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Crims Island Habitat Restoration in the Columbia River Estuary-Fisheries Monitoring and Evaluation, 2006

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, near Clatskanie, Oregon, restored 38 ha (94 ac) of tidal marsh and swamp in the tidal freshwater portion of the lower Columbia River. The restoration was 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 in 2003 and 2004 prior to restoration, which began in August 2004. During 2006, the USGS began post-restoration monitoring. This report summarizes 2006 data and compares pre- and post-restoration monitoring data to evaluate project success. Because 2003 sampling did not begin until late May, after the seasonal peak of juvenile salmon abundance, pre- and post-restoration comparisons in this report are primarily between 2004 and 2006.

Restoration, which occurred from August 2004 to September 2005, reduced elevations in the interior of the island by 2 ft and increased tidal flow. The elevation reduction created 77 acres of tidal emergent marsh where none previously existed and 17 acres of intertidal channels. Cattle which had been grazing the island for over 50 years were removed. Soil excavated from the site was deposited in upland areas ringing the tidal marsh for upland forest establishment. Excavation deepened and widened an existing 'T-channel' to increase tidal flow to the interior of the island. The west arm of the existing 'T-channel' was extended westward and connected into Bradbury Slough to create a second outlet to the main river. Secondary channels were constructed off of the existing 'T-channel' and tidal mudflats were now inundated at high tide to increase rearing habitat complexity for juvenile salmonids.

Prior to restoration, 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 August. 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 Restoration Site than in the Reference Tidal Marsh before and after restoration.

Smaller subyearling Chinook consumed dipteran adults and larvae in backwater habitats and larger subyearling Chinook salmon primarily consumed *Daphnia* and *Corophium* in mainstem habitats. Chironomid larvae, *Corophium*, and oligochaetes dominated the benthic invertebrate community, while chironomid adults, aphids, and gastropods dominated the drift invertebrate community. Juvenile salmon fed more intensively in the Reference Tidal Marsh relative to the Restoration Site and the

Columbia River Mainstem prior to restoration. However, after restoration, subyearling Chinook fed more intensely and had a diet more similar to that found in the Reference Tidal Marsh. While invertebrate density did not significantly change after restoration, invertebrate diversity significantly decreased in the benthos and the drift. However, the overall abundance of chironomids actually increased in the Restoration Site after restoration. Because juvenile salmonids feed most intensively on chironomids in backwater habitats, insect diversity, while important to overall ecosystem function, may not limit the abundance of juvenile salmon.

Macro-detritus exported from Crims Island backwaters was primarily composed of reed canarygrass, black cottonwood, and Eurasian water milfoil in the unrestored habitats, but was composed primarily of sedges and rushes in the Reference Tidal Marsh. 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 unrestored habitats. Prior to restoration, total organic carbon levels were highest in the Reference Tidal Marsh coinciding with silt and sand relative to unrestored habitats that were primarily composed of silt and clay. Restoration unexpectedly exposed a layer of highly productive sediments in the restoration area. Over time, these sediments will likely stabilize to productivity levels in the Reference Tidal Marsh as newly emergent vegetation establishes.

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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 (3,000 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 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 was degraded. The restoration of Crims Island reduced the elevation of the project area by two feet to remove invasive vegetation and allow re-establishment of a tidal marsh plant community. In addition, subtidal channels were 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 monitored and evaluated the pre- and post-restoration responses of the fisheries community at Crims Island.

Our objectives in 2006 were to: 1) describe seasonal use and habitat preferences of juvenile salmon and other fishes in newly restored backwater, reference tidal marsh, and demersal mainstem habitats, 2) describe juvenile salmon diet preferences and the invertebrate community, 3) describe the plant community, macro detritus export, and productive capacity of backwater sites, and 4) create a geo referenced topographic map of Crims Island to document landscape changes resulting from restoration and those which will naturally occur over time.

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. 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 areas within the Crims Island complex (Figure 1). First, a natural tidal marsh site (hereafter referred to as Reference Tidal Marsh) 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 Reference 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 sampled the mainstem Columbia River on the north side of Gull Island (hereafter referred to as the Columbia River Mainstem). 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 mainstem. Sampling locations at the Reference Tidal Marsh and the Columbia River Mainstem were identical to those sampled in 2003 (Haskell et al. 2005) and 2004 (Haskell et al. 2006). However in 2006 we reallocated our resources toward sampling more sites in the restoration area, which provided a much larger sampling area after restoration. Therefore, while in 2004 we sampled every week, in 2006 we sampled every other week with an increased number of sampling sites within the restoration area.

Prior to restoration for 2004 sampling, we had a single sample site in the existing T-channel located at the south end of Crims Island. The T-channel was a steep banked man-made channel which ran north from Bradbury Slough into the interior portion of Crims Island and then forked into two smaller perpendicular channels, one which runs east and the other which runs west to form the 'T'. Both of these smaller channels ended in the interior of the island and regularly dewatered during low tide. The main T-channel was semi tidal and had only ingress/egress channel to the interior portion of Crims Island. Prior to restoration, the sediment in the channel bottom was clay with softer sediments which regularly sloughed from the banks. Anecdotal information and evidence of erosion indicated that the original channel was narrower and had widened substantially over time. The upland area was wet during spring and early summer and was generally vegetated with exotic reed canarygrass.

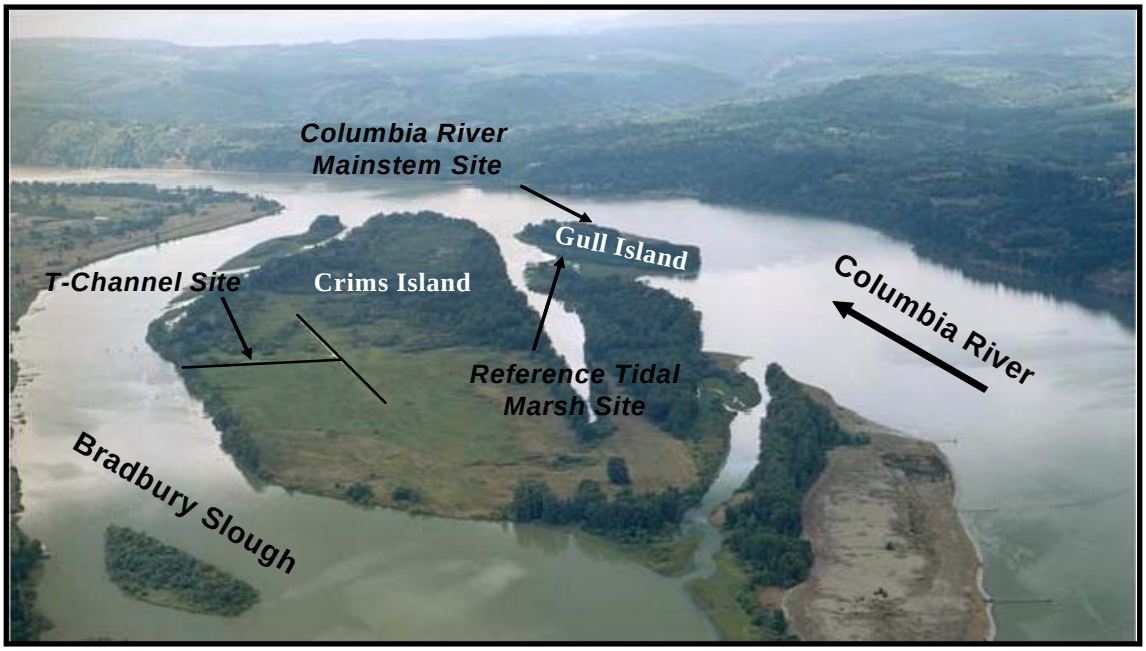

Figure 1. –Pre-restoration aerial photo of the Crims Island Complex with USGS sampling sites in 2004 (U.S. Army Corps of Engineers 2001).

After restoration, the study site at Crims Island changed dramatically and we changed our sampling locations to effectively sample newly created habitat. The main T-channel was widened and deepened and the west arm of the T-channel, which had previously ended in the interior portion of the island, was excavated westward and connected back into Bradbury Slough. This connection provided a second ingress/egress channel to the interior portion of Crims Island. These primary channels now carried too great a volume of water for us to sample with paired fyke nets as we did in 2003 and 2004. During excavation four secondary channels and numerous tertiary channels were created. We established four mini fyke net sites in tertiary channels and four beach seine sites on tidal mud flats (Figure 2). Tidal mud flats were inundated only at high tide (intertidal) while tertiary channels remained inundated throughout the tidal cycle (subtidal). Mini fyke nets had frames that were 3 ft (0.9 m) high by 4 ft (1.2 m) wide with 5 ft (1.5 m) wings that were staked to channel banks. The nets were generally fished for 2 hr on both an incoming and an outgoing tide. During four sample periods we were unable to fish mini fyke nets because the water level was too high too effectively fish them. At each of our four beach seine sites we conducted single net hauls either toward or parallel to shore.

Figure 2. -Aerial photo of Crims Island with restoration complete depicting USGS sampling sites in 2006. Photo taken in December, 2005 during low tide with tidal mud flats exposed.

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 other week from March 6 through August 9, 2006. We used beach seines and fyke nets with 4.7 cm mesh to capture fish at Crims Island. Beach seine sites were sampled by pulling the seine parallel to or toward shore for a distance of about 50 m. 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 by counting the number of individuals for each species in a single aquarium net scoop and then multiplying the numbers by the total number of net scoops. Fish identification followed Page and Burr (1991). Concurrent with beach seine 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: seine haul length, water depth, water velocity, and water temperature measured at a distance of 1, 7.5, and 15 m from shore.

Residence Time

In 2006, 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 (e.g., 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 could 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 or 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 until marking. Water temperature in the net pens was similar to that in the capture area. Methods used in marking followed those developed by Mohler (1997) for juvenile Atlantic salmon. Prior to marking, a 1.5% (15 $g \cdot L^{-1}$) 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. This technique is known as 'Osmotic Induction' and allows for rapid induction of the fluorescent dye into fish tissues. 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 in the Restoration Site and the Reference Tidal Marsh on May 2 2006. Marked fish were randomly assigned to one of two release groups. One group was released into the Restoration Site (N=932) and the other group was released into the Reference Tidal Marsh (N=447). Both releases occurred at about the same time. Beach seines and fyke nets were used to recapture marked fish from May 2 to May 7, 2006.

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 location.

Stomach Sampling

We collected stomach contents from 10 subyearling Chinook using non-lethal lavage in the Reference Tidal Marsh, Columbia River Mainstem, and the Restoration Site monthly from March through August. 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 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

We sampled drift invertebrates, benthic invertebrates, and detrital drift at the Reference Tidal Marsh, the Restoration Site, and the Columbia River Mainstem monthly. 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 neuston samples at each site using a metered 150-micron mesh drift net with a rectangular 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 neuston net was used to calculate the amount of water sampled. All samples were preserved in 95% ethanol for laboratory analysis.

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 Sea-Bird Model SBE-39 tide gauges in the Restoration Site 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. Our water depth information was also used to estimate when sampling locations were dewatered and to edit water temperature data from data loggers accordingly. We also used Onset HOBO Water Temp Pro water temperature loggers set to record water temperature every 15 min at all of our beach seine and fyke net sites.

Carbon Sampling

We collected monthly soil and water samples at Crims Island in 2006 to quantify the productive capacity of our sample sites after restoration. Sediment samples were used to estimate Total Organic Carbon (TOC) at the Restoration Site, Columbia River

Mainstem, and the Reference Tidal Marsh sites before and after restoration. We also 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 monthly 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 monthly to estimate TOC. Sediment and water samples were analyzed by Test America Analytical Testing Corporation, Beaverton, Oregon.

Plant Survey

On September 18 and October 11, 2006 we conducted a plant survey in newly restored habitat at Crims Island and the Reference Tidal Marsh following protocols developed by Roegner et al. (2006). We established linear baselines for quadrant sampling in both the Reference Tidal Marsh and the Restoration Site on Crims Island. Baselines were generally established perpendicular to the elevation gradient. Plants were identified following Cooke (1997) and Hitchcock and Cronquist (1976). Plants were grouped into wetland classification types following U.S. Fish and Wildlife Service (1989).

Topographic and Bathymetric Survey

To document landscape changes resulting from restoration, we conducted a topographic and bathymetric survey of Crims Island and the Reference Tidal Marsh for comparison to a similar survey we conducted in 2003 prior to restoration. The topographic survey was conducted using a Trimble 5700 RTK (Real Time Kinematic) GPS (Global Positioning System). For our survey we used an established control point on Crims Island and three rovers to collect geo-referenced elevation points at a one second interval. The RTK GPS has an advertised horizontal accuracy of $\pm$1.45 cm and a vertical accuracy of $\pm$ 2.45 cm. To collect bathymetric data in subtidal channels, we used a Biosonics DT-X Series Digital Echosounder and transducer with integrated RTK GPS. Using this system we were able to collect over 200,000 geo-referenced elevation points in the Restoration Site on Crims Island and the Reference Tidal Marsh. The survey not only documents landscape changes resulting from restoration but provides a benchmark to examine future changes that will naturally occur over time.

