Prepared in cooperation with the Portland District of the U.S. Army Corps of Engineers

Crims Island—Restoration and Monitoring of Juvenile Salmon Rearing Habitat in the Columbia River Estuary, Oregon, 2004–10

Scientific Investigations Report 2011–5022

U.S. Department of the Interior
U.S. Geological Survey

Cover: Aerial photograph of Crims Island shortly after restoration. The picture is looking westward down the Columbia River with Bradbury Slough on the left. Photograph taken by Kenneth Tiffan, U.S. Geological Survey, December 14, 2005.

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KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Datums

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

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Crims Island—Restoration and Monitoring of Juvenile Salmon Rearing Habitat in the Columbia River Estuary, Oregon, 2004–10

By Craig A. Haskell and Kenneth F. Tiffan

Abstract

Under the 2004 Biological Opinion for operation of the Federal Columbia River Power System released by the National Marine Fisheries Service, the U.S. Army Corps of Engineers (USACE), the Bonneville Power Administration (BPA), and the Bureau of Reclamation (Reclamation) were directed to restore more than 4,047 hectares (10,000 acres) of tidal marsh in the Columbia River estuary by 2010. Restoration of Crims Island near Longview, Washington, restored 38.1 hectares of marsh and swamp in the tidal freshwater portion of the lower Columbia River. The goal of the restoration was to improve habitat for juveniles of Endangered Species Act (ESA)-listed salmon stocks and ESA-listed Columbian white-tailed deer. The U.S. Geological Survey (USGS) monitored and evaluated the fisheries and aquatic resources at Crims Island in 2004 prior to restoration (pre-restoration), which began in August 2004, and then post-restoration from 2006 to 2009. This report summarizes pre- and post-restoration monitoring data used by the USGS to evaluate project success. We evaluated project success by examining the interaction between juvenile salmon and a suite of broader ecological measures including sediments, plants, and invertebrates and their response to large-scale habitat alteration.

The restoration action at Crims Island from August 2004 to September 2005 was to excavate a 0.6-meter layer of soil and dig channels in the interior of the island to remove reed canary grass and increase habitat area and tidal exchange. The excavation created 34.4 hectares of tidal emergent marsh where none previously existed and 3.7 hectares of intertidal and subtidal channels. Cattle that had grazed the island for more than 50 years were relocated. Soil excavated from the site was deposited in upland areas next to the tidal marsh to establish an upland forest. Excavation deepened and widened an existing T-shaped channel to increase tidal flow to the interior of the island. The western arm of the existing ‘T-channel’ was extended westward and connected to Bradbury Slough to create a second outlet to the main river. New intertidal channels were constructed from the existing ‘T-channel’ and tidal mudflats became inundated at high tide to increase rearing habitat for juvenile salmonids. The restoration action resulted in a 95-percent increase in available juvenile salmon rearing habitat.

We collected juvenile salmon and other fishes at Crims Island and a nearby reference site using beach seines and fyke nets annually from March through August during all years. Benthic invertebrates were collected with sediment corers and drift invertebrates were collected with neuston nets. Juvenile salmon stomach contents were sampled using lavage. Vegetation and sediments characteristics were surveyed and we conducted a topographic/bathymetric survey using a RTK (real time kinematic) GPS (global positioning system).

The fish assemblage at Crims Island, composed primarily of threespine stickleback (*Gasterosteus aculeatus*), non-native banded killifish (*Fundulus diaphanus*), peamouth chub (*Mylocheilus caurinus*), subyearling Chinook salmon (*Oncorhynchus tshawytscha*) (hereinafter referred to as subyearlings), and small numbers of juvenile chum salmon (*Oncorhynchus keta*), did not differ appreciably pre- and post-restoration. Subyearlings were the primary salmonid collected and were seasonally abundant from April through May during all years. The abundance of juvenile salmon declined seasonally as water temperature exceeded 20 °C in the Reference site by mid-June; however, subyearlings persisted at the Mainstem site and in subtidal channels of the Restoration site through the summer in water temperatures exceeding 22 °C. Residence times of subyearlings in Crims Island backwaters generally were short consisting of one or two tidal cycles. Median residence time was longer in the Restoration site than in the Reference site pre- and post-restoration.

