U.S. Army Corps of Engineers
Portland District

Crims Island Habitat Restoration in the Columbia River Estuary-Fisheries Monitoring and Evaluation, 2004

Final Report of Research

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EXECUTIVE SUMMARY

Under the Biological Opinion, the U.S. Army Corps of Engineers (USACE) and the Bonneville Power Administration (BPA) are directed to restore over 4,047 ha (10,000 ac) of tidal marsh in the Columbia River Estuary by 2010. Restoration of Crims Island would restore 253 ha (625 ac) of tidal marsh and swamp on Crims Island in the lower Columbia River. The restoration is being initiated to improve habitat for juveniles of listed salmon stocks and Columbian white tailed deer. The U.S. Geological Survey (USGS) monitored and evaluated the fishery resources at Crims Island prior to restoration, which began in August 2004.

Fish assemblages at Crims Island were primarily composed of threespine stickleback, banded killifish, subyearling Chinook salmon, and peamouth. Small numbers of juvenile chum salmon were also encountered. Subyearling Chinook salmon were most abundant in late March and April at the onset of sampling. Seasonal declines of juvenile salmon were associated with higher water temperature (>20°C) in the Reference Tidal Marsh by mid June; however, fish persisted at a Columbia River main-stem site through September. Residence times of individual subyearling Chinook salmon in Crims Island backwaters were generally short consisting of one or two tidal cycles. Median residence time was longer in the T-channel (4-13 h) than in the Reference Tidal Marsh site (1 h).

Chironomid larvae, *Corophium*, and oligochaetes dominated the benthic invertebrate community, while chironomid adults, aphids, and gastropods dominated the drift invertebrate community. Smaller subyearling Chinook consumed dipteran adults and larvae in backwater habitats and larger subyearling Chinook salmon primarily consumed *Daphnia* and *Corophium*. Juvenile salmon fed more intensively in the Reference Tidal Marsh relative to the T-channel—the primary area of restoration at Crims Island—and the Columbia River Mainstem.

Macro-detritus exported from Crims Island backwaters was primarily composed of reed canarygrass, black cottonwood, and Eurasian water milfoil in the degraded T-channel, but was composed primarily of sedges and rushes in the Reference Tidal Marsh. Restoration of the T-channel area at Crims Island will likely decrease the amount of reed canarygrass and will increase the amount of native sedges and rushes after tidal inundation is restored. Sediments at Crims Island were primarily composed of larger-grained sand at the Columbia River Mainstem, a mix of sand and silt at the Reference Tidal Marsh, and silt and clay in the T-channel. Total organic carbon levels were highest in the Reference Tidal Marsh coinciding with silt and sand relative to the degraded T-channel which was primarily composed of silt and clay.

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ACKNOWLEDGEMENTS

We thank our colleagues at the Columbia River Research Laboratory, U.S. Geological Survey for their assistance. In particular we thank Tobias Kock and Joe Warren for assistance with field data collection. We appreciate the cooperation of Maureen Smith and Alan Clark, U.S. Fish and Wildlife Service, Blaine Ebberts and Taunja Berquam, Portland District, U.S. Army Corps of Engineers. Funding for this project was provided by the U.S. Army Corps of Engineers, Portland District, Portland, Oregon (Contract W66QK240581541).

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INTRODUCTION

Anadromous salmon returns to the Columbia River have declined to the point where many salmon stocks originating in the lower Columbia River are now listed under the endangered species act (ESA). Under the ESA, lower Columbia River Chinook salmon, chum salmon, and coho salmon are designated as “threatened”. These declines and subsequent listings were historically associated with over harvest and more recently, with the loss of juvenile rearing habitat. In the Columbia River Estuary, the loss of tidal marsh habitat (defined as being inundated during a portion of the tidal prism) has been estimated at 8,094 ha (20,000 ac) of tidal swamp, 4,047 ha (10,000 ac) of tidal marsh, and 1,214 ha (3000 ac) of tidal flats due to diking, dredging, and filling (Northwest Power and Conservation Council 2001).

Under RPA 160 of the 2000 Biological Opinion, the National Marine Fisheries Service calls on the U.S. Army Corps of Engineers (USACE) and the Bonneville Power Administration (BPA) for the protection and enhancement of at least 4,047 ha (10,000 ac) in the lower 46 miles of the Columbia River Estuary by 2010. To address this mandate, the USACE and cooperators identified Crims Island as a site to restore 253 ha (625 ac) of tidal marsh habitat. Although Crims Island is located outside of the bounds of the Columbia River Estuary at river kilometer (rkm) 87, the island complex is strongly tidal, is currently used by juvenile salmonids, and has the potential to increase export of nutrients to the estuary. A large portion of the interior of the island was drained over 70 years ago by constructing a ditch that we refer to as the T-channel. This area was used for agriculture and cattle grazing, and the existing habitat in this area is degraded. The restoration of Crims Island involves reducing the elevation of the project area by two feet to remove invasive vegetation and allow re-establishment of a tidal marsh community. In addition, subtidal channels will be constructed to increase habitat complexity and allow for adequate water exchange between tidal cycles. This is the first effort of its kind in the lower Columbia River and little is known about the potential response of juvenile salmon to this type of habitat restoration. The USGS is currently monitoring and evaluating the pre- and post-restoration responses of the fisheries community at Crims Island.

The objectives of 2004 work were to: 1) describe seasonal use and habitat preferences of juvenile salmon and other fishes in existing backwater and tidal marsh habitats at Crims Island, 2) describe juvenile salmon diet preferences and the invertebrate community in existing reference habitats at Crims Island, and 3) describe detrital export and productive capacity of backwater reference sites prior to restoration.

METHODS

Study Site and Sampling Locations

All sampling for this project occurred within the Crims Island complex in the tidal fluvial portion of the Columbia River Estuary near Clatskanie, Oregon (Figure 1). The ‘island complex’ as defined here includes Crims Island, Gull Island and smaller neighboring islands that are all connected by dry land at low tide and in periods of seasonally low river flows. The Crims Island complex is located at rkm 87 and is beyond the farthest upstream extent of salinity intrusion (Simenstad et al. 1990). Tides at Crims Island are semi diurnal with about 7 h of ebb and 5 h of flood tide. Tidal flux ranges from 0.6 to 2.1 m as reported 1.1 km downstream of Crims Island (USGS gage #14246900, http://waterdata.usgs.gov/nwis).

We sampled at three distinctly different sites within the Crims Island complex. First, a natural tidal marsh site located on neighboring Gull Island was used as a reference site for marsh restoration on Crims Island and served as a benchmark for fisheries habitat restoration. The sediment there is generally silty sand. A looped channel that bisects the tidal marsh is connected to the main river at high tide and to the subtidal channel separating Crims and Gull Islands through most of the tidal cycle. The Reference Tidal Marsh site frequently dewaters during low tide. We also established a site in the existing T-channel located on the south end of Crims Island. The T-channel is a steep banked man-made channel which runs north from Bradbury Slough into the interior portion of Crims Island and then forks into two smaller perpendicular channels, one which runs east and the other which runs west form the 'T'. Both of these smaller channels dead-end in the interior of the island and regularly dewater during low tide. The main channel is semi tidal and is the only ingress/egress channel to the interior portion of Crims Island. Sediment in the channel bottom is clay with softer sediments regularly sloughing from the banks. Anecdotal information and evidence of erosion indicate that the original channel was narrower and has widened substantially over time. The upland area is wet during spring and early summer and is predominately vegetated with exotic reed canarygrass. Finally, we sampled the main-stem Columbia River on the north side of Gull Island. This site had no vegetation and the sediment was sand. This sampling site was selected for comparison of backwater habitats relative to existing near-shore habitat on the Columbia River main stem.

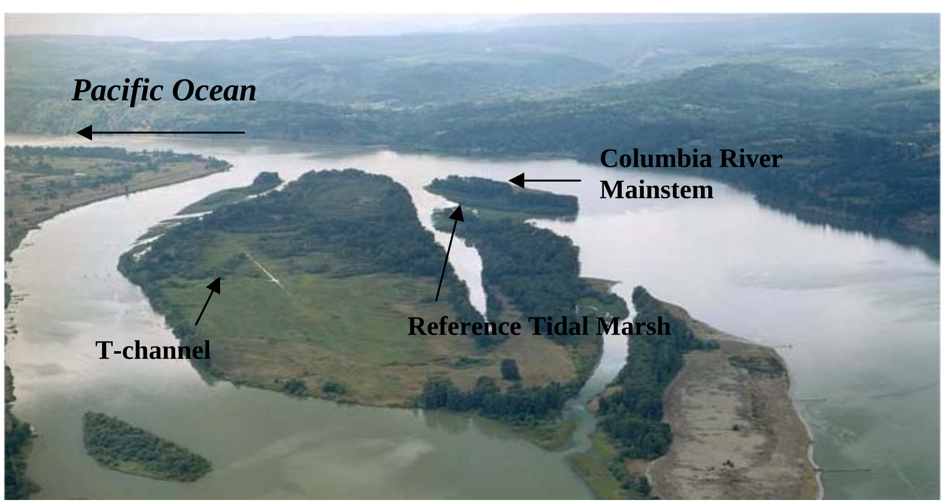

Figure 1. -Pre restoration aerial photo of the Crims Island Complex with USGS sampling sites in 2004 (U.S. Army Corps of Engineers, 2001).

Fish Sampling

Fish assemblages at Crims Island were sampled to document seasonal fish abundance, timing of habitat use, and life history. Data collection focused on juvenile salmon, however other fishes were also identified, measured, and enumerated. We sampled fish every week from March through August 2004 at the T-channel, Reference Tidal Marsh, and the Columbia River Mainstem. We used beach seines and fyke nets with 4.7 cm mesh to capture fish at Crims Island in 2004. Beach seines (15.2 m) were used at the Reference Tidal Marsh and the Columbia River Mainstem sites. Beach seine sites were sampled by pulling the seine parallel to shore for a distance of roughly 50 m. The T-channel was sampled with dual fyke nets; one facing upstream and the other facing downstream. Fyke nets were suspended from a wooden beam support system and raised and lowered with the flood and ebb tide with pulleys and a hand crank mounted on both shores. We attached floats to the frame of the fyke nets for use in the deeper water of the channel. We also attached additional netting to the bottom of each wing because of the greater depths in the channel and 3/16" chain to the bottom of the wings to insure that the net remained on the channel bottom. This configuration enabled us to simultaneously collect fish moving in either direction in the T-channel and to raise and lower the nets with changes in tide. Fish were generally collected from both nets at 1-h intervals. The T-channel site has only a single entry/exit point. This system allowed us to catch every fish that was entering or exiting the T-channel. Forty juvenile salmonids of each species and life history type were measured to the nearest millimeter fork length, weighed to the nearest 0.1 g, and released. Forty individuals of all other species were measured and released. When large numbers of non-salmonid juveniles were present, total numbers for these species were estimated before release. Fish identification followed Page and Burr (1991).

