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The Fraser River plume: some preliminary observations on the distribution of juvenile salmon, herring, and their prey

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ABSTRACT

Zooplankton and fish densities in the southern Strait of Georgia were observed to coincide with variations in surface salinities resulting from the outflow of the Fraser River. Vertical net hauls in the euphotic zone revealed that copepods, amphipods, and euphausiids were significantly more abundant per m^3 in the brackish estuarine plume (surface salinities ~ 10–15 ppt) when compared to the area covered by the freshwater of the Fraser River plume (0–10 ppt) and the region of the Strait of Georgia (25–30 ppt) unaffected by the outflow of the Fraser River.

The estuarine and riverine plumes had significantly higher fish densities (adult and juvenile herring, and juvenile salmonids [excluding chinook]) than the Strait of Georgia region, with no significant differences in densities of juvenile chinook salmon observed between regions. The highest catches of juvenile salmonids were at the boundary between the estuarine plume and the Strait of Georgia. Zooplankton found in the stomach contents of both adult and juvenile herring suggested that the herring were filter-feeding on the zooplankton in the estuarine plume. Juvenile salmonids fed primarily on small unidentifiable juvenile fish. The existence of increased densities of prey items in the estuarine plume is proposed to be the primary mechanism resulting in increased residence time in this region by outmigrating juvenile salmonids. Utilization of aggregated zooplankton could lead to increased salmonid growth rates and therefore to enhanced survival of individuals utilizing the Fraser River plume environment.

Key words: Fraser River estuary, salmon, herring, juvenile fish, zooplankton, prey of juvenile fish

INTRODUCTION

The Fraser River empties into the southern Strait of Georgia, British Columbia, with a maximal discharge of 8×10^3 m^3 s^{-1} occurring in June (Anon., 1988). Two plumes are formed by the river's input: a freshwater riverine plume and a brackish water estuarine plume. The riverine plume (salinity 0–10 ppt) is formed on each ebb tide. The extent of the riverine plume varies primarily with the damming effect of the tides, with a small plume formed during neap tides and a maximum distribution of the freshwater plume during spring tides. Onshore winds result in an increase in the tidal height at the mouth of the river, thus amplifying the damming effect and decreasing the normal extent of the plume. The estuarine plume (salinity ~ 10–15 ppt) in this study is defined as the remnants of previous riverine plumes that have usually been transported from the mouth of the river by the residual circulation of the Strait of Georgia and wind. Both the estuarine and riverine plumes usually contain enhanced concentrations of nitrate + nitrite when compared with the Strait of Georgia surface waters (when unaffected by wind mixing) during late spring, summer, and fall, due primarily to the entrainment of nutrients at the toe of the salt wedge (Geyer and Farmer, 1989; St. John, unpub. data) and deep water entrainment under the riv-

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erine plume as the plume moves seaward. The addition of nutrients from the river is usually secondary, especially during July and August, when river NO_3 is approximately 2 μg at.1^{-1} (Clark and Drinkman, 1980). Thus, the Fraser River plume is a mechanism by which nutrients can be added to the surface euphotic zone resulting in an increase in primary production in the southern Strait of Georgia.

The southern Strait of Georgia, due to the effects of freshwater input, sediment loading, and variability in primary production, produces a complex environment for zooplankton and fish. Sediment contained in the freshwater during periods of high river discharge reduces light levels under the Fraser River plume (Harrison et al., 1991), thus reducing predation rates as the search area for visual predators is diminished. For this reason, the area covered by the plume may become a refuge from predators for organisms able to determine their vertical and horizontal distributions, such as juvenile salmonids and herring.

The low-salinity water of the riverine plume may also act as a boundary to the distribution of marine organisms, resulting in the aggregation of marine plankton at the halocline due to positive phototaxis and active avoidance of the freshwater lens (Marshall and Orr, 1955; Harder, 1968). Juvenile salmonids, during their outmigration from the Fraser River into the Strait of Georgia, must acclimatize to a high-salinity marine environment. This period of smoltification may be made more gradual by utilizing the gradients of salinity found in the Fraser River estuary, rather than being immediately exposed to the high salinity water of the Strait of Georgia (Iwata and Komatsu, 1984).

