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An Examination of the Effects of Slough Habitat Reclamation in the Lower Fraser River, British Columbia: Detrital and Invertebrate Flux, Rearing and Diets of Juvenile Salmon

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AN EXAMINATION OF THE EFFECTS OF SLOUGH HABITAT RECLAMATION IN THE LOWER FRASER RIVER, BRITISH COLUMBIA: DETRITAL AND INVERTEBRATE FLUX, REARING AND DIETS OF JUVENILE SALMON

by

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A dyked tidal marsh in the Fraser River estuary was reclaimed by breaching a dyke and excavating a tidal channel system to improve tidal flushing and provide new rearing and feeding habitat for juvenile salmon. The physical and biological features of this marsh were monitored and compared with features of an adjacent reference marsh and tidal creek habitat. The reclaimed site was more actively flushed than the reference marsh and as a result had a greater detrital and invertebrate flux. The fresh excavation in the reclaimed marsh provided good colonizing sites for amphipods (Eogammarus sp. and Corophium salmonis), chironomids and mysids, but both marshes had a net import of invertebrate fauna at most times of year (except July).

Sockeye were the most frequently caught salmonid and increased in length by 33% between early May and late June. Chinook, chum, pink and coho also fed and reared in both marshes during different periods in the spring and summer. The juvenile salmon, especially sockeye and chinook, selected a broad range of prey, many of which were also caught in drift net samples at the entrances to the marshes. Dyke removal and channel excavation can achieve a net gain in productive juvenile salmon habitat.

Key words: marsh, juvenile salmon, detritus, epibenthos, fish diet

RÉSUMÉ

Macdonald, J. S., R. U. Kistritz and M. Farrell. 1990. An examination of the effects of slough habitat reclamation in the lower Fraser River, British Columbia: detrital and invertebrate flux, rearing and diets of juvenile salmon. Can. Tech. Rep. Fish. Aquat. Sci. 1731: 59 p.

On a restauré un marais littoral endigué dans l'estuaire du fleuve Fraser en enlevant une digue et en creusant un réseau de canaux à marée pour améliorer la circulation d'eau des marées et procurer un nouvel habitat pour l'élevage et l'alimentation des saumons juvéniles. Les caractéristiques physiques et biologiques de ce marais ont été surveillées et comparées avec celles d'un marais témoin adjacent et de l'habitat des canaux à marée. Le site restauré avait une meilleure circulation d'eau que le marais de référence et, par conséquent, son apport de détritus et d'invertébrés était supérieur. Les travaux d'excavation récents dans le marais restauré ont fourni de bons sites de colonisation pour les amphipodes (Eogammarus sp. et Corophium salmonis), les chironomides et les mysidacés, mais les deux marais présentaient une importation nette d'invertébrés à la plupart des époques de l'année (sauf en juillet).

Le saumon rouge était le salmonidé le plus souvent pêché; sa longueur augmentait de 33 p. 100 entre le début de mai et la fin de juin. Le saumon quinnat, le saumon kéta, le saumon rose et le saumon coho s'alimentaient et croissaient dans les deux marais au cours de différentes périodes au printemps et à l'été. Le saumon juvénile, surtout le saumon rouge et le saumon quinnat, sélectionnaient une grande variété de proises, dont bon nombre étaient également capturées dans les échantillons des filets dérivants à l'entrée des marais. L'enlèvement de la digue et l'excavation des canaux à marée peuvent permettre de réaliser un gain net d'habitat productif pour le saumon juvénile.

Mots clés: marais, saumon juvénile, détritus, épibenthos, alimentation des poissons

INTRODUCTION

Estuarine sloughs, marshes and mudflats are valuable feeding and rearing habitats for selected species of juvenile salmon during their migration from the Fraser River estuary. These habitats may provide a low tide refuge from river currents and have an abundance of prey organisms (Levy and Northcote 1981). Tilbury Slough is one such relatively undisturbed habitat found in the Fraser River estuary (Fig. 1). Most similar sloughs have been partially or entirely filled or otherwise altered by shoreline developments. An estimated 70% of the original Fraser River wetlands have been lost since the 1860s (Fraser River estuary study, summary). Portions of Tilbury Slough have been lost through dyking and infilling with sand dredged from the river (Dorcey et al. 1983).

In recognition of the need to protect remaining sloughs from further habitat degradation, Fisheries and Oceans Canada (DFO) acquired title to the intertidal area of Tilbury Slough and embarked on a series of studies and phased programs designed to manage the Slough. A general discussion of Tilbury Slough ecosystem and suggestions of specific management options are provided by Dorcey et al. (1983). Subsequent to this initial planning phase, DFO implemented a reclamation project that involved breaching a remnant dyke to improve water circulation in the marsh area (Fig. 1) and they installed a shearboom at the mouth of the slough to minimize wood debris accumulation. The dyke, constructed in the late 1800s to protect agricultural lands from tidal flooding encloses 5 ha of intertidal marsh. An old breach in the dyke has provided limited access for flooding. The intertidal marshes outside the dyke along the slough margin are dominated by the sedge _Carex lyngbyei_, bullrushes _Scirpus validus_, and reeds _Juncus_ spp. However, before reclamation efforts the marsh behind the dyke was dominated by cat-tail (_Typha latifolia_), willow and alder. This vegetation is found in areas with low tidal flushing rates, large amounts of freshwater influence and poor drainage where sediment and plant litter accumulate. Primary and secondary production in the dyked marsh was gradually being lost to the aquatic ecosystem as the dyked area became increasingly terrestrial in nature.

To improve tidal circulation and flushing in the dyked marsh, networks of drainage channels were excavated and connected to a new opening in the dyke (Fig. 1). It was envisaged that the reclamation work would improve the exchange of organic matter and invertebrates between the slough and the dyked marsh habitat and would provide additional rearing and feeding areas for juvenile salmon. In this way the productive juvenile salmon habitat in Tilbury Slough would be enhanced. This report describes the results of studies designed to test these objectives.

We are aware of only two published reports describing habitat reclamation involving estuarine marsh, slough and tidal channel habitat in British Columbia. Tutty et al. (1983) present results of fish and benthic sampling in a previously dyked estuarine slough that was a portion of the Englishman River estuary. Ryall (1985) presents fish sampling data from a tidal channel and marsh located in the Squamish River estuary. Habitat restoration efforts in estuarine locations of the United States have also been studied (e.g. Lewis and Bunce 1980, Mitchell 1982). However, because of large differences in salinity, and other physical, chemical and biological factors, detailed data comparisons between the results from these studies and our results are inappropriate.

Details on the research design and discussion of data are presented in this report. A complete presentation of all the research data is provided in a separate data report (Kistritz and Macdonald in prep.).

METHODS

SITE DESCRIPTION

Tilbury Slough is located on the south bank of the Main Arm of the Fraser River estuary (Fig. 1). A tidal channel 800 m long and 25 m wide that dries only during extreme low tides is surrounded by a mudflats and tidal marshes. A dyked marsh existed on the south side of the Slough.

In October, 1985 a dyke was constructed to partition the dyked marsh into two areas: 1. the channelized area (enhanced site E) and; 2. an unmodified control area (unenhanced site U) (Fig. 1). Site E is approximately 2.5 times larger than site U and its channels have twice the surface area (Fig. 2). The channels were dug with a backhoe on pads. Excavated material was used to build a dyke to separate site E from site U. From the lowest elevations (0.3 m) in each site a breach in the dyke opened into Tilbury Slough. The top of the channels are at 1.0 m elevation, the toe of the dyke is at approximately 1.5 m and the high water level is at about 2.0 m (Fig. 2). All measures are from the geodetic datum.

Due to proximity, the two sites may not be entirely independent of each other. However, the study area presented a unique opportunity to compare physical, biological and chemical aspects of a restored aquatic habitat to a naturally regenerating tidal channel system located in a marsh that had experienced the same historic degree of human alteration. Comparisons were made from samples of the tidal waters flowing in and out of each of the dyked marsh basins.

Unless otherwise stated, all sampling and measuring occurred at both channel entrances over an eight hour period during a complete flood and ebb cycle. Sampling dates were selected to encompass the highest flood tides of the year, and to ensure that the dyked marsh system was drained before and after each sampling period. Physical data, chemical data, drift organisms, and detritus were sampled on February 9, April 6, May 5, June 26, July 24, October 14, and December 4, 1986. Fish were sampled approximately once every two weeks between May 5 and June 30 1986 to coincide with known downstream migration periods.

HYDROLOGIC COMPARISONS

Surface areas of both sites, at various elevations were determined using a digital planimeter and a 1:500 Scale contour map of Tilbury Slough. Water surface elevation was measured at site E in order to calculate water volumes entering and exiting the study sites. Elevations to the nearest cm were measured at approximately one half hour intervals throughout the duration of one full tidal cycle on June 27, 1989 (approximately 8 hours). Elevations measured from a reference benchmark to the water surface were converted to geodetic datum. Volume estimates and surface areas were later used to express data on a per unit volume basis.

Surface water velocity was measured at site E entrance only, to check calculations of water volume. Water velocities were measured at roughly half hour intervals over the course of a tidal cycle. The time it took for a floating object to travel a fixed distance (m) was used to estimate velocity. To improve accuracy, velocity calculations were based on the average of triplicate measurements.

TEMPERATURE, CONDUCTIVITY AND DISSOLVED OXYGEN

A YSI dissolved oxygen meter, a thermometer and a conductivity meter were used hourly during a full tidal circle to determine if oxygen and temperature levels were suitable to support juvenile salmon. Data from the two sites, collected during each sampling period, were compared using two tailed t-tests.

TOTAL ORGANIC CARBON (TOC)

Water samples (n=3), collected in glass sample vials (100 mL) covered with nitex mesh were taken from the middle of the water column, and used to estimate total organic carbon levels (dissolved and suspended particulate carbon <0.1 mm particle size) during a full tidal cycle (ebb and flood). Upon return to the lab samples were stored in a refrigerator (3°C) and analyzed within 6 hours using the combustion-infrared method with a Beckman Model 215A infrared carbon analyzer at the Civil Engineering Department, UBC (Standard Public Health Assoc. 1981). Blank samples and samples spiked with 10 $mg \cdot L^{-1}$ of a standard carbon solution were run to assure analytical quality. Minimum detectable concentrations were 0.1 $mg\ carbon \cdot L^{-1}$. Using two-tailed t-tests we compared TOC concentrations, between flood and ebb samples taken at each site and between sites.

ORGANIC DETRITUS

Organic carbon that was larger than 0.1 mm cannot be measured by the methods used to estimate TOC described above. Much of this material comprises the remains of dead marsh plants, leaf litter, and wood debris; some of which floats on the surface and some of which is in the water column. For the purposes of this study, organic material larger than 0.1 mm found in the water column was sampled with a net placed on the bottom at each channel entrance. Each net had a 0.1 mm mesh size, a 30 by 30 cm square mouth which opened into the current. Detritus was collected from a sample jar at the codend of the net during slack water following both flood and ebb tides, during every sampling period. Samples were immediately frozen and later ashed at 500°C to determine total organic content.

The net movement (flux) of detritus during each sampling period, was estimated by comparing weights of samples from flood and ebb. Inter-site comparisons were made after multiplying the data from site U by six to adjust for differences in water volumes and channel entrance areas. Adjustment was necessary because flood volumes in site E were twice that of site U, and the effective sampling area in the channel entrance of site E was three times larger.

DRIFT ORGANISMS

Drift organisms were sampled at the same time and in the same net used for the organic detritus described above. In the laboratory epibenthic and planktonic invertebrates (larger than 0.1 mm) were counted, weighed, and sorted into 19 taxonomic categories (for more taxonomic detail refer to Kistritz and Macdonald in prep.). Near bottom drift organisms were captured preferentially since the sampler was positioned on the channel bottom. The size of each taxonomic category entering or leaving the slough, on each sampling date was compared to its pooled median value for the entire study to determine periods of greatest abundance. Median values were used to correct for the bias caused by the periodic occurrence of very large catch sizes. A category was described as "abundant" when the number caught on a particular date was greater than the median number caught throughout the study. Numbers less than the median value were classified as "present".

The abundance and type of drift organisms caught at both sites were compared and the direction of invertebrate movement was determined by comparing numbers of invertebrates caught during flood and ebb tides. Stomach contents of salmon caught at both sites were compared to drift samples.

FISH

Fish were trapped on six occasions between May 5 and June 30. Fish that entered the experimental areas on the flood tide were trapped as they left during the ebb tide using a beach seine net positioned across the channel entrance. At low slack tide, when only a shallow pool of water remained, the net was pursed and fish were removed and preserved in 10% formaldehyde. Fish were sorted, identified, measured, and weighed in the laboratory (University of British Columbia, Dept. of Zoology). Chinook smolts (1+) were separated from chinook fry (0+) based on length (> or < 65 mm).

Fish utilization of the experimental areas was compared. Catch sizes of fish in each area were divided by the surface area and multiplied by a scaling factor of 2 to compensate for 50% sampling gear efficiency (Levy et al. 1979).

$$\text{Density (Site E)} = \text{Total catch} \cdot 4508\ m^{-2} \times 2$$
$$\text{Density (Site U)} = \text{Total catch} \cdot 1680\ m^{-2} \times 2$$

Catch data used for these calculations are presented by Kistritz and Macdonald (in prep.).

Regression analysis was performed on the juvenile salmon length data to determine if the size of fish increased during our sampling period. Mean length values and 95% confidence limits during each collection period are presented to demonstrate trends. Data were best described with a linear relationship.

If sufficient salmon were caught 15 to 20 stomachs per species were examined and prey items were identified and enumerated. Prey items were sorted into 19 taxonomic categories; many of which were also identified in the drift net samples.

Stomach content data were expressed as percent frequency of occurrence (PFO, i.e. each prey category (X) was described as N containing X/N x 100 where N is the number of fish). Interspecific and intersite diet comparisons were made among sockeye, pink, chinook and chum salmon fry captured at each of the two sites. On occasions when catches of a particular species were too small to warrant diet analysis, spatial and temporal diet comparisons could not be made (e.g. coho fry).

RESULTS AND DISCUSSION

HYDROLOGIC COMPARISONS

Site E, being larger than site U, contained a larger volume of water (Fig. 3). Small differences between flood and ebb volumes at each site are due to incomplete drainage of water in the channels at low tide. At a high tide about 10% of the total water volume was contained in the channels, the rest overflowed the channels and remained in the confines of the dykes.

The dyked basins were almost completely drained during the low tides that preceded and followed the sampling periods. The highest tides of the sampling year occurred on June 27 and on December 4 (Fig. 4).

Water velocity and rates of water level change were slightly greater during flood than during ebb tide (Fig. 5). The maximum flood velocity (64 $cm \cdot s^{-1}$) was measured on July 24, 1987 at the mouth of site E. Current velocities at site U, while not measured, appeared to be considerably less than those at site E. Site U has a much larger channel entrance and a smaller volume than site E.