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°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, dried, and weighed.

Data Analysis

Subyearling Chinook salmon fork length and Index of Feeding, benthic and drift invertebrate density, and benthic and drift invertebrate diversity were compared using two-way analysis of variance (ANOVA) with the main effects sample site (Reference Tidal Marsh, Columbia River Mainstem, Restoration Site) and year (2004, 2006). Interactive effects between year 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 invertebrate abundances were transformed ($\log_{10}$) 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:

$$H = \underset{i=1}{\overset{k}{p_i}} \log_{10} p_i$$

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 of 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

Fish assemblages were primarily composed of threespine stickleback (*Gasterosteus aculeatus*), peamouth (*Mylocheilus caurinus*), subyearling Chinook salmon, and banded killifish *(Fundulus diaphanous*). Three-spine stickleback were the most abundant fish collected in seine hauls and fyke nets, representing over 62 % of the total catch (Table A.1.). Eleven of the twenty one species encountered were exotic (52 %). Banded killifish accounted for the vast majority of exotic fish captured. On May 6, 2006, we captured an Amur Goby (*Rhinogobius brunneus*) at one of our fyke net locations. The fish, native to eastern Asia and named for the Amur River, was the first ever recorded in the Columbia River, though some have been recorded in the tributary, East Fork Lewis River. The identity of the specimen was verified by Dr. Barbara Shields, a geneticist at Oregon State University.

Subyearling Chinook Salmon Abundance and Size

All salmonids collected were juveniles and nearly all of these were subyearling Chinook salmon. In total, we collected 6,340 juvenile salmonids, of which 6,282 were subyearling Chinook salmon, 45 were juvenile chum salmon, and 13 were yearling Chinook salmon. Our sampling indicated that juvenile salmon were present in Crims Island backwaters when we initiated sampling in early March and persisted until early July. Juvenile chum salmon were captured in March and April. 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 where small numbers persisted until early August (Figure 3). 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.

After restoration the number of subyearling Chinook utilizing Crims Island increased and density was lower than that observed in the Reference Tidal Marsh. Prior to restoration where we sampled the entire water volume moving into Crims Island, fyke net CPUE in the Restoration Site was $11.46 \cdot hr^{-1}$ (range 0 to $74.98 \cdot hr^{-1}$), whereas after restoration, mean fyke net catch was $4.98 \cdot hr^{-1}$ (range 0 to $39.13 \cdot hr^{-1}$) subyearling Chinook $\cdot hr^{-1}$ from four tertiary channels, a small fraction of the entire water volume. In 2006, mean beach seine density in the Reference Tidal Marsh was $0.032 \cdot m^{-2}$ (range 0 to

0.150 · m^{-2}) and in the Restoration Site mean density was 0.016 · m^{-2} (range 0 to 0.044 · m^{-2}).

Comparisons between pre- and post-restoration subyearling Chinook salmon timing in the Restoration Site revealed that the seasonal presence of juvenile salmon was similar with fish arriving at the onset of sampling in early March and persisting into early July, however the timing of peak abundance was different. Beach seine densities from 2006 in the Reference Tidal Marsh and the Restoration Site exhibited similar peaks in mid May to early June, though densities were generally greater in the Reference Tidal Marsh (Figure 4). Prior to restoration, subyearling Chinook densities were greatest in March and early April and then declined steadily throughout the season. Seasonal density comparisons between fyke net and beach seine were generally different; however, high water precluded fyke net sampling during four sample periods, which could have altered the general trend.

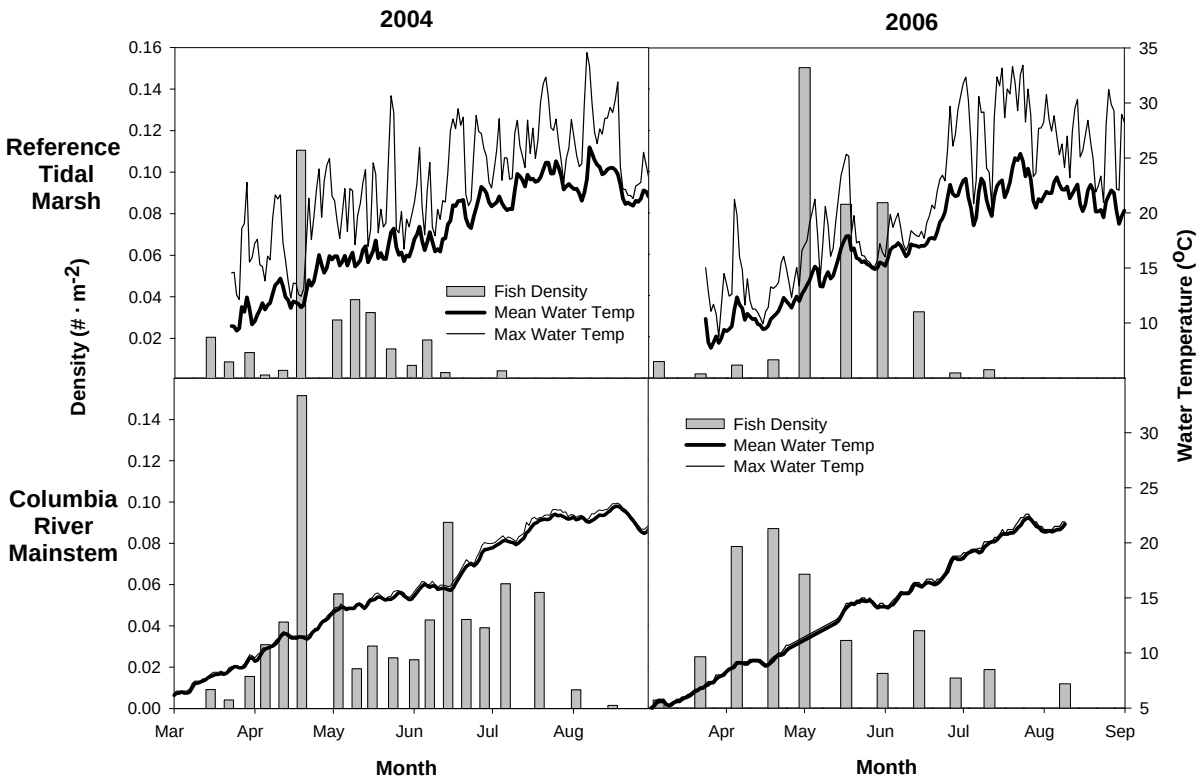

Figure 3. -Subyearling Chinook salmon density in the Reference Tidal Marsh (top panels) and the Columbia River Mainstem (bottom panels) in 2004 (left panels) and in 2006 (right panels).

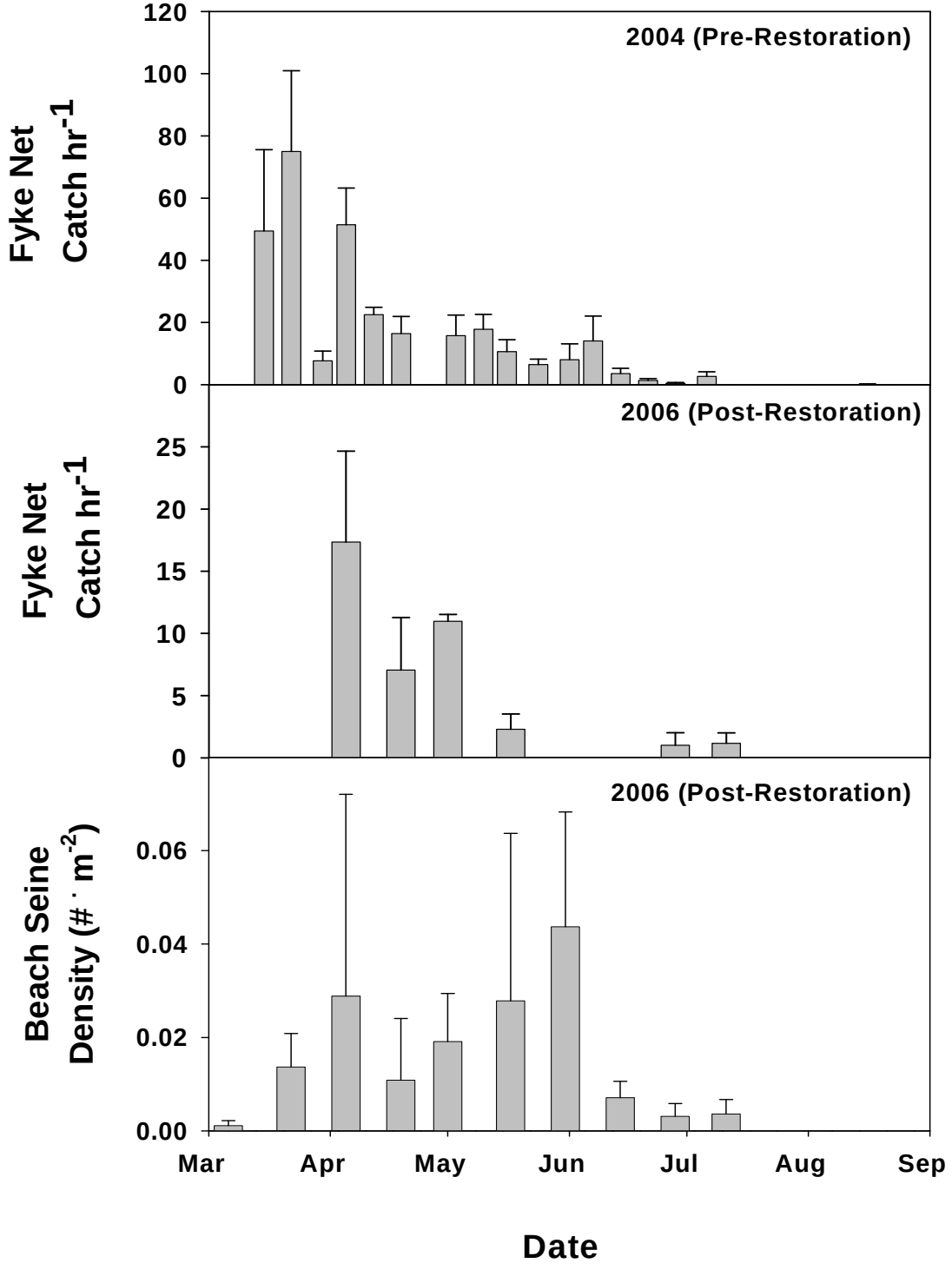

Figure 4. –Mean (STD) subyearling Chinook salmon CPUE collected using fyke nets at a single location in the Restoration Site in 2004 prior to restoration (top panel), mean (STD) CPUE using mini fykes at four locations in smaller tertiary channels in 2006 after restoration (middle panel), and mean (STD) density collected using beach seines at four locations (bottom) at the Restoration Site in 2006.

We captured and measured 1,140 subyearling Chinook salmon at our sample sites in 2006. Subyearling Chinook salmon were generally smaller at the Reference Tidal Marsh and the Restoration Site compared to the Columbia River Mainstem prior to restoration, however, size distributions for the three sites were similar after restoration (Figure 5). The majority of subyearlings captured in the Restoration 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 6). Increases in mean fork length in the Reference Tidal Marsh and the Restoration Site were detectable over time as mean fish size increased from 40 to 60 mm. Patterns at the Columbia River Mainstem site were more variable over time. Pre- and post-restoration comparisons of fish size indicated that after restoration larger subyearling Chinook salmon appeared in the Restoration Site later in the sampling season as opposed to prior to restoration (Figure 6). During mid May to mid July 2006, mean sizes ranged from 60 to 80 mm whereas in 2004, prior to restoration, fish mean size was about 60 mm.

Larger subyearling Chinook were present in the Restoration Site after restoration compared to before restoration, however, a similar pattern was also found in our tidal marsh reference site where no restoration occurred. A two-way ANOVA revealed that both main effects (site and year) and the interaction effect for subyearling Chinook salmon fork length were all significant; therefore we analyzed each effect separately. One-way ANOVA's for year at each site revealed that subyearling Chinook salmon fork length was significantly greater in the Restoration Site after restoration in 2006 (FL = 61.22 mm) than prior to restoration in 2004 (FL = 48.11 mm), however, subyearling Chinook salmon fork length was also significantly greater in the Reference Tidal Marsh in 2006 (FL = 59.08 mm) when compared to 2004 (FL = 52.22 mm) where no restoration occurred. In the Columbia River Mainstem, fork lengths from 2006 (FL = 60.88 mm) and 2004 (FL = 59.22 mm) were not significantly different. Site specific ANOVA's for fork length revealed that while in 2006 the three sites were not significantly different, in 2004, subyearling Chinook fork length in the Columbia River Mainstem (FL = 59.22 mm) was significantly greater than in the Reference Tidal Marsh (FL = 52.22 mm), which was significantly different than fork length in the Restoration Site (FL = 48.11 mm).