Concurrent with fish collections, data were collected at each site to describe the physical habitat following the methods of Key et al. (1994). The following information was collected at each beach-seine site: water depth, water velocity, and water temperature measured at a distance of 1, 7.5, and 15 m from shore. Turbidity was measured to the nearest 0.1 Nephelometric Turbidity Unit (NTU).

Residence Time

In 2004, we used a new marking technique to describe the residence time of Chinook fry and juveniles in rearing habitats at Crims Island. Because conventional marking techniques (PIT tagging, telemetry) are inappropriate for marking fry, we used Calcein, a fluorochrome dye, to batch mark Chinook salmon fry and juveniles at Crims Island. This innovative technique leaves a permanent mark on bony structures and scales and is easily detectable using a specifically designed ultraviolet light detector, but is otherwise undetectable. Furthermore, large numbers of small salmon can be simultaneously marked while remaining in water with minimal handling. Calcein has already been used successfully with Atlantic salmon fry, and laboratory trials indicated no adverse effects and no increased predation risk to marked fish (Mohler 1997; Mohler et al. 2002). This drug is still awaiting FDA approval, however the USGS is registered as a member of an INAD (Investigational New Animal Drug) with the USFWS for initial use and testing of this product. Because this technique can be used to mark very small fish and is detectable through the life of a fish, it may be an important, non-lethal monitoring tool for Pacific salmon.

We marked subyearling Chinook salmon for residence time estimation because they were the most abundant salmonid in the study area. Fish were collected with beach seines or fyke nets and held in net pens attached to a floating dock in Bradbury Slough for 1-3 d prior to marking. Water temperature in the net pens was typically less than in the capture area. Methods used in marking followed those developed by Mohler (1997) for juvenile Atlantic salmon. Prior to marking, a 1.5% ($15g \cdot L^{-1}$) salt solution and a 0.5% Calcein solution were prepared in separate plastic basins using fresh river water. Subyearling Chinook salmon were marked by placing about 150 fish in a plastic basin with a mesh bottom that was stacked in another unmodified plastic basin of the same size, which contained fresh river water. Fish were marked by first placing them into the salt solution for 3.5 min followed by brief draining and then immediately placing them into the Calcein solution. Fish were kept in the Calcein solution for 3.5 min before being returned to fresh river water for recovery. After marking, fish were held in net pens over night prior to release.

We released subyearling Chinook salmon marked with Calcein at Crims Island to estimate residence time at the T-channel and the Reference Tidal Marsh on two separate occasions in 2004. The first release was made on April 23 and the second release was made during May 17-19. During the first release, marked fish were randomly assigned to one of two release groups. One group was released into the T-channel (N=453) and the other group was released into the Reference Tidal Marsh (N=474). Both releases occurred at about the same time. During the second release period fish were first captured, marked, and released into the Reference Tidal Marsh (N=984). Unmarked fish that were collected during the subsequent 2-d recapture period were then marked and released into the T-channel (N=430). After release of the second group into the T-channel, we recaptured fish in the T-channel for an additional 2 d. All fish marked for residence time analysis were less than 60 mm and were captured using a beach seine in the Reference Tidal Marsh.

Recaptured fish were examined for marks using a Sea-Mark Calcein detector inside a small tent to block ambient light and create a dark environment for mark detection. Recaptured fish were kept in an aerated 5-gallon bucket with fresh river water before mark verification. Under the blue light emitted from the calcein detector, marked fish appeared fluorescent green, and marks were most evident in the fin rays. After examination, marked fish were moved to another bucket, counted, and released back into the study site. Unmarked fish were either removed and kept for subsequent marking or released back into the study site. The frequency distribution of recaptured fish was plotted over time. From this we calculated the percent recapture rate and median residence time for each release period and location.

Stomach Sampling

Every other week from March through August, we collected stomach contents from 10 subyearling Chinook using non-lethal lavage in the Reference Tidal Marsh, T-channel, and the Columbia River Mainstem. The lavage instrument was a 30-ml syringe with a 100 µL pipette tip affixed to the end. Each fish was anesthetized and the pipette tip inserted to the head of the stomach. Distilled water was used to back flush the contents of the stomach into a Whirl-Pak, which was frozen on dry ice for subsequent laboratory analyses. In the past, USGS personnel have used this technique to successfully remove up to 93% of the stomach contents of Chinook salmon as small as 42 mm in the Snake and Columbia rivers.

Invertebrate and Detrital Sampling

Every other week, we sampled drift invertebrates, benthic invertebrates, and detrital drift at the Reference Tidal Marsh, the T-channel, and the Columbia River Mainstem. Ten replicate benthic samples were collected from each site using 174.6-cm^3 PVC coring device (McCabe and Hinton 1996) to analyze the benthic invertebrate community. We also collected three replicate drift samples at each site using a metered 150-micron mesh drift net with a mouth opening of 35 x 50 cm to analyze drift invertebrates and detritus. The sampling frame and net were towed through the water at a constant boat speed for 5 min. A General Oceanics flow meter attached inside the mouth of the net was used to calculate the amount of water sampled. All samples were preserved in 95% ethanol for laboratory analysis.

Carbon Sampling

We collected soil samples and water samples at Crims Island in 2004 to quantify the productive capacity of our sample sites prior to restoration. We collected monthly sediment samples to estimate Total Organic Carbon (TOC) at the T-channel, Columbia River Mainstem, and the Reference Tidal Marsh sites prior to restoration. We collected a single sample from each site to analyze median grain size and percent sand/silt/clay at our three sampling sites. We assumed that there would be no seasonal change in sediment characteristics at sample sites (McCabe et al. 1997) and that our resources would be better allocated investigating seasonal changes in carbon levels. A single sediment sample was collected at each site during each sample period for TOC analysis using the same method used for benthic invertebrate collection. We also collected a single whole water sample at each of our three sites during each sample period to estimate TOC.

Water Temperature and Depth Monitoring

Water temperature and depth data were collected at our sampling sites to examine trends in fisheries data relative to these metrics. We placed staff gages in the T-channel and the Reference Tidal Marsh to develop a relationship between water level recorded by a USGS gage (site #14246900) on the Columbia River located 1.1 km downstream near Quincy, Oregon and our backwater sampling sites. There was a strong degree of association between the USGS gage and our staff gages placed in the Reference Tidal Marsh (R^2= 0.97) and the T-channel (R^2= 0.98). Therefore, we used the Quincy gage heights to predict water depth in our sample. Our water depth information was also used to estimate when sampling locations were dewatered. Water temperature probes were placed in the Reference Tidal Marsh, T-channel, and near our Columbia River Mainstem beach seine site. We used Onset HOBO Water Temp Pro water temperature loggers set to log every 15 min. The USGS has conducted extensive quality control tests on these loggers for precision, accuracy, and response time (Haskell et al. 2004).

Pre-construction Fish Salvage

Prior to the beginning of construction at Crims Island, a tide gate was installed at the entrance to the T-channel so the T-channel could be dewatered. We sampled fish on August 27, 2004 prior to tide gate placement to insure that no ESA-listed salmonids would be present and subsequently entrapped in the T-channel after installation was completed. After the tide gate was installed, the USGS salvaged fish from the T-channel on September 8 and September 10 and released them into Bradbury Slough. Fish were collected using the suspended fyke net system as described earlier and a small beach seine (0.74 m height x 3.15 m width) to corral fish into the fyke net. Fish were identified, counted, and released into Bradbury Slough.

Laboratory Analysis

In the laboratory, we identified invertebrates collected from benthic, drift, and stomach samples and detritus collected from drift samples. Invertebrate samples were stained with Rose Bengal to facilitate sorting. Invertebrates and plant matter were identified to the Family level with the aid of a dissecting microscope. Identification of aquatic and terrestrial invertebrates followed Pennak (1989) and Borror and White (1970), respectively. Identification of plant matter followed Petrides and Petrides (1998), Washington Department of Ecology (2001), and DiTomaso and Healy (2003). After enumeration of invertebrates, we recorded wet weights of taxonomic groups, dried groups for 24 h at 60^{o}C in a drying oven, and recorded dry weights. Detritus was grouped by Family, blotted, weighed, dried for 24 h, and the dry weight recorded. Organisms from fish stomachs were identified to the lowest practical taxon, enumerated, and dried and weighed.

Data Analysis

Fish, benthic and drift invertebrate catch between major habitat types (e.g., backwater, channel, etc.) and seasonal sampling periods were compared using two-way analysis of variance (ANOVA) with habitat type and seasonal sampling period as the main effects. Interactive effects between sampling period and sampling site were examined prior to the main effects. The mean number of taxa, mean number of individuals per taxa (organisms $\cdot$ m^{-2}), and standard deviation (SD) for each sampling site were calculated. Normal probability plots and plots of residual versus predicted means were used to assess the assumptions of normality and non-constant variance, respectively.

All fish and invertebrate abundances were transformed prior to statistical analysis to normalize distributions. When interactive effects were detected in an ANOVA, main effects were analyzed separately using two separate one-way ANOVA's for site and sample period. A Student-Newman-Keuls (SNK) multiple range test was used to test for significance.

We used two community structure indices to measure diversity between sampling sites: the Shannon-Weaver index for Diversity (H) and Evenness (J). Diversity (H) is expressed as:

$$H = \sum_{i=1}^{k} p_i \log_{10} p_i$$

where k = number of categories (taxa) and p_i = the number of observations in a category/sample.

The second index was Evenness (J), which expresses the observed diversity as a proportion of the total possible diversity, ranging from 0 to 1, with 1 being the highest possible diversity given the total number of taxa present in the study area. Evenness is expressed as:

$$J = H/\log_{10} k$$

where H=Shannon-Weaver index and k=number of categories (taxa).

The number, weight, and frequency of occurrence of prey items were used to determine the importance of prey items, using the Index of Relative Importance (IRI) (Pinkas et al. 1971). IRI values were then converted to percentages (McCabe et al. 1986; Muir and Emmett 1988). High percent IRI values indicated greater importance of a food group among prey taxa. We also utilized an Index of Feeding (IF) to characterize feeding intensity. The IF is simply the weight a fish's stomach contents divided by the total weight of the fish (McCabe et al. 1986), which standardizes feeding between fish of different sizes.

RESULTS

Fish Assemblages

We sampled fish at Crims Island weekly from March 15 to June 28 and biweekly from July 6 to August 27, 2004. Fish assemblages were primarily composed of threespine stickleback (*Gasterosteus aculeatus*), subyearling Chinook salmon, banded killifish *(Fundulus diaphanous*), and peamouth (*Mylocheilus caurinus*). All salmonids were juveniles and nearly all of these were subyearling Chinook salmon. Three-spine stickleback was the most abundant fish collected in seine hauls and fyke nets, representing over 58%of the total catch (Table A.1.). Ten of the nineteen species encountered were exotic (53%), which represented 18% of the total catch. Banded killifish accounted for 97% of the exotic fish captured.