TEMPERATURE, CONDUCTIVITY AND DISSOLVED OXYGEN

Water temperature and conductivity was similar at site E and U (Figs. 6 and 7). Temperatures and salinities in another Fraser River estuary slough (Deas Slough) and in adjacent regions in the Main Arm were similar to Tilbury Slough and showed similar temporal patterns (Nassichuk et al. 1984b; Birtwell et al. 1987b). Coolest temperatures were from December to February and highest salinities occurred during winter low river flow.

Mean dissolved oxygen values (Fig. 8) and oxygen saturation levels (Fig. 9) were consistently higher at site E due to greater water turbulence at the site's entrance ($P<0.05$). Dissolved oxygen values were similar to most of the values recorded by Birtwell et al. (1987b) in Deas Slough with the exception that hypoxic conditions never occurred during our study. Unlike the sampling done at Deas Slough our sampling was limited to channel entrances with no attempt being made to sample deeper regions of the slough were residual saline water may have been found. The temperature and oxygen regime of ebb and flood water in both of the channel entrances was suitable for the temporary residence of juvenile salmon.

TOTAL ORGANIC CARBON

At both sites TOC concentrations were lowest in February (3-4 $mg \cdot L^{-1}$), fluctuated between 6 and 9 $mg \cdot L^{-1}$ during spring and summer, and declined to below 6 $mg \cdot L^{-1}$ by December (Figs. 10 and 11). There was no net movement of TOC into or out of the dyked marsh through the breached dyke. Concentrations of TOC in flood and ebb waters showed a significant difference ($P<0.05$) at site E on October 14 only. The study site may represent a sub-system of tidal channels and marsh habitat within a much larger area of marsh habitat (e.g. Tilbury Slough). Organic matter production at the study sites may be masked by equal levels of production in Tilbury Slough.

Concentrations of TOC can be more dependent on transportation by storm events than by tidal action (Chalmers et al. 1985). Large amounts of TOC wash off exposed marsh surfaces during periods of heavy rainfall. Unfortunately this study was not designed to examine the effects of heavy rainfall on carbon inupt. Further research should concentrate on the effects of storm induced TOC transport in Tilbury Slough particularly during periods immediately after habitat alteration.

During flood tides organic matter is more likely to enter site U than site E ($P<0.05$), (e.g. July and Oct., Fig. 11) due to the location of its entrance at the head of Tilbury Slough (Fig. 1). During ebb flow however, TOC concentration did not differ among sites, was higher at site E (May) or was higher at site U (July) (P measured at 0.05). Therefore, in terms of movement of dissolved and particulate organic matter (<0.1 mm in size), this study was not able to show an effect due to habitat restoration. Difficulties with proximity of sampling sites, differences in the morphometry of the basin and orientation of the breaches, and the lack of data before habitat alteration began prevented us from making clear conclusions regarding TOC from this study.

ORGANIC DETRITUS

The channels constructed at site E provided for better flushing action than the existing channels at the control site. Therefore, more detritus was caught at site E than site U throughout the year (Fig. 12). Site E was a source of detritus for Tilbury Slough (net export) during late winter and spring months when accumulations of the previous year's marsh plant litter were flushed out of the study area. During the growing season (June), detritus entering the study area was apparently trapped by the newly growing vegetative shoots. In autumn and early winter, the remaining standing vegetative shoots trapped plant litter originating from both inside and outside the study area (e.g. December) or plant litter became dislodged and was flushed out (e.g. October) (Fig. 12). Similar seasonal patterns of detritus flux have been observed at other tidal marsh locations in the Fraser River estuary (Kistritz et al. 1979). This study was not designed to test the long term effects of enhancement, but as the channels stabilize and marsh plants are established detrital output from site E will likely remain high.

DRIFT ORGANISMS

Nineteen categories of drift invertebrates and several species of fish fry were captured (Table 1). Gastropods and pelecypods were present during the duration of the study. Dipteran pupae, Corixids, Chironomid larvae, and fish fry were abundant throughout the spring and summer (Table 2). Eogammarus confervicolus was abundant at all seasons and Neomysis mercedis was abundant from June through to December.

There was greater import of invertebrates than export particularly at site E (Fig. 13). Freshly disturbed sites likely provided an ideal habitat for colonizing species such as Corophium sp. (Tutty et al. 1983). Corophium salmonis as well as dipteran pupa, Gnorimosphaeroma sp., Hirudinae, Chironomid larvae, Eogammarus confervicolus and Neomysis mercedis, were more abundant, or in some cases occurred exclusively, at site E (Table 2). However, high water velocities such as those at site E, may produce better sampling efficiencies by reducing trap avoidance by mobile organisms causing a bias towards higher catches at site E.

Export of invertebrates from the marshes occurred most frequently in mid-summer and was made-up primarily of large numbers of Neomysis sp. (Fig. 13). While most of the invertebrates captured during this study were epibenthic species, Neomysis was planktonic and therefore was more prone to move in and out of marshes with currents, never actually colonizing benthic habitats. It is probable that the large export of Neomysis sp. in July from site E occurred because of the large import of mysids during the preceding collection period in June (Fig. 13).

FISH

Eighteen different species of fish including all five species of Pacific salmon, were captured during six sampling dates between May 5 and June 30, 1986 (Table 3). Three-spine stickleback, prickly sculpin, peamouth chub and redside shiner dominated the catches during most sampling periods and juvenile chinook (0+, 1+) and sockeye (0+) salmon were periodically very abundant (Table 4). In contrast to these results, sampling in March through July 1977 revealed only 9 species of fish in Tilbury Slough and of those only two were salmonids (Fisheries and Environment Canada et al. 1977). They were chum and chinook, chum being the most abundant. Nassichuk et al. (1984a) found of all species of Pacific salmon in Tilbury Slough and adjacent regions during the spring and summer of 1976 and 1977. Chum, chinook and sockeye were the most abundant. Differences in catch size and catch composition among studies may be due to differences in the methods and locations of sampling or to year class strength variation.

Habitat utilization and growth by juvenile salmon

More sockeye fry (0+) were caught than any other species of fish. Catches began in May and peaked at nearly 400 fry per trap ($0.50 \cdot m^{-2}$) on June 2nd (Fig. 14).

Rearing by sockeye fry in the Fraser River estuary has been reported in only a few studies. Most rear in lakes for one year or more before migrating to sea as smolts (Hart 1973). A small Fraser River sockeye catch is reported by Harder (1988) although there is no indication as to whether these were smolt or fry. Rosberg and Byers (1985) captured 44 sockeye fry from late May to late June in the summer in the South Arm of the Fraser River. A small number of 0+ and 1+ sockeye (<100) were captured in the Tilbury Slough area by Nassichuk et al. 1984a) in the spring and summer of 1977 and 1978. Birtwell et al. (1987a) reports a large number of underyearling sockeye rearing in Deas Slough for a five month period in the spring and summer of 1977. As with this study their peak catches were in June and fish size increased as the season progressed (Fig. 15). This study provides additional support for the hypothesis that sockeye fry unlike sockeye smolts (1+), which are transient members of estuarine communities, utilize intertidal channels and marshes as rearing areas.

Size increases (lengths) of sockeye fry captured during the 60 D sampling period ranged from 30% (site E) to 33% (site U). Increases were statistically different from zero ($P < 0.05$) but no difference in size occurred between sites ($P > 0.05$). Sockeye underyearlings (n=11) caught by Nassichuk et al. (1984a) in the Tilbury Slough area increased in length from 28 mm in May 1977 to 46 mm in July 1977. Fish size increases cannot be attributed entirely to growth because emigrations of larger fish were likely replacing outmigrants for the slough as the season progressed.

The abundance of sockeye fry at site U (Fig. 14) may indicate an avoidance of high water velocities (at the site E channel entrance) or a tendency to distribute themselves to the upper portion of tidal channels (Levy et al. 1979, Birtwell et al. 1987). If the latter explanation is accepted, salmon in Tilbury Slough are more likely to encounter the entrance to site U due to its location (Fig. 1).

Pink fry were the second most abundant salmon species caught during this study (Fig. 16). They are a transitory resident in the Fraser River estuary and therefore were not present long enough to detect any increase in length (Levy et al. 1979, Rosberg and Byers 1985). Maximum abundance occur during April or May in even numbered years in marsh habitats of the Fraser River estuary. Few are caught after May (Macdonald 1984). Maximum densities reported by Levy et al. (1979), of 0.054 per m^2 were less than the 0.12 per m^2 reported in this study, using similar sampling methods. Nassichuk et al. (1984a) did not capture pink in Tilbury Slough but reported small catches (n=15) at sites adjacent to the slough on Gravesend Reach. Pink showed a tendency to occupy site E as opposed to site U likely because pink do not deviate very far from the main river channel during outmigration.

Chinook were the third most abundant and the most consistently caught salmon species in this study (Fig. 17). They were caught throughout May and June. Unlike other salmon species, both smolts (i.e. >65 mm length) and fry were captured but smolts comprised only 4% of the total catch (n=15). Peak chinook densities ($0.080 \cdot m^{-2}$) occurred on June 2, coinciding with the peak sockeye catch. During this study chinook fry densities were less than those measured at marsh sites downstream (Levy et al. (1979), 0.17 to 0.28 m^2) or upstream of Tilbury Slough (Harder (1988) 0.020 to 0.69 m^2). Harder's results were based on different sampling techniques than those used in this study or by Levy. Nassichuk et al. (1984a) caught large numbers of chinook (0+ and 1+) in the Tilbury Slough area between March and July 1976-77.

Size increase of chinook fry of 24% (site E) and 27% (site U) ($P < 0.05$) (Fig. 18) is attributable to growth of fish resident in the vicinity of Tilbury Slough and from the emigration of larger fish as the season progressed. Underyearling captured by Nassichuk et al. (1984a) increased in length from 39 mm to 63 mm between March and June 1977. Rosberg and Byers (1985) found chinook and chum size increases that were similar to those found in this study. Chinook and to a lesser extent chum may rear for several weeks in the Fraser estuary, particularly in estuarine tidal marshes that do not dewater at low tide (Dunford 1975; Levy and Northcote 1981; Levy et al. 1979; Rosberg and Byers 1985). During estuarine residency chinook grow rapidly.

Juvenile chinook salmon fry were able to distribute themselves throughout the off-channel habitat provided at both sites. Despite differences in the distance of channel entrances to the mouth of Tilbury Slough and differences in water depth and water velocities, neither site was used by fry to a greater extent than the other. Although only 15 smolts were caught during this study, eleven of them came from site E. Smolts being transient in nature were more likely to be found at sites adjacent to the mainstem of the river.

Juvenile chum densities were lower than juvenile chinook densities and peaks of abundance occurred two weeks earlier (Fig. 19). There was no clear difference in site use. The density of chum fry measured in this study were lower than those reported by Levy et al. (1979) (0.12-0.23 m^{-2}), Harder (1988) (0.088-0.17 m^2) and Nassichuk et al. (1984a) (CPUE = 3.6-20.2 fish).

Coho fry occurred sporadically and infrequently at the experimental sites (Fig. 20). Rosberg and Byers (1985) caught only coho smolts, not fry during their surveys of the lower Fraser estuary.

Diet of juvenile salmon

Sockeye fry consumed 18 of the 19 food categories identified in this study (Table 5). Items most frequently consumed (greater than 10% PFO) were copepods, chironomids (especially adults), Hemiptera, Homoptera, and Collembola (Fig. 21). Terrestrial insects were taken more frequently at site

E and copepods more frequently at site U. This pattern may be related to differences in current velocities at the two sites.

Similar food items, particularly chironomids and copepods were identified in juvenile sockeye captured in other Fraser River marshes (Dunford 1975; Birtwell et al. 1987a; Northcote et al. 1979). The presence of these food items, which also occurred in the drift net samples indicates sockeye feed opportunistically on food that is available and likely produced in marsh habitats. This implies a dependence between sockeye salmon and the marsh habitats that act as benthic detrital sources for the production of drift animals (e.g., chironomids and other aquatic insects) (Northcote et al. 1979). However, sockeye, unlike most estuarine fish also derived a large portion of their food from terrestrial sources (e.g., hemipterans and homopterans) (Northcote et al. 1979).

Pink fry feed less in estuaries than other salmonid species (Rosberg and Byers 1985, Levy et al. 1979). Of the six fish examined only three contained food and they had fed on only 4 of the 19 potential prey items (Table 5). Harpacticoid copepods and adult dipterans were consumed most frequently (Fig. 22). These results are consistent with the description of pink diets by Levy et al. (1982) from his investigations at other Fraser estuary habitats. Pink, like sockeye fry, feed on planktonic food when current velocities were low (copepods, site U) and surface food in stronger currents (dipterans, site E).

Chinook fry in the Fraser River estuary fed on a wide variety of prey items (18 of the 19 categories, Table 5) but concentrated on dipterans, particularly adult chironmids, and other terrestrial insects (Fig. 23), Levy et al. (1979), Northcote et al. (1979), Rosberg and Byers (1985), and Delaney and Olmsted (1981) reached similar conclusions. Insects remain an important dietary item during the early marine phase of their life as they occupy sandflats habitats at the mouth of the estuary (Levings 1982), but fish fry and epibenthic organisms such as Eogammarus sp. and Neomysis sp., are also consumed frequently. Chinook respond in an opportunistic manner to the prey available in marsh habitats. Their dependence on a food web that is based on detrital sources emphasizes the importance of lower Fraser River marshes for their detrital production capabilities.

Chum fry diets were less diverse than chinook and sockeye diets (Fig. 24). Prey items most frequently consumed were chironomids, harpacticoid copepods, Eogammarus sp. and the insects hemiptera, homoptera and collembola. These findings are consistent with an earlier investigation of chum diets in Tilbury Slough (Delaney and Olmsted 1981) and studies at other locations in the Fraser River estuary (Levy et al. 1979, Rosberg and Byers 1985). Diets were similar at each site except that collembola were more frequently consumed at site E during the May 22 and June 2 collections (Fig. 24). As with other species of salmon, the diets of chum indicate that they depend on marsh habitats as a source of benthic detrital production (Northcote et al. 1979).

Interspecific differences in diet occurred. All fish consumed large numbers of insects, particularly chironomids. This supports Northcote et al. (1979) who concludes that insects make an overwhelming contribution to food chains of fish in the lower Fraser River. However, harpacticoid copepods were also important prey items, contributing to the diets of sockeye, pink and chum salmon to a greater extent than to the diets of chinook salmon. Chinook, and to a lesser extent chum, consume amphipods (Eogammarus sp., Corophium sp.) and Neomysis sp. (chinook only). Similar interspecific diet differences are described by Levy et al. (1982) for Fraser estuary salmonids, and by Healey (1982) for salmonids in the Fraser and other Pacific Coast estuaries.