Spatial and temporal variability of planktonic organisms and fish in the marine environment have been attributed to interaction between the behavioral responses of the organisms and physical flow phenomena (Haury et al., 1978; Mackas and Louttit, 1988). Behavioral responses of plankton to physical flow phenomena may result in markedly anomalous distributions of planktonic organisms. One example is the enhanced densities of plankton observed when a buoyant surface plume at the mouth of a river enters the marine environment. The interaction between the downwelling velocities of the saltwater at the leading edge of a plume (e.g., Luketina and Imberger, 1989) and the buoyancy of particles or positive phototactic behavior of planktonic organisms results in an aggregation of plankton in the zone of convergence at the leading edge of a plume. The resultant aggregation occurs vertically on the order of meters and horizontally on the order of hundreds of meters to kilometers, depending on the volume of the river discharge, the magnitude of tidal fluctuations, and wind influence. Aggregations of the copepod *Neocalanus plumchrus* observed at the edge of the Fraser River plume have been attributed to these mechanisms (Mackas and Louttit, 1988). Aggregations of planktonic prey have been suggested as a cause of aggregations of major fish stocks (Uda and Ishino, 1958; Laurs et al., 1984; Fielder and Bernard, 1987).

In this study we compare the densities of zooplankton in the euphotic zones of the riverine plume, estuarine plume, and the Strait of Georgia, during the period of peak outmigration of juvenile salmon from the Fraser River. The distributions of juvenile salmonids and Pacific herring are examined with respect to habitat utilized, as well as prey availability and utilization, in order to determine whether fish distributions overlap observed aggregations of their prey.

MATERIALS AND METHODS

Four regions were sampled between June 12 and 23, 1989. They were the riverine plume, the estuarine plume, the Strait of Georgia (an area unaffected by the Fraser River plume and referred to as “the Strait”), and the boundary region at the interface between the estuarine plume and the riverine plume (boundary) (Fig. 1). The location of the plume boundary varied with wind, tidal height, and volume of river discharge.

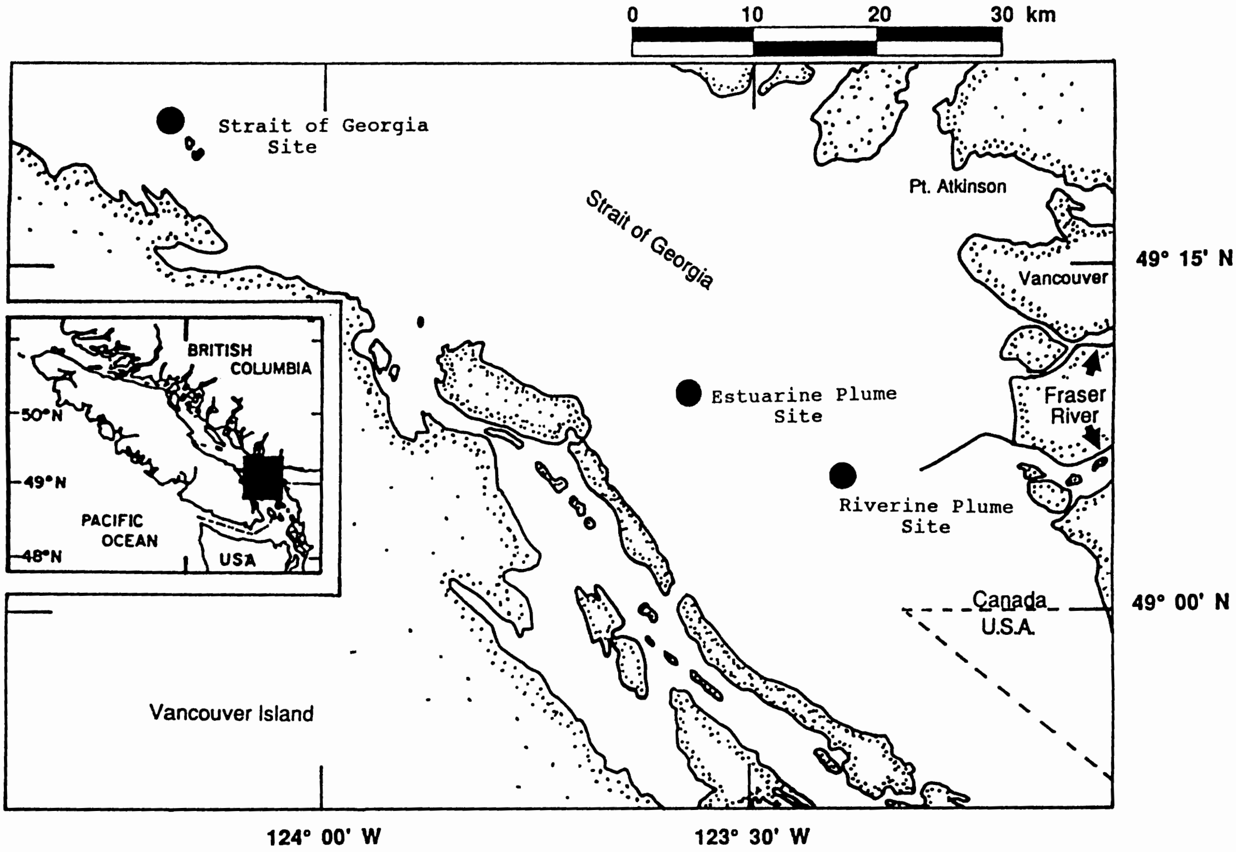
Vertical profiles (to 25 m) of salinity and temperature were obtained using an InterOcean 514A CSTD equipped with a model 513D probe. These data were logged onto a computer and plotted in real-time using a custom software program (Jones et al., 1991).

