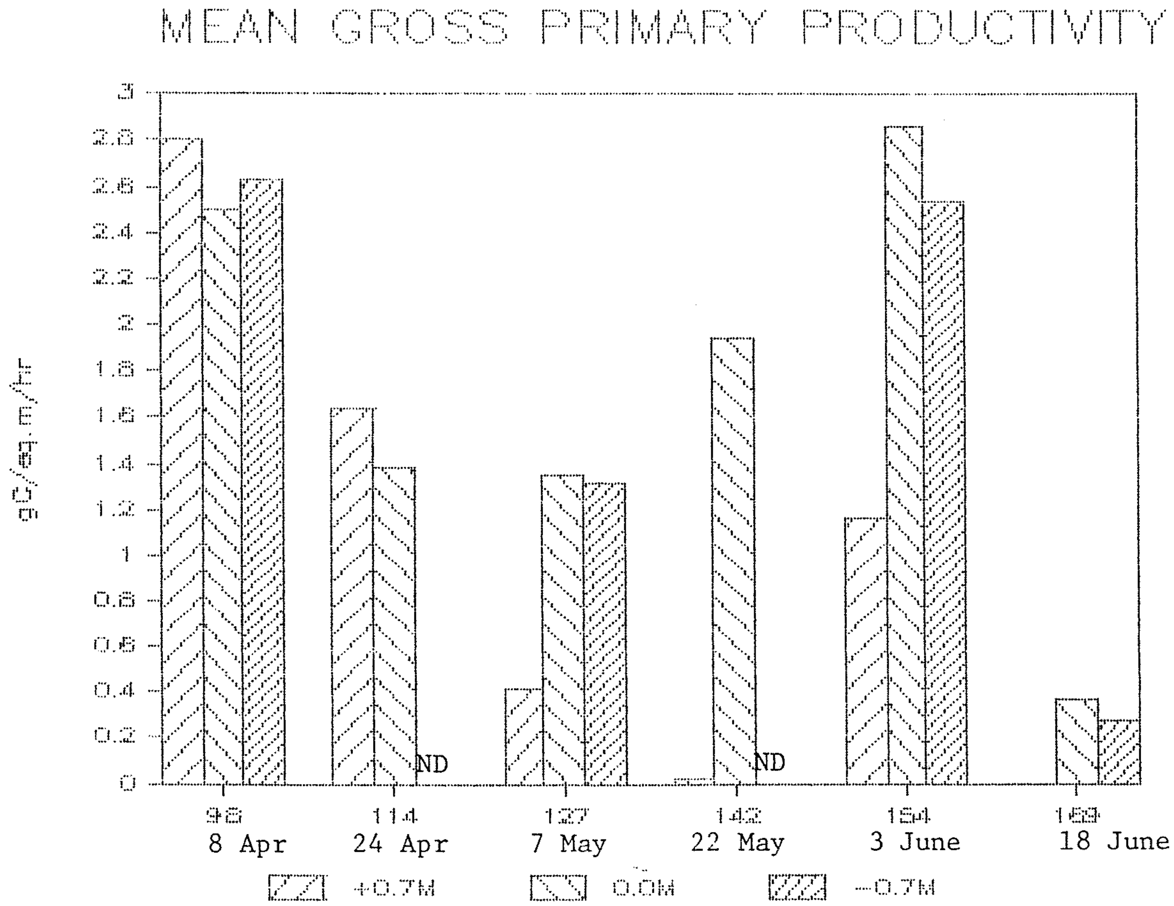

Figure 9. Mean gross periphyton productivity by tidal elevation and sampling date.

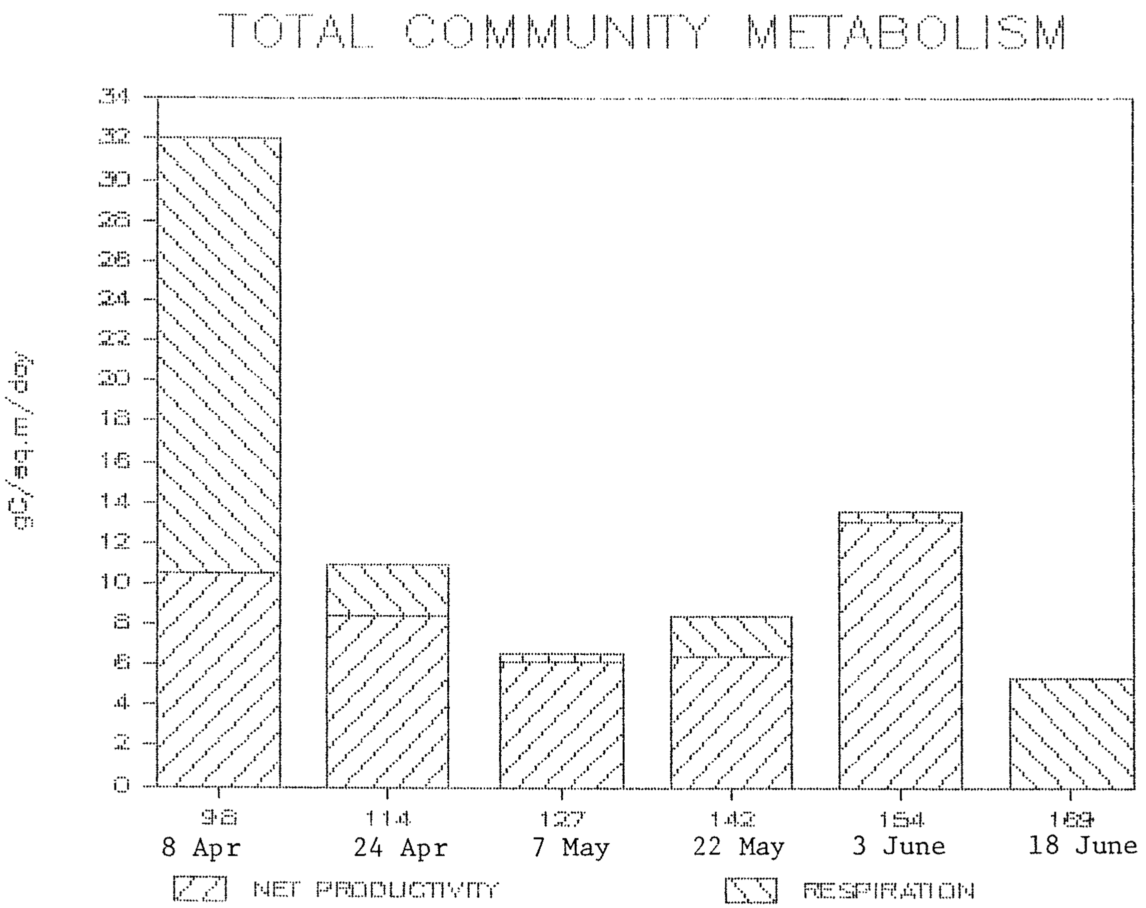

Figure 10. Daily total periphyton community metabolism (= gross productivity) for the mitigation beach for each sampling date.