Small (mean = 55.7 millimeters) subyearlings primarily consumed dipteran adults and larvae in backwater habitats, while large (mean = 60.0 millimeters) subyearlings consumed *Daphnia* and *Corophium* in nearshore mainstem habitats. At all sites, chironomid larvae, *Corophium*, and oligochaetes were dominant in the benthic invertebrate community, whereas chironomid adults and aphids were dominant in the drift invertebrate community. Based on feeding indexes,

subyearlings fed more intensively in the Reference site than in the Restoration and Mainstem sites prior to restoration. However, post-restoration, subyearlings fed more intensively in the Restoration site than in the Reference site and their diet was more similar to that of fish found in the Reference site. Although invertebrate density at the Restoration site did not change significantly post-restoration, invertebrate diversity initially decreased before returning to pre-restoration levels. However, the overall abundance of chironomids actually increased in the Restoration site post-restoration. Although juvenile salmon can feed preferentially, our results indicated that subyearlings fed most intensively on chironomids in backwater habitats and insect diversity, although important to overall ecosystem function, did not appear to limit their abundance.

Although we were unable to estimate salmon abundance pre-restoration, a 95-percent increase in available habitat coupled with the large numbers of subyearlings with high condition factors collected post-restoration indicate that the project was largely a success in creating suitable rearing habitat for subyearlings. Catch data indicated that more subyearlings per hour were accessing restored habitat compared to unrestored habitat. We estimated total subyearling numbers ranging from 11,000 to 13,000 in the Restoration site post-restoration. Our before-after-control-impact paired series (BACIPS) study design permitted data analysis using *t*-tests to evaluate response to restoration and indicated that restored habitat contained larger subyearlings than unrestored habitat. Future monitoring efforts could benefit from sampling additional reference sites and evaluating higher-order metrics, such as survival or growth, to gauge restoration success.

Further creation of shallow water rearing habitat will likely benefit subyearlings compared to other juvenile salmon life histories because subyearlings tend to migrate seaward using productive shallow backwaters instead of mainstem habitats more so than yearling Chinook salmon and large subyearlings. Much research in the lower Columbia River is directed toward the survival of large subyearlings using mainstem habitats. Estimating survival and growth of small subyearlings using restored habitats can help in planning and implementing off-channel restoration projects in the future.

Introduction

The Columbia River estuary is critically important to anadromous Pacific salmon (*Oncorhynchus* spp.) and steelhead (*Oncorhynchus mykiss*) because juvenile fish use the estuary for rearing and to transition from the freshwater to the marine environment. Productive estuarine ecosystems provide juvenile salmon with abundant food resources and a diversity of habitats (Healey, 1991). Historically, the Columbia River estuary was a complex and dynamic place that facilitated a wide range of juvenile life history diversity (Rich, 1920; Bottom and others, 2005). Thus, salmon evolved using a ‘spread the risk’ strategy where life history diversity favored metapopulation survival in a variable environment. However, estuarine habitat modifications during the 20th century coincided with a precipitous decrease in salmon numbers and diversity with many stocks of Columbia Basin salmon now listed under the Endangered Species Act (ESA) (U.S. Office of the Federal Register, 2005).

Although all salmon stocks use the Columbia River estuary as juveniles to some degree, mounting evidence suggests that shallow estuarine habitat is particularly important for rearing subyearling Chinook salmon (*Oncorhynchus tshawytscha*) (hereinafter referred to as subyearlings). This life history type is common to many stocks that originate throughout the Columbia River basin. For example, Spring Creek National Fish Hatchery, located 32 km upstream of Bonneville Dam, releases 10–15 million Tule stock fall Chinook salmon annually between March and May. In early June, upriver stocks of fall Chinook begin passing Bonneville Dam, including 10–30 million fall Chinook salmon smolts from the Hanford Reach (Paul Hoffarth, Washington Department of Fish and Wildlife, oral commun., 2006). Hanford Reach Chinook salmon comprise most of the naturally produced Chinook salmon in the Columbia River basin (Huntington and others, 1996; Dauble and Watson, 1997). Natural production of subyearlings also occurs in various tributaries to the Columbia River downstream of the Bonneville Dam. Research indicates that (1) the role that the Columbia River estuary plays in the survival of these fish is important, and (2) these stocks could benefit from habitat restoration in the Columbia River estuary (Roegner and others, 2010).