Light levels at depth were determined with a (Li-Cor Model Li-185B) light meter equipped with a Li-Cor Instruments 192S Underwater Quantum Sensor to determine the depth at which light intensity was 1% of surface light (euphotic zone).

Zooplankton sampling

Triplicate vertical zooplankton hauls were conducted through the euphotic zone (tow speed ~ 1 m s^{-1}), with a 303 μm mesh SCOR net at the same time as the vertical profiles for temperature and salinity at the riverine plume, estuarine plume, and Strait of Georgia regions. Sampling of the boundary feature between the estuarine plume and the riverine plume for zooplankton was not possible due to the lack of mobility of the vessel and the transitory nature of the feature. Zooplankton densities per m^3 were determined from the

Figure 1. Location of the study area and the three sampling sites in the Strait of Georgia, British Columbia, Canada. The boundary site (not shown) was usually found between the riverine and estuarine plumes, and it was variable in location due to wind and tidal conditions.



1% light depth to the surface with the volume filter determined by net mouth area and depth of the haul. In the riverine plume region, the depth of the freshwater lens was removed from the calculation of zooplankton density because no zooplankton were obtained in this lens of the riverine plume (St. John, unpub. data). Zooplankton samples were preserved in a 4% borax buffered formalin solution upon capture (Parsons et al., 1984a). In the laboratory, samples were filtered through a 471 μm sieve, thus selecting for organisms of the size utilized by the fish species captured. Those organisms that were retained were counted, using a dissecting microscope and a Bogorov tray. Large items, such as adult euphausiids, hydromedusae, chaetognaths, and larval fish, were removed individually from each sample and counted. Samples were then quantified for the groups Amphipoda, Euphausiacea, Copepoda, and miscellaneous larval fish (all larval fish were obtained in the vertical hauls with the 303 μm SCOR net). When analysis of the sample was prohibitive due to number of organisms, the samples were subsampled, utilizing the Folsom splitter technique (Horwood and Driver, 1976). A minimum of 100 individuals of each group was enumerated. Species identification and quantification were performed on copepods following Fulton (1968) and Gardner and Szabo (1982). Due to the large number of copepods per sample, species identification was carried out on the first 100 copepods.

Fish sampling

A midwater trawl with a 4 m × 4 m mouth was used to obtain fish samples in each region (Whitehouse and Levings, 1989). Nylon mesh side panels varied from 9.0 cm mesh at the mouth to 0.5 cm mesh in the codend. The net was attached to 1.25 m × 0.4 m trawl doors, deployed with single wire warp and towed at ~ 1 m s^{-1}. The trawl was maintained at the surface during surface sampling by two floats attached to the arc of the head-rope (for details, see Whitehouse and Levings, 1989). For deep-water hauls, the floats were removed from the head rope and additional cable was deployed. Depths were determined by wire angle with the top of the net maintained at ~ 10 m. All densities were standardized to catch-per-unit effort (individuals caught per hour), with the majority of trawls occurring during daylight hours (day, $n = 51$; night, $n = 19$). In order to determine if gear avoidance due to visibility occurred, day to night abundances were compared.

The fish captured by trawling were identified to species. All salmonids ($n = 40$ for juvenile chinook salmon, and $n = 20$ for all other salmonid species) as well as representative samples of herring ($n = 36$) were preserved in 10% formalin upon capture and transferred to alcohol within two weeks of capture. In the laboratory, fish stomachs were examined and prey were identified and counted. Due to the inability of obtaining an accurate sample of the patchy distribution of zooplankton prey available to the fish species, utilization of selectivity indices to examine feeding relationships was deemed inappropriate.