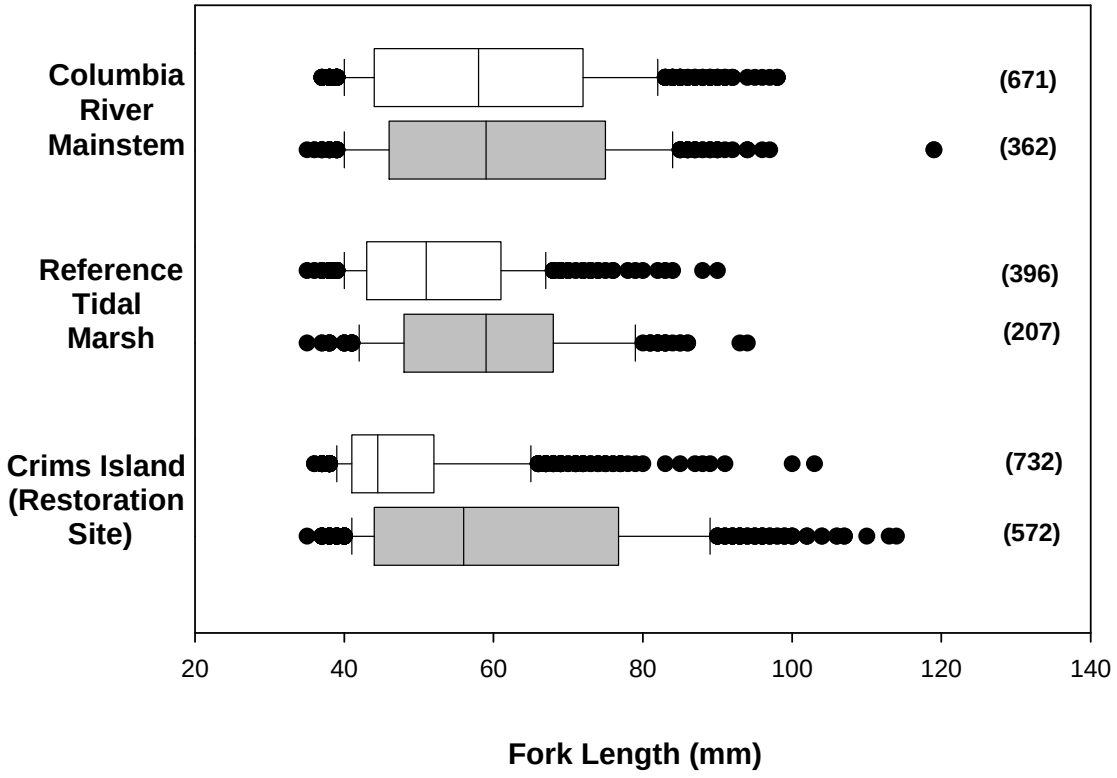

Figure 5. -Fork length characteristics of subyearling Chinook salmon collected from three different locations at Crims Island in 2004 prior to restoration (white boxes) and in 2006 after restoration (gray boxes). Data are presented in quartiles with boxes representing the 25th and 75th percentiles, the box mid point identifying the median, and whiskers identifying the 10th and 90th percentiles. Values outside whiskers are represented by solid circles and the numbers measured are in parentheses.

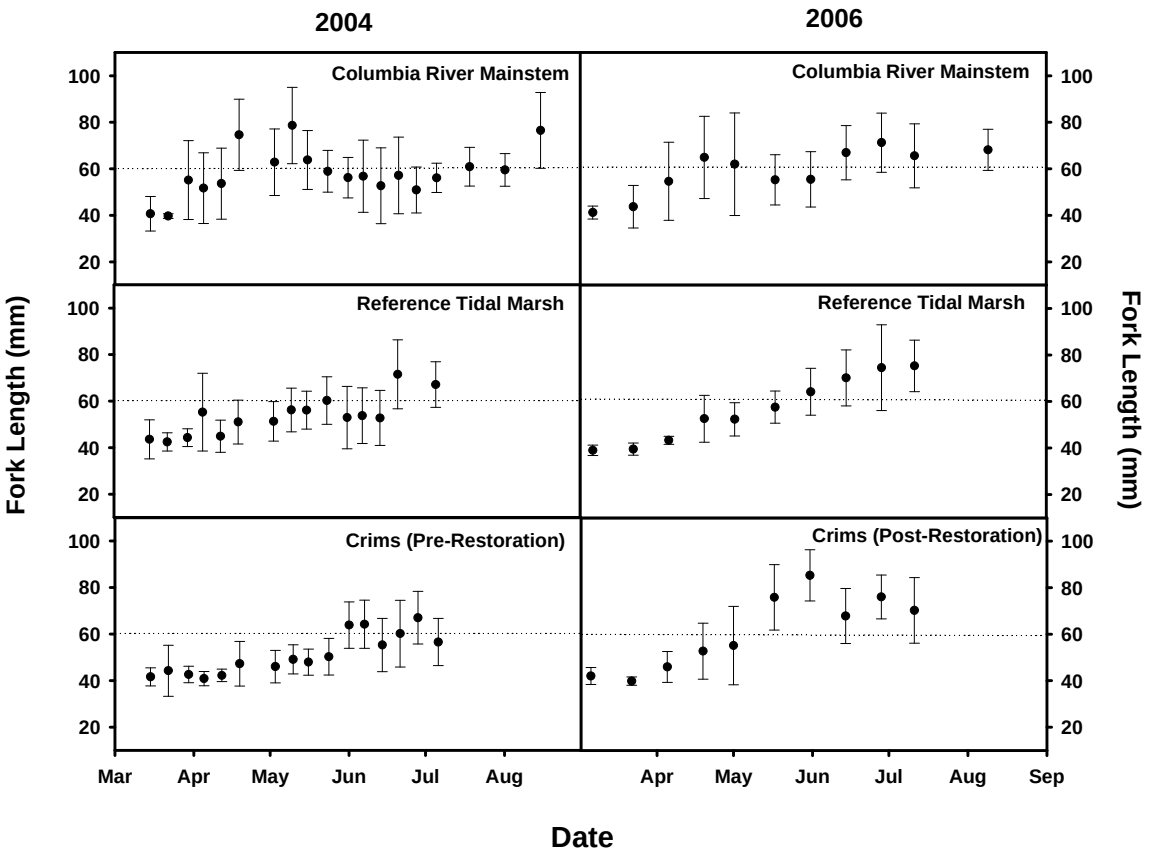

Figure 6. –Seasonal variation in subyearling Chinook salmon mean (± SD) fork length collected at the Columbia River Mainstem, Reference Tidal Marsh, and the Crims Island Restoration Site in 2004 prior to restoration (left panels) and after restoration in 2006 (right panels). Dashed reference line placed at 60 mm for site comparisons.

Residence Time

We released 447 and 932 subyearling Chinook salmon in the Reference Tidal Marsh and Restoration Site, respectively, in 2006 to estimate site specific residence time. 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. Median residence times of fish in the Restoration Site (median= 50.2 hr) in 2006 were longer compared to before restoration (median = 12.7 hr) but low sample sizes and varied effort between the two years make meaningful comparisons difficult. In the Reference Tidal Marsh in 2004, pre-restoration monitoring, median residence time was substantially less (median = 1 hour) than in 2006 monitoring (median residence = 43.1 hours) (Figure 7).

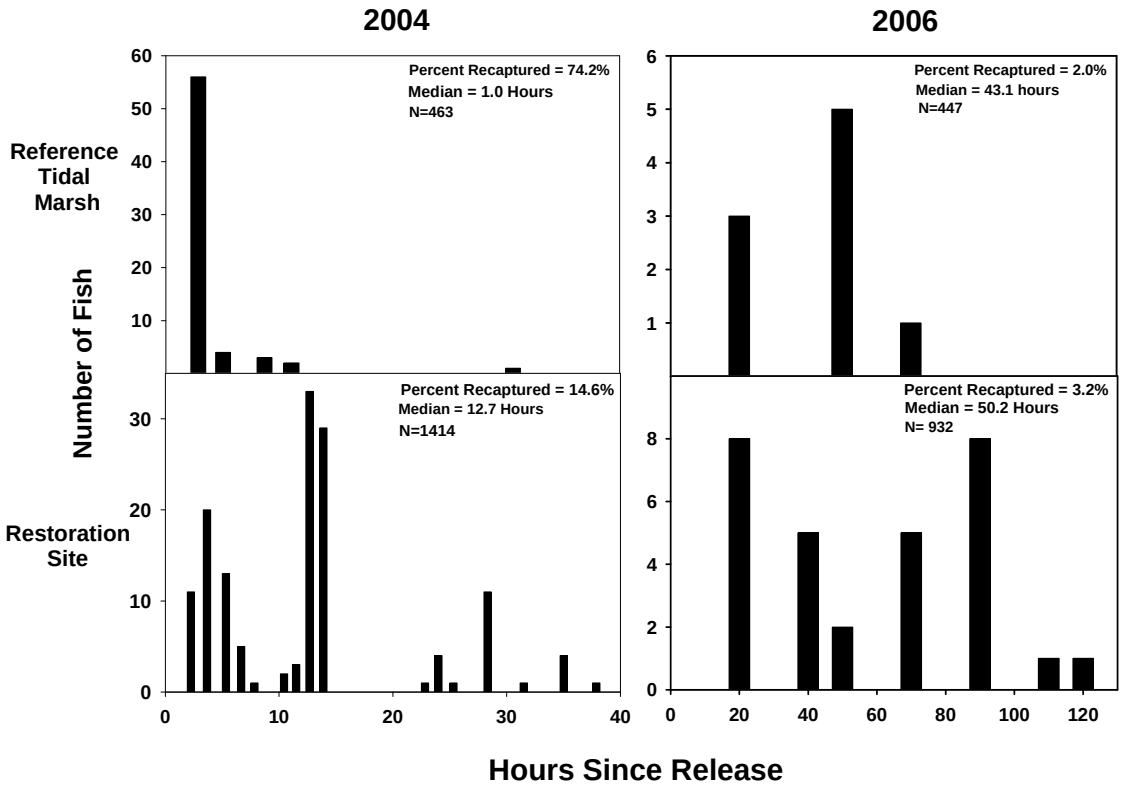

Figure 7. –Residence times of subyearling Chinook salmon marked with Calcein and released into the Reference Tidal Marsh (top panels) and the Restoration Site on Crims Island (bottom panels) prior to restoration in 2004 (left panels) and after restoration in 2006 (right panels).

Prey Selection and Feeding

After restoration, percent IRI values in the Restoration Site were more similar to those in the Reference Tidal Marsh than they were to the T-channel in 2004. Subyearling Chinook salmon primarily ate Dipterans in the Reference Tidal Marsh and a combination of *Daphnia*, amphipods (*Corophium*), and Dipterans in the Restoration Site and the Columbia River Mainstem prior to restoration; however after restoration fish in the Restoration Site consumed a much higher IRI percentage of Dipterans (Figure 8). When the components used for calculating IRI were examined individually, they revealed that Dipterans represented the highest percentage by number of prey items in the Reference Tidal Marsh, while *Daphnia* represented the highest percentage by number in the Columbia River Mainstem, and the Restoration Site (Table A.2.). The highest percentage by weight was dominated by Dipterans at the Reference Tidal Marsh and Restoration Site, but by Amphipods at the Columbia River Mainstem. Over the entire sample period in 2004, 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 Restoration Site. Over a similar sampling period in 2006 we found 0 empty stomachs in the Reference Tidal Marsh, 2 empty stomachs (3.3%) in the Columbia River

Mainstem, and 2 empty stomachs (4.0%) in the Restoration Site after restoration. We did not find any evidence that prey selection varied seasonally before or after restoration.