Anadromous salmon returns to the Columbia River basin have declined to the point where 13 Columbia River Evolutionary Significant Units are now listed under the ESA. In the lower Columbia River alone, lower Columbia River Chinook salmon, chum salmon (*Oncorhynchus keta*), and coho salmon (*Oncorhynchus kisutch*) are all designated as “threatened” (U.S. Office of the Federal Register, 2005). All these stocks migrate seaward through the lower Columbia River as juveniles before entering the ocean. Salmon declines and subsequent listings historically were associated with over harvest, hydropower development, and agricultural practices, but more recently the loss of juvenile rearing habitat in the estuary has been recognized as a contributing factor (National Marine Fisheries Service, 2004, 2008). In the Columbia River estuary, tidal marsh acreage has decreased by 43 percent and tidal swamp acreage has decreased by 77 percent from 1870 to 1983 due to diking, dredging, and filling (Thomas, 1983). Hydrodynamic models developed by Kukulka and Jay (2003) indicated a 62 percent decrease in shallow-water habitat (water depth from 0.1 to 2 m) between river kilometer (rkm) 50 and rkm 90 of the Columbia River due to diking and decreased flow during the seasonal spring freshet (May–July).

To mitigate for the loss of estuarine habitat, the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service called for the U.S. Army Corps of Engineers (USACE) and the Bonneville Power Administration (BPA) to protect and enhance at least 4,047 ha of shallow-water habitat in the lower 74 km of the Columbia River estuary by 2010 (National Marine Fisheries Service, 2000). In response, the USACE and cooperators identified Crims Island as a site to restore and create tidal marsh habitat under the assumption that existing habitat was limiting the survival of ESA-listed juvenile salmon as they migrated to the Pacific Ocean. Although Crims Island is at rkm 87, slightly upstream of the estuary proper, the entire 235 km of the tidally influenced Columbia River downstream of Bonneville Dam is considered part of the estuary by resource managers (fig. 1). Furthermore, the estuarine ecosystem is influenced by both the marine environment and upstream riverine processes making management and restoration complicated.

This report summarizes pre- and post-restoration monitoring data used by the USGS to evaluate project success. We evaluate project success by examining the interaction between juvenile salmon and a suite of broader ecological measures including sediments, plants, invertebrates, fish and their response to large-scale habitat alteration. Restoration at Crims Island was the first large-scale effort of its kind in the lower Columbia River. As such, little was known about the potential response of juvenile salmon to this type of habitat modification. Therefore, the USGS monitored and evaluated the fish community pre- (2004) and post- (2006–09) restoration. Our specific objectives were to: (1) describe responses of the fish community, invertebrate community, sediment characteristics, and productivity to restoration by comparison to reference sites, (2) describe changes in the seasonal habitat use and prey use of subyearling Chinook salmon, (3) describe changes in the plant community 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 use this information to classify habitat types and identify their value to salmon.

Study Area and Restoration Action

The Crims Island Complex is in the tidal fluvial portion of the Columbia River estuary near Longview, Washington (fig. 1). The 'island complex' as defined here includes Crims Island, Gull Island, and smaller neighboring islands that are all connected at low tide and during periods of seasonally low river flows. The Crims Island Complex is 87 km from the Pacific Ocean (rkm 87) and 146 km downstream of Bonneville Dam (rkm 233), the first mainstem dam encountered when traveling up the Columbia River. Crims Island is upstream of salinity intrusion (Simenstad and others, 1990) in the tidal freshwater portion of the estuary. Tides at Crims Island are semi-diurnal with about 7 h of ebb and 5 h of flood tide. Mean tides range from 0.6 to 2.1 m as reported 1.1 km downstream of Crims Island (USGS gage #14246900, http://waterdata.usgs.gov/nwis).