Subyearling Chinook Salmon Abundance and Size

Our sampling indicated that juvenile salmon were present in Crims Island backwaters when we initiated sampling in mid March and persisted until early July. Peak abundance of subyearling Chinook salmon was highest in late April to early May, but by late June fish were primarily found at the Columbia River Mainstem site (Figure 2). Declining abundance of subyearling Chinook salmon was associated with increased water temperature. As water temperature exceeded 20°C at backwater sampling sites, Chinook salmon abundance declined and few were captured in water temperatures above 22°C. Small numbers of salmon persisted in the Columbia River Mainstem through July and August. Water temperature monitoring indicated that tidal differences between mean and maximum temperatures were greatest in the Reference Tidal Marsh and smallest in the Columbia River Mainstem.

We captured and measured 1,861 subyearling Chinook salmon at our three sample sites in 2004. Subyearling Chinook salmon were generally smaller at the Reference Tidal Marsh and the T-channel compared to the Columbia River Mainstem (Figure 3). The majority of subyearlings captured in the T-channel and reference sites were smaller than 60 mm and the mean size of fish did not vary greatly in either site from mid March until June (Figure 4). Despite generally constant mean size over the sample period, increases in mean fork length in the Reference Tidal Marsh and the T-channel were detectable over time as mean fish size increased from 40 to 60 mm. Patterns in the Columbia River Mainstem were more variable over time.

Pre-construction Fish Salvage

After placement of the tide gate prior to restoration in the T-channel, we attempted to remove any fish remaining in the T-channel, particularly ESA-listed salmonids. We captured no juvenile salmonids, but we did collect primarily banded killifish, mosquitofish, and other species (Table 1). We removed 116 and 139 fish from the T-channel on September 8 and September 10, respectively and released them into Bradbury Slough (Table 1).

Residence Time

We released 1,458 and 883 subyearling Chinook salmon in the Reference Tidal Marsh and the T-channel, respectively, in 2004 to estimate residence time (Table 2). Residence time of subyearling Chinook salmon in Crims Island rearing habitats was short with most of the fish leaving backwater areas within one or two tidal cycles, however residence times of fish in the T-channel were longer than those in the Reference Tidal Marsh. In the Reference Tidal Marsh, residence time was 1 hour during the second release period (Figure 5); no fish were recaptured from the first release. In the T-channel, median residence time was 3.9 h during the first release and 12.7 h during the second release (Figure 6). We recaptured only 6.7% of marked fish in the Reference Tidal Marsh in the second release period. In the T-channel, we recaptured 74.2% and 32.6% of fish marked in the first and second release periods, respectively.

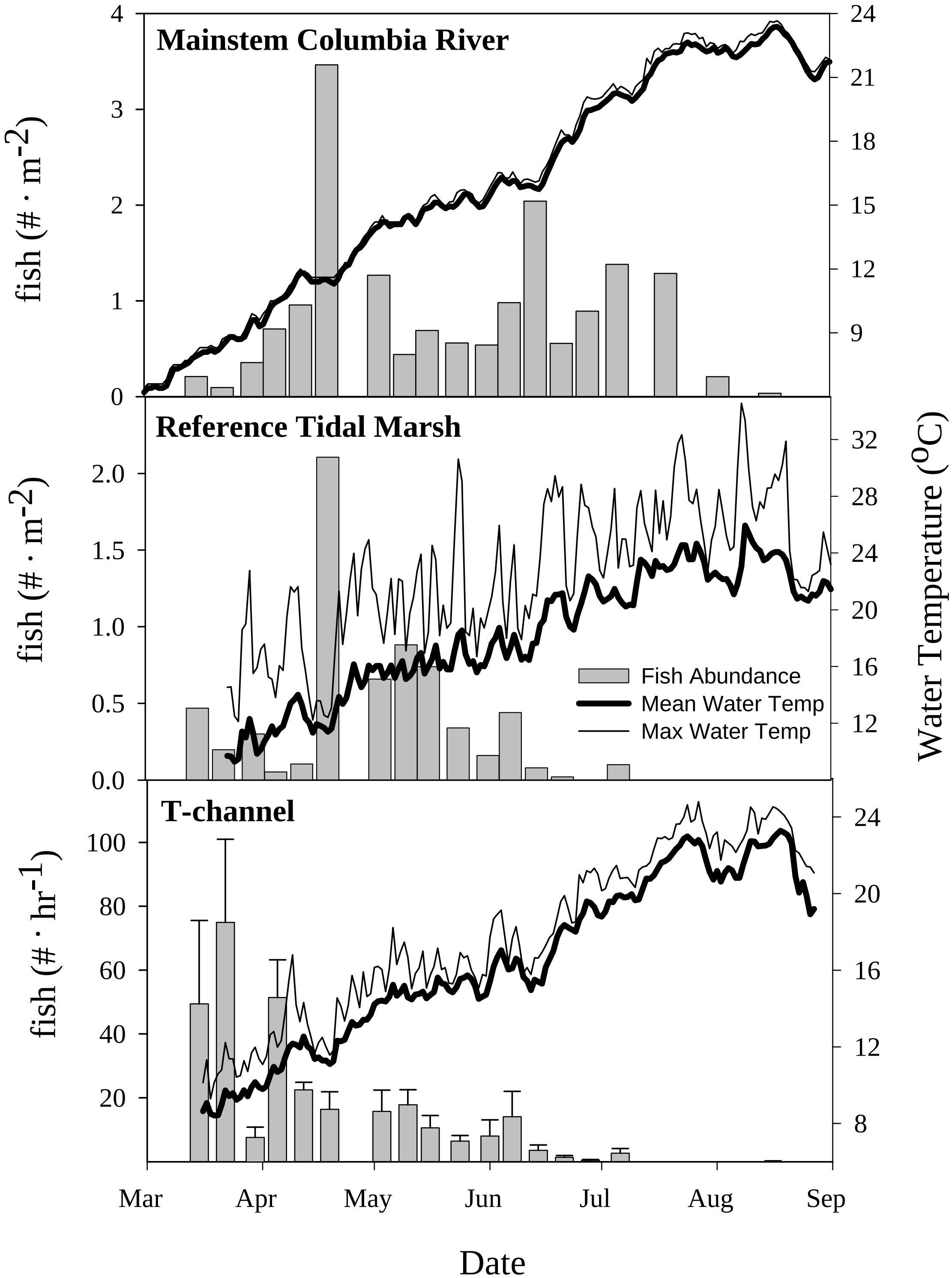

Figure 2. -Seasonal abundance of subyearling Chinook slamon, mean water temperature, and maximum water temperature collected at the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel, Crims Island, 2004.

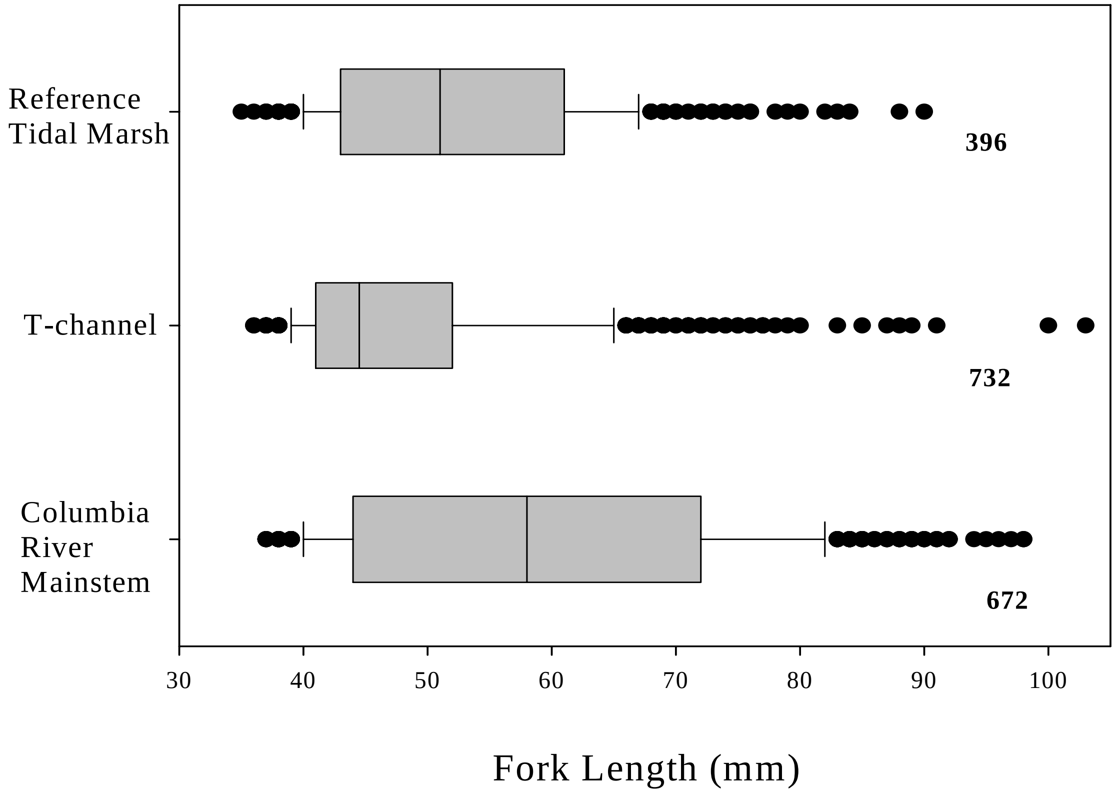

Figure 3. -Fork length characteristics of subyearling Chinook salmon collected from three different locations at Crims Island, March-September 2004. Data is presented in quartile distribution with outliers and the total number sampled.

Table 1. -Common name, life stage, and number of fish captured in the T-channel and released into Bradbury Slough after placement of the tide gate prior to restoration at Crims Island on September 8 and September 10, 2004.