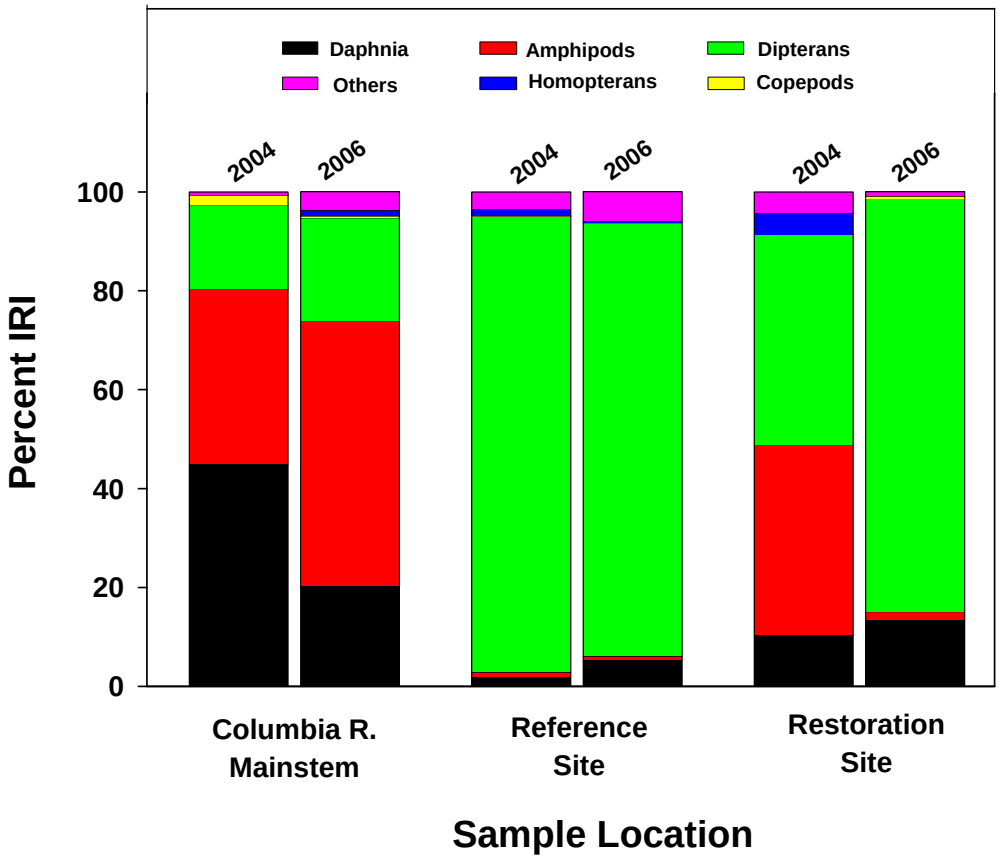

Figure 8. –Index of relative importance (IRI) of subyearling Chinook salmon feeding in the Columbia River Mainstem, Reference Tidal Marsh, and the Restoration Site in 2004 prior to restoration (left bars at each site) and in 2006 after restoration at the Restoration Site (right bars at each site).

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 Restoration Site, and the Columbia River Mainstem sites before and after restoration (Figure 9). From the onset of sampling in mid March until mid May, the time of greatest Chinook salmon abundance, IF values in the Restoration Site were far lower than those observed in the Reference Tidal Marsh and the Columbia River Mainstem prior to restoration. After restoration, IF values in the Restoration Site increased substantially and were generally higher than those observed for the Columbia River Mainstem but lower than those observed for the Reference Tidal Marsh.

Our analysis indicated no significant effect of restoration on subyearling Chinook Index of Feeding. ANOVA revealed no significant yearly differences in IF, but

that IF in the Reference Tidal Marsh was significantly greater than IF in the Restoration Site and the Columbia River Mainstem ($F = 26.93$, $P < 0.05$). Index of feeding in the Restoration Site was significantly greater than IF in the Columbia River Mainstem, but there was no significant difference in IF in the Restoration Site between 2004 and 2006. There was no significant interaction between our main effects variables (year, site).

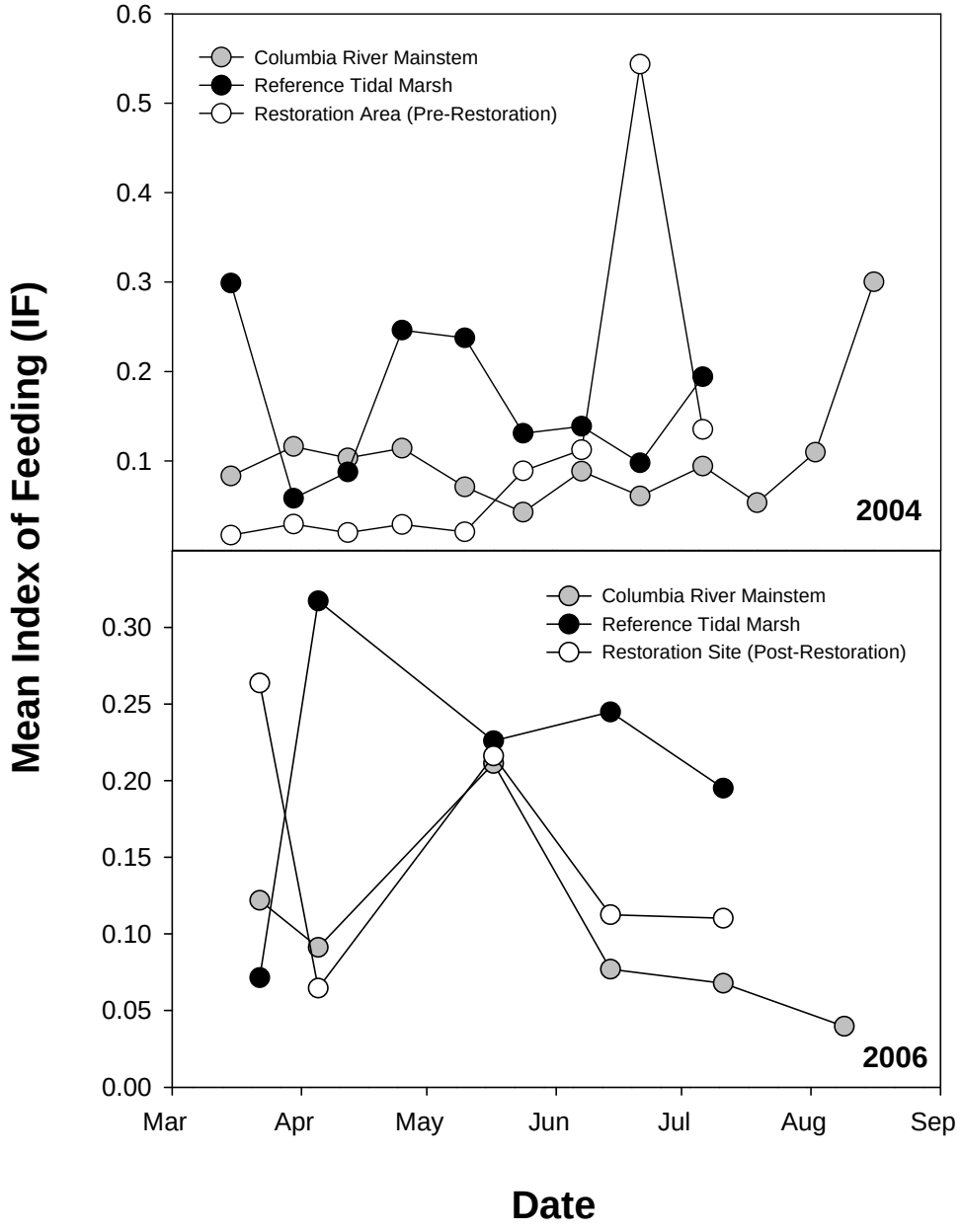

Figure 9. –Seasonal changes in mean index of feeding (IF) for subyearling Chinook salmon collected at the Columbia River Mainstem (black circles), Reference Tidal Marsh (gray circles), and the Restoration Site on Crims Island (white circles) in 2004 prior to restoration (top panel) and in 2006 after restoration (bottom panel). Each point represents the mean of replicates (usually 10 fish) collected at each site for each sample period.

Benthic Invertebrates

Benthic invertebrate density was generally greatest in the Reference Tidal Marsh, followed by the Restoration Site, and the Columbia River Mainstem (Table A.6.). The benthic invertebrate community at all sites was dominated by chironomid larvae (Diptera:Chironomidae) (30.7%), oligochaetes (28.3 %), and *Corophium* (15.0%) (Table A.3.). In 2004, mean abundance ranged from 0 to 7,816 $\cdot$ m^{-2} in the Columbia River Mainstem, 2,662 to 9,362 $\cdot$ m^{-2} in the Reference Tidal Marsh, and from 1,202 to 4,638 $\cdot$ m^{-2} in the Restoration Site. In 2006, mean abundance ranged 515 to 5,755 $\cdot$ m^{-2} in the Columbia River Mainstem, 4,380 to 13,400 $\cdot$ m^{-2} in the Reference Tidal Marsh, and from 944 to 5,497 $\cdot$ m^{-2} in the Restoration Site (Figure 10). Prior to restoration the overall density of chironomid larvae in the benthos was 2,677.18 $\cdot$ m^{-2} and 1,059.42 $\cdot$ $^{-2}$ in the Reference Tidal Marsh and the Restoration Site, respectively. After restoration the density of chironomid larvae was 2,247.69 $\cdot$ m^{-2} and 1,803.88 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site.

Our analysis revealed no significant difference in benthic invertebrate density resulting from restoration. There was a significant interaction between our main effects variables year and site (ANOVA, $F = 5.74$, $P = 0.003$), so we analyzed our main effects separately. When examined without the effect of site (each site separately), the Reference Tidal Marsh and the Columbia River Mainstem both had significantly greater densities of benthic invertebrates in 2006 than in 2004, however, there was not a significant difference in benthic invertebrates at the Restoration Site between 2004 (mean = 2,462.4 $\cdot$ m^{-2}) and 2006 (mean = 2,376.5 $\cdot$ m^{-2}). When examined without the effect of year (each year separately), all sites were significantly different from one another in both 2004 and 2006. In 2004, benthic invertebrate density was greatest in the Reference Tidal Marsh, Restoration Site, and Columbia River Mainstem, respectively. In 2004, benthic invertebrate density was greatest in the Reference Tidal Marsh, Columbia River Mainstem, and the Restoration Site, respectively. Therefore it appears in a relative sense, benthic invertebrate density decreased in the Restoration Site after restoration, though the difference was not significant, and density became less similar than that observed in the Reference Tidal Marsh.

Restoration reduced the diversity of benthic invertebrates in the Restoration Site. In our analysis of benthic invertebrate diversity, we had a significant interaction between year and site ($F = 8.04$, $P < 0.05$). Therefore, we analyzed the effect of restoration and sample site on benthic invertebrate diversity separately. When examined without the effect of sample site, our one-way ANOVA's and means test revealed significantly less benthic invertebrate diversity after restoration in 2006 at Crims Island than prior to restoration in 2004 ($F = 13.19$, $P < 0.05$). In the Reference Tidal Marsh, benthic invertebrate diversity was significantly greater in 2006 relative to 2004, and in the Columbia River Mainstem there was no significant difference between 2004 and 2006 benthic invertebrate diversity. When the benthic invertebrate diversity at individual sites was examined without the effect of year, our ANOVA's revealed that benthic invertebrate diversity values in 2004 at the Restoration Site and Reference Tidal Marsh were significantly greater than the Columbia River Mainstem, but not significantly

different from one another. However, in 2006, benthic invertebrate diversity at the Reference Tidal Marsh was significantly greater than both the Restoration Site and the Columbia River Mainstem.

Drift Invertebrates

Drift invertebrate density was generally greatest in the Reference Tidal Marsh followed by the Restoration Site, and the Columbia River Mainstem (Table A.7.). Chironomid (Diptera:Chironomidae) adults (46.1%), springtails (Collembola:Entomobryidae) (18.0%), and aphids (Homoptera:Aphidae) (8.9%) dominated the drift invertebrate community (Table A.4.). Prior to restoration, mean drift invertebrate density ranged from <0.01 to 0.25 $\cdot$ m^{-2} in the Columbia River Mainstem, 0.03 to 0.89 $\cdot$ m^{-2} in the Restoration Site, and 0.06 to 1.86 $\cdot$ m^{-2} in the Reference Tidal Marsh. After restoration mean drift invertebrate density ranged from 0.01 to 0.08 $\cdot$ m^{-2} in the Columbia River Mainstem, 0.06 to 0.27 $\cdot$ m^{-2} in the Restoration Site, and 0.06 to 0.67 $\cdot$ m^{-2} in the Reference Tidal Marsh (Figure 10). Prior to restoration, chironomid adults were found at overall densities of 0.194 $\cdot$ m^{-2} and 0.104 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site. After restoration, chironomid adults were found at densities of 0.087 $\cdot$ m^{-2} and 0.116 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site. Although total drift invertebrate density generally decreased in the Restoration Site after restoration, it appears that chironomid (the most abundant invertebrate), density increased.