Crims Island has seen significant changes over time resulting from homesteading, diking, filling, cattle grazing, and finally the restoration described here. Originally named Baker's Island by the Vancouver Expedition in 1792, Lewis and Clark passed the island on November 6, 1805, with Clark noting in his journal that they stopped to eat on the long narrow island but that the hunters could not get very far inland due to the extensive undergrowth. On their return journey up the Columbia River in March 1806, Lewis and Clark named it Fanny's Island. In 1927, the island was finally named Crims Island after James F. Crim, who homesteaded the island in the 1870s. Today, the total area of Crims and Gull Islands is about 300 ha, but its shape and hydrology have been altered due to the construction of low dikes around the perimeter. Drainage ditches were excavated and tide gates installed to reduce tidal inundation and the island was used extensively for agriculture until the tide gates failed. A small herd of cattle continued to graze the island until they were relocated pre-restoration in 2005 (fig. 2).

Restoration at Crims Island was designed to restore natural habitat forming and maintenance processes. Restoration proceeded by first dividing the unrestored marsh area into 10 "watershed" areas for which relations were developed between diurnal tidal prism and watershed area. Channels were designed following Williams and others (2002). Next, the top 0.6 m of the vegetated marsh plain elevation was excavated to remove non-native reed canarygrass (*Phalaris arundinacea*) and to allow establishment of a native tidal marsh plant community. The marsh plain was excavated to the same elevation as nearby Gull Island. The existing subtidal channels were widened and deepened to increase habitat complexity and allow for adequate water exchange between tidal cycles (fig. 3). New secondary channels were excavated to a depth ranging from 1.8 to 3.0 m beneath the original marsh plain and smaller intertidal tributary channels were constructed 0.9 m deep and 0.9 m wide with the expectation that channel banks would slough and create natural 'U'-shaped channels over time. Overall, 37.5 ha of wetlands were created (table 1) and an estimated 148,000 m^3 of material was excavated and placed in an adjacent upland area to establish a riparian forest (U.S. Army Corps of Engineers, 2004).