Statistics

Both fish and zooplankton densities in the surface euphotic zone were compared among regions using a one-way analysis of variance (ANOVA, $p \leq 0.05$). Separate tests were performed for each of six taxonomic groups of zooplankton (*Neocalanus plumchrus* plus *Calanus* spp., other copepods, amphipods, euphausiids, decapod larvae, and fish larvae) and four groups of fish (juvenile chinook salmon, other salmonids, adult herring, and juvenile herring). When significant differences occurred, inter-region comparisons were made with a Tukey multiple range test ($p \leq 0.05$, Sokal and Rohlf, 1969).

RESULTS

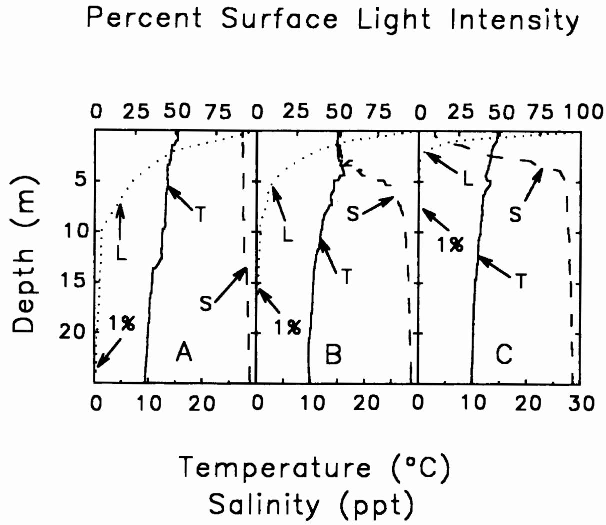
Water column characteristics

Profiles in the Fraser River plume typically displayed a low-salinity surface layer (depth 1–4 m), with high suspended sediments, which reduced light penetration. The depth at which there was 1% of the surface light intensity was observed to be 7 to 8 m in the riverine plume (Fig. 2c), 16 m in the estuarine plume (Fig. 2b), and 24 m in the Strait of Georgia (Fig. 2a).

Zooplankton distributions

The mean density of the group Amphipoda in the euphotic zone of the estuarine plume was 249 individuals per m^3 ($n = 21$), greater ($p \leq 0.05$) than in the other regions. The riverine plume and the Strait of Georgia mean densities of 42 ($n = 6$) and 50 ($n = 9$) individuals per m^3, respectively (Fig. 3) were not significantly different.

Figure 2. Typical water column characteristics of salinity (S), temperature (T), and light (L) at three stations: (A) Strait of Georgia, (B) the estuarine plume, and (C) the riverine plume. The 1% light depth is also shown.



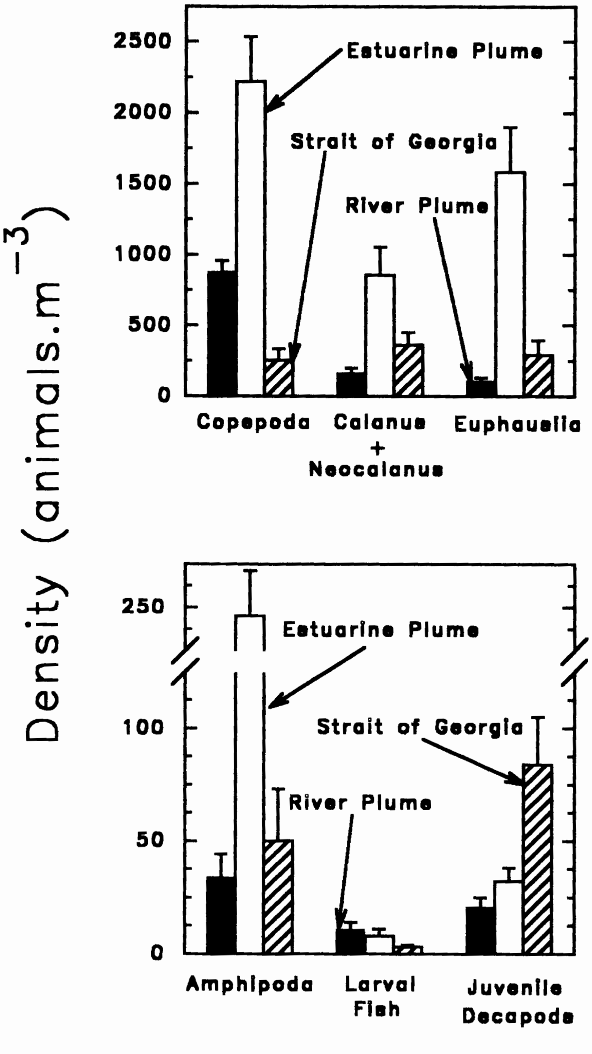
Densities of the group Copepoda (excluding *Neocalanus* and *Calanus* spp.) were quite variable within and among all regions. Mean densities of 2.2×10^3 individuals per m^3 ($n = 21$) in the estuarine plume were greater ($p \leq 0.05$) than densities in the Strait of Georgia (2.5×10^2 m^{-3}; $n = 9$) but not significantly different than the densities found in the riverine plume (1.0×10^3 m^{-3}; $n = 6$). Differences between the latter two regions were not significant (Fig. 3).