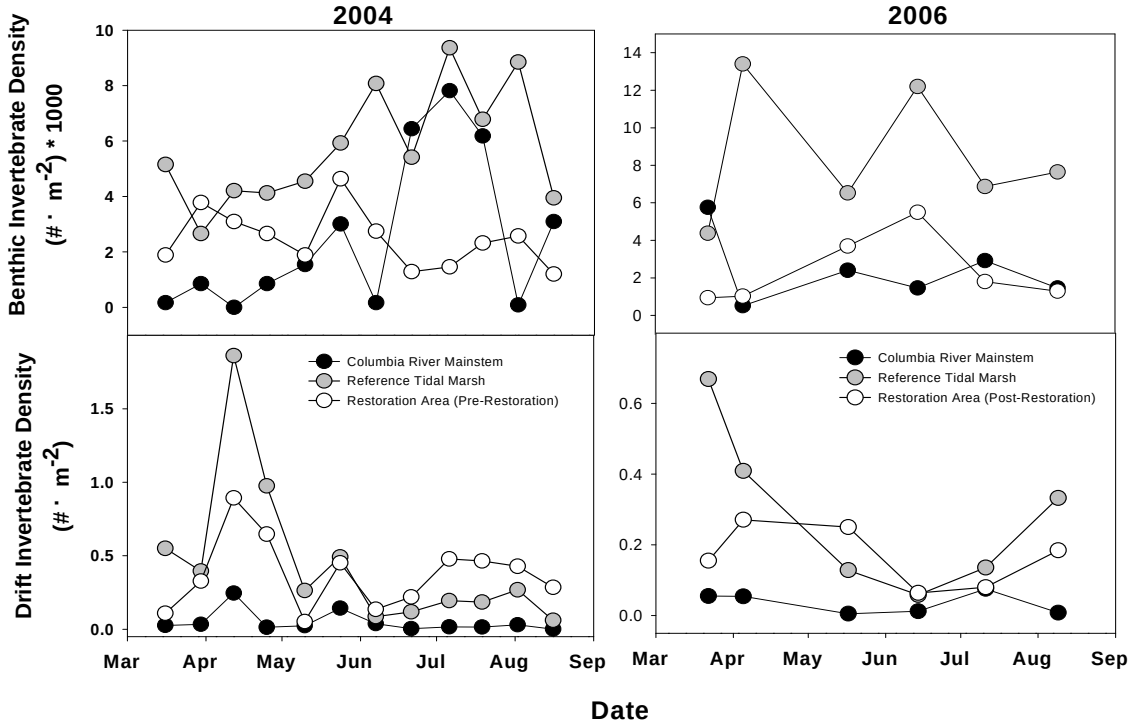

Figure 10. –Seasonal change in mean benthic invertebrate density (top panels) and mean drift invertebrate density (bottom panels) collected at from the Columbia River Mainstem (black dots), the Reference Tidal Marsh (gray dots), and the Restoration Site on Crims Island (white dots) in 2004 prior to restoration (left panels) and in 2006 after restoration (right panels). Each point represents the mean of three replicates for each sample period at each site.

Although densities in 2004 before restoration were substantially greater than densities after restoration, our analysis revealed no significant difference in drift invertebrate density resulting from restoration,. Our two-way ANOVA indicated that drift invertebrate density was significantly greater in the Reference Tidal Marsh and the Restoration Site relative to the Columbia River Mainstem (ANOVA, $F = 22.17$, $P < 0.01$) and that drift invertebrates were significantly greater in 2004 than in 2006 (ANOVA, $F = 5.39$, $P = 0.02$). However, drift invertebrate density in the Reference Tidal Marsh and the Restoration Site were not significantly different from each other. There was no significant interaction between our main effects variables (year and site). Therefore, drift invertebrate densities in the Restoration Site before (mean = $0.350 \cdot m^{-2}$) and after restoration (mean = $0.168 \cdot m^{-2}$) were not significantly different because densities in our other sites were also greater in 2004.

Restoration decreased drift invertebrate diversity at the Restoration Site on Crims Island. Our ANOVA for drift invertebrate diversity revealed a significant interaction between year and site ($F = 11.72$, $P < 0.05$), therefore we analyzed the main effects separately by completing two one-way ANOVA's. When these main effects were examined individually, drift invertebrate diversity was significantly lower in the Restoration Site in 2006 than in 2004, however in the Reference Tidal Marsh and the Columbia River Mainstem sites; there was no significant difference between 2004 and 2006. When site specific differences were analyzed, drift invertebrate diversity was significantly greater in 2004 in the Restoration Site than in the Reference Tidal Marsh and the Columbia River Mainstem, but in 2006, all three sites were not significantly different from one another.

Detritus

The amount of macro detritus available for export generally decreased after restoration. Prior to restoration, detritus collected from Crims Island was primarily composed of reed canarygrass (12.2%), black cottonwood (6.3%), and Eurasian water-milfoil (5.0%) with the remainder being unidentifiable debris and wood (Table A.5.). After restoration detritus collected from Crims Island was primarily composed of reed canarygrass (16.0%), willow (6.6%), and sedges (4.6%) There were no site specific seasonal trends in detritus; however, detritus collected in the Restoration Site was composed primarily of reed canarygrass and Eurasian water-milfoil, while detritus from the Reference Tidal Marsh was primarily composed of rushes and sedges. Prior to restoration, mean weights of detritus were $0.97 \text{ mg} \cdot m^{-2}$, $17.79 \text{ mg} \cdot m^{-2}$, and $51.36 \text{ mg} \cdot m^{-2}$ for the Columbia River Mainstem, the Reference Tidal Marsh, and the Restoration Site, respectively. After restoration, mean weights of detritus were $0.49 \text{ mg} \cdot m^{-2}$, $3.57 \text{ mg} \cdot m^{-2}$, and $2.64 \text{ mg} \cdot m^{-2}$ for the Columbia River Mainstem, the Reference Tidal Marsh, and the Restoration Site, respectively. The large decrease in mean detrital weight was the result of far less wood, debris, and reed canarygrass being collected in the Restoration Site after restoration in 2006, though a similar yet less dramatic decrease was also observed in the Reference Tidal Marsh.

Sediment Characteristics

Sediments at the Columbia River Mainstem and the Reference Tidal Marsh sites were generally similar to each other but differed from those in the Restoration Site. Prior to restoration, median grain size was greatest in the Columbia River Mainstem (0.18 mm) and smallest in the Restoration Site (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 Restoration Site sediment was predominately composed of silt and clay with small amounts of sand. After restoration, the Restoration Site exhibited a higher percentage of sand and a lower percentage of clay and silt. In the Reference Tidal Marsh we observed a smaller proportion of sand and a larger proportion of silt in 2006 relative to samples collected in 2004 (Table 1).

Table 1. -Median grain size, percent sand, percent silt, and percent clay from sediment samples collected prior to restoration on March 16, 2004 and after restoration on March 23, 2006 at the Columbia River Mainstem, the Reference Tidal Marsh, and the Restoration Site on Crims Island.

Location Sediment Parameter	**2004**	**2006**
Columbia River Mainstem		
Median Grain Size (mm)	0.180	0.170
Percent Sand	96.2	93.1
Percent Silt	2.3	6.1
Percent Clay	1.5	0.8
Reference Tidal Marsh		
Median Grain Size (mm)	0.160	0.087
Percent Sand	86.4	64.2
Percent Silt	10.6	30.9
Percent Clay	3.0	5.0
Restoration Site	**Pre-Restoration**	**Post-Restoration**
Median Grain Size (mm)	0.008	0.037
Percent Sand	1.6	39.9
Percent Silt	59.5	44.3
Percent Clay	38.9	15.9

In the Restoration Site, productivity increased by an order of magnitude after restoration (Figure 11). Prior to restoration, sediment TOC values ranged from 5.08 to 10.20 $g \cdot kg^{-1}$ in the Restoration Site and after restoration in 2006, TOC values ranged from 40.00 to 251.00 $g \cdot kg^{-1}$. Sediment data collected in 2003 by the U.S. Army Corps of Engineers at Crims Island indicated TOC values ranging from 5.4 $g \cdot kg^{-1}$ to 36.6 $g \cdot kg^{-1}$ (U.S. Army Corps of Engineers 2003). TOC levels in both water and sediments were generally higher in the Reference Tidal Marsh in 2006 relative to 2004, however in the Restoration Site there was a decrease in water TOC levels after restoration. Water TOC values ranged from 3.39 to 4.26 $mg \cdot L^{-1}$ prior to restoration, and from 1.99 to 3.64 $mg \cdot L^{-1}$ after restoration. In the Columbia River Mainstem, water and sediment TOC levels were low and were occasionally less than the detection limit.

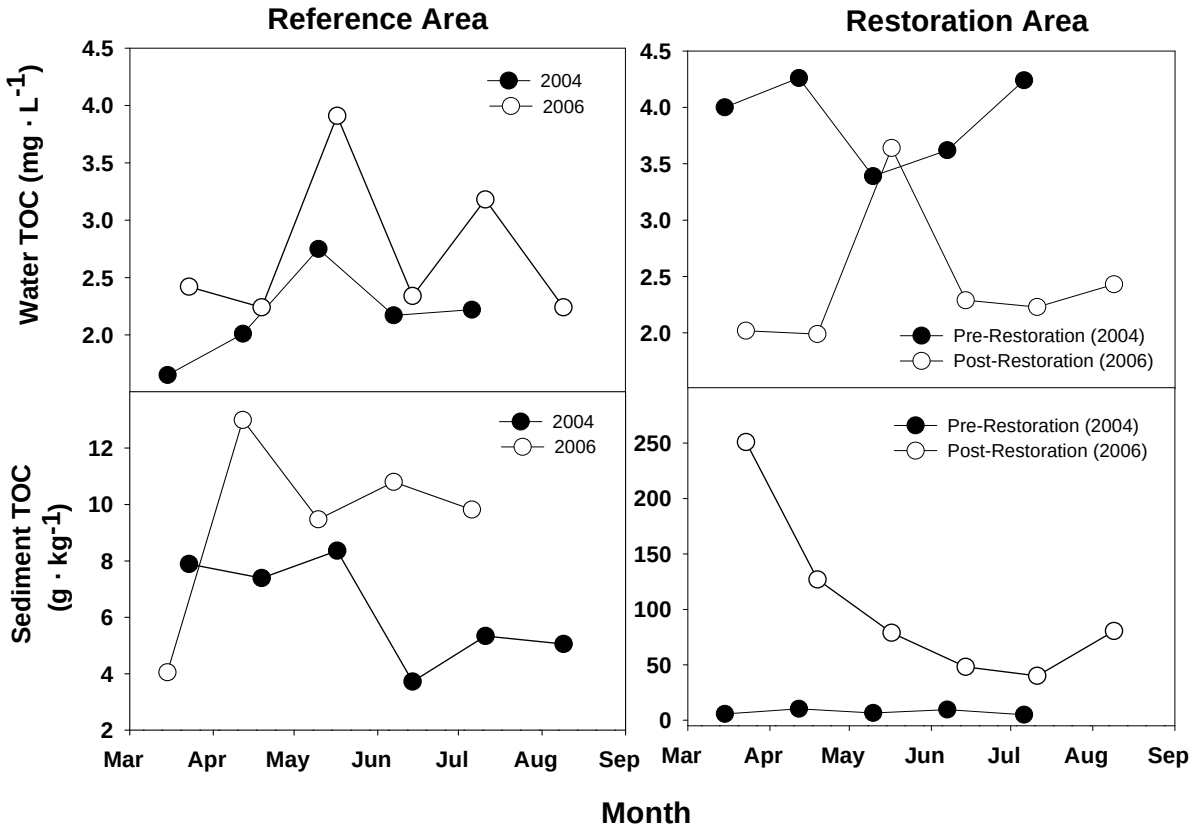

Figure 11. –Seasonal changes in total organic carbon (TOC) in water samples (top panels) and sediment samples (bottom panels) collected in the Reference Tidal Marsh (left panels) and Crims Island Restoration Site (right panels) prior to restoration in 2004 (black circles) and after restoration in 2006 (white circles).

Plant survey

Our plant survey found 38 species of plants in the Restoration Site and 16 species of plants in the Reference Tidal Marsh (Table A.8.). Of the 38 species of plants collected in the Restoration Site, 5 (13.2%) were introduced species, while in the Reference Tidal Marsh, 2 out of 16 (12.5%) species encountered were introduced. At the Reference Tidal Marsh, we encountered nodding beggar-ticks (*Bidens cernua*) and birdsfoot-trefoil (*Lotus corniculatus*). In the Restoration Site we encountered the introduced species: celery-leaved buttercup (*Ranunculus sceleratus*), purple loosestrife (*Lythrum salicaria*), threesquare tule (*Scirpus triqueter*), marsh cudweed (*Gnaphalium uliginosum*), and nodding beggar-ticks. The invasive, reed canarygrass (*Phalaris arundinacea*), which was abundant at Crims Island before and after restoration, was generally restricted to upland areas and was not encountered in our surveys.

Topographic and Bathymetric Survey

During our post-restoration elevation survey we collected over 200,000 geo-referenced elevation points at Crims Island to document landscape changes occurring from restoration and to provide a benchmark for future changes. Elevation gradients

clearly defined all excavated channels resulting from restoration and showed that 2-3 ft. of elevation had generally been removed from the interior portion of the island and that newly excavated channels were now present (Figure 12). From our survey it was evident that the two openings to Crims Island were being widened and deepened by the incoming tide. Smaller, newly formed pilot channels in the interior portion of the island, were too small to be captured by our survey, but were visually evident in many places.