Thirteen of the 19 prey item categories (74%) were captured in the drift net samples (Table 6). Therefore fish exploited the food source that was available in marshes at Tilbury Slough. This includes fish fry and epibenthic animals, such as chironomid larvae, Eogammarus sp. and Neomysis sp. Juvenile salmon are opportunistic feeders, able to adjust their feeding habits to the presence of different prey. For example, Corophium salmonis, which was not caught in the drift of site U, but was abundant at site E, appeared frequently in the diets of chinook fry caught at site E.

Despite interspecific differences in diet, sockeye, chum and chinook fry and to a lesser extent pink fry (because of its short estuarine residency time) all depend heavily on food chains that are based on detrital production. While much detrital production may originate from upstream sources (Northcote et al. 1979) evidence suggests that the availability of insects and their consumption by fish in lower Fraser River marshes is directly related to the presence of estuarine marsh plants (Levy et al. 1982). If we define productive capacity as a habitats ability to support or produce healthy fish or biological material upon which fish depend, the dyke breaching and channel construction in Tilbury Slough created a net gain in productive capacity by increasing available rearing space and affording access to previously alienated marsh grass and invertebrate production. The importance of this type of habitat to the fishery resource is supported by the demonstrated densities of juvenile salmon using this habitat type, their use of the invertebrate production provided by this habitat type and the implication of growth associated with the increase in length by some salmonid species during the period they occupy the Tilbury Slough area.

While the enhanced area did not support the same numbers of juveniles as the adjacent natural unmanipulated area; a lag factor must be recognized before a rehabilitated area stabilizes. Use of the "new" habitat was immediate and may be enhanced subsequently by increasing breach width and redesigning the orientation and alignment of the breaches. Restoring lower Fraser River tidal wetlands by breaching or removing remnant dykes and channelizing is a cost effective means of creating a net gain in productive habitats. This improvement strategy should be pursued actively where evidence indicates that downstream migrants will benefit through access to low velocity, vegetated rearing/nursery areas.

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Table 1. Taxonomic listing of 19 categories of organisms caught in drift nets at the entrance to each site during 1986.

	Drift classification
Leeches (HIRUDINEA)	
	Hirudinea
Crustaceans (CRUSTACEA)	
Opposum Shrimps (MYSIDACEA)	
	Neomysis mercedis
Aquatic Sow Bugs (ISOPODA)	
	Gnorimoshphaeroma oregonensis
Shrimps (AMPHIPODA)	
	Eogammarus confervicolus
	Corophium salmonis
Arachnids (ARACHNIDA)	
Mites (ACARINA)	
	Acari
Insects (INSECTA)	
Springtails (COLLEMBOLA)	
	Collembola
Mayflies (EPHEMEROPTERA)	
	Ephemeroptera (adult)
	Ephemeroptera (nymph)
Damselflies (ODONATA)	
	Odonata (nymph)
Water Beetles (COLEOPTERA)	
	Corixidae
True Flies (DIPTERA)	
	Dipteran (adult)
	Dipteran (pupa)
	Dipteran (larva)
	Chironomid (adult)
	Chironomid (pupa)
	Chironomid (larva)
	Other invertebrates
	Fish Fry

Table 2. Presence and abundance of 19 categories of drift net organisms captured at the entrance to each site during 1986. Symbols are as follows: P = present (number < median value of pooled data); A = adundant (number > median value of pooled data); E = enhanced site; U = unenhanced site; blank = absent

Drift item	Feb 9		Apr 6		May 4		June 26		July 24		Oct 14		Dec 4	
	E	U	E	U	E	U	E	U	E	U	E	U	E	U
1. Dipteran (adult)		P	P						P	P				
2 Dipteran (pupa)							A	P	A	P				
3. Dipteran (larva)							P							
4. Gnoriosphaeroma sp.			P		A		P	P	P		A	P		
5. Corixidae			P	P	A	P	A	A	A	A	P	P		A
6. Chironomid (adult)							P							
7. Chironomid (pupa)						P								
8. Chironomid (larva)					A	A	A	A	A					P
9. Acari					A			P		P				
10. Corophium salmonis	P				A		P						A	
11. Hirudinae							A		P					
12. Eogammarus confervicolus	A	A	A		A	P	A	P	P	P			A	A
13. Collembola		P												
14. Fish fry				P	P		A		A	A				
15. Ephemeroptera (adult)							P							
16. Ephemeroptera (nymph)							P							
17. Odonata (nymph)							P					P		
18. Neomysis mercedis	P		P		P		A	P	A	A	P	A	A	P
19. Other invertebrates		P			P		P							

Table 3. List of fish species caught at the entrance to each site during 1986

Salmonids		
1.	Chinook	(Onchorhyncus tshawaytscha)
2.	Chum	(Onchorhyncus keta)
3.	Pink	(Onchorhyncus gorbuscha)
4.	Sockeye	(Onchorhyncus nerka)
5.	Coho	(Onchorhyncus kisutch)
Other Fish		
6.	Longfin Smelt	(Spirinchus thaleichthys)
7.	Three-spine Stickleback	(Gasterosteus aculeatus)
8.	Prickly Sculpin	(Cottus asper)
9.	Staghorn Sculpin	(Leptocottus armatus)
10.	Peamouth Chub	(Mylocheilus caurinus)
11.	Starry Flounder	(Platichthys stellatus)
12.	Redside Shiner	(Richardsonius balteatus)
13.	Eulachon	(Thaleichthys pacificus)
14.	Brown Catfish	(Ictalurus nebulosus)
15.	River Lamprey	(Lampetra ayresi)
16.	Largescale Sucker	(Catostomus macrocheilus)
17.	Carp	(Cyprinus carpio)
18.	Brassy Minnow	(Hybognathus hankinsoni)

Table 4. Numbers of each species of fish caught during each collecting trip in 1986, at the entrance to each site. All salmonids caught were fry (0+) with the exception of chinook which were fry and smolts.

Composition	Percent											
	May 5		May 19		May 22		June 2		June 16		June 30	
Site /	E	U	E	U	E	U	E	U	E	U	E	U
Salmonids												
Chinook	4		15	<1	36	20	30	13	10	1	2	1
Chum	6		3	0	20	8	3	2	0	0	0	0
Pink	63		19	0	4	1	0	0	0	0	0	0
Sockeye	10		0	<1	0	2	40	62	33	53	48	6
Coho	4		0	0	0	0	0	0	0	0	0	<1
TOTAL	87		37	1	60	31	73	77	43	54	50	7
Other Fish												
Longfin Smelt	5		3	0	9	2	<1	<1	0	0	0	0
3-spine Stickleback	4		36	69	15	45	8	2	16	8	24	36
Prickly Sculpin	2		0	4	8	3	15	5	14	15	24	14
Staghorn Sculpin	<1		0	0	0	0	0	0	0	0	0	0
Peamouth Chub	0		8	13	3	5	3	0	11	2	0	24
Starry Flounder	<1		0	0	0	0	2	<1	0	0	1	0
Redside Shiner	0		7	13	2	11	<1	2	14	21	0	10
Eulachon	0		5	0	0	<1	0	0	<1	0	0	0
Brown Catfish	0		2	<1	1	0	0	<1	0	<1	0	0
River Lamprey	0		2	<1	0	0	0	0	0	0	0	0
Largescale Sucker	0		0	<1	0	<1	0	0	0	0	0	9
Carp	0		0	<1	0	0	0	0	0	0	0	<1
Brassy Minnow	0		0	<1	2	1	0	0	0	0	0	0
TOTAL	13		63	99	40	69	27	12	56	46	49	93

Table 5. Listing of organisms found in juvenile salmon stomachs captured at the entrance of each site during 1986

Prey classification		
Crustaceans (CRUSTACEA)		
	Opposum Shrimps (MYSIDACEA)	
		Neomysis mercedis
	Shrimps (AMPHIPODA)	
		Eogammarus confervicolus
		Corophium salmonis
	Water Fleas (CLADOCERA)	
		Cladocera
	Copepods (COPEPODA)	
		Copepods (harpacticoid)
		Copepods (other)
Arachnids (ARACHNIDA)		
	Mites (ACARINA)	
		Acari
Insects (INSECTA)		
	Springtails (COLLEMBOLA)	
		Collembola
	True Flies (DIPTERA)	
		Dipteran (adult)
		Dipteran (pupa)
		Dipteran (larva)
		Chironomid (adult)
		Chironomid (pupa)
		Chironomid (larva)
		Ceratopogonid (adult)
		Ceratopogonid (larva)
	True Bugs (HEMIPTERA)	
	Scale Insects (HOMOPTERA)	
		Hemiptera or Homoptera
		Other invertebrates
		Fish Fry
		(empty stomach)

Table 6. Comparative list of organisms found in fish stomachs and in drift net samples taken at the entrance of each site in 1986. Arrows indicate differences in the composition of the two lists.

Drift item	Prey item
1. Dipteran (adult)	1. Dipteran (adult)
2. Dipteran (pupa)	2. Dipteran (pupa)
3. Dipteran (larva)	3. Dipteran (larva)
4. Gnorimosphaeroma sp.<========>	4. Copepod (harpacticoid)
5 Corixidae <=================>	5. Copepod (other)
6. Chironomid (adult)	6. Chironomid (adult)
7. Chironomid (pupa)	7. Chironomid (pupa)
8. Chironomid (larva)	8. Chironomid (larva)
9. Acari	9. Acari
10. Corophium salmonis	10. Corophium salmonis
11. Hirudinae <=================>	11. Hemiptera or Homoptera
12. Eogammarus confervicolus	12. Eogammarus confervicolus
13. Collembola	13. Collembola
14. Fish Fry	14. Fish Fry
15. Ephemeroptera (adult) <======>	15. Cladocera
16. Ephemeroptera (nymph) <======>	16. Ceratopogonid (adult)
17. Odonata (nymph) <===========>	17. Ceratopogonid (larva)
18. Neomysis mercedis	18. Neomysis mercedis
19. Other invertebrates	19. Other invertebrates

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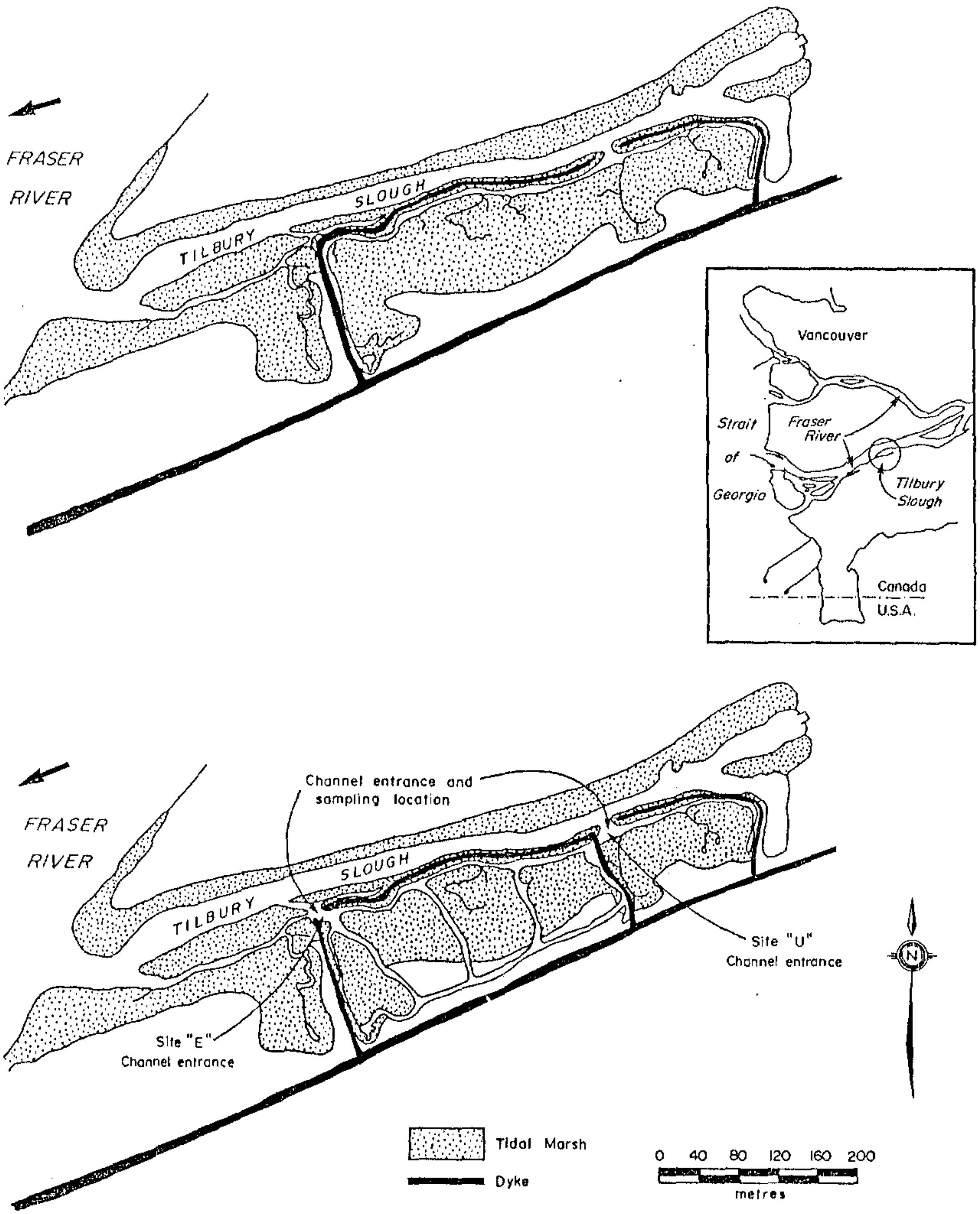

Fig. 1. Tilbury Slough study area before and after habitat restoration showing sample site locations at the entrance to the enhanced (Site E) and unenhanced (Site U) areas. Note the beaches in the dyke to allow access from Tilbury Slough and the newly constructed dyke separating the 2 sites.