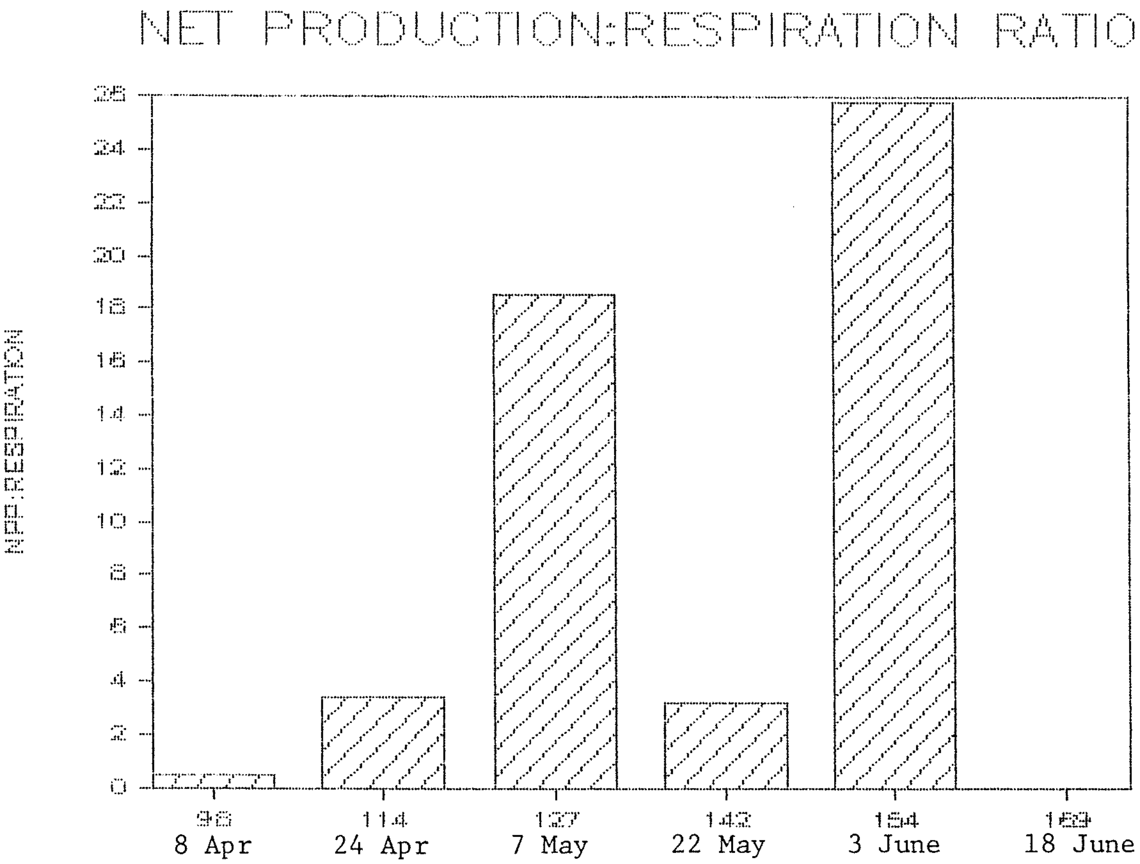

Figure 11. Periphyton net production to respiration ratio for each sampling date.

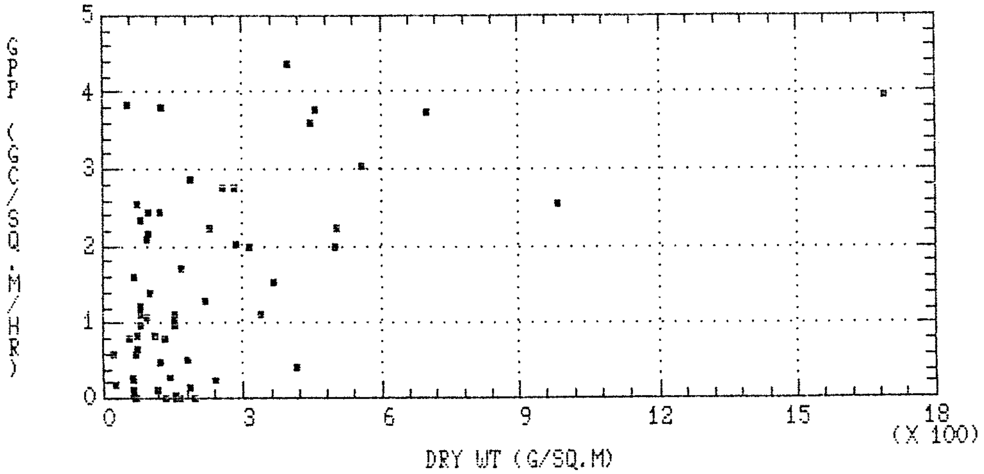

Figure 12. Relationship between periphyton dry weight and gross community production.

rate using these assumptions. This daily rate was multiplied by 11.8, which was the average number of days between samplings (i.e. 71 days for the total sampling period divided by 6 samplings). These rates for the 11.8 day periods were summed, and NPP and R were added to yield a total GPP for the period of 907 gC/m^2. The area we concentrated our sampling (i.e. +0.7 to -0.7 m MLLW) was 302 m^2, and total GPP for the plot is then 273 kgC. GPP extrapolated for the entire beach is 716 kgC. Assuming that carbon is 40% of the algal dry weight (Westlake 1963) and that dry weight is 10% of wet weight (Thom et al. 1984), GPP for the beach during the period of study was 17,900 kg (20 tons) of wet algal biomass.

Epibenthic Zooplankton Assemblage

Overall, 219 categories of epibenthic organism taxa and life history stages were identified (Table 1). Harpacticoid copepods were the most speciose group, including at least 44 discrete taxa (species, species groups, or genera), exclusive of life history stage. Species richness in other taxa was very low in comparison, e.g., only four gammarid amphipods and calanoid copepods.