Common Name	Life Stage	September 8	September 10
Banded killifish	Adult	27	51
Mosquitofish	Adult	47	32
Northern pikeminnow	Juvenile	5	3
Peamouth	Juvenile	0	10
Sculpin	Adult	5	3
Sucker	Juvenile	1	2
Sunfish	Juvenile	19	25
Threespine stickleback	Adult	12	13
Totals		**116**	**139**

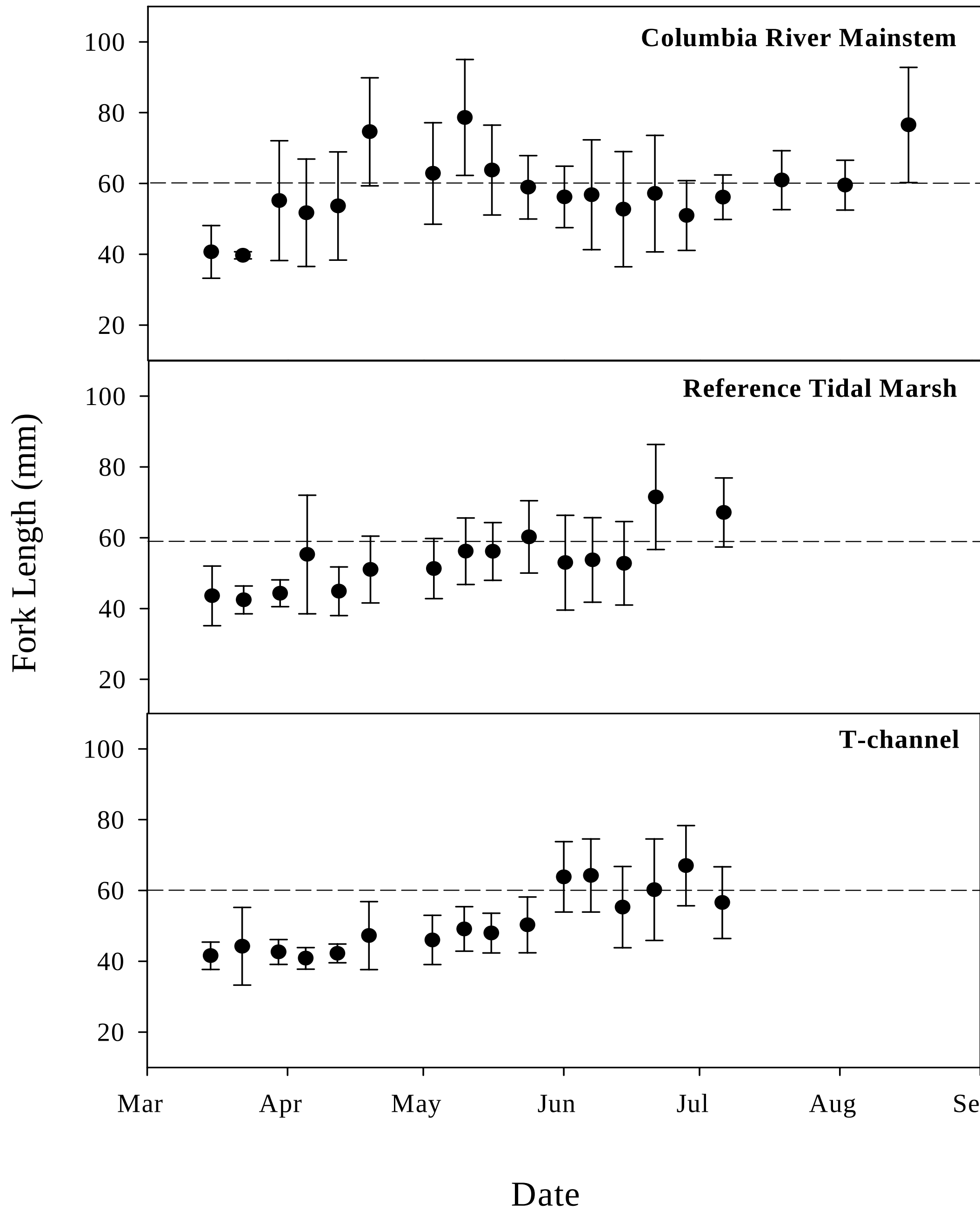

Figure 4. -Seasonal variation in subyearling Chinook salmon mean (+ SD) fork length collected at the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel at Crims Island, 2004. Dashed reference line placed at 60 mm for site comparison.

Table 2. -Release date, release time, release site, number of Calcein marked subyearling Chinook salmon released, number of recaptured fish, and percentage of marked fish recaptured at Crims Island, Columbia River Estuary, 2004.

Release date	Release time	Release site	Number released	Number recaptured	Percent recaptured
4/23/04	9:30	Reference Tidal Marsh	474	0	0.0
4/23/04	10:00	T-channel	453	336	74.2
5/17/04	5:22	Reference Tidal Marsh	984	66	6.7
5/19/04	7:35	T-channel	430	140	32.6
Totals			**2341**	**542**	**23.2**

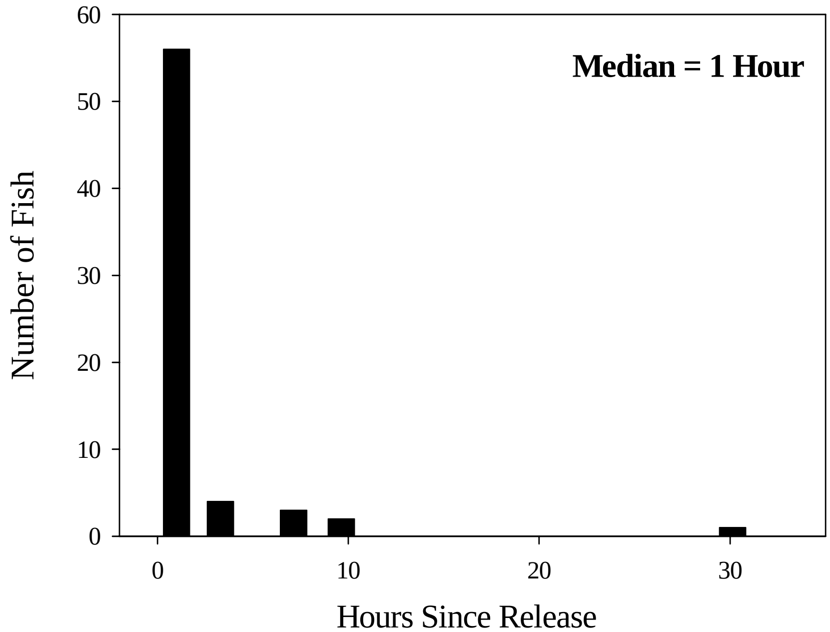

Figure 5. -Residence time of subyearling Chinook salmon marked with Calcein and released into the Reference Tidal Marsh, Crims Island, May 17, 2004.

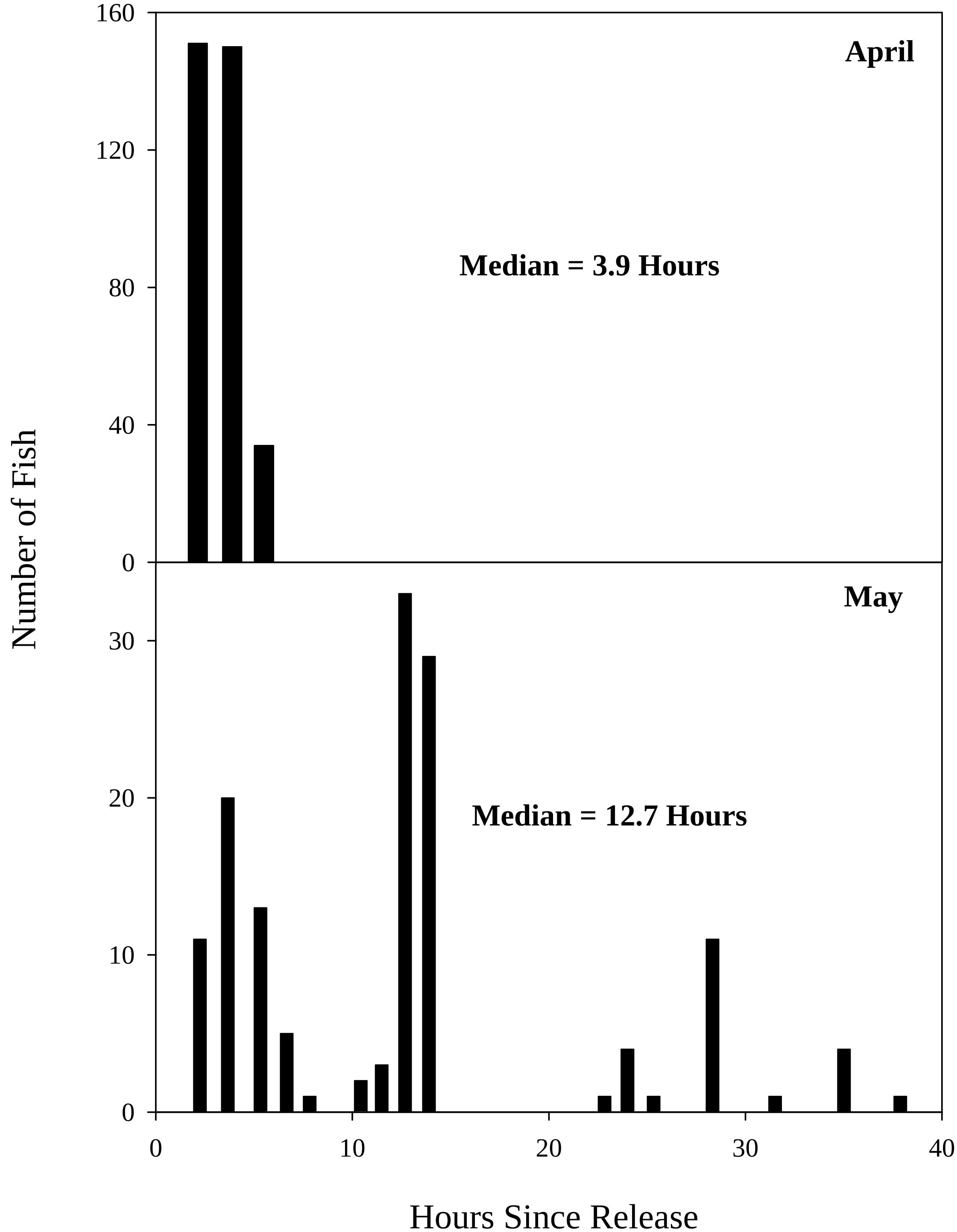

Figure 6. -Residence time of subyearling Chinook salmon marked with Calcein and released into the T-channel on April 23 (top) and May 19 (bottom) at Crims Island, 2004.

Prey Selection and Feeding

IRI values indicated that subyearling Chinook salmon primarily ate chironomids in the Reference Tidal Marsh, but ate a combination of prey items in the T-channel and the Columbia River Mainstem (Figure 7). In the T-channel, fish consumed a combination of dipterans, amphipods (primarily *Corophium*), and *Daphnia*. In the Columbia River Mainstem, subyearling Chinook salmon consumed *Daphnia*, amphipods, and to a lesser extent, Dipterans. Over the entire sample period, we found 2 empty stomachs (2.4%) in the Reference Tidal Marsh, 2 empty stomachs (1.9%) in the Columbia River Mainstem, and 10 empty stomachs (11.9%) in the T-channel. We did not find evidence that prey selection varied seasonally.