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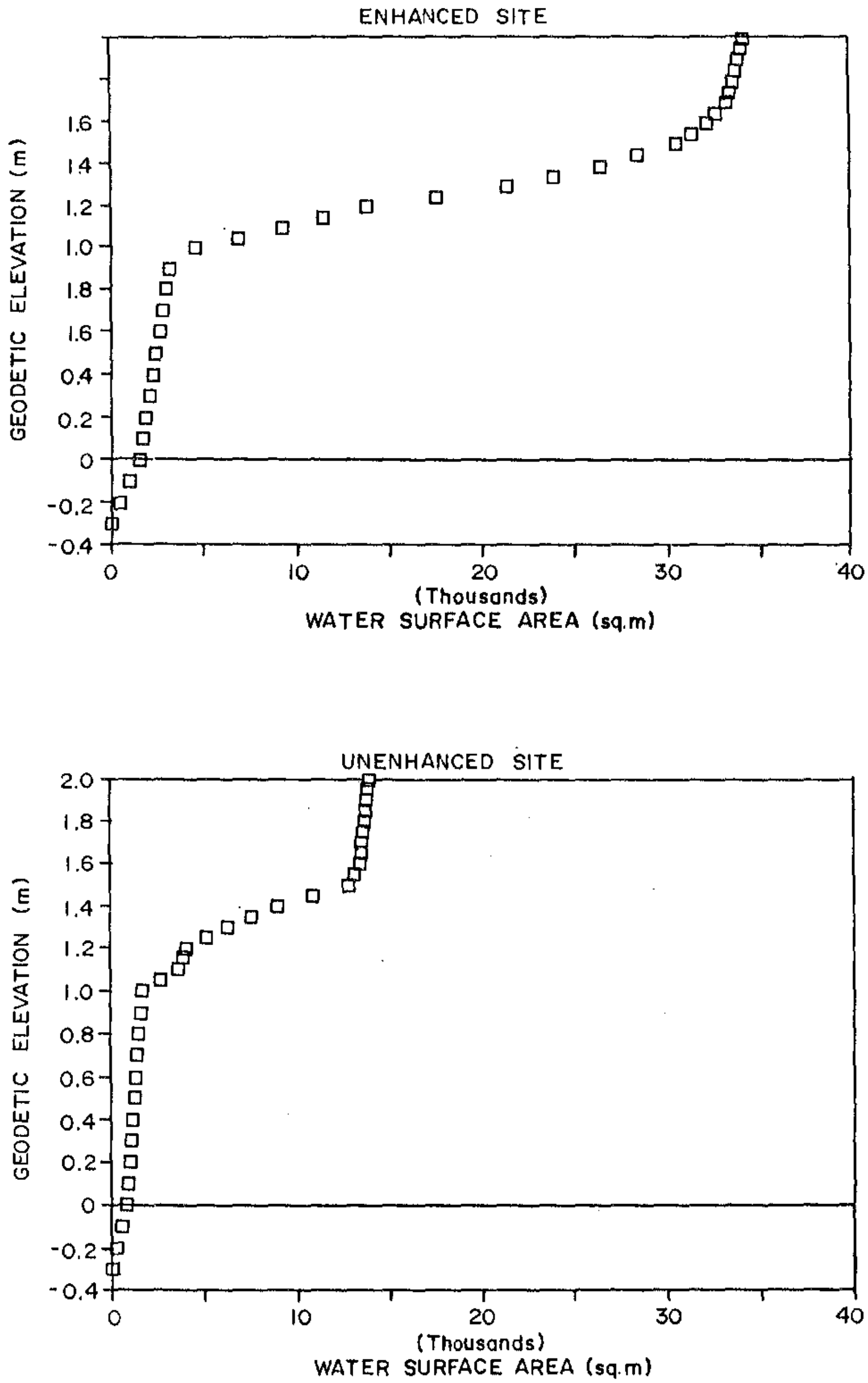

Fig. 2. Surface area in relation to tidal height at the channel entrances to each site.

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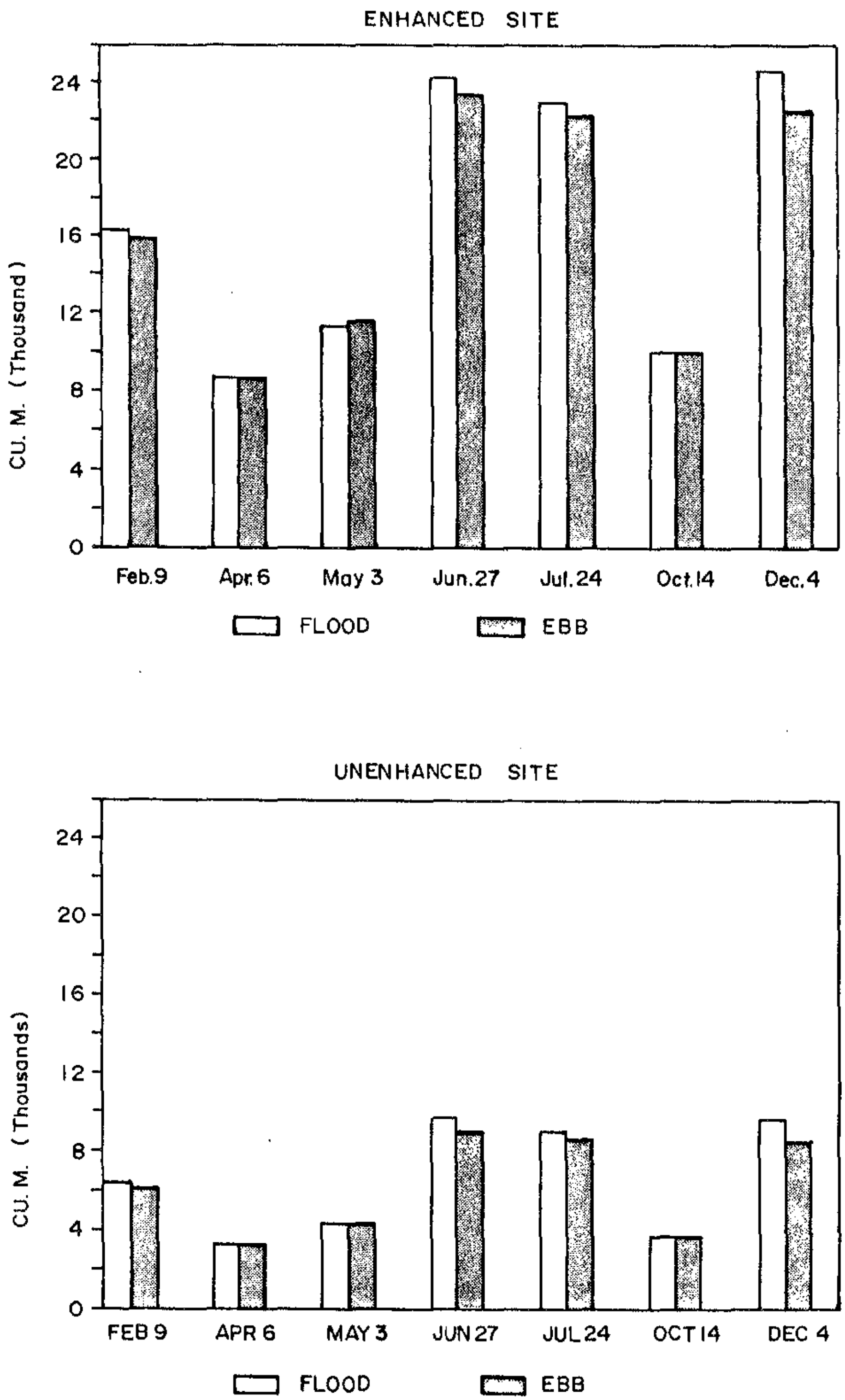

Fig. 3. Calculated ebb and flood water volumes on sampling dates during 1986.

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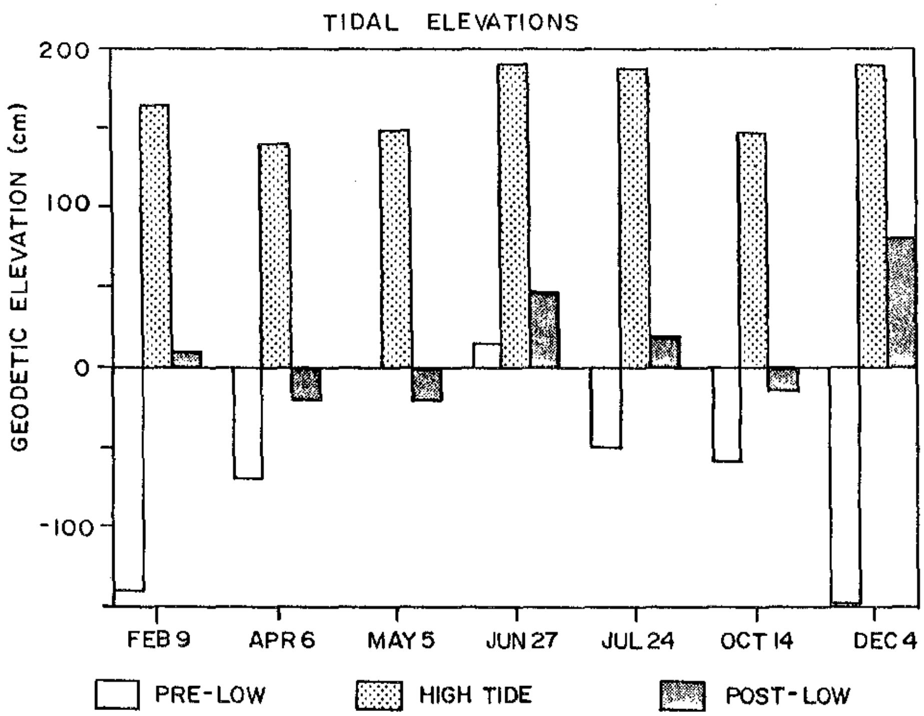

Fig. 4. Low and high tidal elevations before, during, and after the sampling periods in 1986.

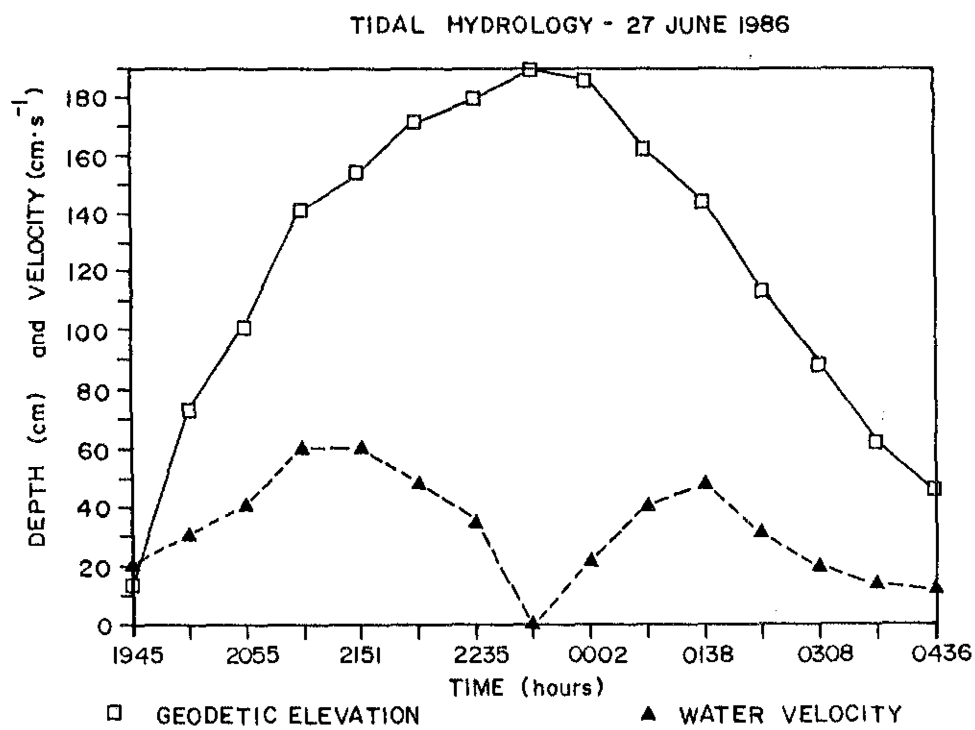

Fig. 5. Typical changes in water elevation and velocity during tidal cycle on June 27 1986.

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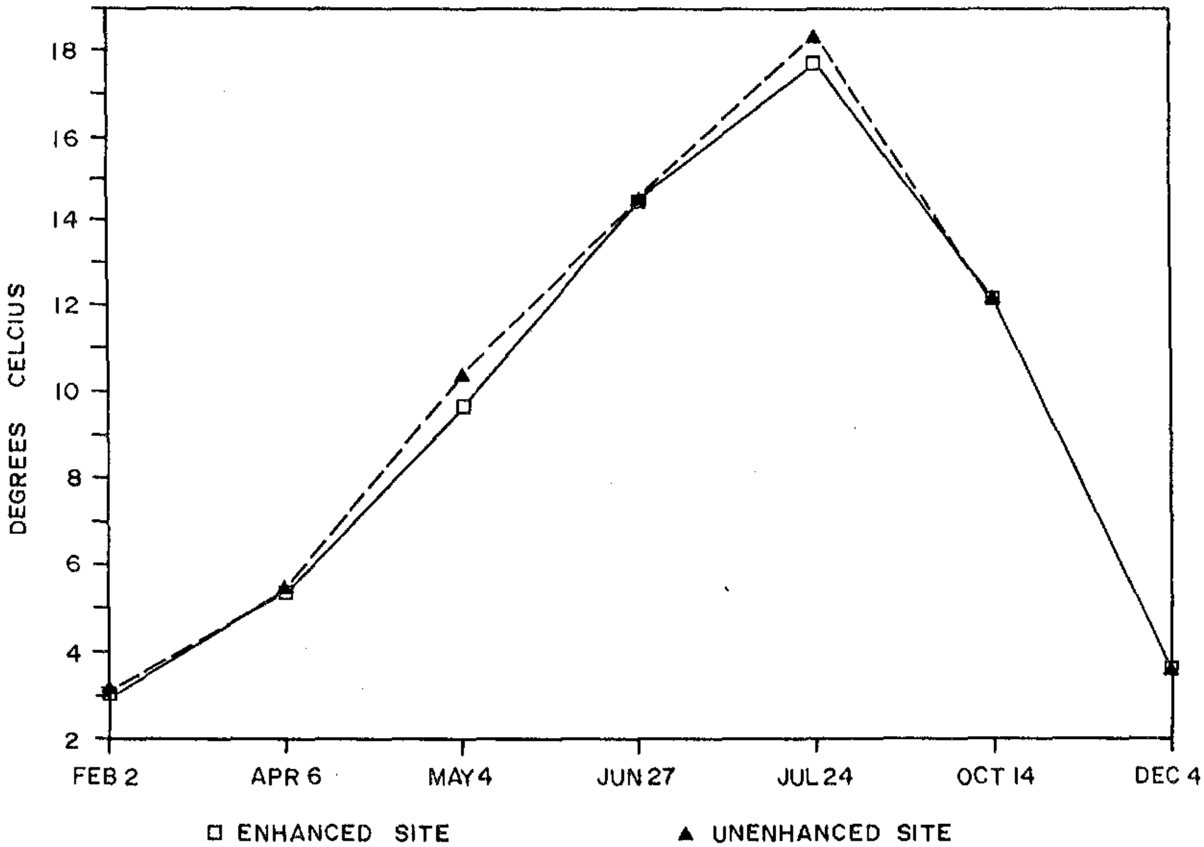

Fig. 6. Mean seasonal water temperatures at the channel entrance to each sample site in 1986.