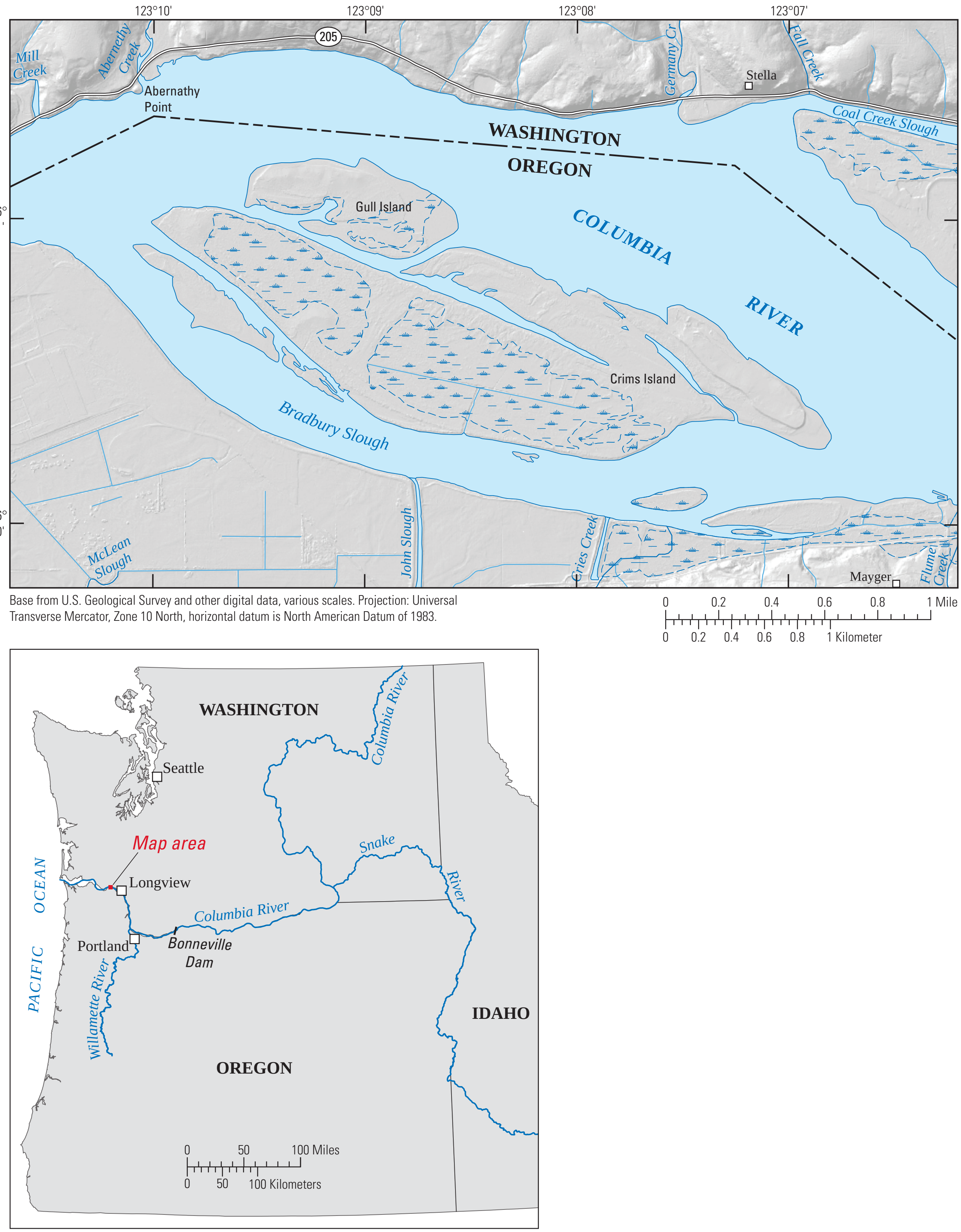

Figure 1. Crims and Gull Islands where restoration, monitoring, and research occurred from 2004 to 2009, Columbia River estuary, Oregon.