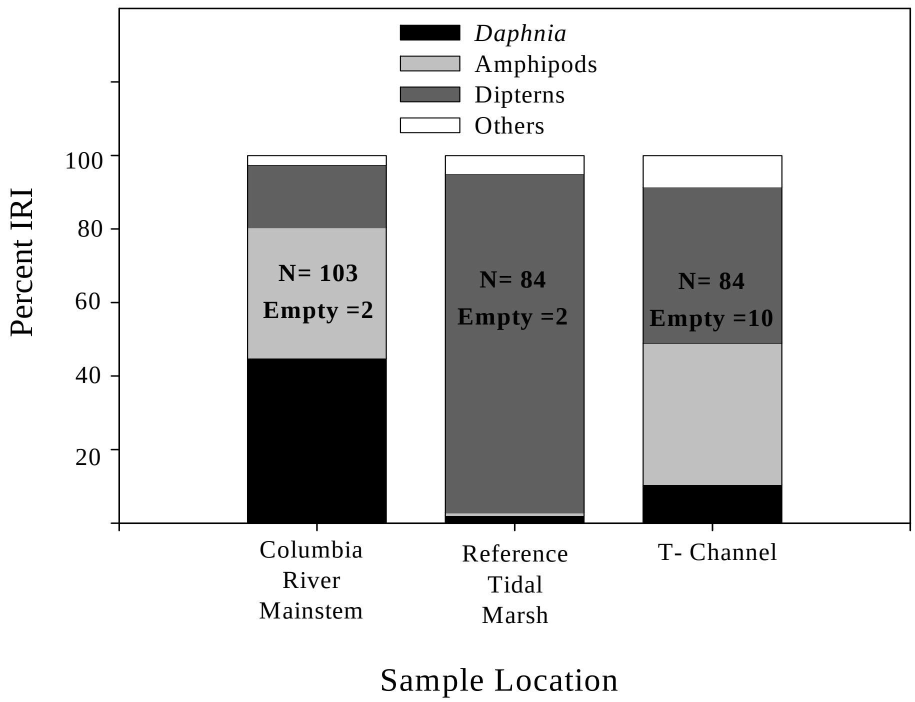

Figure 7. -Index of relative intensity (IRI) of subyearling Chinook salmon feeding in the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel, Crims Island, 2004.

Mean index of feeding was seasonally variable at all sample locations, however IF values were generally higher for the Reference Tidal Marsh relative to the T-channel, and the Columbia River Mainstem sites (Figure 8). A single data point collected from the T-channel on June 21 was over 5 times greater than typical IF values at that location. From the onset of sampling in mid March until mid May, the time of greatest Chinook salmon abundance, IF values in the T-channel were far lower than those observed in the Reference Tidal Marsh and the Columbia River Mainstem. When both main effects variables (sample period, site) were used in the same model, Analysis of Variance indicated no significant difference in index of feeding for site, sample period, or the interaction term. However, when both main effects variables were run in separate ANOVA's, there was a significant difference for site but not for sample period. For the site ANOVA, IF was significantly greater in the Reference Tidal Marsh than in the T-channel or Columbia River Mainstem.

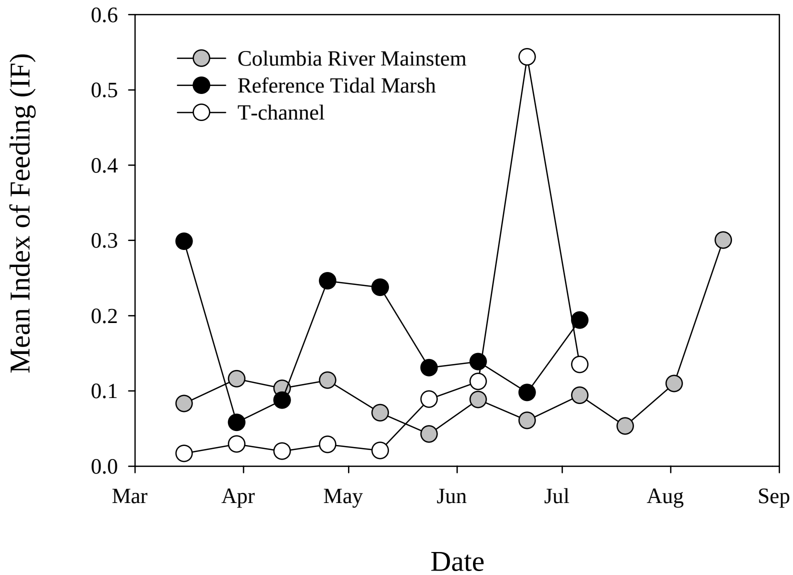

Figure 8. -Seasonal changes in mean index of feeding (IF) for subyearling Chinook salmon collected at the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel sites, Crims Island, 2004.

Benthic Invertebrates

The benthic invertebrate community at Crims Island was dominated by chironomid larvae (35.6%), *Corophium* (26.5%), and oligochaetes (14.0 %) (Table A.2.). *Corbicula fluminea*, an introduced bivalve, represented 3.3% of invertebrates collected at Crims Island in 2004. Mean sample abundance ranged 0 to 7816 · m^{-2} in the Columbia River Mainstem, 2662 to 9362 · m^{-2} in the Reference Tidal Marsh, and from 1202 to 4638 · m^{-2} in the T-channel (Figure 9). Mean benthic invertebrate density was greatest at the Reference Tidal Marsh during 10 of the 12 sample periods and was generally greatest from early June to mid August. There was a significant interaction between sampling period and site, so we analyzed the effect of sampling period and site individually. Benthic invertebrate density was significantly greater in the Reference Tidal Marsh than in the T-channel and the Columbia River Mainstem sites (ANOVA, $P < 0.05$). Total benthic invertebrate density was significantly greater in late May than all other sample periods and significantly less in early August relative to all other sample periods.

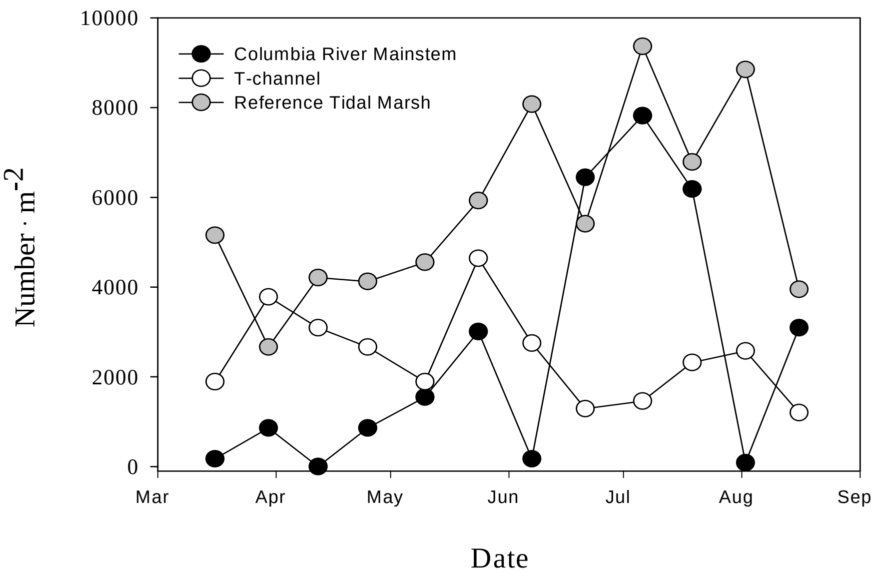

Figure 9. -Seasonal changes in benthic invertebrate density collected at the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel sites, Crims Island, 2004.

Benthic invertebrate diversity calculated using the Shannon-Weaver index (H) was significantly greater in the Reference Tidal Marsh and the T-channel than in the Columbia River Mainstem, but not significantly different from one another. Despite a lack of statistical significance, benthic invertebrate diversity in the Reference Tidal Marsh was greater than in the T-channel in ten of the twelve sample periods.

Drift Invertebrates

Chironomid adults (44.9%), aphids (11.1%), and gastropods (6.4%) dominated the drift invertebrate community. Mean drift invertebrate density ranged from 286 to 12,598 $\cdot$ m^{-2} in the Columbia River Mainstem, 6,585 to 111,382 $\cdot$ m^{-2} in the T-channel, and 8,876 to 134,288 $\cdot$ m^{-2} in the Reference Tidal Marsh (Figure 10). Drift invertebrate density was greatest in the Reference Tidal Marsh from mid march to mid May; however, from late May to late August drift invertebrate density was greater in the T-channel. For the entire sampling season, ANOVA revealed that drift invertebrate density in both the Reference Tidal Marsh and the T-channel was significantly greater than in the Columbia River Mainstem, but not significantly different from one another. A significant interaction between site and sampling period revealed that the effect of sampling site on drift invertebrate density is dependent on sampling period. Drift invertebrate density in the Columbia River Mainstem was least during all twelve sample periods, however there was a statistically significant difference in drift invertebrate density between sample periods. The diversity of drift invertebrates was significantly greater in the T-channel relative to the Reference Tidal Marsh and the Columbia River Mainstem.

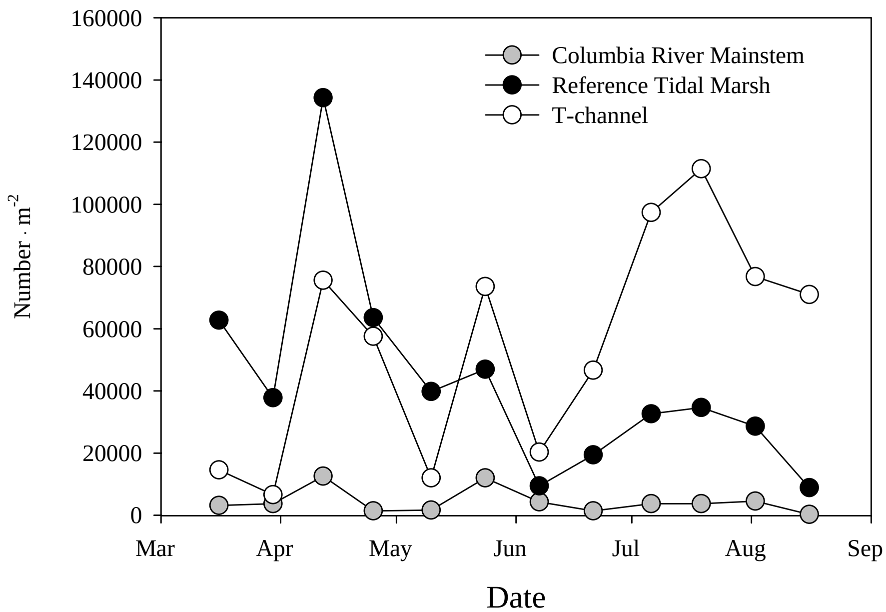

Figure 10. -Seasonal changes in drift invertebrate density collected at the Columbia River Mainstem, Reference Tidal Marsh, and the T-channel sites, Crims Island, 2004.