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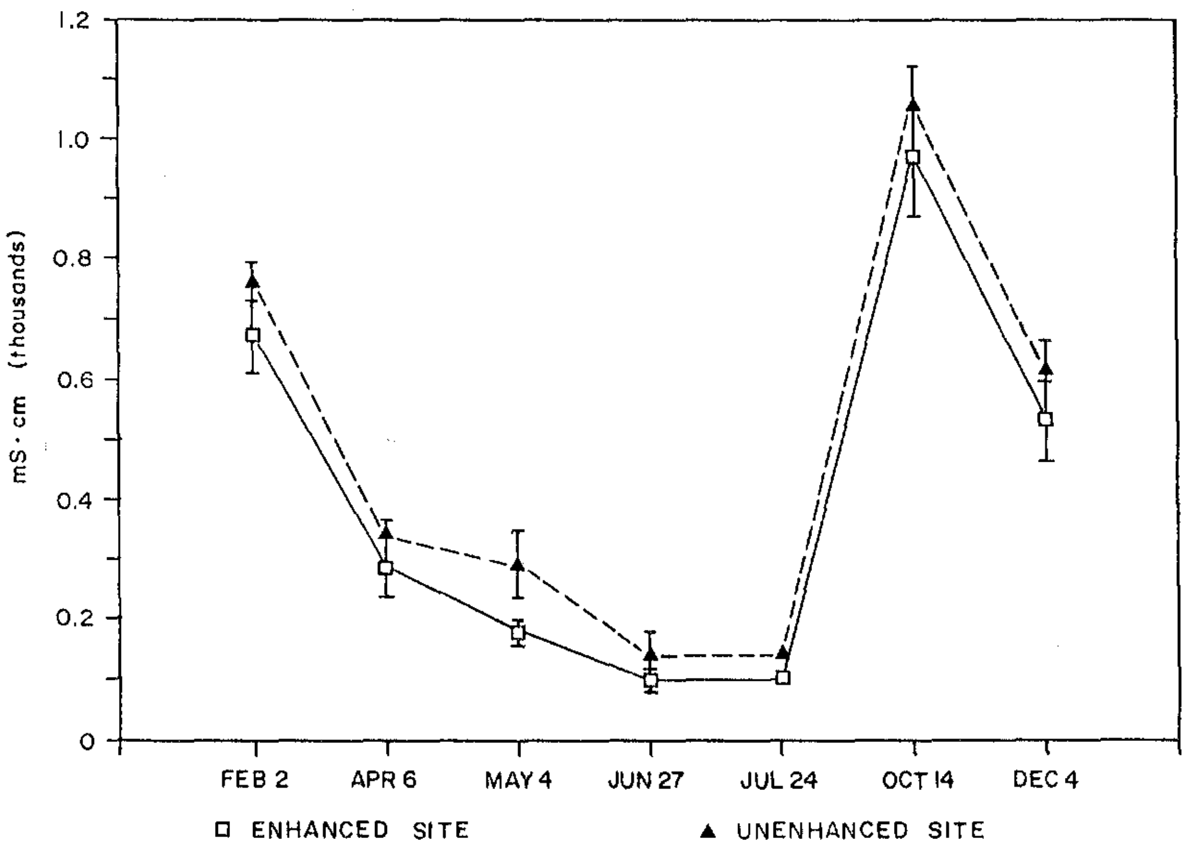

Fig. 7. Seasonal changes in mean conductivity values at each sample site in 1986. Variation during the 8 hour sampling period is presented as one standard error about the mean (n=6).

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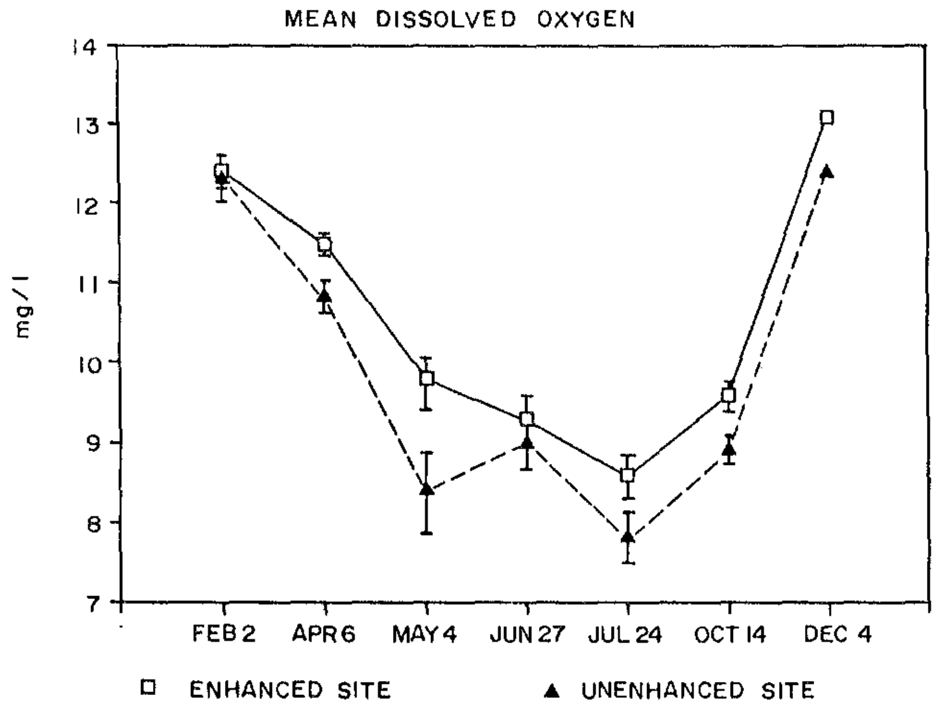

Fig. 8. Seasonal changes in mean dissolved oxygen values at each sample site in 1986. Variation during the 8 hour sampling period is presented as one standard error about the mean (n=6).

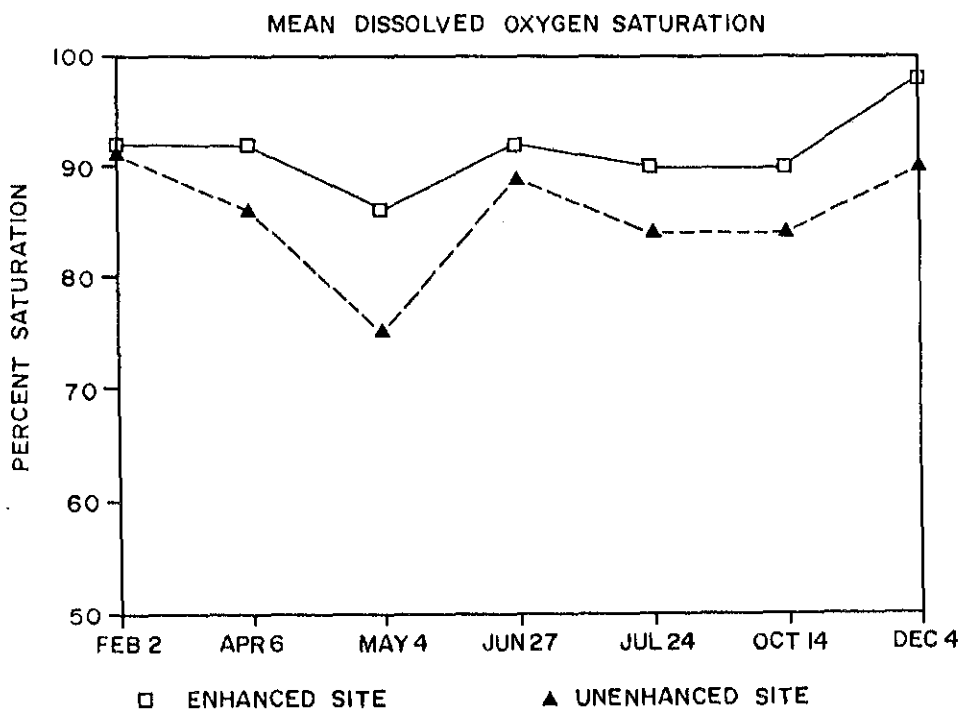

Fig. 9. Seasonal changes in mean dissolved oxygen saturation at each sample site in 1986.

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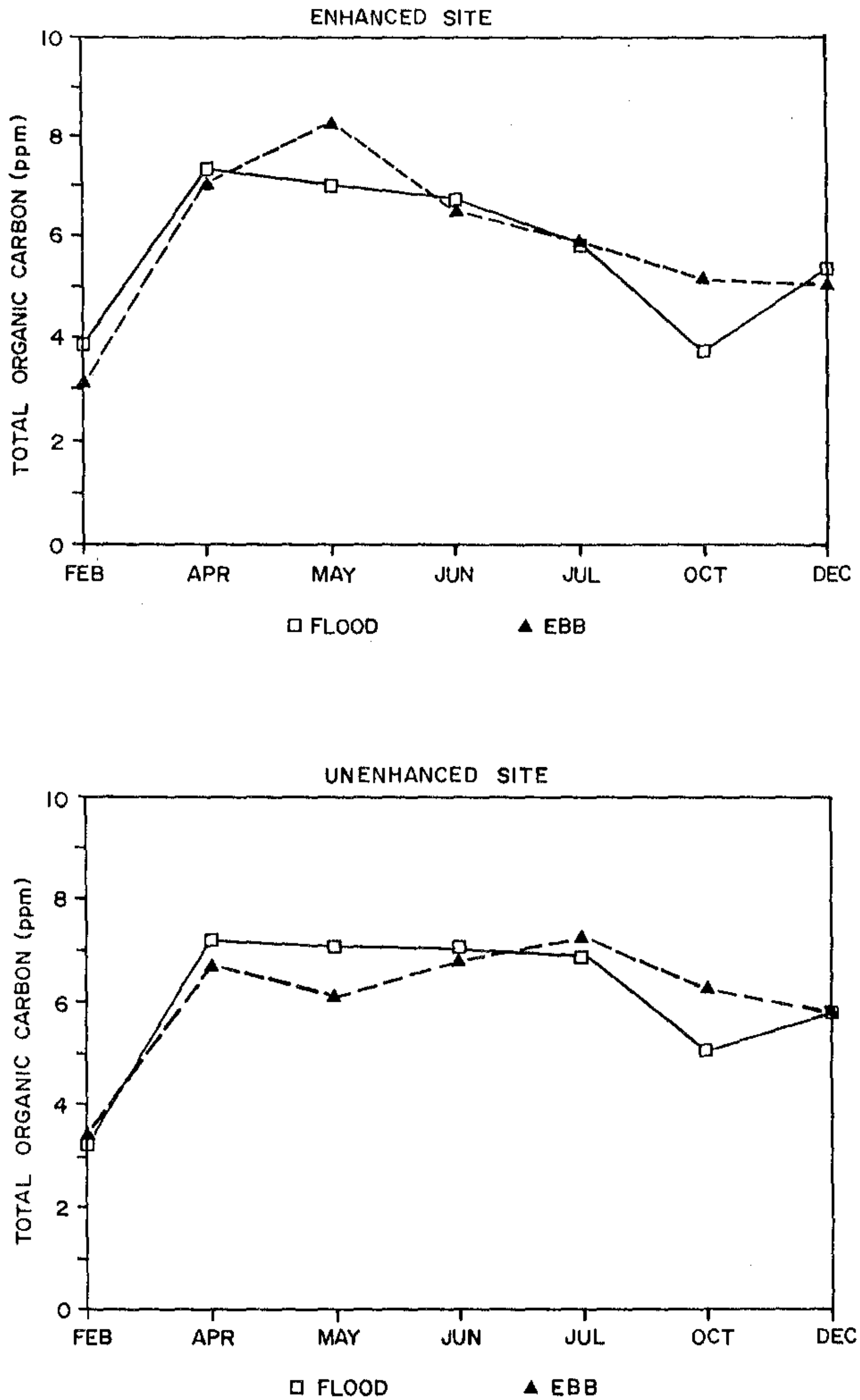

Fig. 10. Comparison of mean total organic carbon concentrations (n=6) during flood and ebb tides at each sample site in 1986.

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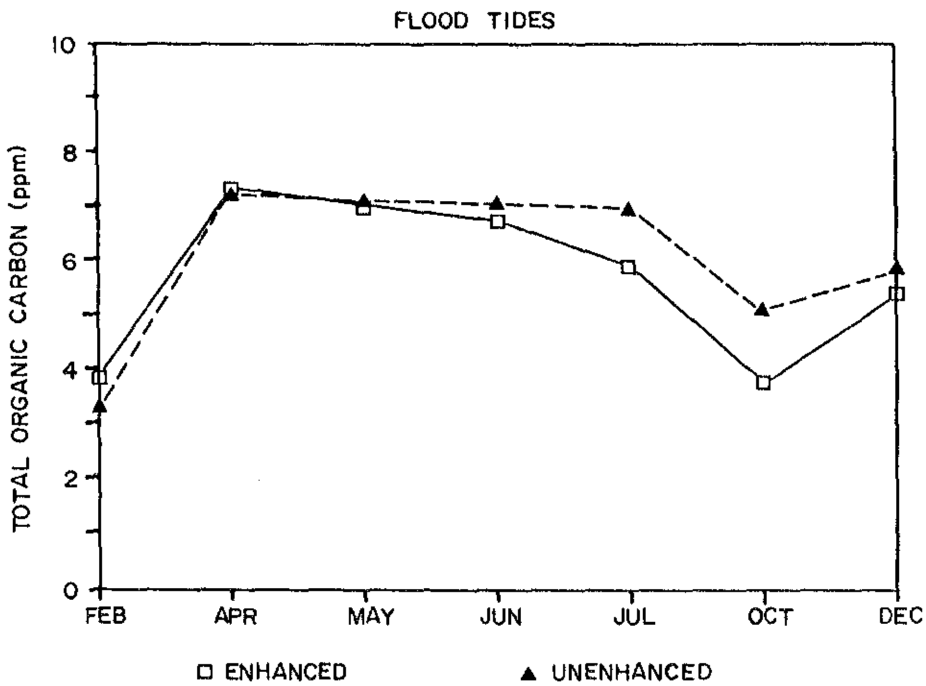

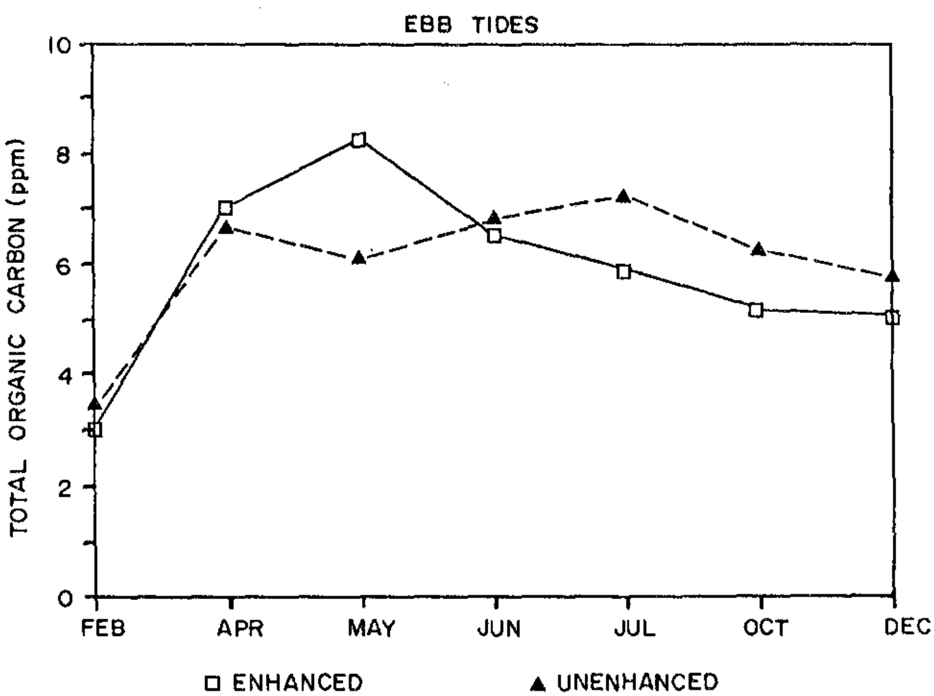

Fig. 11. Comparison of mean total organic carbon concentration (n=6) at the entrances to site E and site U during flood and ebb tide during 1986.