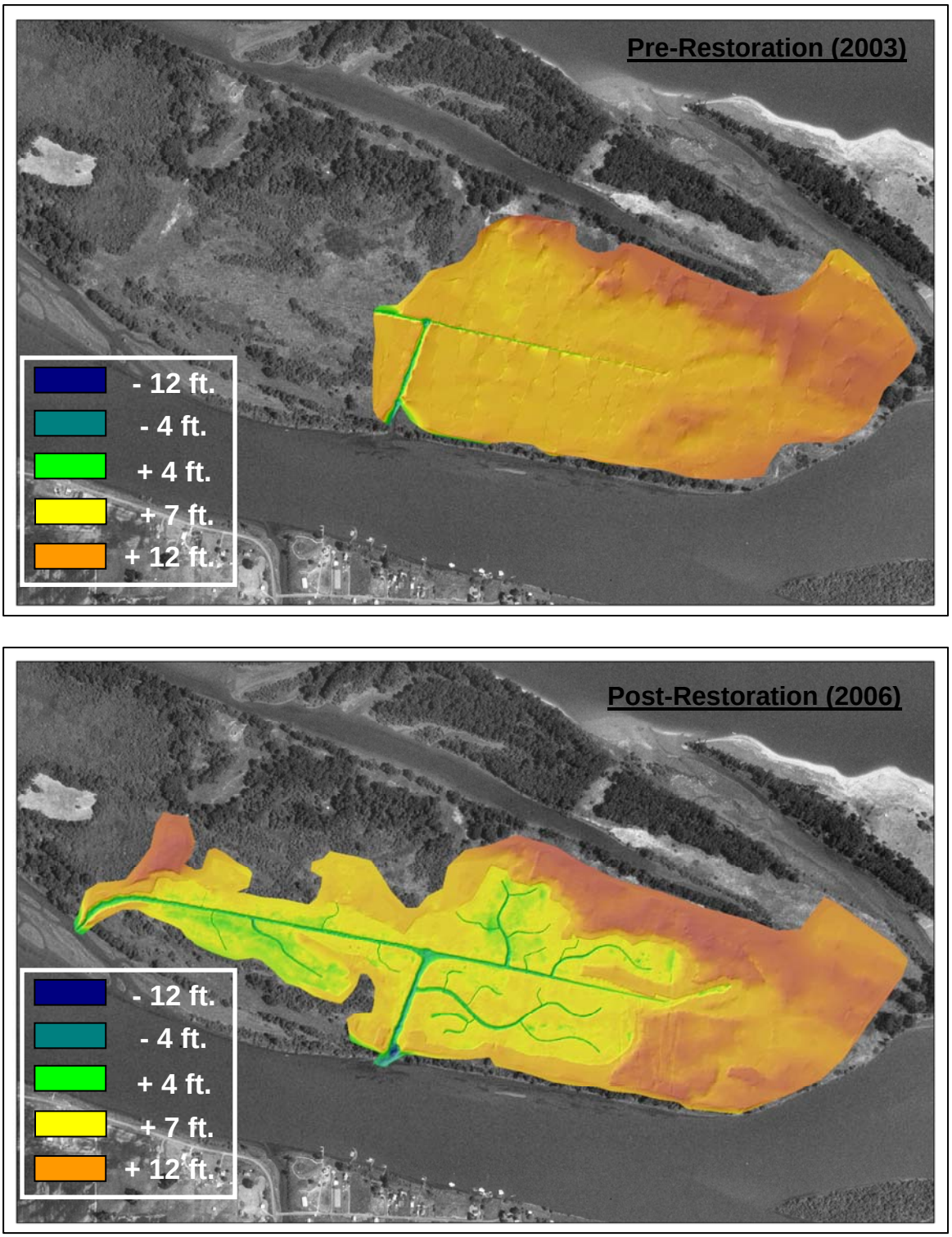

Figure 12. – Results of geo-referenced elevation survey the Crims Island Restoration Site conducted prior to restoration in 2003 (top panel) and after restoration in 2006 (bottom panel).

DISCUSSION

Restoration activities at Crims Island primarily benefited subyearling Chinook salmon as they were the primary salmonid species we collected during our sampling both in 2004 and 2006. We also collected some juvenile chum salmon in March and April, but the small numbers collected made it difficult to ascertain the benefit of restored habitats to them. Subyearling Chinook salmon were present in Crims Island backwaters when we initiated sampling in early March and likely began arriving earlier. Rich (1920) found subyearlings in the lower Columbia River beginning in December, but they were most numerous in March and April. The seasonal peak of subyearlings at Crims Island was in late March to early April. Seasonal trends from subyearling Chinook salmon after restoration indicated that restoration did not alter seasonal trends. However, fork length data indicated that larger subyearlings were accessing restored backwaters from mid May to mid July when compared to pre-restoration data.

Understanding size differences of subyearling Chinook salmon in lateral (pelagic vs. intertidal) and downstream (upper vs. lower estuary) habitats are crucial to understanding the importance of differing estuarine habitats to juvenile salmon rearing. Although our data cannot address downstream differences, it gives insight into differences in lateral habitats. McCabe et al. (1986) reported significantly larger subyearlings inhabiting pelagic vs. intertidal areas of the upper (tidal freshwater) and lower estuary (saline). In that study, pelagic areas were open water areas sampled with purse seines and intertidal areas were peripheral to the main river and sampled with beach seines. Backwaters, sloughs, and smaller tidal habitats were not sampled. In our study, all three of our sample sites were intertidal and only one (Columbia River Mainstem, a sandy, sloping beach) is likely comparable to the intertidal habitats sampled by McCabe et al. (1986). Our three sites differed greatly in sediment type, distance from the Columbia River thalweg, vegetation, and subyearling Chinook fork length characteristics. Our data are consistent with the hypothesis that as subyearlings grow they are increasingly found in main channel habitats similar to our Columbia River Mainstem site. Therefore, smaller tidal habitats, such as sloughs, marshes, and the restored habitat at Crims Island, are most important to the earliest life history stages of subyearling Chinook.

After restoration the number of subyearling Chinook utilizing Crims Island for feeding and growth increased but density was less than that of our reference site in the Reference Tidal Marsh. Prior to restoration, mean fyke net CPUE in the Restoration Site was $11.46 \cdot hr^{-1}$ (range 0 to $74.98 \cdot hr^{-1}$), whereas after restoration mean fyke net catch was $4.98 \cdot hr^{-1}$ (range 0 to $39.13 \cdot hr^{-1}$). These data are misleading because fyke net sampling in 2004 sampled the entire volume of water moving into Crims Island, whereas in 2006, because the volume of water and habitat had increased so dramatically, we were able to sample only a small fraction of the water volume moving into the island. If we were to multiply our fyke net catch by the number of tertiary channels in the whole island, the total number of subyearling Chinook would be far greater than the total collected in pre-restoration sampling. For this reason, pre- and post-restoration CPUE's are generally not comparable, but Reference Tidal Marsh and Restoration Site densities

are comparable because both were sampled with beach seines and therefore provide fish estimates in terms of area sampled. These data indicate that in 2006, mean density in the Reference Tidal Marsh was $0.032 \cdot m^{-2}$ (range 0 to $0.150 \cdot m^{-2}$) and in the Restoration Site mean density was $0.016 \cdot m^{-2}$ (range 0 to $0.044 \cdot m^{-2}$). Sampling efficiency in the Reference Tidal Marsh may have been greater because we sampled a subtidal channel of lower elevation where fish were likely concentrated, whereas in the Restoration Site we sampled a tidal mudflats of higher eleavtion. Densities of subyearling Chinook salmon in the Restoration Site will likely increase to levels similar in the Reference Tidal Marsh as vegetation establishes and invertebrate density and diversity increase.

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. In 2006, juvenile salmon used Crims Island backwaters for one or two tidal cycles, similar to residence time estimates prior to restoration (Haskell et al. 2006). Residence times were longer in the Restoration Site 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 Restoration Site has many newly created subtidal channels which do not dewater during low tide and therefore, fish are more likely to reside at this site over successive tides. In contrast, the Reference Tidal Marsh intertidal channels are at a higher elevation and completely dewater during low tide. Fish residing in the Reference Tidal Marsh exit the site at low tide and apparently do not re-enter on successive flood tides. Because parts of the Reference Tidal Marsh drain directly to the main stem Columbia River, there is little chance that fish exiting via this route will return on successive high tides. Yearly differences in median residence times in the Reference Tidal Marsh were likely due to changes in our recapture methodology. In 2004, we released marked fish and then conducted hourly beach seines for 24 hr. In 2006, we similarly released marked fish, but then conducted beach seines once every day for a week to recapture fish. While the two methodologies produced slightly different residence time estimates, they both indicated that residence time is short and most fish leave a specific site on the outgoing tide and do not return on the next incoming tide. Subtidal channels created during restoration likely increase subyearling Chinook residence time, however, fish generally do not reside at the Crims Island complex for many days. Residence time of subyearlings at specific sites such as Crims Island may increase with decreasing distance to the Pacific Ocean.

The short residence time in specific backwater habitats underscores the need for a downriver continuum of suitable rearing habitat. The Crims Island complex lies in the tidal freshwater portion of the upper 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 Restoration Site, 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 rear as they migrate seaward.

In 2004 and 2006 we used Calcein to batch mark large 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 and 1,329 in 2006, 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 intrusive and stressful Pan-Jet method. 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. Future studies of residence time of smaller subyearlings will be similarly challenged in selecting a marking method which properly characterizes the earliest life history stages of subyearling Chinook salmon because they are too small for marking using PIT, radio, or acoustic tags.

While subyearling Chinook prey item assemblage changed after restoration, the intensity at which they fed remained similar to pre-restoration conditions. Prior to restoration, 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 un-restored habitats. After restoration, diet in the Restoration Site contained a much higher percentage of Dipterans and a lower percentage of Amphipods than prior to restoration and generally became more similar to that of fish in the Reference Tidal Marsh. However, the intensity at which subyearling Chinook fed in the Restoration Site was significantly lower than that in the Reference Tidal Marsh, both before and after restoration, likely because invertebrate density was significantly less in the Restoration Site than in the Reference Tidal Marsh.

While invertebrate density did not significantly change after restoration, invertebrate diversity significantly decreased in the benthos and the drift. Although excavation in the Restoration Site apparently increased sediment productivity, it also removed all vegetation. The temporary loss of emergent vegetation and benthic algae in the Restoration Site likely played a role in the decreased invertebrate diversity and water TOC observed there. Tanner et al. (2002) reported a similar situation on a dike breach restoration project on Spencer Island in the Snohomish River Estuary, Washington. In that case, a restored site had less invertebrate diversity and fewer invertebrate taxa after restoration than reference sites, but the numerical abundance of Dipterans, the most important juvenile salmon prey item, was similar. They hypothesized that an increase in insect diversity was associated with a non tidal portion of the marsh where water level was stable relative to an unstable tidal portion. This hypothesis is certainly inconsistent with the results reported here because the Reference Tidal Marsh and Restoration Site are tidal, but the Reference Tidal Marsh dewaters during low tide, but still has higher invertebrate diversity. With increased emergent vegetation in the Restoration Site over time, invertebrate diversity will likely increase as will juvenile salmon feeding intensity.

Before and after restoration, chironomids were the most abundant invertebrate in the drift and the benthos at Crims Island and the Reference Tidal Marsh. Many studies of subyearling Chinook salmon diet in the Columbia River have shown the importance of aquatic insects, particularly chironomids, to subyearlings (McCabe et al. 1986; Muir and Emmett 1988). Subyearlings are opportunistic feeders and will exploit any abundant food source, but our data indicate that they feed more intensively when primarily feeding on chironomids. Prior to restoration the overall density of chironomid larvae in the benthos was 2,677.18 $\cdot$ m^{-2} and 1,059.42 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site, respectively. After restoration the density of chironomid larvae was 2,247.69 $\cdot$ m^{-2} and 1,803.88 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site. In the drift, prior to restoration, chironomid adults were found at densities of 0.194 $\cdot$ m^{-2} and 0.104 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site. After restoration, chironomid adults were found at densities of 0.087 $\cdot$ m^{-2} and 0.116 $\cdot$ m^{-2} in the Reference Tidal Marsh and the Restoration Site. Habitat restoration increased the overall density of chironomid prey for subyearling Chinook salmon likely because inundated emergent vegetation, more prevalent in restored habitats at Crims Island, is conducive to chironomid production (Independent Scientific Group 2000).

After restoration, sediment in the Restoration Site exhibited a greater percentage of sand, and a smaller percentage of silt and clay, a makeup more similar to that in the Reference Tidal Marsh. Surprisingly, sediments in newly restored habitat were much more productive than prior to restoration, though it did not appear that carbon was being assimilated into the water column, because water TOC in the Restoration Site decreased after restoration. Excavation likely unearthed a layer of highly productive sediment, which may have been previously unavailable to plants. Over time, sediment TOC levels should decrease to a level similar to the Reference Tidal Marsh, benefiting the plant community at Crims Island and the lower Columbia River Estuary as these nutrients are exported downstream. The higher levels of water TOC levels in the Reference Tidal Marsh indicate higher water column productivity than in the Restoration Site 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. Total organic carbon levels were probably lower in the Restoration Site prior to restoration because only in upper ends of the arms of the T-channel was terrestrial vegetation inundated at high tide. Reduced elevations in the restoration area should promote the establishment of an emergent vegetation community that will function more like the Reference Tidal Marsh. Therefore, we expect the productive capacity as measured by water TOC and invertebrate diversity of the Restoration Site to increase.