The density of all epibenthic organisms averaged (±1 s.d.) 76,471 ±104,100.2 m^{-2}, ranging from 5,375 to 705,000 m^{-2}. The corresponding standing crop averaged 2.129 +4.213 g wet wt m^{-2}. Harpacticoid copepods predominated both numerically and gravimetrically, comprising 90.2% of the total abundance and 79.8% of the total standing crop (Table 1); other common, though not prominent, taxa were gammarid amphipods (2.0% and 10.2%, respectively), calanoid copepods (1.2%, 2.0%), cyclopoid copepods (1.9%, 1.7%), and barnacle larvae (1.8%, 1.8%).

The chronology of standing stock over time indicated a shift in density

Table 1 Summary of taxa and life history stage composition and standing stock of organisms collected during sampling of epibenthos at Slip 1 mitigation beach, Commencement Bay, Washington, 8 April-19 June 1985.

Taxa	Life History Stage1	Density				Standing Crop			
		mean	±1 s.d.	range	%	mean	±1 s.d.	range	%
Coelenterata									
Hydrozoa									
Hydroidea	D,W	3.9	18.9	62.5- 125.0	*1	**2	0.00	0.006- 0.013	*
Platyhelminthes									
Turbellaria	C	429.9	1,091.4	62.5- 6,250.0	0.6	0.877	0.04	0.006- 0.250	0.6
Aschelmintes									
Nematoda	C	1,179.3	2,203.9	62.5- 14,375.0	1.5	0.912	0.02	0.006- 0.063	0.7
Annelida									
Polychaeta	6,7	23.4	99.3	62.5- 750.0	*	0.001	0.00	0.006- 0.025	0.1
Polynoidae	7	1.0	7.8	62.5- 62.5	*	0.006	0.00	0.006- 0.006	*
Syllidae	7,C,L	16.6	85.0	62.5- 625.0	*	0.002	0.01	0.006- 0.063	0.1
Nephtyidae	7	1.0	7.8	62.5- 62.5	*	**3	0.00	0.006- 0.006	*
Spionidae	7	8.8	62.9	62.5- 500.0	*	**	0.00	0.006- 0.025	*
Capitellidae	7	2.0	15.6	125.0- 125.0	*	**	0.00	0.006- 0.006	*
Oligochaeta	C	127.8	386.2	62.5- 2,500.0	0.2	0.021	0.07	0.011- 0.425	1.0
Mollusca									
Gastropoda	6	1.0	7.8	62.5- 62.5	*	**	0.00	0.006- 0.006	*
Mesogastropoda	6,7	4.9	20.2	62.5- 125.0	*	**	0.00	0.006- 0.006	*
Littorinidae									
<u>Littorina scutulata</u>	M	143.5	222.5	62.5- 1,187.5	0.2	0.005	0.01	0.006- 0.042	0.3
Pelecypoda	7	2.0	15.6	125.0- 125.0	*	**	0.00	0.013- 0.013	*
Arthropoda									
Arachnida									
Halacaridae	8,C	4.9	20.2	62.5- 125.0	*	0.001	0.00	0.006- 0.025	*
Crustacea									

Ostracoda									
Podocopa	C	4.9	23.1	62.5-125.0	*	**	0.00	0.006-0.013	*
Copepoda	2	44.6	101.1	62.5-416.7	0.1	0.002	0.01	0.006-0.042	0.1
Calanoida	2,F	191.1	456.5	62.5-2,916.7	0.3	0.010	0.02	0.006-0.125	0.5
Calanus sp.	F	21.2	94.5	62.5-625.0	*	0.002	0.01	0.006-0.042	0.1
Paracalanidae									
Paracalanus sp.	8,A,F	30.3	113.6	62.5-625.0	*	0.003	0.01	0.006-0.063	0.1
P. parvus	F	2.9	17.4	62.5-125.0	*	**	0.00	0.006-0.006	*
Pseudocalanidae									
Microcalanus sp.	8,A	2.9	17.4	62.5-125.0	*	**	0.00	0.006-0.006	*
Pseudocalanus sp.	8,F	2.9	13.3	62.5-62.5	*	**	0.00	0.006-0.006	*
Stephidae	A,F	115.9	348.5	125.0-2,250.0	0.2	0.005	0.01	0.006-0.075	0.2
Temoridae									
Eurytemora americana	8,A,F,L	557.4	1,902.8	62.5-14,583.3	0.7	0.023	0.05	0.006-0.333	1.1
Acartiidae									
Acartia clausi	8	7.8	37.8	125.0-250.0	*	0.001	0.00	0.006-0.025	*
Harpacticoida	2,F,M	2,840.8	3,590.8	62.5-18,750.0	3.7	0.035	0.04	0.006-0.138	1.6
Tegastidae									
Tegastes sp.	8	2.0	11.0	62.5-62.5	*	**	0.00	0.006-0.006	*
Ectinosomidae	8,A,F,L,U	3,447.7	7,146.8	125.0-37,750.0	4.5	0.034	0.05	0.006-0.250	1.6
Halectinosoma sp.	8,L	7.8	37.8	125.0-250.0	*	**	0.00	0.006-0.013	*
Harpacticidae									
Harpacticus sp.	8,L,N,O	14.6	82.4	437.5-500.0	*	**	0.00	0.006-0.006	*
H. compressus	L	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
H. spinulosus	8	1.8	14.2	113.6-113.6	*	**	0.00	0.011-0.011	*
H. uniremis	F,L,N,O,U	9,762.6	32,125.4	62.5-252,500.0	12.8	0.899	3.07	0.006-24.250	42.2
H. sp. A-*uniremis* group	L,N,O	85.0	216.0	62.5-1,250.0	0.1	0.010	0.03	0.006-0.125	0.5
H. sp. B-*uniremis* group	8,L,E,F	10.7	42.5	62.5-	*	0.001	0.00	0.006-	*