Densities of *Neocalanus* spp. and *Calanus* spp. in the estuarine plume (8.6×10^2 organisms per m^3; $n = 21$), were greater ($p \leq 0.05$) than densities found in the riverine plume (2.0×10^2 m^{-3}; $n = 6$) or the Strait of Georgia (3.6×10^2 m^{-3}; $n = 9$). Densities of *Neocalanus* spp. and *Calanus* spp. in the Strait and the riverine plume were not significantly different.

Densities of euphausiids in the estuarine plume (1.6×10^3 organisms per m^3; $n = 21$) were greater ($p \leq 0.05$) than densities in the riverine plume (1.3×10^2 m^{-3}; $n = 9$), but not significantly different from the densities observed in the Strait (4.5×10^2 m^{-3}; $n = 6$) (Fig. 3). Differences in euphausiid densities observed between the riverine plume and Strait were not significant.

Larval fish captured were members of the family Osmeridae (probably the eulachon *Thaleichthys pacificus*; J. Marlieve, pers. comm.) flushed from their spawning grounds in the lower Fraser River (Hay et al., 1989).

Figure 3. Daylight densities of six zooplankton groups and larval fish per m^3 in the euphotic zone, at the riverine plume, estuarine plume, and Strait of Georgia stations. Error bars represent ± 1 S.E.



Mean densities of individuals per m^3 were 8.3 ($n=21$) in the estuarine plume, 10.8 ($n=6$) in the riverine plume and 2.6 ($n=9$) in the Strait of Georgia (Fig. 3). Densities were not significantly different among regions due to the high variability between samples. The high variability is indicative of contagious distributions of larval fish in all regions. The estuarine plume region did not contain the highest mean densities, but this region did contain the highest densities observed in a single sample (58 individuals per m^3). Examination of only those samples that contained larval fish gave significant differences in mean densities among the regions ($p \leq 0.05$). These were 18 ($n=10$), 11 ($n=5$), and 8 ($n=3$) individuals per m^3 in the estuarine and riverine plumes and the Strait of Georgia respectively.

FISH DISTRIBUTIONS

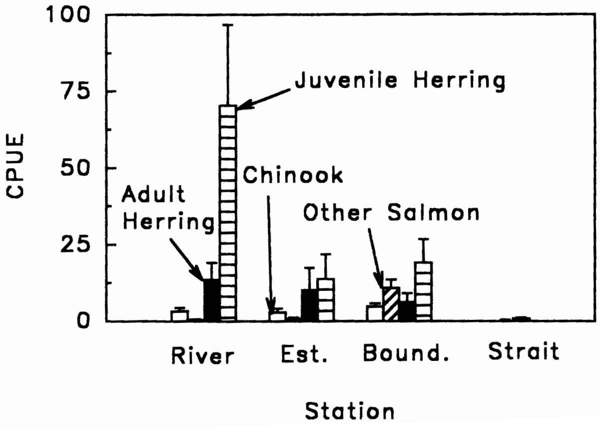
Juvenile chinook salmon (*Oncorhynchus tshawytscha*) were not captured in the Strait of Georgia region (Fig. 4). No significant differences in CPUE were found among the other regions, despite several large catches at the boundary region (riverine plume, 2, $n=21$; estuarine plume, 1.4, $n=18$; the boundary, 4.4, $n=13$, individuals h^{-1}).

Juvenile coho (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) were also caught in the trawl. When combined, the CPUE of these two species (8.9 h^{-1}; $n=13$), was greater ($p \leq 0.05$) in the boundary region than at other sites. Catches in the riverine plume (0.4 h^{-1}; $n=21$), estuarine plume (0.5 h^{-1}; $n=18$), and the Strait of Georgia (0.2 h^{-1}; $n=18$) were not significantly different (Fig. 4).

Densities of adult herring (*Clupea harengus pallasi*) > 1 yr; > 115 mm in length) in the riverine plume were greater ($p \leq 0.05$) (13.9 h^{-1}, $n=21$) than in the Strait of Georgia (0.5 h^{-1}, $n=18$). Densities were 10.4 h^{-1} ($n=18$) in the estuarine plume and 6.8 h^{-1} ($n=13$) in the boundary region.