Detritus

Detritus collected from Crims Island was primarily composed of reed canarygrass (12.2%), black cottonwood (6.3%), and Eurasian water-milfoil (5.0%) (Table A.4.). There were no discernable within-site seasonal trends in mean detritus collected from our three sites using the drift sampler, however, detritus collected in the T-channel was composed primarily of reed canarygrass and Eurasian water-milfoil, while detritus from the Reference Tidal Marsh was primarily composed of rushes and sedges. Mean weights of detritus were 0.97 mg $\cdot$ m^{-2}, 17.79 mg $\cdot$ m^{-2}, and 51.36 mg $\cdot$ m^{-2} for the Columbia River Mainstem, T-channel, and the Reference Tidal Marsh, respectively.

Sediment Characteristics

Sediments at the Columbia River Mainstem and the Reference Tidal Marsh sites were similar to each other but differed from those in the T-channel. Median grain size was greatest in the Columbia River Mainstem (0.18 mm) and smallest in the T-channel (0.008 mm). Sediments at the Columbia River Mainstem and Reference Tidal Marsh sites were predominately composed of sand, but the Reference Tidal Marsh contained a greater percentage of silt. The T-channel sediment was predominately represented by silt and clay with small amounts of sand (Table 3).

Table 3. -Median grain size, percent silt, percent sand, and percent clay from sediment samples collected at Crims Island, March 16, 2004.

Site	Median Grain Size (mm)	Percent Silt	Percent Sand	Percent Clay
Reference Tidal Marsh	0.160	10.6	86.4	3.0
T-channel	0.008	59.5	1.6	38.9
Columbia River Mainstem	0.180	2.3	96.2	1.5

Total organic carbon levels in both water and sediments were generally highest in the Reference Tidal Marsh followed by the T-channel and Columbia River Mainstem. In the Columbia River Mainstem, sediment TOC levels were below the detection limit. Water TOC levels were highest in the Reference Tidal Marsh and lowest in the Columbia River Mainstem for all sample periods (Figure 11A). However, seasonal trends were different between sites. In the Reference Tidal Marsh, peak water TOC occurred in mid April, declined sharply to a minimum in early May, and then increased through early July. Water TOC levels in the T-channel increased through the spring, peaked in early May, and then decreased to lower levels throughout the summer. Water TOC steadily increased throughout the entire sampling season in the Columbia River Mainstem. Seasonal trends in sediment TOC were similar between the Reference Tidal Marsh and the T-channel with peaks evident in mid April and early June (Figure 11B).

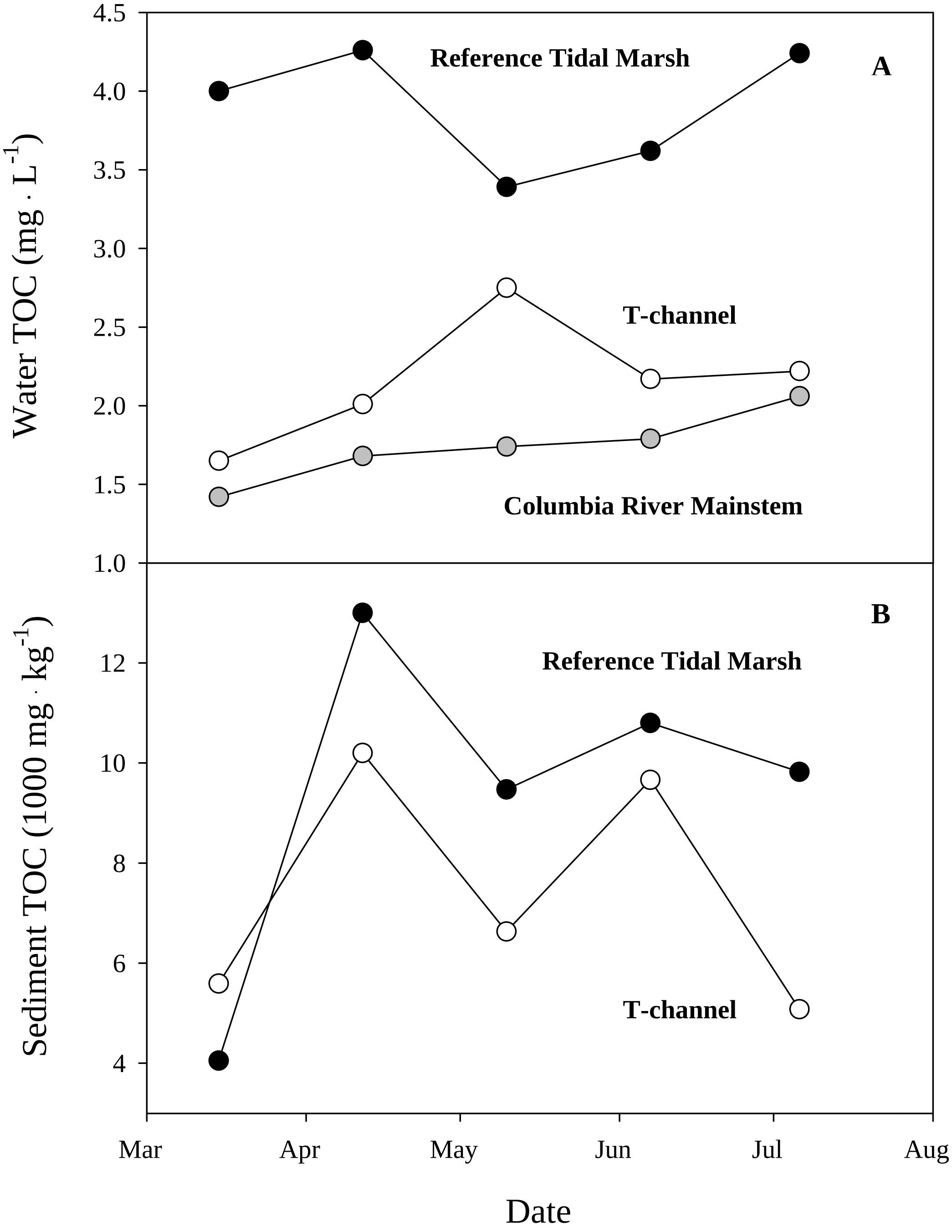

Figure 11. -Seasonal changes in total organic carbon (TOC) of the sediment (top) and the water (bottom) collected in the Reference Tidal Marsh, T-channel, and the Columbia River Mainstem, Crims Island, 2004.

DISCUSSION

Restoration activities at Crims Island will most likely benefit subyearling Chinook salmon as they were the primary salmonid species we collected during our sampling. We also collected fewer juvenile chum salmon, but they were evenly distributed across our sample sites. Subyearling Chinook salmon were present in Crims Island backwaters when we initiated sampling in mid March and probably begin arriving earlier. Rich (1920) found subyearlings in the lower Columbia River as early as December, but they were most numerous in March and April. In 2003, we did not initiate sampling until April 29 and therefore subyearling Chinook salmon accounted for a smaller overall percentage of fish catch relative to 2004 sampling. The seasonal peak of subyearlings at Crims Island in 2004 probably coincided with our first few sampling trips in late March and early April. In the future, we will begin fish sampling and residence time studies in late January or early February to better define the seasonal distribution of salmonids in Crims Island habitats.

In 2004, we improved upon our method for estimating residence time of juvenile salmon in Crim Island habitats by using Calcein to batch mark greater numbers of fish. Calcein has several advantages for estimating residence time compared to the Pan-Jet needleless inoculator that we used in 2003. Using Calcein, we were able to mark and release 2,341 fish in 2004 compared to only 272 fish marked with a Pan-Jet in 2003. Furthermore, fish were able to be marked in water and individual fish handling was eliminated. This enabled us to mark very small fry that could not have been marked using the more intensive and stressful Pan-Jet. For each release period in 2004, we captured and accumulated fish over successive days, batch marked them with Calcein, and released them all as a single release group. The benefit of this method, relative to the Pan-Jet method, was that we were able to obtain larger release groups for residence time analysis. One of the shortcomings of this approach was that we held fish in net pens for up to 3 d prior to release (two days prior to marking and one day after) to obtain sufficient numbers of fish for a release. However, this did allow us to evaluate delayed mortality from collection and marking. During our second sampling period (May 17-19) we experienced high mortality of fish prior to marking. We attribute this mortality to crowding in the beach seine with large numbers of banded killifish combined with higher water temperature at the time of capture. In the future, we will make shorter seine hauls so that fish will be less concentrated in an individual seine haul. Because Calcein can be used to mark very small fish and is likely detectable through the life of a fish, it may be an important, non-lethal monitoring tool for Pacific salmon.

Although subyearling Chinook salmon are present from March to July, residence time of individuals in Crims Island backwaters is short and fish demonstrate little site fidelity. Fish used Crims Island backwaters for only one or two tidal cycles, which was similar to residence time estimates in 2003 (Haskell et al. 2005). Residence times were longer in the T-channel than in the Reference Tidal Marsh, which was likely due to differences in habitat type and site morphology rather than the quality of the habitat. The lower portion of the T-channel contains water during low tide (subtidal) and therefore fish are more likely to reside at this site over successive tides. In contrast, the Reference

Tidal Marsh is at a higher elevation and completely dewaters during low tide (intertidal). Fish residing in the Reference Tidal Marsh are moved completely out of the site at low tide and apparently do not move back on a flood tide. In addition, since part of the Reference Tidal Marsh drains directly to the main stem Columbia River, there is likely little chance that fish exiting via this route will return. Because subtidal channels will be created during the restoration of the T-channel area, fish will not have to exit the area during low tide, which may increase their residence time in post-restoration habitats.

The short residence time in backwater habitats underscores the need for a downriver continuum of suitable rearing habitat. However, because residence time data is lacking in the Columbia River, it is unknown whether residence time in backwaters increases with decreasing distance to the Pacific Ocean. The Crims Island complex lies in the tidal freshwater portion of the Columbia River Estuary above the Estuary Turbidity Maxima Zone, a transition zone of brackish water where freshwater plankton die and become an important part of the detrital base transported to more productive areas downstream. Food resources and juvenile salmon energetic requirements are undoubtedly different in the saline lower Columbia River estuary than in the upper estuary. Fish in the lower Columbia River Estuary may spend more time in tidal marsh habitats as they adjust physiologically to the saline environment and grow prior to ocean entry. However, our capture of many newly emergent Chinook fry indicates that backwaters at Crims Island are likely among the first areas encountered by many subyearlings. Whether or not restoration increases residence time of juvenile salmon in the T-channel area, it will create additional rearing habitat and therefore a more continuous succession of habitats in the lower Columbia River. This continuum of rearing habitat is particularly important to subyearling Chinook salmon because they actively feed and intermittently rear as they migrate seaward.