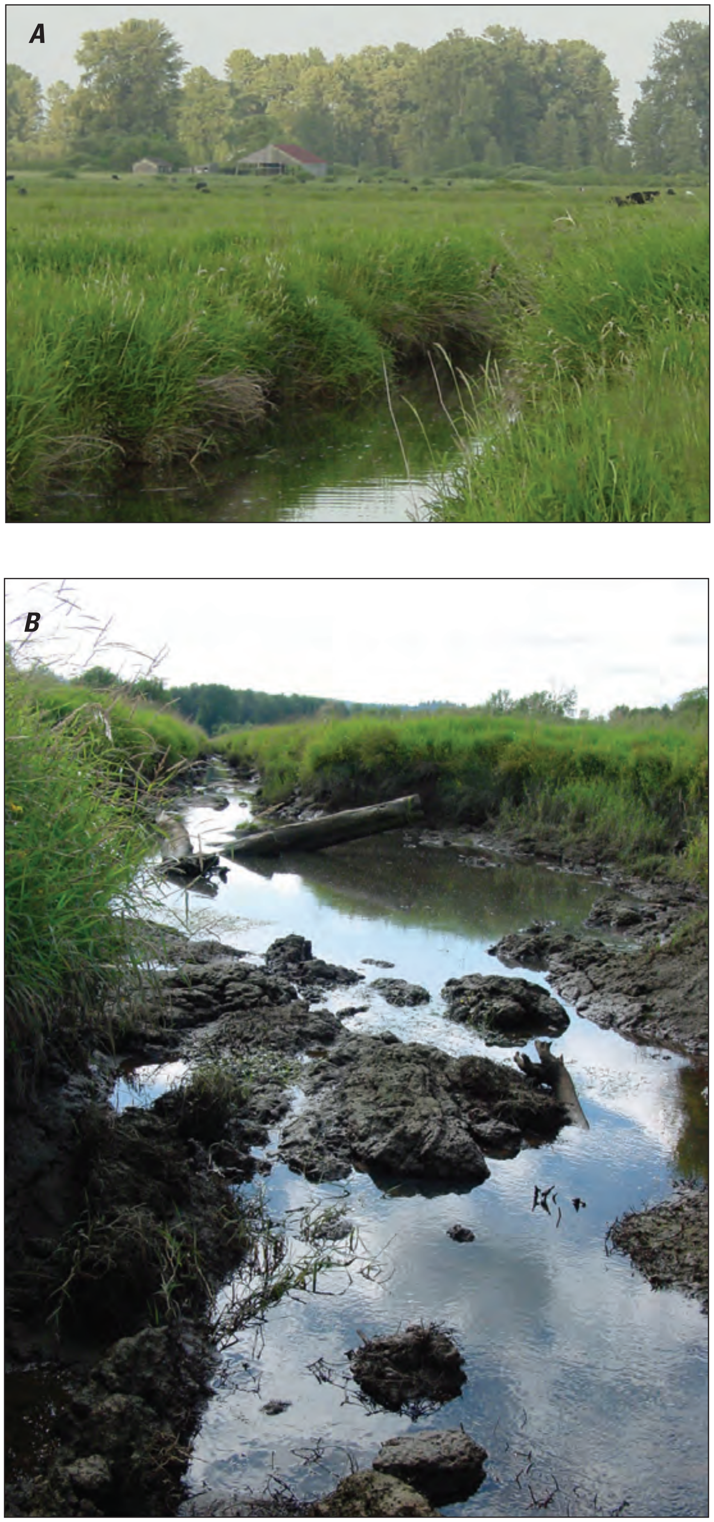

Figure 2. Habitat at Crims Island in 2004 prior to restoration, Columbia River estuary, Oregon. (Photographs taken by Craig Haskell, U.S. Geological Survey, January 16, 2004)

Figure 3. Excavation at Crims Island, Columbia River, Oregon, 2005. (Photographs taken by Craig Haskell and Ken Tiffan, U.S. Geological Survey, October 17, 2005).

Table 1. Estimated hectares of marsh plain and intertidal and subtidal channels pre- and post-restoration at the Restoration site and at the Reference site, Columbia River estuary, Oregon.

[–, no data]

Habitat	Estimated hectares		
	Restoration site		Reference site (Gull Island)
	Pre-restoration (2004)	Post-restoration (2006–09)	
Marsh plain	–	34.4	7.0
Intertidal channel	–	0.5	0.4
Subtidal channel	0.6	3.2	–
Total	0.6	38.1	7.4

Methods

Sampling Locations

All sampling occurred at three areas within the Crims Island Complex (fig. 4). First, a natural intertidal marsh site (hereinafter referred to as the Reference site) on neighboring Gull Island was used as a reference and benchmark for restoration on Crims Island. The Reference site consisted of 7.0 ha of vegetated marsh plain and 0.4 ha of intertidal channels. The sediment is silty sand. A looped channel that bisects the Reference site 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 site occasionally dewaters during low tide and as seasonal flow subsides after the spring freshet. We also sampled the mainstem Columbia River on the northern side of Gull Island (hereinafter referred to as the Mainstem site). This site had no aquatic or emergent vegetation, the sediment was sand, and the site was selected to compare backwater habitats to existing near-shore habitat on the Columbia River mainstem. Finally, we sampled sites within the restored area (hereinafter referred to as the Restoration site). All sites were sampled during 2004, 2006, 2007, and 2008, but only the Restoration site was sampled with a reduced and focused effort in 2009.

Sampling Design

We used a before-after-control-impact paired series (BACIPS) approach to compare subyearling fork length, condition factor, corrected prey weight (total prey weight expressed as a percentage of total fish weight), benthic and drift invertebrate density, and benthic and drift invertebrate diversity with the Reference site as the ‘Control’ and the Restoration site as the ‘Impact’ site. Both sites were sampled during each sampling trip, forming the resulting paired series. With this method, differences between the control and impact sites are the dependent variable and time (pre-restoration versus post-restoration) is the single factor. A two-sample *t*-test can then be used to compare the differences in site pairs pre-restoration to differences post-restoration (Stewart-Oaten and others, 1986). In all instances, each site time value is a mean of actual measurements of fish. We did not incorporate the Mainstem site into these particular analyses because the habitat there generally was dissimilar to that of the impact and control sites (Underwood, 1994).