The riverine plume had higher densities (63.9 h^{-1}) ($p \leq 0.05$) of juvenile herring (30–55 mm in length) than the Strait of Georgia (8.7 h^{-1}), the estuarine

Figure 4. Densities of fish (juvenile and adult herring, juvenile chinook, and juvenile salmonids other than chinook salmon) caught in a midwater trawl at stations representing the riverine plume (River), estuarine plums (Est.), boundary region (Bound.), and Strait of Georgia station (Strait) during the day. Error bars represent ± 1 S.E., and densities are in catch per unit effort (number of individuals caught per hour).



plume (9.1 h^{-1}), and the boundary region (17.5 h^{-1}) (Fig. 4). No significant differences were found among the other regions. Variation among samples within regions was extremely high for most fish species, suggesting that distributions were of a contagious nature.

In the estuarine plume, densities of chinook and coho salmon, and steelhead trout, did not differ between day and night samples ($p \geq 0.05$) (Fig. 5). In the riverine plume, all salmonids were caught during the day but only chinook were captured at night (but at lower densities). In both plumes, all salmonids were caught at the surface. In the Strait of Georgia, all salmonids were caught in deep water trawls during the day.

Adult herring densities in both plumes were highest at the surface during the day, but surface and deep samples did not differ significantly at night. Juvenile herring densities were highest in the riverine plume at the surface during the day. Differences between day and night densities were likely larger than recorded because of increased gear visibility and subsequent fish avoidance during daytime trawls.

Resource utilization

Juvenile salmon fed primarily on larval and juvenile fish. Eighty percent of the prey items were unidentifiable fish parts, probably from the families Osmeridae and Clupeidae. Other common prey items in order of abundance were terrestrial insects, juvenile decapods, and euphausiids.

Juvenile and adult herring consumed a wider variety of prey items than the salmonids. Organisms identified included Copepoda, Amphipoda, Cladocera, Mollusca, and Euphausiia. Herring diets more closely reflected the available zooplankton than did the salmonid diets. This suggests that herring were less selective in obtaining their prey than salmon. Larval herring have been observed to filter-feed in the presence of high densities of prey (Gibson and Ezzi, 1985), supporting our observations in this study.

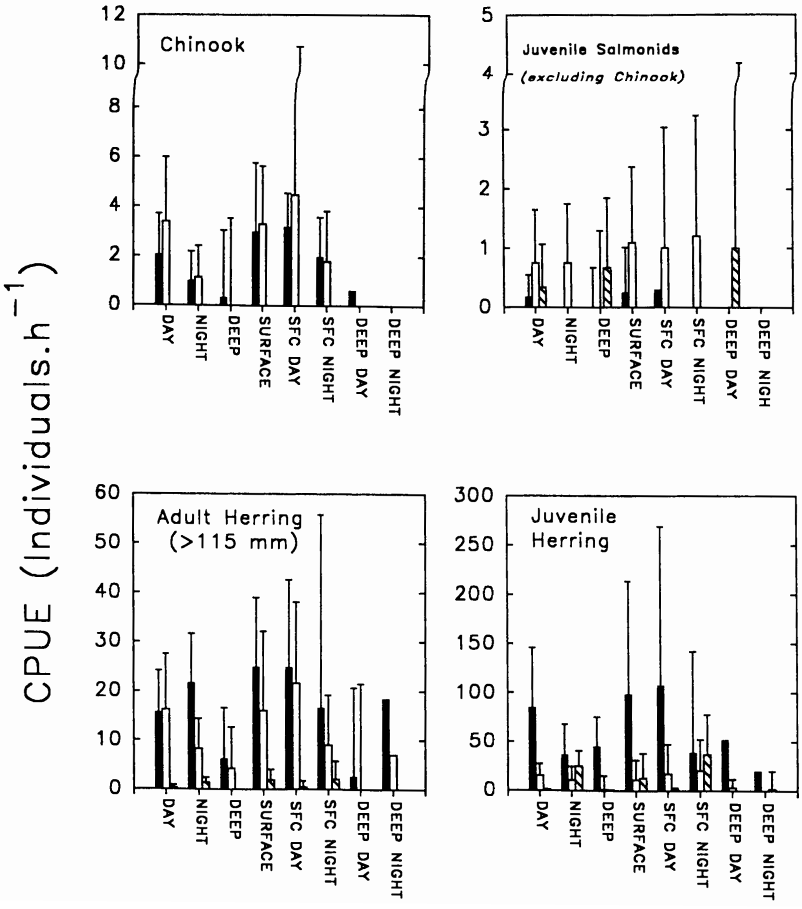


Figure 5. Catch time and depth of fish caught by trawling at three stations representing the riverine plume (River; filled bar), estuarine plume (Est.; open bar), and Strait of Georgia station (Strait; crosshatched bar), between June 12th and 23rd, 1989. Error bars represent ± 1 S.E. Densities are in catch per unit effort (number of individuals caught per hour). Samples from the boundary region are not included because sampling in this region occurred only during daylight hours. Day and night data represent catches over the whole water column, while deep and surface samples include data over the entire 24 h period.