Our results indicated that subyearling Chinook salmon fed more intensively, and almost exclusively, on chironomids in the Reference Tidal Marsh, but fed less intensively on a more diverse prey assemblage in the T-channel. Overall, chironomids were the most abundant invertebrate in the drift and the benthos at Crims Island and were most abundant in the Reference Tidal Marsh. Other studies of subyearling Chinook salmon diet in the Columbia River have shown the importance of aquatic insects, particularly chironomids, to subyealrings (McCabe et al. 1986; Muir and Emmett 1988). Subyearlings are opportunistic feeders and will exploit any abundant food source. Habitat restoration in the T-channel area will likely increase the overall density of chironomid prey for subyearling Chinook salmon because inundated emergent vegetation that should become established is conducive to chironomid production (Independent Scientific Group 2000). Terrestrial Homopterans are also important to subyearling Chinook salmon in the Snake and Columbia rivers (USGS unpublished data), but were not abundant in subyearling stomachs at Crims Island in spite of being abundant in the drift. It is possible that chironomids are more preferred than Homopterans at Crims Island, but exploitation of Homopterans may increase after restoration because there will be more vegetated shoreline areas that increase the opportunity of these organisms to enter the drift.

The restoration of Crims Island is intended to convert the degraded T-channel, which passes through a monoculture stand of reed canarygrass, into a series of intertidal channels with a diverse plant assemblage consisting of rushes and sedges as are present at the reference site on Gull Island (Figure 11). The establishment of emergent vegetation on Crims Island will increase detrital export to the estuary. Major changes have occurred in detrital pathways that historically existed in the Columbia River Estuary. First, overall detrital exports have been reduced due to the loss of emergent vegetation and benthic

Figure 12. -Artists' rendition of proposed restoration of the 'T-channel' area at Crims Island (U.S. Army Corps of Engineers, 2004).

algae in the lower Columbia River. Second, phytoplankton biomass has increased substantially after the construction of dams and reservoirs. Reservoir-produced phytoplankton is now transported downstream to the estuary and has partly replaced nutrient input that historically came from emergent vegetation (Prahl et al. 1997; Bottom et al. 2001). Organic carbon is now primarily supplied through autochthonous microdetritus derived from phytoplankton assemblages, whereas historically it was supplied through allochthonous macrodetritus derived from emergent vegetation (Sherwood et al. 1990) including large woody debris (LWD). The restoration of Crims Island will increase the growth and subsequent export of emergent vegetation to the estuary and help restore estuarine food webs.

The higher levels of both water and sediment total organic carbon levels in the Reference Tidal Marsh indicate higher productivity than in the T-channel or Columbia River Mainstem. The established emergent marsh vegetation community in the Reference Tidal Marsh provides a continual source of organic matter that after decomposition supplies carbon to both the water and sediments. TOC levels were probably lower in the T-channel because only in upper ends of the arms is terrestrial vegetation inundated at high tide. Reducing elevations in the restoration area should promote the establishment of an emergent vegetation community that will function more like the Reference Tidal Marsh. If so, we expect the productive capacity as measured by TOC and invertebrate density of the restored T-channel area to increase.

Restoration at Crims Island will effectively create more habitat for juvenile salmon rearing that in time will likely be of the same quality as that found in the Reference Tidal Marsh. More juvenile salmon will probably utilize restored habitats relative to unrestored habitats because restored habitats will have a greater diversity of prey items, fish will feed more intensively, and fish will have the added benefit of longer residence time. Future years monitoring should incorporate methods that not only estimate the number of fish per unit area restored, but sample in more than one habitat type within the restored area. The restored area will have both subtidal channels, which currently exist in a degraded form in the unrestored habitat, and intertidal mudflats. After restoration, both habitat types can be sampled within the restored area to better evaluate the success of restoration efforts in creating habitat complexity.

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APPENDIX

Table A.1. -Scientific name, common name, life stage, percent occurrence, and percent of total of fishes collected with beach seines and fyke nets at Crims and Gull islands, Columbia River Estuary, 2004.

Scientific Name	Common Name	Life Stage	Percent Occurrence	Percent Of Total
Catostomidae				
Catostomus spp.	Unidentified sucker	Juv	8.39	0.18
Centrarchidae				
Lepomis macrochirus[1]	Bluegill	Juv	6.45	0.07
Pomoxis nigromaculatus[1]	Black crappie	Juv	0.65	<0.01
Lepomis gibbosus[1]	Pumpkinseed	Both	11.6	0.14
Micropterus salmoides[1]	Largemouth bass	Juv	3.87	0.03
Lepomis spp.[1]	Unidentified sunfish	Juv	3.87	0.16
Clupeidae				
Alosa sapidissima[1]	American shad	Juv	4.52	0.13
Cottidae				
Cottus bairdi	Mottled sculpin	Adult	12.9	0.10
Cyprinidae				
Cyprinus carpio[1]	Common carp	Adult	0.65	0.03
Ptychocheilus oregonensis	Northern pikeminnow	Both	18.7	0.21
Mylocheilus caurinus	Peamouth	Both	19.4	1.32
Fundulidae				
Fundulus diaphanus[1]	Banded killifish	Both	70.3	17.19
Gambusidae				
Gambusia affinis[1]	Mosquitofish	Both	0.65	0.01
Gasterosteidae				
Gasterosteus aculeatus	Threespine stickleback	Both	90.3	58.45
Ictaluridae				
Ameiurus spp.[1]	Bullhead	Juv	0.65	<0.01
Pleuronectidae				
Platichthys stellatus	Starry flounder	Juv	10.3	0.11
Salmonidae				
Oncorhynchus tshawytscha	Yearling Chinook salmon	Juv	5.16	0.11
Oncorhynchus tshawytscha	Subyearling Chinook salmon	Juv	83.2	22.46
Oncorhynchus kisutch	Yearling coho salmon	Juv	3.87	0.11
Oncorhynchus kisutch	Subyearling coho salmon	Juv	2.58	0.02
Oncorhynchus keta	Chum salmon	Juv	11.61	0.21
Oncorhynchus clarki	Cutthroat trout	Juv	0.65	<0.01
Oncorhynchus mykiss	Steelhead	Juv	0.65	<0.01
Prosopium williamsoni	Mountain whitefish	Juv	3.87	0.03

[1] Exotic species

Table A.2. -Scientific name, total number, percent occurrence, and percent of total benthic invertebrates collected at Crims Island, Columbia River, 2004.

Scientific name	Total Number	Percent Occurrence	Percent of Total
Amphipoda			
Corophiidae			
Corophium salmonis	330	24.17	22.00
Corophium spinicorne	68	8.61	4.53
Gammaridae			
Gammarus spp.	3	0.56	0.20
Coleoptera			
Elmidae	3	0.83	0.20
Diptera			
Ceratopogonidae	138	22.78	9.20
Chironomidae	534	47.22	35.60
Sciomyzidae	1	0.28	0.07
Ephemeroptera			
Ephemerelidae	1	0.28	0.07
Gastropoda	11	2.22	0.73
Hemiptera			
Corixidae	2	0.28	0.13
Hydracarina	1	0.28	0.07
Nematoda	147	17.78	9.80
Odonata	1	0.28	0.07
Oligochaeta	210	30.56	14.00
Ostracoda	1	0.28	0.07
Pelecypoda			
Corbiculidae			
Corbicula fluminea[1]	49	10.56	3.27

[1] Exotic species

Table A.3. -Scientific name, life stage, and percent occurrence of drift invertebrates collected at Crims Island, Columbia River Estuary, 2004.

Scientific Name	Aquatic or Terrestrial	Total Number	Percent Occurrence	Percent of Total
Amphipoda				
Corophiidae				
Corophium salmonis	Aquatic	32	16.67	0.77
Corophium spinicorne	Aquatic	22	13.89	0.53
Gammaridae				
Gammarus	Aquatic	115	24.07	2.76
Anisogammarus	Aquatic	1	0.93	0.02
Araneae	Terrestrial	91	45.37	2.19
Coleoptera				
Cantharidae	Terrestrial	1	0.93	0.02
Chrysomelidae	Terrestrial	11	6.48	0.26
Coccinellidae	Terrestrial	7	6.48	0.17
Curculionidae	Aquatic	8	6.48	0.19
Dytiscidae	Aquatic	5	4.63	0.12
Elateridae	Terrestrial	1	0.93	0.02
Elmidae	Aquatic	41	16.67	0.98
Haliplidae	Aquatic	7	4.63	0.17
Hydrophilidae	Aquatic	3	1.85	0.07
Ptilodactylidae	Terrestrial	1	0.93	0.02
Scarabaeidae	Terrestrial	5	2.78	0.12
Staphylinidae	Aquatic	50	26.85	1.20
Unknown		40	23.15	0.96
Collembola				
Entomobryidae	Aquatic	59	26.85	1.42
Hypogastruridae	Aquatic	16	10.19	0.38
Sminthuridae	Aquatic	4	3.70	0.10
Unknown		1	0.93	0.02
Decapoda				
Astacidae				
Pacifasticus connectens	Aquatic	1	0.93	0.02
Dermaptera				
Forficulidae	Terrestrial	1	0.93	0.02
Diplopoda	Terrestrial	1	0.93	0.02
Diptera				
Ceratopogonidae	Aquatic	2	1.85	0.05
Chironomidae	Aquatic	1870	88.89	44.90
Culicidae	Aquatic	1	0.93	0.02
Dixidae	Terrestrial	178	44.44	4.27
Sciomyzidae	Aquatic	78	33.33	1.87
Syrphidae	Terrestrial	1	0.93	0.02
Tachinidae	Terrestrial	1	0.93	0.02
Tipulidae	Aquatic	8	7.41	0.19
Unknown		18	11.11	0.43
Ephemeroptera	Aquatic	2	1.85	0.05
Gastropoda	Aquatic	266	40.74	6.39
Hemiptera				
Belostomatidae	Aquatic	6	3.70	0.14
Corixidae	Aquatic	129	25.00	3.10
Gerridae	Aquatic	2	1.85	0.05
Miridae	Terrestrial	8	3.70	0.19
Saldidae	Aquatic	34	16.67	0.82
Tingidae	Terrestrial	11	3.70	0.26

Table A.3. -Continued

Scientific Name	Aquatic or Terrestrial	Total Number	Percent Occurrence	Percent of Total
Unknown		9	5.56	0.22
Homoptera				
Aphididae	Terrestrial	461	54.63	11.07
Cicadellidae	Terrestrial	48	20.37	1.15
Hydracarina	Aquatic	49	22.22	1.18
Hymenoptera				
Apidae	Terrestrial	10	8.33	0.24
Braconidae	Aquatic	61	29.63	1.46
Diapriidae	Aquatic	1	0.93	0.02
Eulophidae	Aquatic	2	1.85	0.05
Formicidae	Terrestrial	19	12.96	0.46
Mymaridae	Aquatic	2	1.85	0.05
Pteromalidae	Aquatic	1	0.93	0.02
Scelionidae	Aquatic	13	4.63	0.31
Unknown		125	44.44	3.00
Isopoda				
Asellidae	Aquatic	2	0.93	0.05
Unknown		1	0.93	0.02
Lepidoptera	Aquatic	13	11.11	0.31
Mysidacea				
Mysidae				
Neomysis mercedis	Aquatic	6	3.70	0.14
Odonata				
Coenagrionidae	Aquatic	23	13.89	0.55
Unknown	Aquatic	2	1.85	0.05
Oligochaeta	Aquatic	3	2.78	0.07
Ostracoda	Aquatic	46	5.56	1.10
Pelecypoda				
Corbiculidae				
Corbicula fluminea	Aquatic	8	1.85	0.19
Psocoptera				
Liposcelidae	Terrestrial	1	0.93	0.02
Psocidae	Terrestrial	25	14.81	0.60
Thysanoptera				
Thripidae	Terrestrial	61	22.22	1.46
Trichoptera				
Hydroptilidae	Aquatic	2	1.85	0.05
Limnephilidae	Aquatic	1	0.93	0.02
Unknown	Aquatic	31	12.04	0.74

Table A.4. -Scientific name, common name, percent occurrence, and percent of total weight of detritus collected with drift sampler at Crims and Gull islands, Columbia River Estuary, 2004.