Data Collection

Fish Sampling

Fish were collected at the Mainstem and Reference sites with a 20.7 m beach seine with 4.7 mm mesh. Beach seine sites were sampled by pulling the seine either toward or parallel to shore for a distance of about 50 m. Dramatic changes that accompanied restoration required us to change our sampling gear and strategy to effectively sample the Restoration site. In 2004 pre-restoration, we sampled at a single site in the existing T-channel (fig. 4*A*). The T-channel was a steep banked, manmade channel that extended north from Bradbury Slough into the interior of the Restoration site and then forked into two smaller perpendicular channels—one which ran east and the other which ran west to form the ‘T.’ Both of these small channels ended in the interior of the island and regularly dewatered during low tide. The main T-channel was subtidal and was the only channel leading to the interior of the Restoration site. Pre-restoration, the sediment in the channel bottom was clay and softer sediments that regularly sloughed from the banks. We collected fish in the main T-channel about 100 m from its outlet to Bradbury Slough with two fyke nets—one facing upstream and the other facing downstream. Fyke nets were suspended from a wooden beam support system and were raised and lowered with the flood and ebb tides with pulleys and hand cranks mounted on each shore. Nets were constructed and deployed to occlude the entire channel.

Restoration widened and deepened the main T-channel as well as the western arm of the T-channel, which was excavated westward and connected to Bradbury Slough. These primary channels now carried too great a volume of water for us to sample with paired fyke nets as we did in 2004. Therefore, in 2006, we collected fish from four newly constructed intertidal channels (fig. 4*B*) with small fyke nets deployed to occlude the entire channel. Small fyke nets had frames that were 0.9 m high by 1.2 m wide with 1.5 m wings that were staked to