				250.0				0.013	
H. sp.-obscurus group	8,L,U	94.2	340.0	62.5- 2,500.0	0.1	0.006	0.02	0.006- 0.125	0.3
Zaus sp.	8,L	38.7	180.4	62.5- 1,250.0	0.1	0.004	0.02	0.006- 0.125	0.2
Tisbidae									
Tisbe sp.	8,L	32,952.9	47,249.6	750.0- 205,625.0	43.1	0.293	0.38	0.006- 1.500	13.8
Tachidiidae									
Microarthridion littorale	8,F								
Tachidius triangularis	8	2.9	13.3	62.5- 62.5	*	**	0.00	0.006- 0.006	*
Danielssenia typica	1,8,A,F,L								
Laophontidae	8,F								
Paralaophonte sp.	8,L								
P. congenera	8,L								
P. pacifica	8,L								
P. perplexa	8,L								
Laophonte elongata	8,L								
L. sp. B	8	1.0	7.8	62.5- 62.5	*	**	0.00	0.006- 0.006	*
Pseudonychocamptus spinifer	8,l								
Heterolaophonte discophora	F,L								
H. longisetigera	8,L								
H. hamondi	8,L								
Ameiridae	8,F								
Ameira sp.	8,L								
A. longipes	8	5.9	39.7	62.5- 312.5	*	**	0.00	0.006- 0.006	*
Sarsameira sp.	8	3.9	31.3	250.0- 250.0	*	**	0.00	0.025- 0.025	*
Cletodidae									
Leimia vaga	8,F,L								
Diosaccidae	N	2.9	17.4	62.5- 125.0	*	**	0.00	0.006- 0.013	*
Amonardia perturbata	8,F,L,N								
A. normani	8	23.1	81.3	62.5- 416.7	*	0.002	0.01	0.006- 0.042	0.1
Diosaccus spinatus	8,F,L,N,O,U								
Amphiascopsis cinctus	8,L,N								
Amphiascus minutus	8,L								
A. sp. E-minutus									

group	L	2.0	15.6	125.0-125.0	*	**	0.00	0.013-0.013	*
Stenhelia peniculata	8,A,L								
Amphiascoides sp.	8,L								
A. subdebilis	8,L								
A. sp. A	8	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Canthocamptidae									
Mesochra sp.	8,L								
Thalestridae									
Dactylopodia sp.	F,N								
D. vulgaris	8,L								
D. crassipes	8,L								
D. paratisboides	8,L								
D. sp. A	8,L								
Paradactylopodia sp.	8,L								
P. serrata	8,L								
Parathalestris californica	8	2.0	15.6	125.0-125.0	*	**	0.00	0.013-0.013	*
Diarthrodes sp.	8,A,F								
Parastenheliidae									
Parastenhelia spinosa	8	2.0	15.6	125.0-125.0	*	**	0.00	0.013-0.013	*
Cyclopoida	F	14.6	82.4	125.0-	*	0.001	0.01	0.006-	0.1
Oncaeidae	8	3.9	31.3	250.0-250.0	*	**	0.00	0.025-0.025	*
Oncaea sp.	8	9.8	78.1	625.0-625.0	*	0.001	0.01	0.063-0.063	0.1
Corycaeidae									
Corycaeus sp.	8	9.8	78.1	625.0-625.0	*	**	0.00	0.013-0.013	*
C. anglicus	8,A,F								
Clausiidae	F	9.8	78.1	625.0-625.0	*	0.001	0.01	0.063-0.063	0.1
Oithonidae	A	2.9	23.4	187.5-187.5	*	**	0.00	0.006-0.006	*
Oithona sp.	F	2.0	15.6	125.0 125.0	*	**	0.00	0.006-0.006	*
O. similis	8,A,F								
Cyclopinidae	8,A,F,L								
Cyclopina sp.	8,A,L								
Lichomolgidae	C,F								
Balanomorpha	2,7,E								
Mysidacea									
Mysidae									
Inusitatomysis insolita	C	1.0	7.8	62.5-62.5	*	0.002	0.02	0.156-0.156	0.1
Cumacea									

Nannastacidae									
Cumella vulgaris	7,8								
Isopoda									
Sphaeromatidae									
Gnorimosphaeroma oregonensis	7	1.0	7.8	62.5-62.5	*	**	0.00	0.025-0.025	*
Bopyridae	6,7,C								
Amphipoda									
Gammaridea									
Calliopiidae									
Paracalliopiella pratti	7	3.9	18.9	62.5-125.0	*	0.001	0.00	0.013-0.013	*
Corophiidae									
Corophium sp.	7	2.9	13.3	62.5-62.5	*	**	0.00	0.006-0.006	*
C. brevis	8	1.0	7.8	62.5-62.5	*	0.002	0.01	0.106-0.106	0.1
Gammaridae	7	1,167.8	1,745.4	62.5-8,125.0	1.5	0.081	0.11	0.006-0.438	3.8
Anisogammarus sp.	7	39.1	312.5	2,500.0-2,500.0	0.1	0.002	0.02	0.144-0.144	0.1
A. pugettensis	7	276.8	696.6	62.5-4,125.0	0.4	0.119	0.24	0.019-1.075	5.6
Eogammarus confervicolus	7	33.2	165.2	62.5-1,250.0	*	0.007	0.03	0.038-0.150	0.3
Euphausiacea	2,6								
Decapoda									
Brachyura									
Cancridae									
Cancer sp.	3	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Xanthidae									
Lophopanopeus bellus	3	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Pinnotheridae	3	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Hemigrapsus sp.	3	9.4	54.5	62.5-416.7	*	0.001	0.01	0.006-0.042	*
Insecta	6	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Collembola	C	2.0	11.0	62.5-62.5	*	**	0.00	0.006-0.006	*
Diptera									
Chironomidae	6,8,G								
Phoronida	7	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Ascidiacea	6	1.0	7.8	62.5-62.5	*	**	0.00	0.006-0.006	*
Larvacea	7	1.0	7.8	62.5-	*	**	0.00	0.006-	*

				62.5				0.006	
Teleostei									
Osteichthys									
Cottidae	6	1.0	7.8	62.5-62.5	*	0.007	0.05	0.438-0.438	0.3
unidentified	M	2.9	17.4	62.5 125.0	*	**	0.00	0.006-0.013	*

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1 life history stage codes: 1=egg; 2=nauplius; 3=zoea; 4=megalop; 5=veliger; 6=larva; 7=juvenile; 8=adult; 9=combination of 6, 7, & 8; A=combination of 7 & 8; B=combination of 6 & 7; C=juvenile-adult, sexual maturity unknown; E=cypris; F=copepodid; G=pupa; L=egg-carrying female; N=adult male; U=mating pairs; X=cyphonautes larvae.

from higher (+0.7 m) to middle (0.0 m) and lower (-0.7 m) tidal elevations during the sampling period (Figure 13a). The peak density of all epibenthos at the higher elevation was evident at the first sampling date (April 8) and may have existed for an unknown period prior to that. As epibenthos density declined rapidly at the higher tidal elevation, densities at the middle and lower tidal elevations gradually increased; the highest densities occurring at the 0.0 m tidal elevation at the end of the sampling period (19 June). Chronological patterns in standing crop (Figure 13b) are similar but the relative magnitude of the differences after the initial sampling period are not as pronounced as indicated by the density estimates.