DISCUSSION

The estuarine and riverine plumes produced by the Fraser River have been observed to cause both higher densities and more contagious distributions of both zooplankton and fish than the region of the Strait of Georgia unaffected by freshwater runoff. A number of mechanisms acting separately or in conjunction may result in the distributions of zooplankton and fish observed in this study. These include

- variations in population reproductive rates
- temporal overlap of distribution with sampling period
- refuge from predation
- aggregation or avoidance due to salinity
- aggregation to high densities of potential food organisms
- physical aggregation of organisms due to flow regime.

This study allowed us to examine many of these mechanisms.

Variations in population reproductive rates

Enhanced egg production rates of the zooplankter *Acartia tonsa* are coupled to available food, as well as dry weight and condition factor of the females (Durbin et al., 1983). In a region with enhanced phytoplankton production rates (estuarine plume), increased egg production by copepods occurs. Development rates of marine copepods from nauplii Instar I to adult are on the order of weeks (Klein Breteler et al., 1990; Aksnes and Magnesen, 1988). Thus, for increased egg production in the estuarine plume to lead to increased zooplankton densities, eggs laid in the estuarine plume must remain in this region for several weeks. Thomson (1981), Stacey et al. (1987), and Crean et al. (1988) report a counterclockwise dispersive gyre in the estuarine and riverine plume regions, which may prolong zooplankton residence times, but the residual counterclockwise circulation of the Strait of Georgia (Crean, et al. 1988) should remove these organisms from the estuarine plume region before increases in population densities occur. Therefore, increased zooplankton densities in the estaurine and riverine plumes are not due to increased production of these organisms.

The generation time of the fish captured in this study is on the order of years, and these stocks spawn in other regions (Hart, 1973). Therefore, increased fish densities in the riverine and estaurine plumes are not caused by increased reproductive rates. Fish aggregations in these areas are due to active orientation or passive transport by physical processes.

Temporal overlap of organism distribution with sampling period

Little information exists on the residence times of zooplankton or fish in brackish water plumes. Their presence in these areas may be an artifact of the temporal overlap of sampling effort and migration timing. However, there is no evidence to suggest that zooplankton in the Strait of Georgia actively migrate to the plume region at a specific time in their life history. Aggregations of zooplankton have been attributed to the interactions of physical features of the southern Strait of Georgia (Mackas and Loutitt, 1988). Sampling efforts that coincide with these physical features result in high density estimates.

All species of juvenile salmon outmigrate through the Fraser River plume in the spring (Northcote et al., 1978). Many authors suggest that there are selective advantages for some salmon species to prolong their residence in brackish areas (Iwata and Komatsu, 1984; Macdonald et al., 1988), and have demonstrated residency times of several weeks in estuarine habitats for some species. Sampling efforts that coincide with outmigration of fish from the Fraser River system result in elevated utilization estimates. Estimates are further elevated if stocks prolong their residence times in the Fraser River plume environments. Herring do not spawn near the mouth of the Fraser (Hourston, 1981). Thus, herring found in this region have come from other areas.

Refuge from predation

Examination of the gut contents and densities of spiny dogfish (*Squalus acanthias*), Pacific hake (*Merluccius productus*), and Pacific and river lampreys (*Lampetra tridentatus* and *L. ayresi*) were performed in conjunction with this study, using trawl and gill netting procedures. Preliminary analysis of these data shows high predation rates on juvenile salmonids and herring by lamprey spp. near the plume boundary and under the riverine and estuarine plumes (Beamish et al., unpublished data). Comparison of predation rates with other areas of the Strait of Georgia has not yet been performed, but initial analysis indicates that the plumes do not serve as a refuge for juvenile fish to avoid predation.

Aggregation to high densities of potential food organisms

Orientation toward food particles has been cited as a mechanism that creates aggregations of copepods and euphausiids. Algal exudates containing amino acids elicit feeding motions and oriented swimming in copepods (Poulet and Ouellet, 1982) and euphausiids (Hammer et al., 1983). The euphausiid *Thysanoessa raschii* has been observed to exhibit altered swimming patterns and prolonged exposure to patches of its prey, the diatom *Thalassiosira weissflogii* (Price, 1989). Therefore, behavior that prolongs residence in food patches, such as those described in the estuarine plume (Harrison et al., 1991), will result in aggregated distributions.