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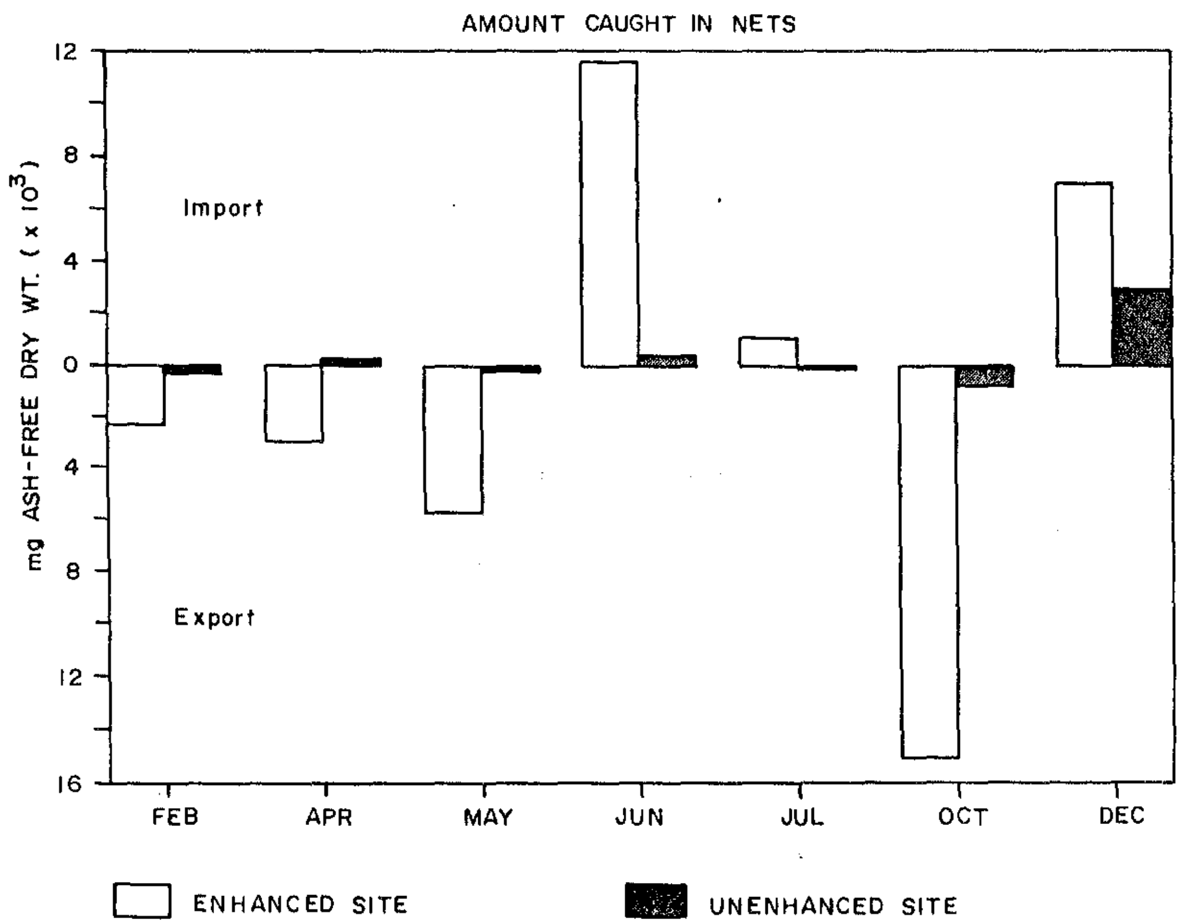

Fig. 12. Detritus flux: the import and export of organic material >0.1 mm in size at the entrance to each site in 1986.

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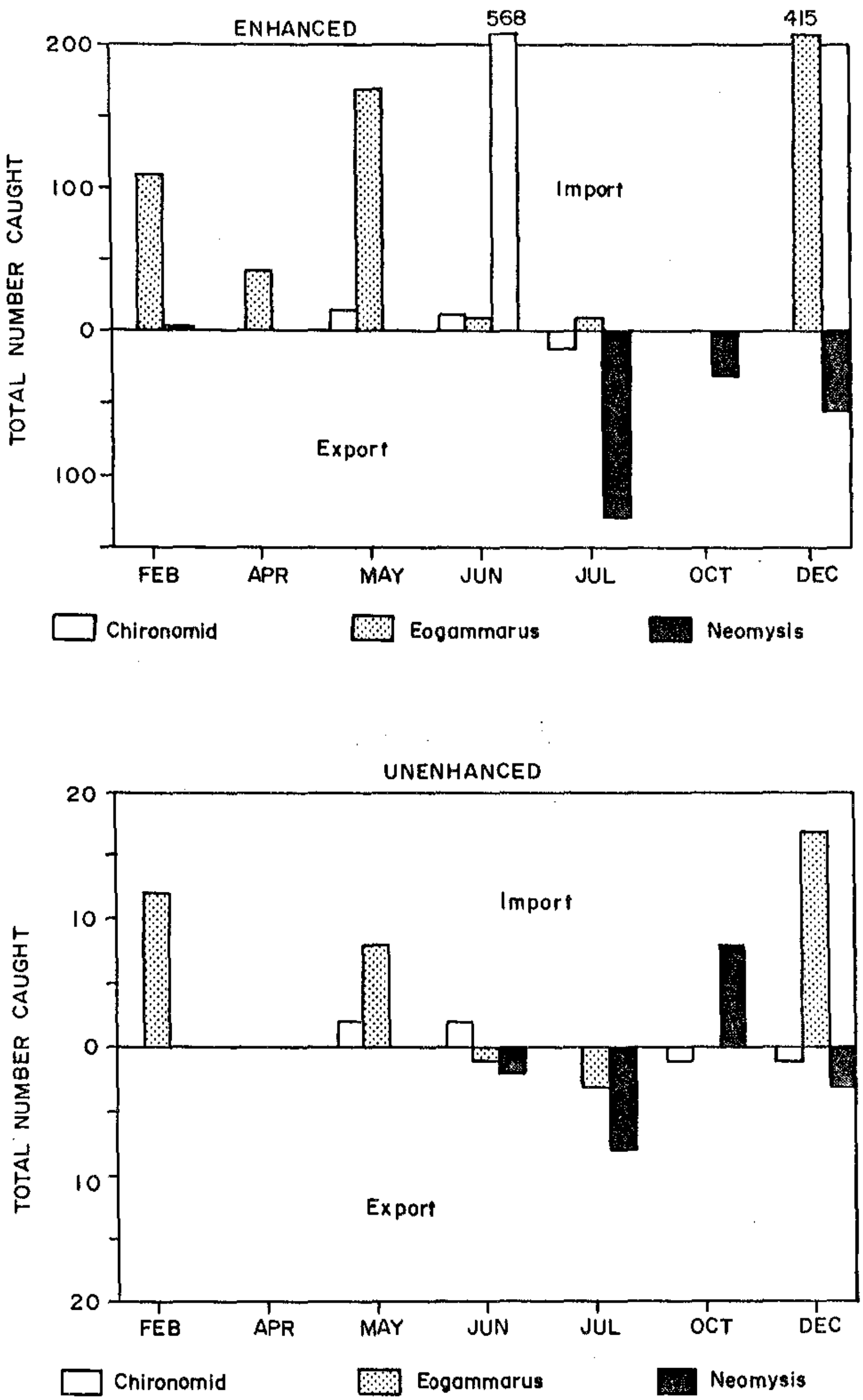

Fig. 13. Epibenthos flux: the import and export of three frequently occurring invertebrates at the entrance to each site in 1986.

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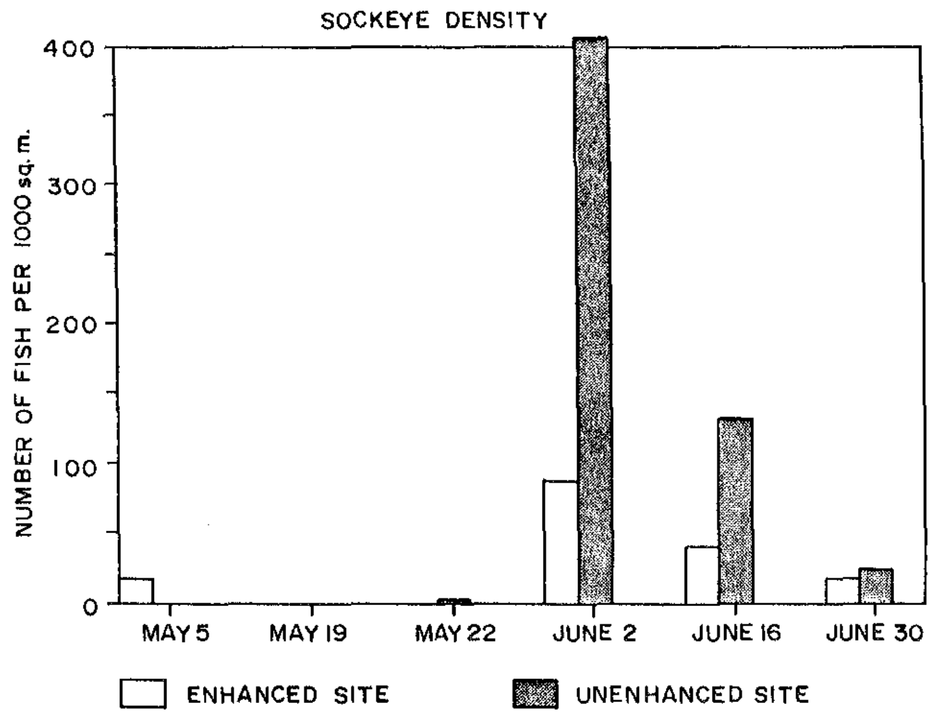

Fig. 14. Density of sockeye salmon fry at the entrance of both sides during each sampling trip in 1986.

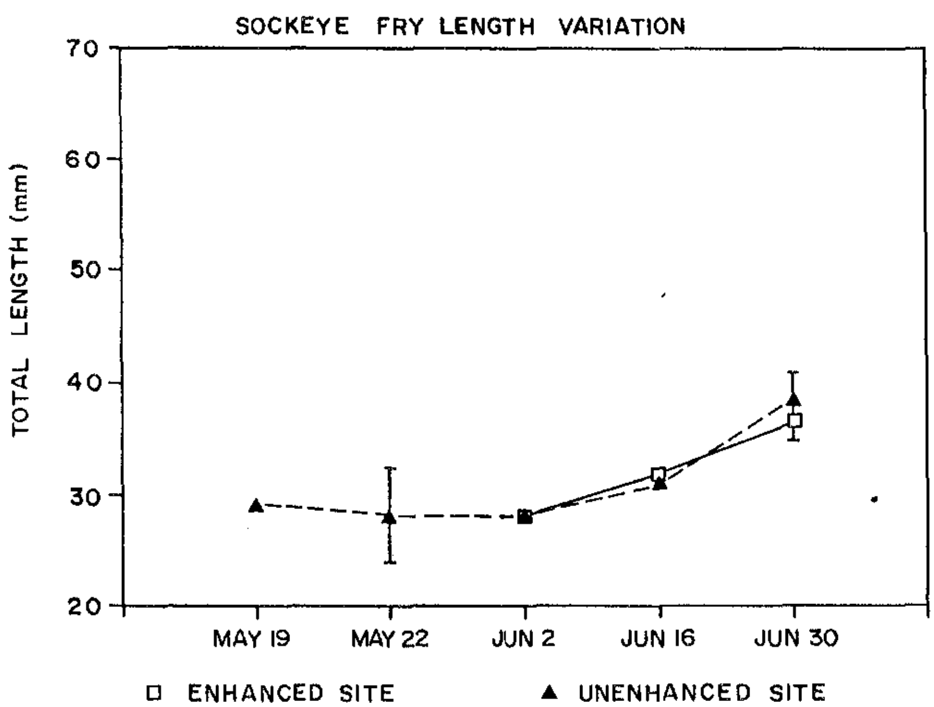

Fig. 15. Variation in mean total length of sockeye salmon fry captured at the entrance to each site with vertical 95% confidence limits of the mean sample sizes on each date in 1986 are presented in Table 4.