Scientific Name	Common Name	Aquatic or Terrestrial	Percent Occurrence	Percent of Total weight
Alismataceae				
Alisma triviale	American water plantain	Aquatic	0.92	<0.01
Asteraceae				
Cirsium arvense[1]	Canada thistle	Terrestrial	1.85	0.07
Cirsium vulgare[1]	Bull thistle	Terrestrial	0.92	0.11
Betulaceae				
Alnus rubra	Red alder	Terrestrial	24.07	2.34
Ceratophyllaceae				
Ceratophyllum demersum	Coontail	Aquatic	8.33	0.03
Cornaceae				
Cornus spp.	Dogwood	Terrestrial	15.74	0.91
Cupressaceae				
Thuja plicta	Western red cedar	Terrestrial	0.92	0.01
Cyperaceae				
Carex spp.	Sedges	Aquatic	4.62	0.13
Eleocharis spp.	Needle spike rush	Aquatic	15.74	0.34
Fabaceae				
Trifolium repens[1]	White clover	Terrestrial	0.92	<0.01
Fontinalaceae				
Fontinalis antipyretica	Common water moss	Aquatic	1.85	<0.01
Haloragaceae				
Myriophyllum spicatum[1]	Eurasian water-milfoil	Aquatic	37.03	5.00
Hydrocharitaceae				
Elodea nuttallii	Nuttall's waterweed	Aquatic	15.74	0.75
Juncaceae				
Juncus spp.	Rushes	Aquatic	24.07	1.93
Lythraceae				
Lythrum salicaria[1]	Purple loosestrife	Terrestrial	0.92	0.12
Poacea				
Phalaris arundinacea[1]	Reed canary grass	Terrestrial	33.33	12.15
Potamogetonaceae				
Potamogeton crispus[1]	Curly leaf pondweed	Aquatic	18.51	0.43
Potamogeton epihydrus	Ribbonleaf pondweed	Aquatic	2.77	0.54
Potamogeton spp.	Pondweed species	Aquatic	11.11	0.26
Rosaceae				
Crataegous douglasii	Black hawthorn	Terrestrial	10.18	0.24
Rosa spp.	Wild rose	Terrestrial	18.51	0.89
Rubus spp.	Blackberry	Terrestrial	1.85	0.08
Salicaceae				
Populus trichocarpa	Black cottonwood	Terrestrial	13.88	6.28
Salix spp.	Willow species	Terrestrial	33.33	1.98
Scrophulariaceae				
Limosella spp.	Mudwort species	Aquatic	2.77	<0.01
Unidentified Wood[2]			15.74	16.82
Unidentified Debris[3]			96.29	48.44

[1] Exotic species

[2] Sticks and bark

[3] Debris included pieces of plant leaves, stems, seeds, filamentous algae, and decomposed plant matter

Table A.5. -Site, date, total number of invertebrates, mean (number · m^{-2}), standard deviation, number of taxa, diversity, and evenness of the benthic invertebrate community at Crims Island, Columbia River, March 16 through August 16, 2004. Ten replicates were collected at each site.

Site	Date	Total	Mean	STD Dev	Taxa	Diversity (H)	Evenness (J)
Mainstem	3/16	2	171.8	362.2	2	0.30	1.00
Reference	3/16	60	5,153.9	1,718.0	4	0.37	0.61
T-channel	3/16	22	1,889.8	1,708.4	4	0.38	0.64
Mainstem	3/30	10	859.0	1,214.8	4	0.47	0.79
Reference	3/30	31	2,662.9	2,669.2	4	0.43	0.71
T-channel	3/30	44	3,779.6	3,167.8	6	0.52	0.67
Mainstem	4/12	-	0	0	-	-	-
Reference	4/12	49	4,209.0	2,575.4	4	0.52	0.86
T-channel	4/12	36	3,092.4	1,774.3	7	0.60	0.71
Mainstem	4/25	10	859.0	905.5	4	0.47	0.79
Reference	4/25	48	4,123.1	2,942.4	4	0.49	0.81
T-channel	4/25	31	2,662.9	2,932.6	6	0.66	0.84
Mainstem	5/10	18	1,546.2	1,755.7	3	0.30	0.62
Reference	5/10	53	4,552.6	4,189.6	4	0.47	0.78
T-channel	5/10	22	1,889.8	1,975.5	8	0.71	0.79
Mainstem	5/24	35	3,006.5	1,729.9	5	0.39	0.56
Reference	5/24	69	5,927.0	3,808.3	6	0.57	0.73
T-channel	5/24	54	4,638.5	3,392.7	9	0.67	0.71
Mainstem	6/7	2	171.8	362.2	2	0.30	1.00
Reference	6/7	94	8,074.5	2,111.9	6	0.63	0.81
T-channel	6/7	32	2,748.8	3,259.6	6	0.58	0.75
Mainstem	6/21	75	6,442.4	2,404.1	4	0.18	0.30
Reference	6/21	63	5,411.6	3,240.7	6	0.61	0.78
T-channel	6/21	15	1,288.5	1,231.6	5	0.41	0.59
Mainstem	7/6	91	7,816.8	2,270.9	4	0.14	0.24
Reference	7/6	109	9,363.0	5,775.8	7	0.56	0.67
T-channel	7/6	17	1,460.3	1,517.8	4	0.52	0.86
Mainstem	7/19	72	6,184.7	2,422.8	2	0.06	0.18
Reference	7/19	79	6,786.0	3,174.3	6	0.55	0.71
T-channel	7/19	27	2,319.3	2,664.8	4	0.29	0.49
Mainstem	8/2	1	85.9	271.6	1	0	-
Reference	8/2	103	8,847.6	5,896.6	5	0.45	0.64
T-channel	8/2	30	2,577.0	2,805.4	5	0.37	0.52
Mainstem	8/16	36	3,092.4	1,578.7	5	0.56	0.79
Reference	8/16	46	3,951.4	2,782.0	5	0.61	0.87
T-channel	8/16	14	1,202.6	1,355.2	4	0.58	0.96
MEAN	**-**	**41.7**	**3579.1**	**2331.9**	**4.6**	**0.44**	**0.68**

Table A.6. -Site, date, total number of invertebrates, mean (number · m^{-2}), standard deviation, number of taxa, diversity, and evenness of the drift invertebrate community at Crims Island, Columbia River, March 16 through August 15, 2004. Three replicates were collected at each site.

Site	Date	Total	Mean	STD Dev	Taxa	Diversity (H)	Evenness (J)
Mainstem	3/16	11	3,149.6	2,161.7	2	0.13	0.43
Reference	3/16	219	62,706.2	7,730.9	11	0.28	0.27
T-channel	3/16	51	14,602.8	9,291.4	11	0.60	0.57
Mainstem	3/30	13	3,722.3	3,471.6	3	0.23	0.49
Reference	3/30	132	37,795.5	16,920.1	14	0.56	0.48
T-channel	3/30	23	6,585.58	4,884.4	13	1.00	0.90
Mainstem	4/12	44	12,598.5	12,516.9	7	0.43	0.51
Reference	4/12	469	134,288.5	74,837.2	21	0.52	0.39
T-channel	4/12	264	75,591.0	16,455.9	33	1.00	0.65
Mainstem	4/25	5	1,431.7	1,312.1	4	0.58	0.96
Reference	4/25	74	63,565.2	-	10	0.50	0.50
T-channel	4/25	201	57,552.2	16,898.3	27	1.04	0.73
Mainstem	5/10	6	1,718.0	859.0	4	0.58	0.96
Reference	5/10	139	39,799.8	7,305.6	10	0.46	0.46
T-channel	5/10	42	12,025.8	9,756.2	14	0.98	0.86
Mainstem	5/24	42	12,025.8	2,577.0	8	0.71	0.78
Reference	5/24	164	46,958.0	16,215.0	11	0.35	0.34
T-channel	5/24	257	73,586.7	15,588.5	33	1.17	0.77
Mainstem	6/7	15	4,294.9	4,545.3	8	0.78	0.87
Reference	6/7	33	9,448.9	5,364.4	9	0.71	0.75
T-channel	6/7	71	20,329.4	5,719.4	21	1.15	0.87
Mainstem	6/14	5	1,431.7	1,312.1	4	0.58	0.96
Reference	6/14	68	19,470.4	2,161.7	10	0.60	0.60
T-channel	6/14	163	46,671.7	6,094.2	30	1.23	0.83
Mainstem	7/6	13	3,722.3	2,761.3	4	0.41	0.68
Reference	7/6	114	32,641.6	17,372.0	16	0.74	0.61
T-channel	7/6	340	97,352.0	30,664.0	28	1.06	0.74
Mainstem	7/19	13	3,722.3	495.9	3	0.37	0.78
Reference	7/19	121	34,645.9	5,522.5	19	0.72	0.56
T-channel	7/19	389	111,382.2	12,516.9	31	0.94	0.63
Mainstem	8/2	16	4,581.3	2,624.3	6	0.65	0.83
Reference	8/2	100	28,633.0	9,461.9	14	0.80	0.70
T-channel	8/2	268	76,736.3	13,371.9	35	1.03	0.67
Mainstem	8/16	1	286.3	495.9	1	0	-
Reference	8/16	31	8,876.2	5,248.5	8	0.73	0.80
T-channel	8/16	248	71,009.7	4,408.0	30	0.98	0.66
MEAN	**-**	**115.7**	**34,303.9**	**9,969.2**	**14.3**	**0.68**	**0.67**