Juvenile Salmonid Prey Availability

As a measure of relative availability of harpacticoid copepods as prey of juvenile salmon, we pooled the density estimates for all adults, ovigerous females, and mating pairs of large, epibenthic taxa known to be preferentially consumed by epibenthic-feeding juvenile salmonids or to be in that size range (Simenstad et al., In prep.). These included: (1) all *Harpacticus* spp.; (2) *Zaus* spp.; and, (3) *Tisbe* sp. The patterns of their densities over the sampling period (Figure 14) basically mirrored that of the total epibenthos. Initially, "potential" salmonid prey comprised 33% to 43% of the total epibenthos density. By April 24, this had risen to 80% but then declined to 26% to 49% on May 7. Thereafter, between 60% and 80% of the total epibenthos density was comprised of prey of epibenthic-feeding juvenile salmonids. The demography of the principal prey taxa indicates that the univoltine *Harpacticus* spp. populations were already at their peak abundance and reproductive activity by the time of the initial sampling date and that the subsequent crash in total epibenthos and prey densities can be attributed to

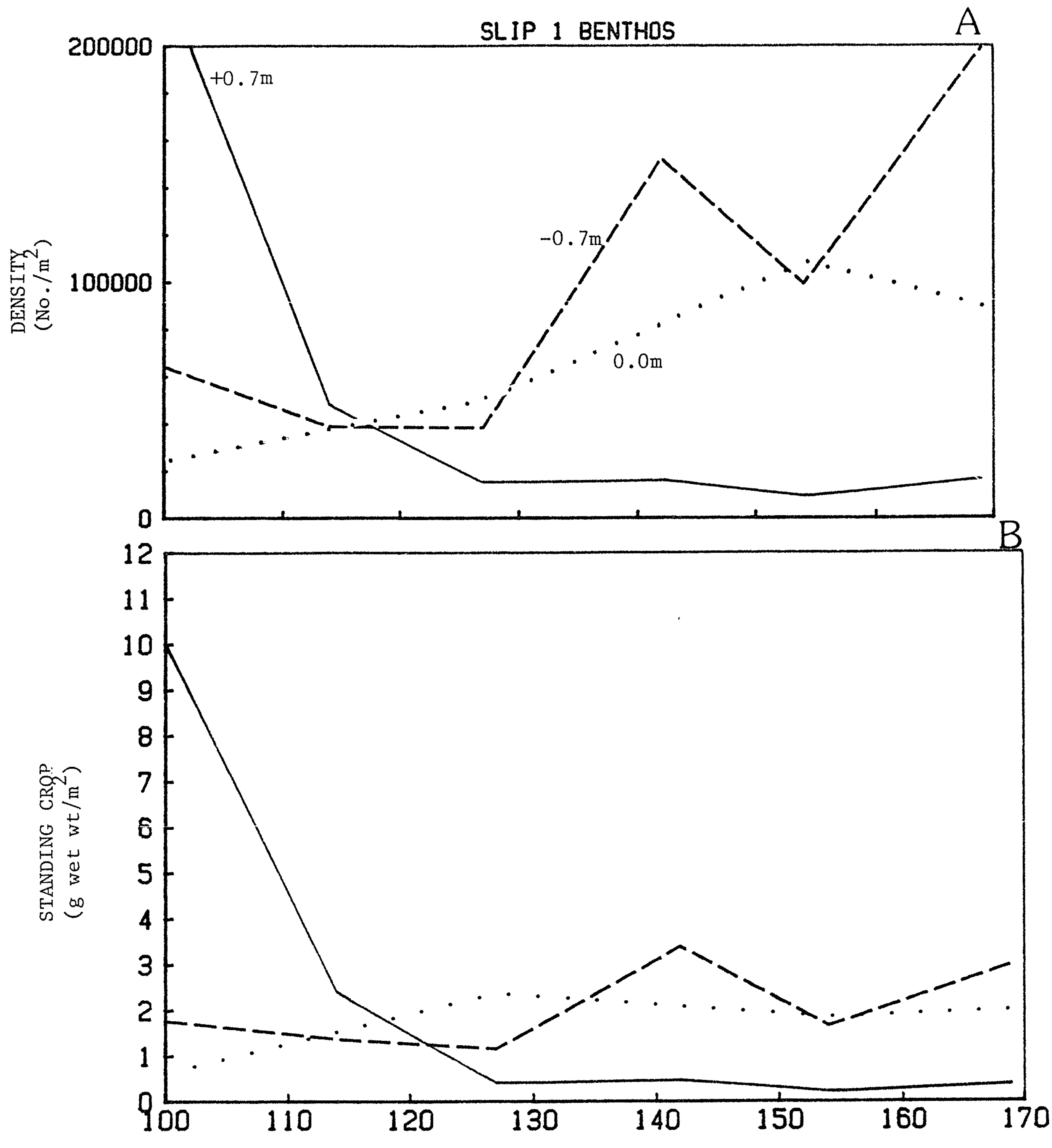

Figure 13. Chronology of total epibenthos density (A; no. m-2) and standing crop (B; g wet wt m-2) at Slip 1 mitigation beach, Commencement Bay, Puget Sound, Washington, from 8 April to 19 June 1985; solid line indicates 0.7-m, dashed line the 0.0-m, and the dotted line the -0.7-m tidal elevations.