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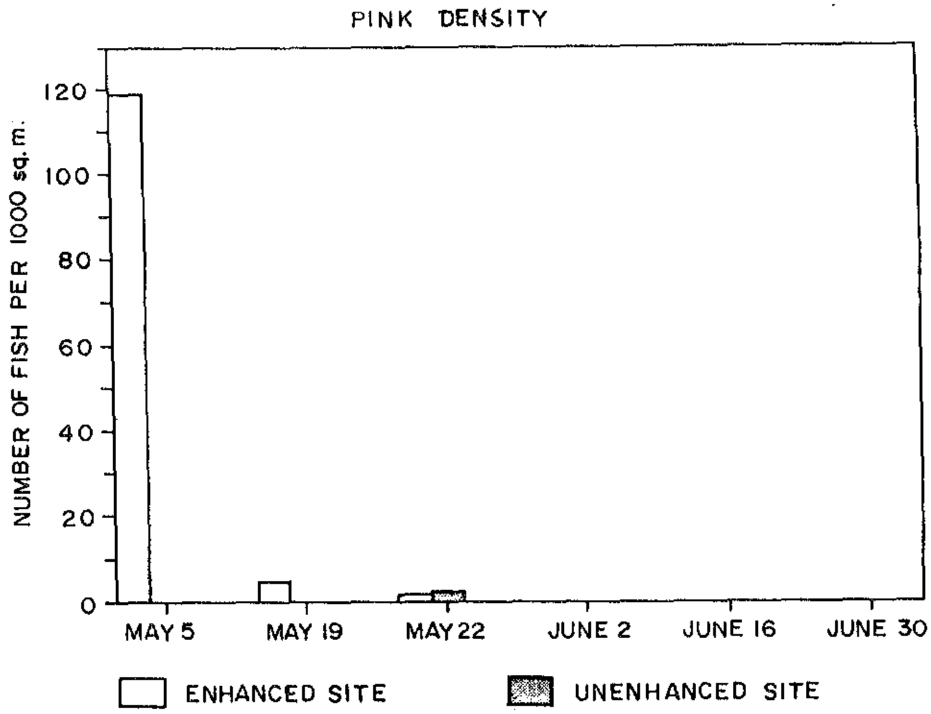

Fig. 16. Density of pink salmon fry at the entrance to both sites during each sampling trip in 1986.

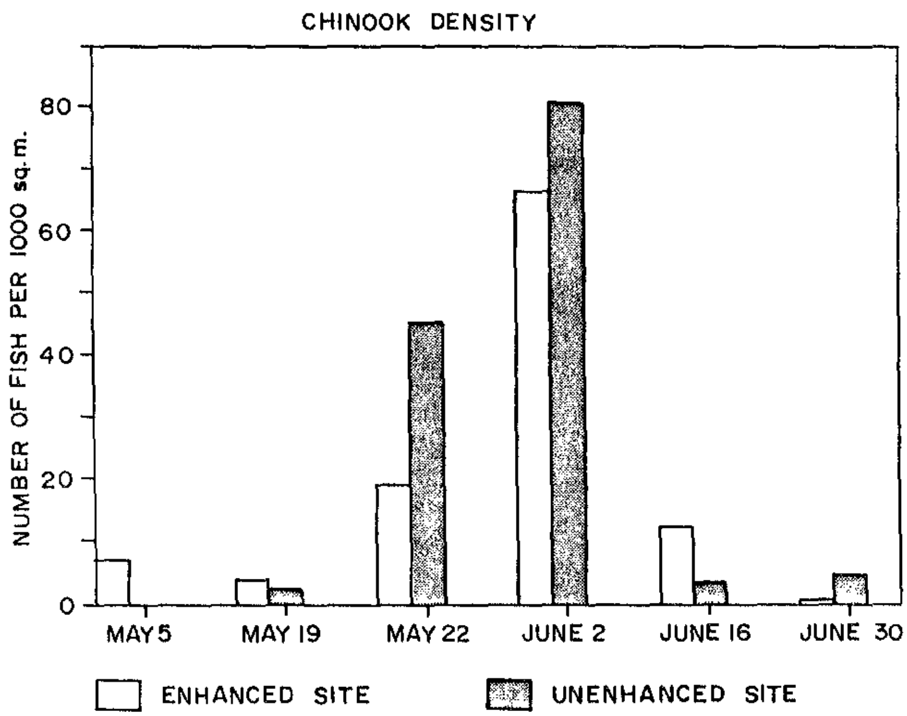

Fig. 17. Density of chinook salmon smolt and fry at the entrance to both sites during each sampling trip in 1986.

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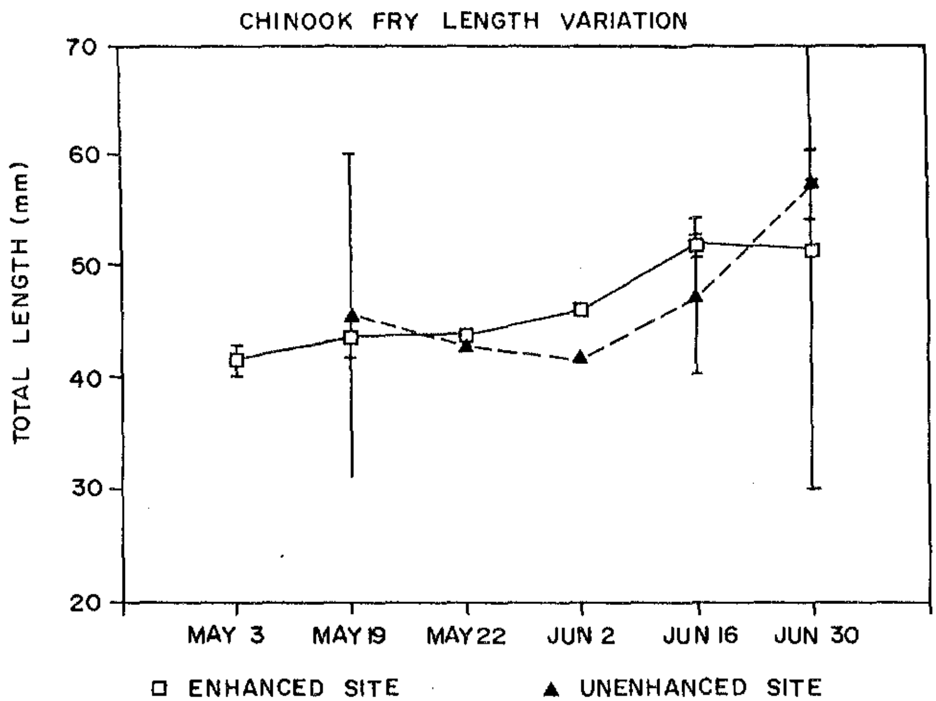

Fig. 18. Variation in mean total length of chinook salmon fry captured at the entrance to each site with vertical 95% confidence limits of the mean sample sizes on each date in 1986 are presented in Table 4.

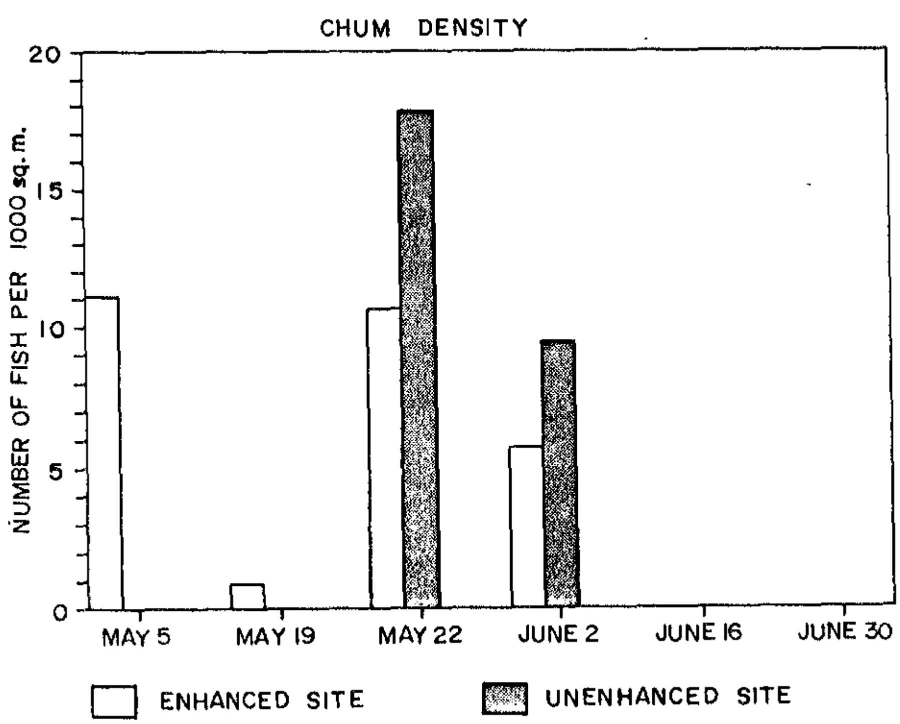

Fig. 19. Density of chum salmon fry at the entrance to both sites during each sampling trip in 1986.

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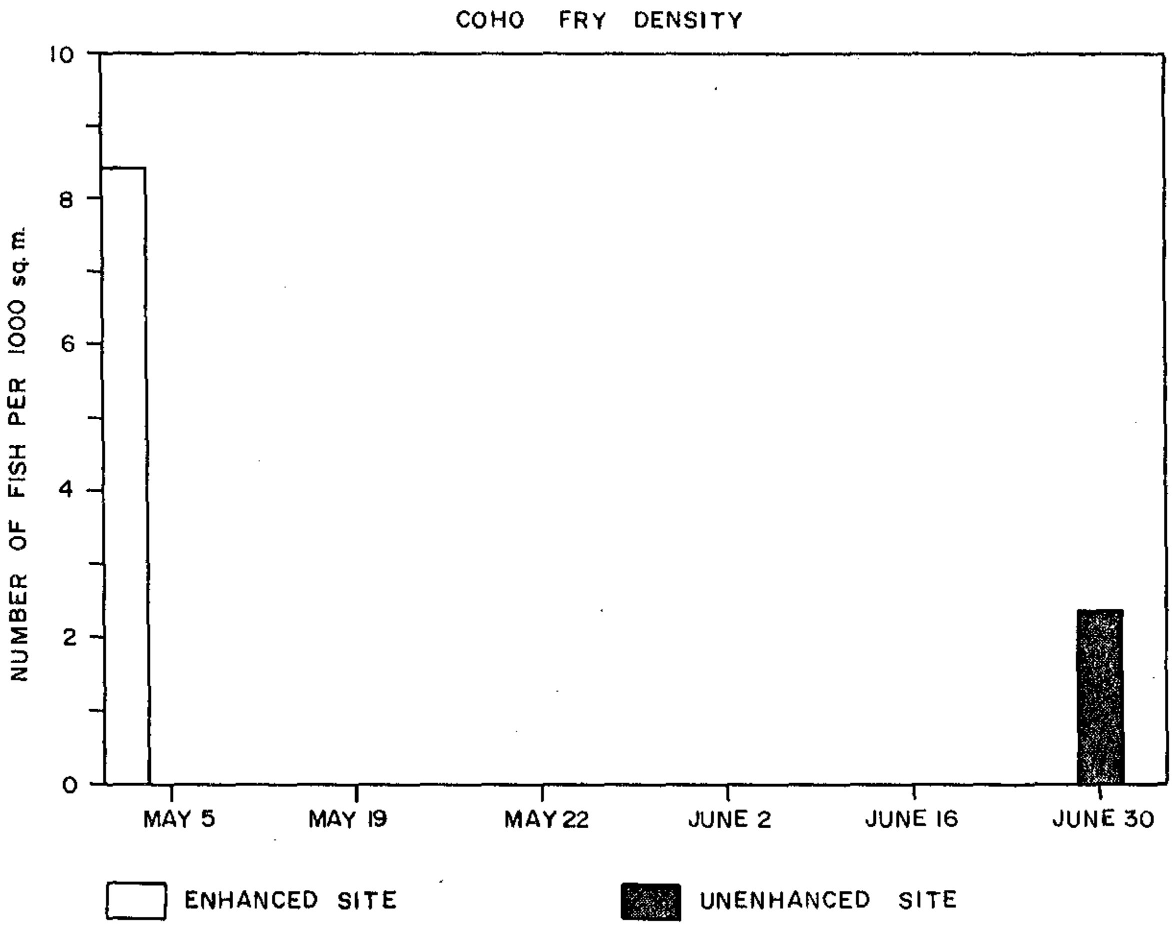
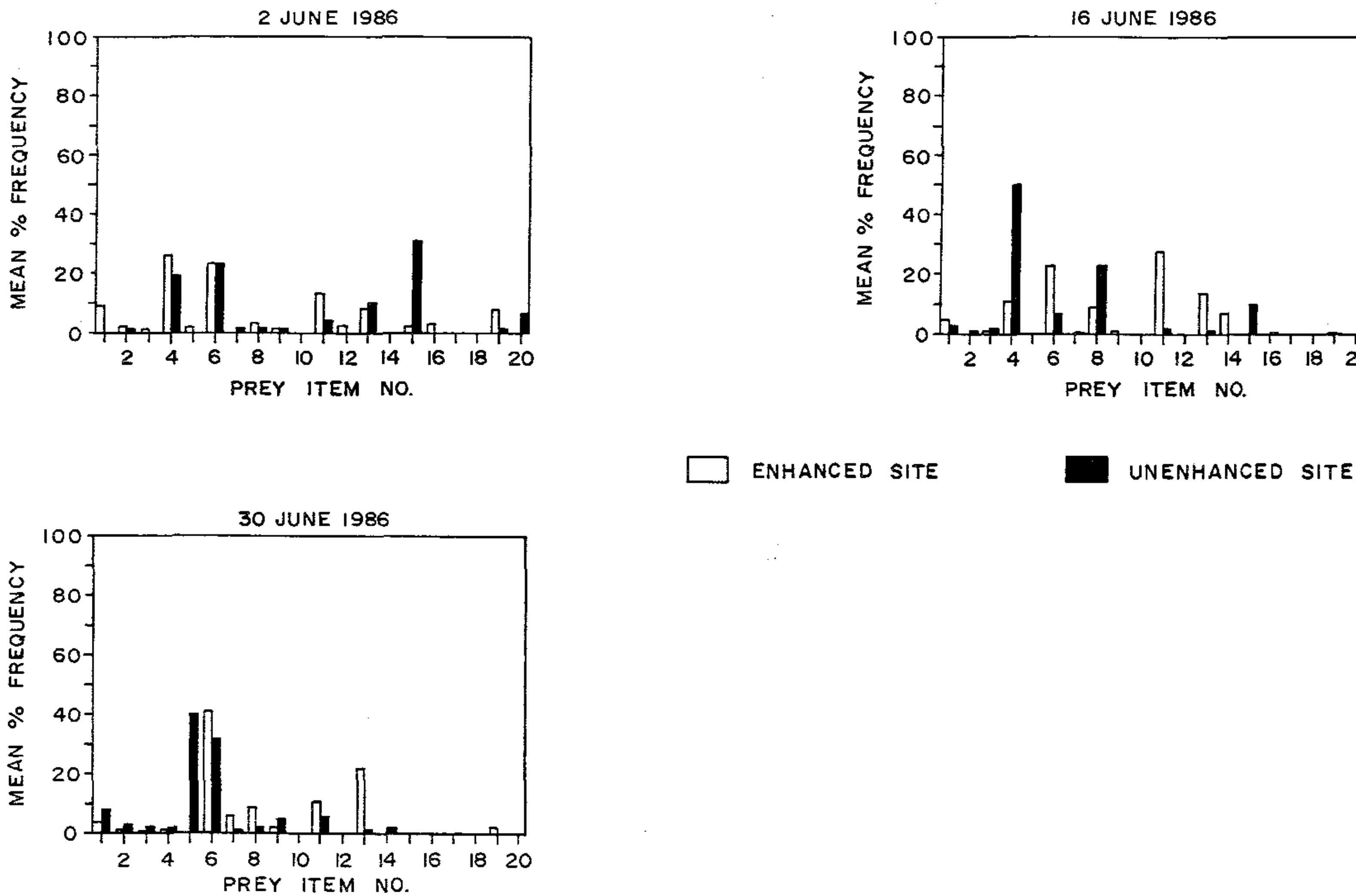


Fig. 20. Density of coho salmon fry at the entrance to both sites during each sampling trip in 1986.