The restoration of Crims Island converted a degraded channel, which passed through a monoculture stand of reed canarygrass, into a series of subtidal channels. In the future a diverse plant assemblage consisting of rushes and sedges as are present at the Reference Tidal Marsh on Gull Island will become established. 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 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.

Selecting a representative reference site was tenuous because we faced the challenge of selecting a reference site that we believed would be similar to newly created habitat. The before-after-control-impact sampling approach we used to collect these data was a good one based on available resources. In effect, we chose two reference sites (Columbia River Mainstem, Reference Tidal Marsh) for comparison to the restoration site. These sites were chosen not because we necessarily believed they would be similar to restored habitat, but because they were different from one another and would contrast whatever habitat was created in the Restoration Site. We chose the Columbia River Mainstem site as a general reference to restored backwaters. That is, will restored backwaters be different from mainstem habitat, and if not, what is the point in restoring off channel habitats? The Reference Tidal Marsh site was chosen because we believed that this site was generally 'ideal' juvenile backwater salmon habitat and our reconnaissance sampling in 2003 revealed many juvenile salmon feeding there. A primary reason that both reference sites were chosen was their proximity to the planned restoration area. Proximity was important because we wanted reference sites that fell longitudinally in the same general area of the Columbia River (downstream areas would have greater salinity influence, upstream areas would have less tidal influence) and because it was logistically preferable to sample nearby sites. Future restoration projects would benefit from the selection of a broader range and greater number of reference sites for comparison to the restoration site, though available resources for monitoring will likely limit the number of reference sites sampled.

Our sampling revealed that newly created habitat at Crims Island was successful insofar that it created additional habitat and juvenile salmon in relatively large numbers were utilizing this habitat. However, our sampling is limited in scope because of the short duration of post restoration sampling. The National Oceanic and Atmospheric Administration (NOAA) recommends a minimum of five years monitoring to assess physical response and a longer period to assess ecological response of restoration activities (NOAA 2004). Therefore, the ultimate success of Crims Island restoration in providing ecological function cannot be fully addressed without further data collection.

Restoration at Crims Island effectively created more habitat for juvenile salmon rearing. Over time this habitat will likely become similar in quality to that found in the Reference Tidal Marsh. More juvenile salmon will continue to utilize restored habitats relative to unrestored habitats because restored habitats will have a greater density of

chironomids, fish will feed more intensively, and fish will have the added benefit of longer residence time. Future monitoring efforts 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 as we did at Crims Island. Restored habitats on Crims Island now have subtidal channels and intertidal mudflats. Both habitat types will ultimately increase the complexity of habitats available to juveniles of listed salmonids in the Columbia River Estuary.

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APPENDIX

Table A.1. – Scientific name, common name, life stage, percent occurrence, and percent of total fishes collected with beach seines and fyke nets at Crims and Gull islands, Columbia River Estuary, 2006.

Scientific Name	Common Name	Life Stage	Percent Occurrence	Percent Of Total
Catostomidae				
Catostomus macrocheilus	Largescale sucker	Both	11.94	0.91
Centrarchidae				
Lepomis macrochirus[1]	Bluegill	Juv	0.75	<0.01
Pomoxis nigromaculatus[1]	Black crappie	Juv	13.43	0.06
Lepomis gibbosus[1]	Pumpkinseed	Both	9.70	0.07
Micropterus dolomieu[1]	Smallmouth bass	Both	2.99	0.01
Lepomis spp.[1]	Unidentified sunfish	Juv	2.24	<0.01
Clupeidae				
Alosa sapidissima[1]	American shad	Juv	2.23	0.19
Cottidae				
Cottus asper	Prickly sculpin	Adult	8.21	0.02
Cyprinidae				
Cyprinus carpio[1]	Common carp	Both	11.94	0.14
Ptychocheilus oregonensis	Northern pikeminnow	Both	18.66	0.44
Mylocheilus caurinus	Peamouth	Both	43.28	18.9
Fundulidae				
Fundulus diaphanus[1]	Banded killifish	Both	47.01	7.35
Gambusidae				
Gambusia affinis[1]	Mosquitofish	Both	0.75	<0.01
Gasterosteidae				
Gasterosteus aculeatus	Threespine stickleback	Both	64.18	62.67
Gobiidae				
Rhinogobius brunneus[1,2]	Amur goby	Juv	0.75	<0.01
Percidae				
Perca flavescens[1]	Yellow perch	Both	19.40	0.70
Sander vitreus[1]	Walleye	Juv	0.75	<0.01
Pleuronectidae				
Platichthys stellatus	Starry flounder	Juv	9.70	0.05
Salmonidae				
Oncorhynchus tshawytscha	Yearling Chinook salmon	Juv	4.48	0.02
Oncorhynchus tshawytscha	Subyearling Chinook salmon	Juv	84.33	8.39
Oncorhynchus kisutch	Coho salmon	Juv	0.75	<0.01
Oncorhynchus keta	Chum salmon	Juv	14.18	0.06
Oncorhynchus mykiss	Steelhead	Juv	0.75	<0.01

[1] Introduced species
[2] First record in the Columbia River

Table A.2. -Percentage by number, percentage by weight, and percentage by occurrence of prey items collected from subyearling Chinook salmon in 2004 prior to restoration and 2006 after restoration at the Reference Tidal Marsh, Columbia River Mainstem, and the Restoration Site at Crims Island, Columbia River Estuary. Bolded taxa and numbers represent those used for IRI analysis as shown in Figure 8 with all unbolded combined into the 'Others' category.

	Percentage by Number					
	2004			2006		
Prey Taxon	Reference Tidal Marsh	Columbia River Mainstem	Restoration Site (Before Restoration)	Reference Tidal Marsh	Columbia River Mainstem	Restoration Site (After Restoration)
Amphipoda	**1.25**	**3.60**	**13.54**	**0.66**	**11.06**	**0.66**
Araneida	1.39	0.02	0.55	0.48	0.42	0.16
Coleoptera	0.20	0.00	0.14	0.04	0.51	0.09
Collembola	0.00	0.00	0.00	10.03	0.14	0.03
Copepoda	**0.13**	**2.17**	**0.00**	**0.33**	**2.17**	**0.25**
Daphnia	**15.94**	**92.56**	**35.98**	**9.77**	**71.31**	**49.97**
Diptera	**75.30**	**1.51**	**31.87**	**75.09**	**12.82**	**48.05**
Ephemeroptera	0.00	0.00	0.00	0.00	0.09	0.00
Fish	0.40	0.00	1.09	0.26	0.00	0.16
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	0.20	0.02	0.68	0.11	0.05	0.00
Homoptera	**2.37**	**0.03**	**13.68**	**1.43**	**0.28**	**0.13**
Hymenoptera	1.12	0.02	0.41	0.33	0.23	0.38
Isopoda	0.00	0.00	1.23	0.00	0.00	0.00
Lepidoptera	0.13	0.00	0.14	0.07	0.05	0.00
Mysidacea	0.07	0.02	0.68	0.77	0.32	0.09
Nematoda	1.38	0.00	0.00	0.59	0.00	0.00
Odonata	0.07	0.02	0.00	0.00	0.09	0.00
Oligochaeta	0.07	0.00	0.00	0.04	0.05	0.00
Pelecypoda	0.00	0.05	0.00	0.00	0.00	0.00
Thysanoptera	0.00	0.00	0.00	0.00	0.05	0.00
Unknown	0.00	0.00	0.00	0.00	0.23	0.03
	Percentage by Weight					
Amphipoda	**2.28**	**58.62**	**27.01**	**3.81**	**63.64**	**5.04**
Araneida	2.11	1.68	0.66	2.55	1.49	0.48
Coleoptera	0.77	0.50	1.84	0.07	1.86	0.08
Collembola	0.00	0.00	0.00	3.76	0.11	0.02
Copepoda	**0.06**	**3.29**	**0.70**	**0.03**	**0.22**	**0.04**
Daphnia	**0.26**	**12.99**	**0.76**	**0.68**	**6.67**	**7.56**
Diptera	**83.58**	**18.81**	**49.55**	**59.79**	**11.08**	**78.47**
Ephemeroptera	0.00	0.00	0.00	0.00	0.53	0.00
Fish	1.57	0.00	5.94	11.55	0.00	5.04
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	0.50	0.07	2.47	0.72	0.12	0.00
Homoptera	**2.97**	**1.41**	**6.53**	**1.50**	**0.32**	**0.17**
Hymenoptera	0.87	1.24	0.42	0.48	0.57	0.60
Isopoda	0.00	0.00	0.51	0.00	0.00	0.00
Lepidoptera	0.29	0.00	0.50	0.09	0.37	0.00
Mysidacea	0.78	0.84	2.78	13.57	9.16	2.43
Nematoda	1.48	0.18	0.32	0.73	0.00	0.00
Odonata	0.07	0.06	0.00	0.00	0.22	0.00
Oligochaeta	2.41	0.00	0.00	0.65	2.97	0.00
Pelecypoda	0.00	0.31	0.00	0.00	0.00	0.00
Thysanoptera	0.00	0.00	0.00	0.00	0.00	0.00

Table A.2. -Continued

Prey Taxon	2004			2006		
	Reference Tidal Marsh	Columbia River Mainstem	Restoration Site (Before Restoration)	Reference Tidal Marsh	Columbia River Mainstem	Restoration Site (After Restoration)
Unknown	0.00	0.00	0.00	0.00	0.69	0.08
			Percentage by Occurrence			
Amphipoda	**11.90**	**54.37**	**29.76**	**15.00**	**68.85**	**21.15**
Araneida	14.29	6.80	5.95	20.00	11.48	9.62
Coleoptera	4.76	0.97	4.76	2.50	3.28	5.77
Collembola	4.76	0.00	7.14	17.50	3.28	1.92
Copepoda	**11.90**	**33.01**	**9.52**	**10.00**	**18.03**	**9.62**
Daphnia	**17.86**	**65.05**	**11.90**	**35.00**	**42.62**	**38.46**
Diptera	**94.05**	**48.54**	**63.10**	**100.00**	**63.93**	**82.69**
Ephemeroptera	0.00	0.00	0.00	2.50	3.28	0.00
Fish	1.19	0.00	2.38	0.00	0.00	1.92
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	4.76	0.97	5.95	5.00	1.64	0.00
Homoptera	**25.00**	**12.62**	**20.24**	**30.00**	**9.84**	**7.69**
Hymenoptera	17.86	5.83	7.14	15.00	6.56	7.69
Isopoda	0.00	0.00	3.57	0.00	0.00	0.00
Lepidoptera	1.19	0.00	1.19	2.50	1.64	0.00
Mysidacea	1.19	1.94	3.57	15.00	9.84	5.77
Nematoda	23.81	2.91	4.76	15.00	0.00	0.00
Odonata	1.19	0.97	0.00	0.00	3.28	0.00
Oligochaeta	1.19	0.00	0.00	2.50	1.64	0.00
Pelecypoda	0.00	1.94	0.00	0.00	0.00	0.00
Psocoptera	1.19	4.85	1.19	0.00	0.00	0.00
Thysanoptera	0.00	0.00	1.19	0.00	1.64	0.00
Unknown	0.00	0.00	0.00	0.00	4.92	1.92

Table A.3. -Scientific name, total number, percent occurrence, and percent of total of benthic invertebrates collected at Crims Island, Columbia River, 2006.

Scientific name	Total Number	Percent Occurrence	Percent of Total
Amphipoda			
Corophiidae			
Corophium salmonis	139	29.44	14.96
Corophium spinicorne	30	10.56	3.23
Corophium brevis	1	0.56	0.11
Corophium spp.	31	4.44	3.34
Diptera			
Ceratopogonidae	36	12.78	3.88
Chironomidae	285	43.89	30.68
Sciomyzidae	2	1.11	0.22
Tipulidae	3	1.11	0.32
Gastropoda	4	2.22	0.43
Nematoda	111	26.11	11.95
Oligochaeta	263	32.78	28.31
Pelecypoda	7	3.33	0.75
Corbiculidae			
Corbicula fluminea[1]	13	6.67	1.40
Unknown	1	1.11	0.11

[1] Introduced species

Table A.4. -Taxa, aquatic or terrestrial classification, total number, percent occurrence, and percent of total drift invertebrates collected at Crims Island, Columbia River Estuary, 2006.