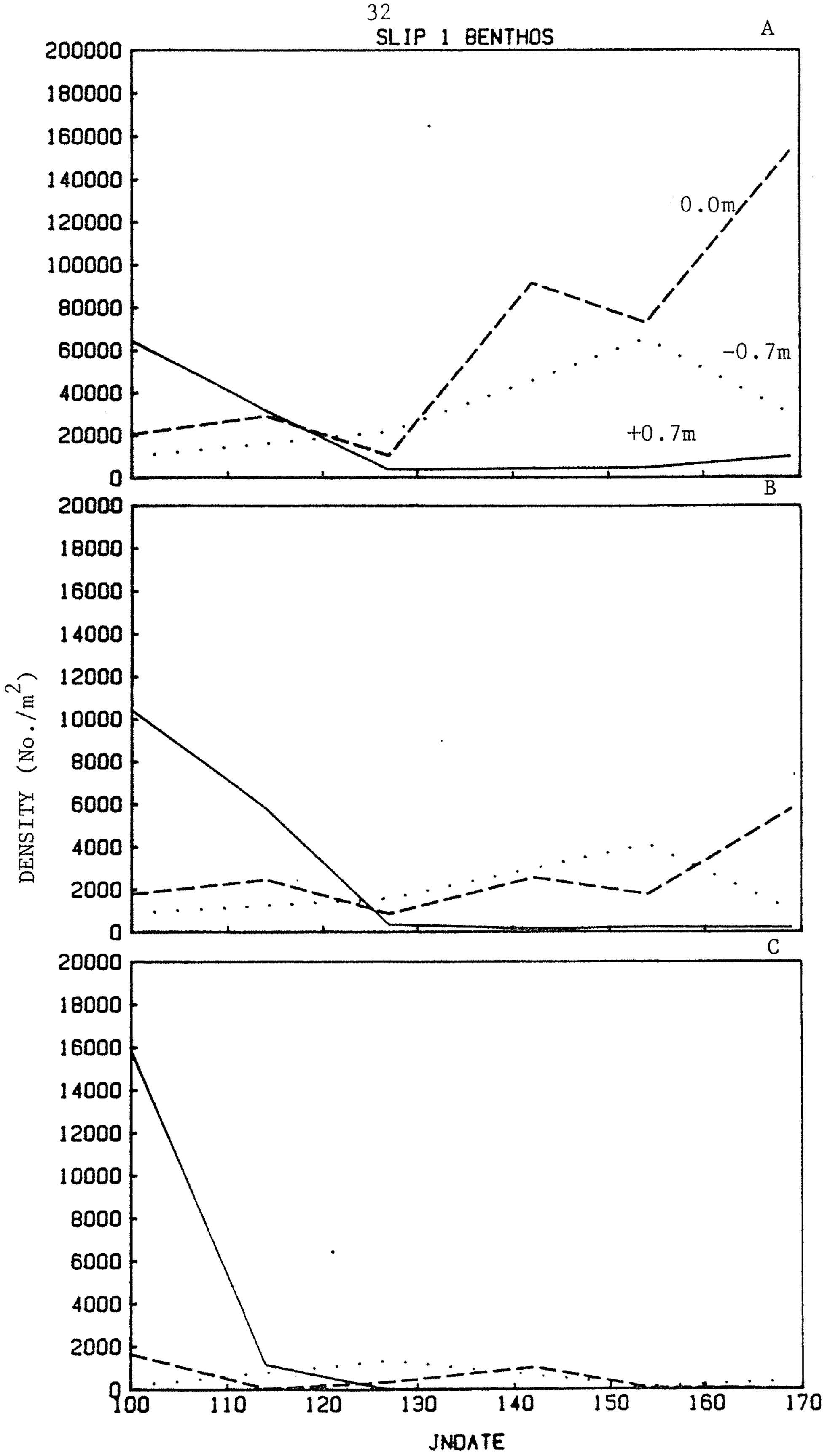

Figure 14. Population demography (density, no. m-2) of adult (A), ovigerous female (B), and mating pair (C) harpacticoid copepods potentially available as prey of epibenthic-feeding juvenile salmonids; see text for definition of potential prey taxa.

their decline. Despite the high incidence of ovigerous female and mating pairs of Harpacticus spp. in April, adults expected as production of this reproductive activity did not appear prominently in subsequent sampling dates. Instead, the gradual increase in adults and ovigerous females was apparently due to the more prolonged development of the multivoltine Tisbe sp. populations.

Juvenile Chum Salmon Food Habits

Three juvenile chum salmon 40 to 47 mm in length (fork length) were examined from the Puyallup Tribe beach seine catches on April 8. The stomachs were between half and completely full and the contents showed little indication of digestion, suggesting that these fish had fed recently and within the local vicinity of Slip 1.

Harpacticoid copepods and fish larvae dominated the IRI prey spectrum, contribution 70% and 29% of ΣIRI (Figure 15); cyclopoid copepods (Corycaeus anglicus) and euphausiid larvae were comparatively unimportant (<1% ΣIRI) components of the diet. The harpacticoids were almost exclusively (96% of total harpacticoid numbers; 68% ΣIRI) from a specific epibenthic group of Harpacticus uniremis, although another epibenthic taxa, Tisbe sp., was also represented to a lesser extent.

Assemblage Linkages

Epibenthos density showed only a weak relationship to periphyton AFDW (Figure 16a). In general, both parameters were greatest during the first sampling date. Periphyton GPP showed a somewhat stronger relationship with epibenthos density (Figure 16b), although the relationship exhibited a variable pattern. For example, on 8 April (Julian date 98) epibenthos density