The orientation of fish to aggregations of potential prey is a well-recognized phenomenon (Ivlev, 1961; Curio, 1976; Hyatt, 1978; Fiedler and Bernard, 1987). Zooplankton aggregations may provide larval and juvenile fish with increased feeding opportunities and higher growth rates. Our stomach content analyses and fish distribution surveys indicate that larval and juvenile Osmerids, as well as juvenile and adult herring, concentrate and feed within estuarine and riverine plumes as well as in the boundary region where zooplankton aggregate. Therefore, any species of planktivorous fish that orients to the plume environment will experience increased densities of potential prey items and therefore improved feeding conditions. For juvenile fish, improved feeding conditions will enhance growth rates and survival (Parsons et al., 1984b).

Salinity effects/physical aggregation

Increased marine zooplankton densities result under the river plume due to downward migration to avoid the freshwater lens. *Pseudocalanus* spp. (the dominant copepod species obtained in our study) have not been observed in salinities below 6 ppt. (Ackefors, 1969; Corkett and McLaren, 1978). *Calanus* spp., which can be the dominant copepod in the Strait of Georgia early in the spring (Mackas et al., 1985) may become acclimatized to salinities as low as 12 to 17 ppt, although rapid changes can be lethal (Marshall et al., 1934; Marshall and Orr, 1955). Examination of the distribution of marine zooplankton with respect to salinity gradients confirms that marine zooplankton avoid low salinity environments; in fact, water with a salinity less than 14 ppt is devoid of marine zooplankton in this region (St. John, unpub. data).

Two physical mechanisms may result in the involuntary introduction and subsequent aggregation of marine zooplankton below the freshwater lens. During flood tide, the deep saline water of the Strait of Georgia advances up the Fraser River under the freshwater layer, forming a salt wedge that contains marine zooplankton (e.g., Geyer and Farmer, 1989; St. John et al., unpublished data). On ebb tides, the salt wedge breaks down and is mixed into the freshwater of the river plume, thus introducing marine zooplankton into the freshwater lens (Geyer and Farmer, 1989).

The second mechanism is due to variations in current velocities between the surface freshwater layer and the subsurface saltwater. As the freshwater layer spreads out across the Strait of Georgia, salt water from below is entrained into the surface layer due to shear layer entrainment (Pederson, 1986). Salt water entrained into the surface plume will contain zooplankton indigenous to the marine environment, thus introducing these marine organisms into the freshwater environment. Both of these mechanisms should lead to increased densities of marine zooplankton at the mouth of the Fraser River in the riverine plume, as current shear is greatest in this region and saltwedge breakdown occurs upstream from this region.

These two mechanisms may in part explain the high densities of planktivorous herring found in association with the riverine plume. Herring, particularly juveniles, are reported to concentrate in nearshore environments (Hourston, 1958) and were more abundant in our samples in the portion of the plume environment that was nearest the shore (i.e., river plume, Fig. 3). Surveys of herring in the Strait of Georgia rarely find large concentrations of larval herring in the vicinity of the mouth of the Fraser River in April (Hourston, 1956; Hay, pers. comm.), but high densities were observed in July (Barraclough, 1967) and in June (this study). Little is actually known about the size or age at which herring begin offshore migrations (Hay et al., 1989). However, we postulate that herring in late spring orient to the interface between the fresh and salt water along the base of the Fraser River plumes, thus benefitting from the increased concentrations of food organisms.

Juvenile salmonids orient more closely to the plume boundary region than other species. This is a tactic that likely maximizes their opportunity to prey on the forage fish that utilize the plume. Association with the plume habitat may also allow outmigrating salmonids to prolong their association with fresh or brackish water, thus allowing a longer period of acclimatization to marine conditions. Lower mortality rates and reduced stress could result. Prolonged association with salinity gradients may also provide salmonids with an orientation mechanism during outmigration (McInerney, 1964).

From this study, the potential importance of freshwater additions to the marine environment is readily apparent. Nutrients from both riverine and marine sources become available due to physical flow phenomena and result in enhanced primary production. Zooplankton and fish populations orient to these increases in primary production and/or are physically aggregated in this region. Future research should be performed on the small scale (cm to meter) variability of organismal behavior and distribution within this spatially and temporally varying physical regime. Species interactions in this region may be critical to understanding variability in the year-class survival of chinook and sockeye salmon as well as of Pacific herring.

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