Taxa	Aquatic or Terrestrial	Total Number	Percent Occurrence	Percent of Total
Amphipoda				
Corophiidae				
Corophium salmonis	Aquatic	9	12.96	0.42
Araneae	Terrestrial	23	29.63	1.08
Coleoptera				
Curculionidae	Aquatic	1	1.85	0.05
Elmidae	Aquatic	5	5.56	0.23
Gyrinidae	Aquatic	1	1.85	0.05
Haliplidae	Aquatic	1	1.85	0.05
Limnebiidae	Aquatic	2	3.70	0.09
Staphylinidae	Aquatic	6	11.11	0.33
Unknown		11	12.96	0.51
Collembola				
Entomobryidae	Aquatic	385	33.33	18.02
Hypogastruridae	Aquatic	5	5.56	0.23
Sminthuridae	Aquatic	3	1.86	0.14
Diptera				
Canaceidae	Terrestrial	15	18.52	0.70
Ceratopogonidae	Aquatic	166	57.41	7.77
Chironomidae	Aquatic	984	94.44	46.05
Dolichopodidae	Aquatic	4	5.56	0.19
Dryomyzidae	Aquatic	29	25.93	1.36
Empidae	Aquatic	2	3.70	0.09
Ephydridae	Aquatic	2	12.96	0.09
Sciomyzidae	Aquatic	8	9.26	0.37
Simulidae	Aquatic	2	3.70	0.09
Syrphidae	Terrestrial	1	1.85	0.05
Tipulidae	Aquatic	9	9.26	0.42
Unknown		9	12.96	0.42
Gastropoda	Aquatic	25	35.19	1.17
Hemiptera				
Corixidae	Aquatic	8	11.11	0.37
Saldidae	Aquatic	15	5.56	0.70
Unknown		6	5.56	0.28
Homoptera				
Aphididae	Terrestrial	191	29.63	8.94
Cicadellidae	Terrestrial	2	3.70	0.09
Delphacidae	Terrestrial	1	1.85	0.05
Unknown		1	1.85	0.05
Hymenoptera				
Apidae	Terrestrial	1	1.85	0.05
Braconidae	Aquatic	53	22.22	2.48
Cynipidae	Terrestrial	10	16.67	0.47
Eulophidae	Aquatic	5	9.26	0.23
Pompilidae	Terrestrial	1	1.85	0.05
Scelionidae	Aquatic	22	22.22	1.03
Unknown		4	5.56	0.19
Lepidoptera				
Noctuidae	Terrestrial	1	1.85	0.05
Tortricidae	Terrestrial	1	1.85	0.05
Mysidacea				
Mysidae				

Table A.4. -Continued

Taxa	Aquatic or Terrestrial	Total Number	Percent Occurrence	Percent of Total
Neomysis mercedis	Aquatic	2	3.70	0.09
Nematoda	Aquatic	1	1.85	0.05
Neuroptera				
Sisyridae	Terrestrial	2	3.70	0.09
Odonata				
Coenagrionidae	Aquatic	3	3.70	0.14
Unknown	Aquatic	1	1.85	0.05
Oligochaeta	Aquatic	28	18.52	1.31
Psocoptera				
Pseudocaeciliidae	Terrestrial	3	5.56	0.14
Psocidae	Terrestrial	4	3.70	0.19
Unknown		2	1.85	0.09
Thysanoptera				
Phloeothripidae	Terrestrial	1	1.85	0.05
Thripidae	Terrestrial	21	20.37	0.98
Trichoptera				
Chloroperlidae	Aquatic	1	1.85	0.05
Perlodidae	Aquatic	1	1.85	0.05
Unknown	Aquatic	2	3.70	0.09
Unknown		6	9.26	0.28

Table A.5. – 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, 2006.

Scientific Name	Common Name	Aquatic or Terrestrial	Percent Occurrence	Percent of Total weight
Asteraceae				
Megalodonta beckii	Water marigold	Aquatic	11.11	0.01
Azollaceae				
Azolla mexicana	Mexican water fern	Aquatic	1.85	0.02
Betulaceae				
Alnus rubra	Red alder	Terrestrial	11.11	2.86
Boraginaceae				
Myosotis laxa	Forget me not	Aquatic	3.70	<0.01
Callitrichaceae				
Callitriche heterophylla	Pond water starwort	Aquatic	5.56	0.19
Callitriche stagnalis	Different leaved water starwort	Aquatic	1.85	0.02
Ceratophyllaceae				
Ceratophyllum demersum	Coontail	Aquatic	12.96	0.77
Cyperaceae				
Carex spp.	Sedges	Aquatic	11.11	4.58
Eleocharis spp.	Needle spike rush	Aquatic	5.56	0.32
Scirpus spp.	Water bulrush	Aquatic	1.85	0.62
Fontinalaceae				
Fontinalis antipyretica	Common water moss	Aquatic	5.56	0.10
Haloragaceae				
Myriophyllum spicatum[1]	Eurasian water-milfoil	Aquatic	20.37	4.12
Hydrocharitaceae				
Elodea nuttallii	Nuttall's waterweed	Aquatic	18.52	0.63
Juncaceae				
Juncus spp.	Rushes	Aquatic	3.70	0.59
Oleaceae				
Fraxinus latifolia	Ash	Terrestrial	9.26	0.64
Poacea				
Phalaris arundinacea[1]	Reed canary grass	Terrestrial	53.70	15.95
Potamogetonaceae				
Potamogeton crispus[1]	Curly leaf pondweed	Aquatic	20.37	1.34
Potamogeton spp.	Pondweed species	Aquatic	3.70	0.24
Salicaceae				
Populus trichocarpa	Black cottonwood	Terrestrial	14.81	1.58
Salix spp.	Willow species	Terrestrial	22.22	6.60
Scrophulariaceae				
Limosella aquatica	Water mudwort	Aquatic	1.85	0.11
Limosella spp.	Mudwort species	Aquatic	5.56	0.34
Wood[2]			11.11	4.81
Debris[3]			92.59	44.87

[1] Introduced species
[2] Sticks and bark
[3] Unidentifiable pieces of plant leave, stems, seed, filamentous algae, and decomposed plant matter

Table A.6. -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 23 through August 9, 2006. Ten replicates were collected at each station.

Site	Date	Total	Mean	STD Dev	Taxa	Diversity (H)	Evenness (J)
Mainstem	3/23	67	5,755.22	2,219.75	3	0.31	0.65
Reference	3/24	51	4,380.84	4,589.32	6	0.61	0.78
Restoration	3/23	11	944.89	1,428.78	3	0.55	0.48
Mainstem	4/20	6	515.39	600.61	3	0.44	0.92
Reference	4/19	156	13,400.32	4,725.74	5	0.47	0.67
Restoration	4/19	12	1,030.79	2,135.03	2	0.24	0.81
Mainstem	5/17	28	2,405.17	1,659.72	5	0.46	0.66
Reference	5/18	76	6,528.31	2,436.33	9	0.79	0.82
Restoration	5/18	43	3,693.65	2,656.85	3	0.10	0.20
Mainstem	6/14	17	1,460.28	1,720.36	2	0.10	0.32
Reference	6/15	142	12,197.64	8,869.75	8	0.56	0.62
Restoration	6/14	64	5,497.53	5,870.80	4	0.14	0.24
Mainstem	7/11	34	2,920.56	1,159.55	4	0.33	0.55
Reference	7/11	80	6,871.91	3,862.80	8	0.70	0.78
Restoration	7/11	21	1,803.88	2,759.78	4	0.25	0.41
Mainstem	8/9	17	1,460.28	1,075.17	4	0.29	0.48
Reference	8/9	89	7,645.00	3,470.38	6	0.62	0.79
Restoration	8/9	15	1,288.48	1,581.31	6	0.57	0.74
MEAN	**-**	**51.6**	**4,433.341**	**2,934.557**	**4.7**	**0.42**	**0.61**

Table A.7. – 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 23 through August 9, 2006. Three replicates were collected at each site.

Site	Date	Total	Mean	STD Dev	Taxa	Diversity (H)	Evenness (J)
Mainstem	3/23	41	0.06	0.03	10	0.83	0.83
Reference	3/24	470	0.67	0.34	11	0.32	0.31
Restoration	3/23	99	0.15	0.06	7	0.20	0.24
Mainstem	4/20	35	0.05	0.04	8	0.62	0.68
Reference	4/19	225	0.41	0.04	16	0.53	0.44
Restoration	4/19	219	0.27	0.04	14	0.36	0.31
Mainstem	5/17	5	0.01	0.01	3	0.41	0.86
Reference	5/18	98	0.13	0.05	16	0.67	0.55
Restoration	5/18	235	0.25	0.02	13	0.21	0.18
Mainstem	6/14	10	0.01	0.01	5	0.64	0.91
Reference	6/14	48	0.06	0.02	11	0.71	0.68
Restoration	6/14	53	0.06	0.01	9	0.60	0.63
Mainstem	7/11	61	0.08	0.03	14	0.86	0.75
Reference	7/11	107	0.14	0.05	21	1.07	0.81
Restoration	7/11	68	0.08	0.02	18	1.08	0.86
Mainstem	8/9	7	0.01	0.00	4	0.50	0.83
Reference	8/9	265	0.33	0.10	23	0.80	0.59
Restoration	8/9	91	0.18	0.10	12	0.68	0.63
MEAN	**-**	**118.7**	**0.16**	**0.05**	**11.94**	**0.61**	**0.62**

Table A.8. -Scientific name, common name, presence in Restoration Site, presence in reference site, and wetland classification of plants surveyed at Crims and Gull islands, Columbia River Estuary on September 18 and October 11, 2006.

Scientific Name	Common Name	Restoration Site (Crims Island)	Reference Site (Gull Island)	Wetland Class[2]
Alismataceae				
Alisma plantago-aquatica	American water-plantain	x	x	OBL
Sagittaria latifolia	Broadleaf arrowhead	x	x	OBL
Boraginaceae				
Myosotis laxa	Small-flower water forget-me-not	x	x	OBL
Caryophyllaceae				
Stellaria crispa	Crisp starwort	x		FAC
Compositae				
Bidens cernua[1]	Nodding beggar-ticks	x	x	FACW+
Gnaphalium uliginosum[1]	Marsh cudweed	x		FAC+
Cruciferae				
Rorippa curvisiliqua	Western yellowcress	x		OBL
Cyperaceae				
Cyperus stigosus	Straw-colored flatsedge	x		FACW
Eleocharis acicularis	Needle spikerush	x		
Eleocharis obtusa	Ovoid spikerush	x		OBL
Eleocharis palustris	Creeping spikerush	x	x	OBL
Rhynchospora alba	Beakrush	x		OBL
Scirpus acutus	Hardstem bulrush	x	x	OBL
Scirpus americanus	Three-square bulrush		x	OBL
Scirpus tabernaemontanii	Soft-stem bulrush	x	x	OBL
Scirpus triqueter[1]	Threesquare tule	x		OBL
Fontinalaceae				
Fontinalis antipyretica	Common water moss	x	x	OBL
Gramineae				
Agrostis spp.	Bentgrass		x	
Glyceria grandis	Reed mannagrass	x		OBL
Leersia oryzoides	Rice cutgrass	x	x	OBL
Hypericaceae				
Hypericum anagalloides	Bog St. John's-wort	x		OBL
Juncaceae				
Juncus acuminatus	Tapertip rush	x		OBL
Juncus articulatus	Jointed rush	x		OBL
Juncus nevadensis	Sierra rush	x		FACW
Juncus supiniformis	Spreading rush	x		OBL
Leguminoseae				
Lotus corniculatus[1]	Birdsfoot-trefoil		x	FAC
Lythraceae				
Lythrum salicaria[1]	Purple loosestrife	x		FACW+
Onagraceae				
Epilobium ciliatum	Watson's willow-herb	x	x	FACW-
Ludwigia palustris	Water purslane	x		OBL
Plantaginaceae				
Plantago major	Broadleaf plantain	x		FACU+
Poacea (Unidentified)	Unidentified grasses	x		
Polygonaceae				
Polygonum hydropiper	Water pepper	x		OBL
Polygonum hydropiperoides	Mild waterpepper		x	OBL

Table A.8. -Continued

Scientific Name	Common Name	Restoration Site (Crims Island)	Reference Site (Gull Island)	Wetland Class[2]
Ranunculaceae				
Ranunculus sceleratus[1]	Celery-leaved buttercup	x		OBL
Salicaceae				
Salix spp.	Willow	x	x	
Sparganiaceae				
Sparganium emersum	Narrow-leaf burreed	x		OBL
Sparganium eurycarpum	Giant burreed	x		OBL
Scrophulariaceae				
Limosella aquatica	Water mudwort	x		OBL
Mimulus guttatus	Common monkeyflower	x	x	OBL
Veronica americana	American speedwell	x		OBL
Veronica anagallis-aquatica	Water speedwell	x		OBL
Typhaceae				
Typha latifolia	Common cattail	x		OBL

[1]Introduced species.
[2]Wetland Classification (OBL= Obligate Wetland Species, FACW= Facultative Wet Wetland Species, FAC= Facultative Wetland Species, FACU= Facultative Upland Species).