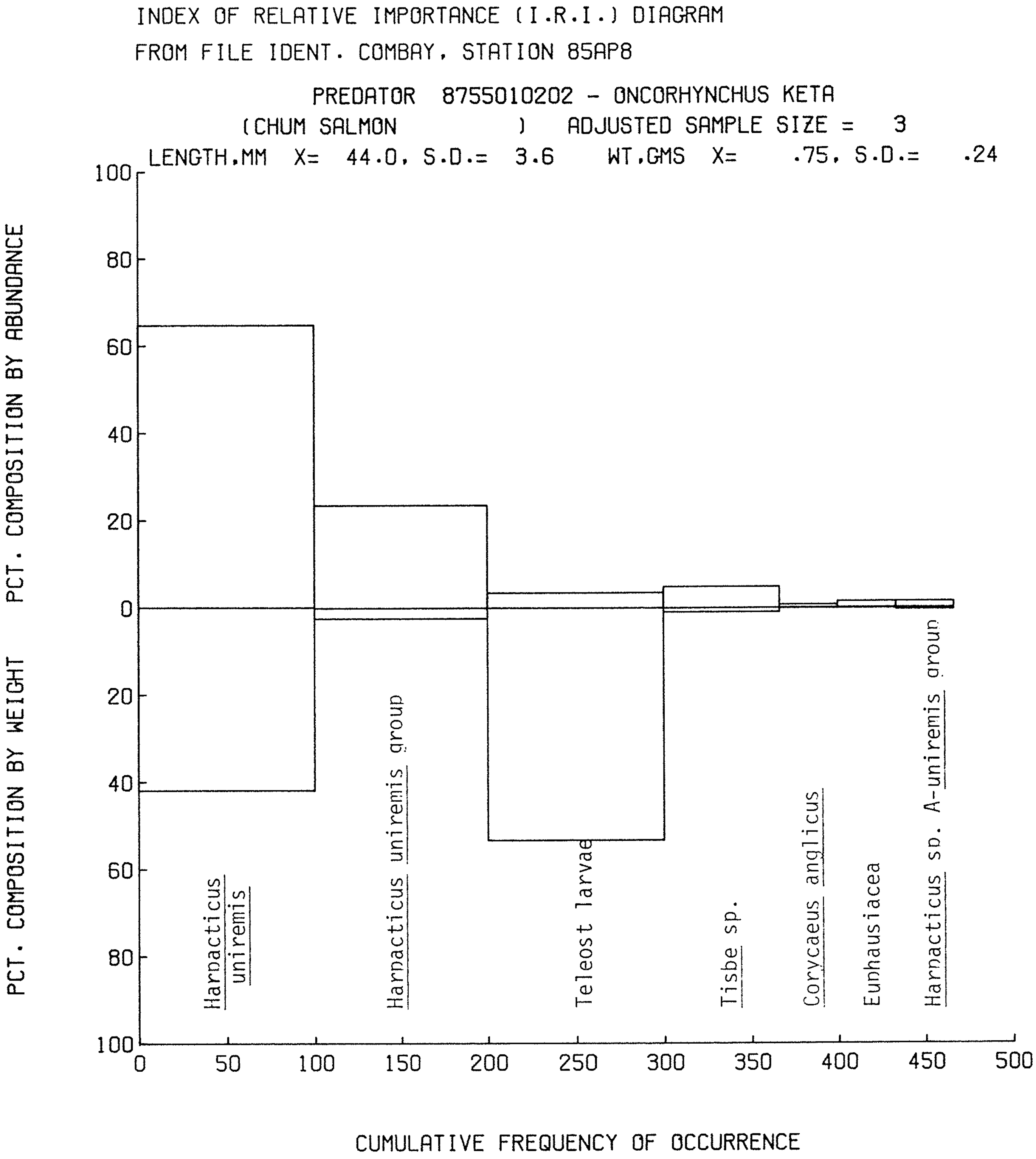

Figure 15. Index of Relative Importance (IRI; see Materials and Methods) prey spectrum of three juvenile chum salmon (Oncorhynchus keta) captured at the Slip 1 mitigation beach, Commencement Bay, Puget Sound, Washington, on 8 April 1985.

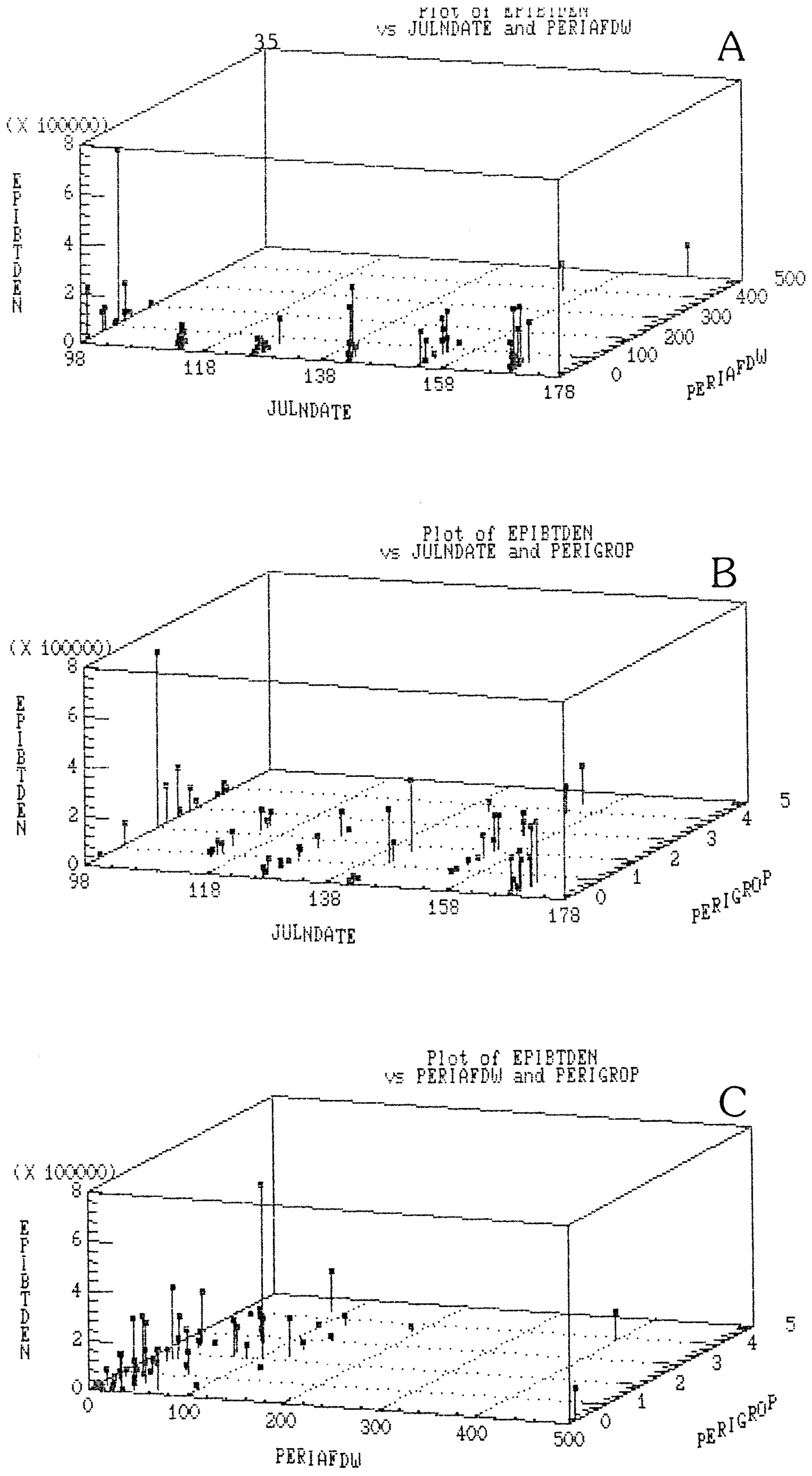

Figure 16. Relationships among epibenthos density (EPIBTDEN), sampling date (JULNDATE), periphyton ash free dry weight (PERIAFDW) and periphyton gross productivity (PERIGROP).

was greatest at intermediate periphyton GPP. In contrast, epibenthos density exhibited a general linear increase with increasing GPP on 3 June (Julian day 142). In general, the highest epibenthos density occurred at times and locations where periphyton AFDW was below 100 g/m^2 and GPP was between 1-3 $gC/m^2/hr$ (Figure 16c).