Fig. 21. Mean percent frequency of occurrence of prey items in sockeye fry stomachs captured at the entrance to each site during June 1986. Sample size on each date was n=15. Symbols on the x-axis are as follows:

1. Dipteran (adult)
2. Dipteran (pupa)
3. Dipteran (larvae)
4. Copepod (Harpacticoid)
5. Copepod (other)
6. Chironomid (adult)
7. Chironomid (pupa)
8. Chironomid (larva)
9. Acari
10. Corpohium salmois
11. Hemiptera or Homoptera
12. Eogammarus confervicolus
13. Collembola
14. Fish fry
15. Cladocera
16. Ceratopogonid (adult)
17. Ceratopogonid (larva)
18. Neomysis mercedis
19. Other invertebrates
20. (empty stomach)


2 JUNE 1986
MEAN % FREQUENCY
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
20
PREY ITEM NO.
16 JUNE 1986
MEAN % FREQUENCY
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
20
PREY ITEM NO.
ENHANCED SITE
UNENHANCED SITE
30 JUNE 1986
MEAN % FREQUENCY
0
20
40
60
80
100
2
4
6
8
10
12
14
16
18
20
PREY ITEM NO.

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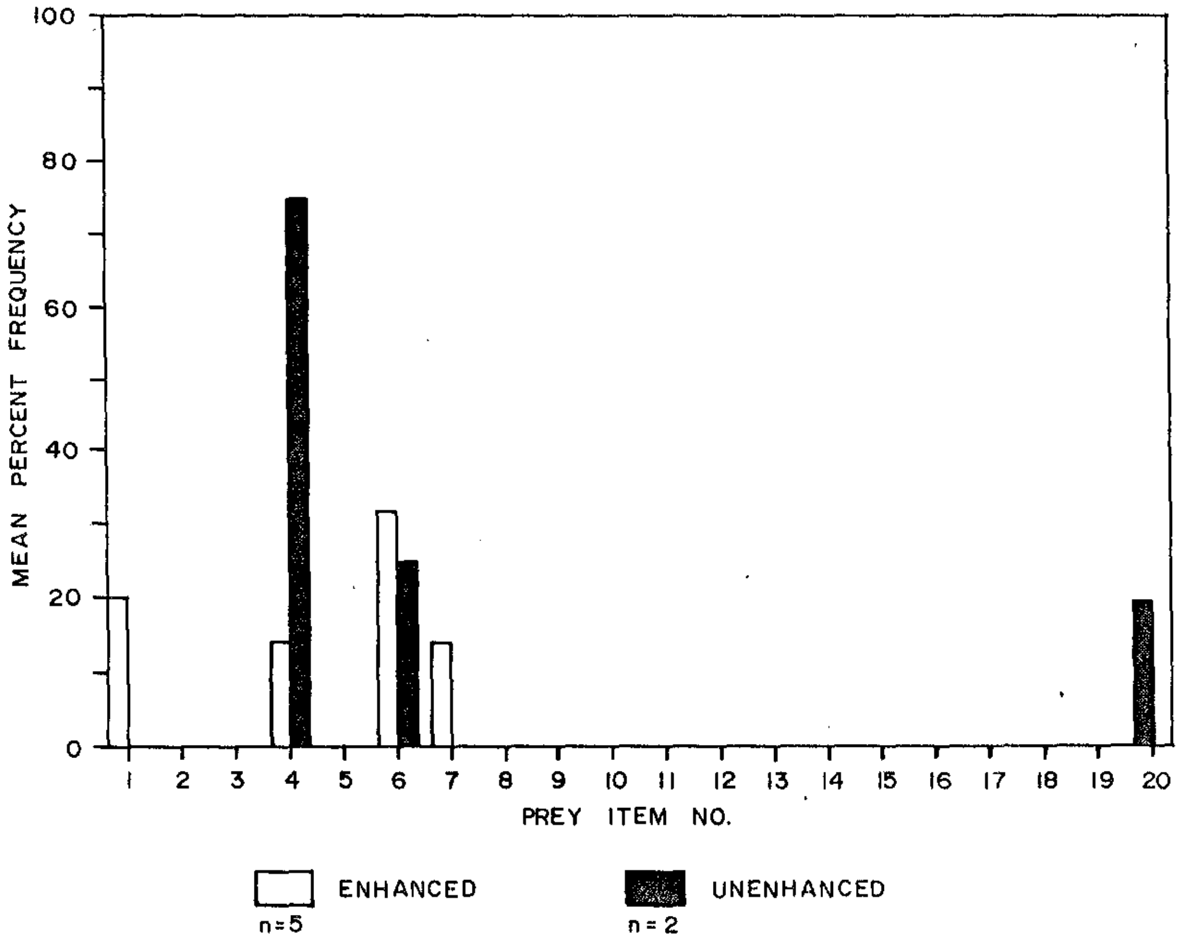


Fig. 22. Mean percent frequency of occurrence of prey items in stomachs of pink fry captured at the entrance to each site in May 1986. Sample sizes were n=5 at the enhanced site and n=2 at the unenhanced site. Refer to Fig. 21 caption for the x-axis legend.

Fig. 23. Mean percent frequency of occurrence of prey items in stomachs of chinook fry captured at the entrance to each site during May and June 1986. Sample sizes for each date are presented in brackets in the legend. Refer to Fig. 21 caption for the x-axis legend.

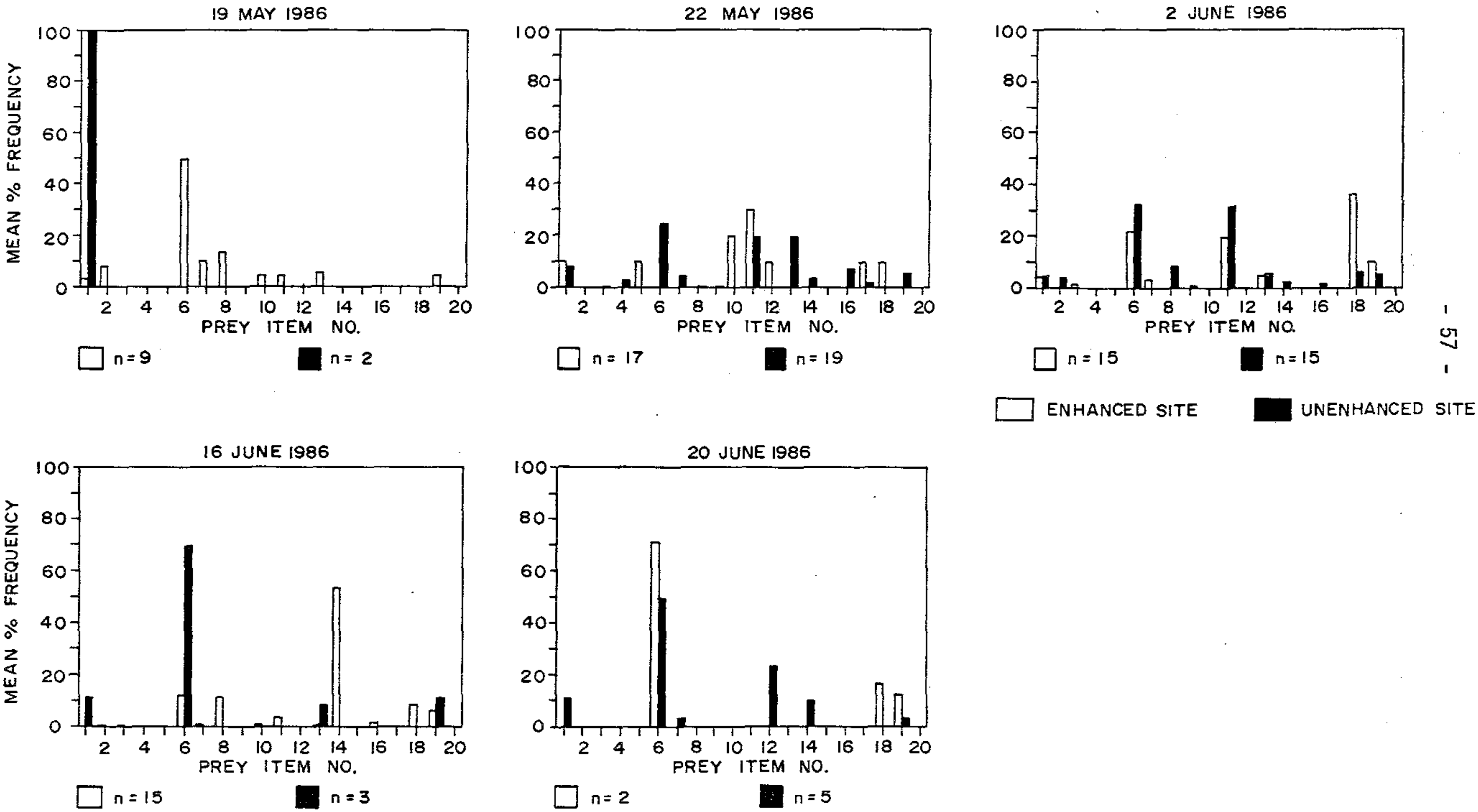
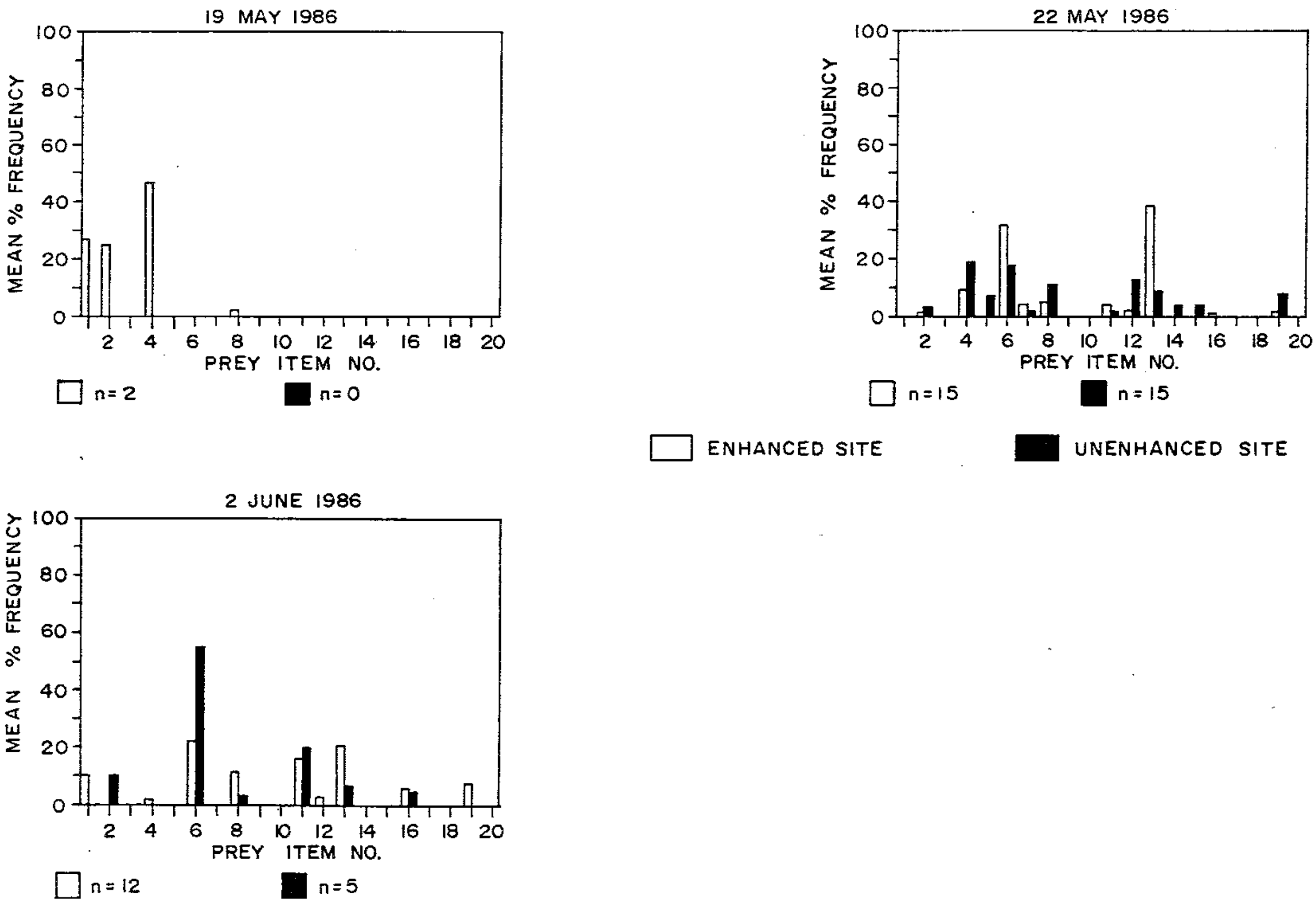

19 MAY 1986
22 MAY 1986
2 JUNE 1986
16 JUNE 1986
20 JUNE 1986
MEAN % FREQUENCY
PREY ITEM NO.
n=9
n= 2
n= 17
n= 19
n= 15
n= 15
n= 15
n= 3
n= 2
n= 5
ENHANCED SITE
UNENHANCED SITE

Fig. 24. Mean percent frequency of occurrence of prey items in stomachs of chum fry captured at the entrance to each site during May and June 1986. Sample sizes for each date are presented in brackets in the legend. Refer to Fig. 21 caption for the x-axis legend.


19 MAY 1986
MEAN % FREQUENCY
PREY ITEM NO.
n= 2
n= 0
22 MAY 1986
MEAN % FREQUENCY
PREY ITEM NO.
n=15
n=15
ENHANCED SITE
UNENHANCED SITE
2 JUNE 1986
MEAN % FREQUENCY
PREY ITEM NO.
n=12
n=5