The two principal taxa of harpacticoid copepods (*Harpacticus uniremis* group, *Tisbe* sp.) found in the stomachs of juvenile chum salmon captured on April 8 are considered to be the behaviorally preferred prey of juvenile chum salmon migrating out of Puget Sound (sub)estuaries (Simenstad and Wissmar 1983; Simenstad et al. In prep.) and other Pacific Northwest estuaries and nearshore marine habitats (Healey 1979, 1982; Sibert 1979; Cordell, In prep.). However, these "foundation" prey taxa did not appear as prevalently in the diets of juvenile chum sampled in Commencement Bay in 1983-1985 (Simenstad et al. In press). Given the almost complete loss of natural estuarine shallow sublittoral habitat in Commencement Bay (Bortleson et al. 1980), the decreased foraging effort on these taxa may actually represent decreased availability rather than behavioral prey switching irrespective of encounter rates of the foundation prey taxa. Although we cannot establish conclusively that these fish were feeding on the *Harpacticus uniremis* and *Tisbe* sp. available in abundance at the Slip 1 mitigation beach on April 8, or at other times when we do not have comparable fish stomach samples, the beach would appear to have been functioning as a viable foraging habitat at that time.

CONCLUSIONS

The beach in Slip 1 supported an assemblage of filamentous and tube dwelling diatoms that exhibited an early spring maximum in standing stock and productivity. The assemblage is typical of the late-winter early-spring flora of nearshore areas in Puget Sound (Thom et al. 1976; Thom 1980; Thom et al. 1984). Following the early spring maximum, the assemblage standing stock declined dramatically. The decline was most pronounced at the highest elevation, perhaps due to increased desiccation stress in late spring and early summer.

The periphyton assemblage at the beach is also typical of moderate to highly disturbed environments in Puget Sound (Thom 1978). This condition is probably due to the unconsolidated substrata (i.e., gravel) used to construct the beach; and to the relatively high variation in water chemistry at the site. Based on previous work in Puget Sound (e.g., Thom et al. 1984) finer grained substrata (e.g., sand) would have supported a different assemblage and potentially productive sediment-associated diatom assemblage. In contrast, larger, more stable substrata (e.g., cobbles) would eventually be colonized by seaweeds. We expect that fine sediment will settle and gradually fill the interstices between the gravel. The period of time necessary to fill the beach to a point where fines dominate the surface substrata is unknown, and may be on the order of several years.

With regard to the epibenthic zooplankton, especially those taxa preyed upon by juvenile salmonids, the Slip 1 beach appeared to form a reasonably good habitat. The productive (on the order of 20 tons of wet algae) algal flora may have supplied a readily utilizable source of carbon to the epibenthos. Diatoms are capable of growing quickly, and have a high turnover rate (Thom and Copping, In prep.) in spring, thus potentially affording a rich source of energy to the epibenthos. Furthermore, the pits and peaks of the beach created zones of relatively high and low standing stocks of periphyton. Due to protection of the flora from desiccation, the pits appeared to contain a higher standing stock of diatoms further into the summer. Our observations also indicated that these pits may support an attendant epibenthic assemblage for a longer period of time. In addition to the potential food resource, the complex matrix of branches and spaces formed by the diatoms was also probably favorable as refuge for small, epibenthic animals such as harpacticoid copepods.

Based on our data, juvenile salmonids probably utilized the prey resources associated with the beach. However, very few stomachs were available to us for analysis, and these were limited to one sampling date. We conclude that the beach did enhance the environment with regard to fish prey available to outmigrating juvenile salmonids.

RECOMMENDATIONS

Several important questions remain regarding construction of juvenile salmonid feeding habitat in general, and, more specifically regarding the Slip 1 beach.

1. What is the long-term fate of the Slip 1 beach? The data we presented above may represent only the early succession of algal and epibenthic colonization of new substrate. Continued development of flora and fauna would not necessarily follow these patterns due to increasing biotic control (e.g. grazing, competition) of the community. We also expect that fine sediment will eventually fill in the beach. Although it is not clear what impact this change will have on the epibenthic assemblage, we can assume that there will be changes in the assemblage composition by

the substrate-sensitive organisms such as harpacticoids.

2. Is the high slope,coarse-grained, heterogeneous, and unconsolidated condition of the Slip 1 the best reasonable physical framework for the enhancement of habitat for juvenile salmonid prey? Would less heterogeneous, finer- or larger-grained substrata increase the amount of desirable salmonid prey resources?
3. Would either real or artificial macrophytes (e.g., eelgrass) further enhance the environment for prey resources? Good evidence exists suggesting that eelgrass does increase both the standing stock and the duration of occurrence of salmonid prey resources in Puget Sound (Thom et al. 1984).
4. What is the complete seasonal story on conditions in Slip 1 with regard to salmonid prey and salmonid utilization of the beach? Appropriate samples taken in late winter (i.e., March) through mid-summer would be required to answer this question.

We recommend that the studies we carried out in 1985 be repeated in 1986, and subsequent years, and that the studies be initiated in February, prior to the initial periphyton/epibenthos bloom. In order to better couple the "performance" of the beach with regard to salmonid use, we recommend that a systematic sampling of juvenile salmonid prey utilization be carried out in conjunction with the periphyton/epibenthos sampling. To provide significant input to future beach projects, we recommend that test plots of finer (sand) sediment and coarser (cobble) be established at the beach in 1986, and monitored in conjunction with the other studies at the beach.

The Slip 1 beach represents one of a very few estuarine wetland enhancement projects in the Northwest that has been a documented success. The beach presents an excellent arena for a continuing series of small studies that could have more far reaching impacts with regard to planning future projects with similar goals. We recommend that the beach be utilized to evaluate the questions we have raised above as a start.

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