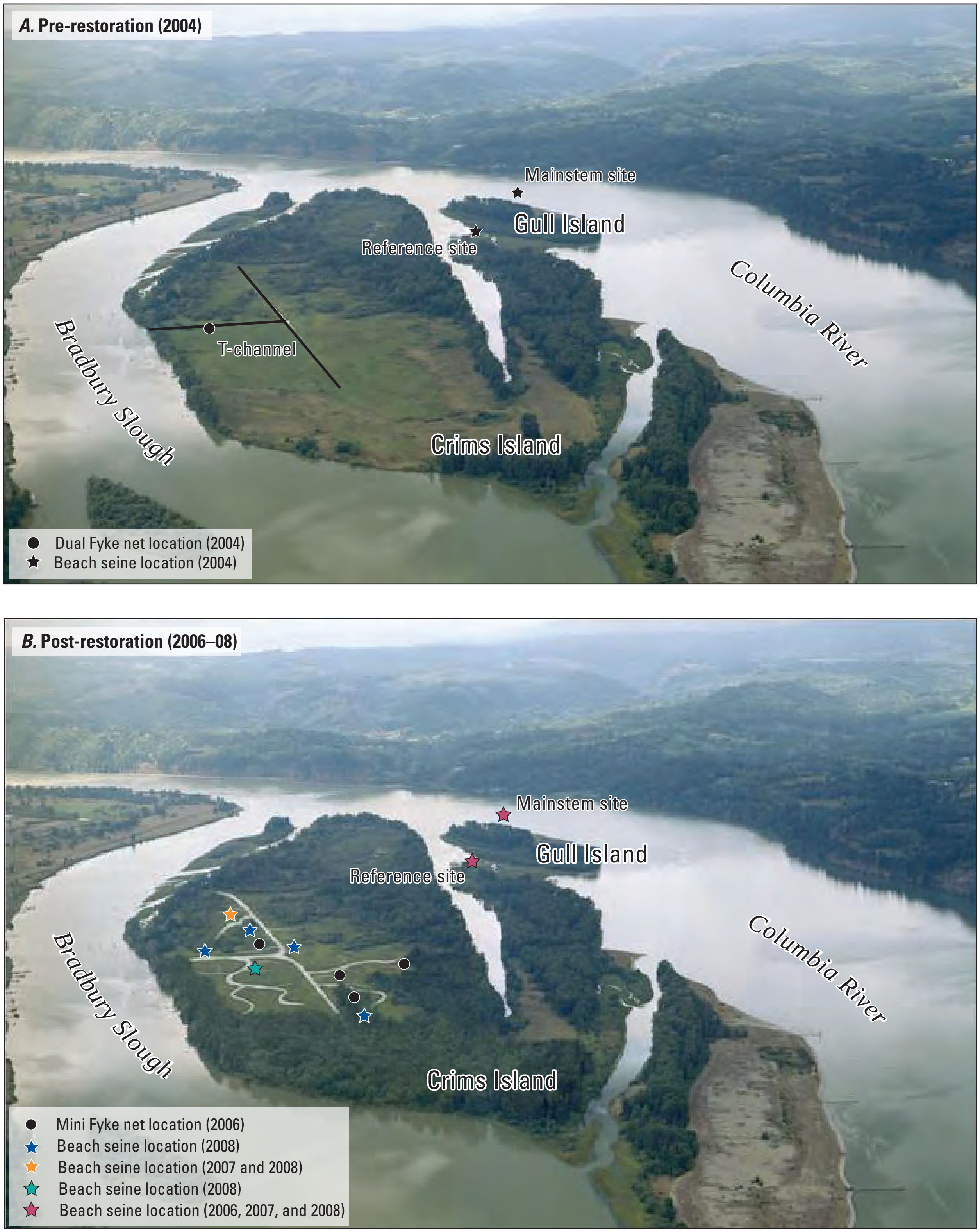

Figure 4. Crims Island Complex and sampling sites pre-restoration and post-restoration, Columbia River estuary, Oregon. (Aerial photographs courtesy of U.S. Army Corps of Engineers, 2004.)

channel banks (fig. 5). The nets generally were fished for 2 h on both an incoming and an outgoing tide. We also used a beach seine to collect fish at high tide from four marsh plain sites in 2006 and from one site in 2007 and 2008 (fig. 4*B*). We sampled weekly from March to September 2004. We sampled every other week from March to August 2006 and 2007, and every other week from March to October 2008.

From each collection, 40 juvenile salmonids of each species and life history type were measured to the nearest millimeter fork length (fig. 6), weighed to the nearest 0.1 g, and released. Forty individuals of each non-salmonid species were measured and released. When large numbers of non-salmonids were collected, we estimated their total numbers 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). Physical habitat data were collected at each sample site following the methods of Key and others (1994) including seine haul length, water depth, water velocity, and water temperature measured at distances of 1, 7.5, and 15 m from shore.

In 2004, 2006, 2007, and 2008, fish assemblages at the Restoration site were sampled to document seasonal fish abundance, timing of habitat use, and fish size. However, we also sampled in 2009 to compare the density and size of subyearlings using different channel types in the Restoration site. In 2009, we randomly selected (without replacement) and sampled 3 (out of 14 possible) intertidal channels and one 50-m segment out of each of 3 subtidal channels every other week from mid-April to late June—the period of greatest subyearling abundance. The three subtidal channels were the West T, East T, and SE channels. The West T contained 14 possible segments, the East T contained 5 possible segments, and the SE channel contained 6 possible segments. Channels were sampled over a 2- to 3-d period during low tide. Small intertidal channels were sampled by blocking the channel outlets with a small fyke net as described earlier with wings that were staked to channel banks. We then walked the entire channel toward the outlet moving fish toward the small fyke net with a small stick seine. We sampled subtidal channel segments by making a single pass across the channel with a 20.7 m beach seine. All juvenile salmonids were counted, measured, and weighed.

Stomach Sampling

We collected stomach contents from subyearlings to quantify differences in their diets between sample sites. Stomach contents were removed from 10 fish with non-lethal lavage from all three sample sites biweekly in 2004, 2007, and 2008. In 2006, we collected stomach contents monthly. The lavage instrument was a 30-mL syringe with a 100 µL pipette tip affixed to the end (fig. 7). Each fish was anesthetized and the pipette tip was inserted to the head of the stomach.

Figure 5. Small fyke net used for sampling intertidal channels post-restoration, Columbia River estuary, Oregon. (Photograph taken by John Olson, U.S. Geological Survey, July 27, 2006.)

Figure 6. Measurement of juvenile chum and fall Chinook salmon at the Restoration site on Crims Island, Columbia River estuary, Oregon. (Photograph taken by Ryan Koch, U.S. Geological Survey, March 22, 2004.)

Figure 7. Collection of stomach contents of subyearling Chinook salmon using lavage, Columbia River estuary, Oregon. (Photograph taken by Ryan Koch, U.S. Geological Survey, March 22, 2004.)

Distilled water was used to back flush the contents of the stomach into a Whirl-Pak®, which was frozen for laboratory analyses. In the past, USGS personnel have used this technique to successfully remove as much as 93 percent of the stomach contents of Chinook salmon as small as 42 mm in the Snake and Columbia Rivers (U.S. Geological Survey, unpub. data, 1996).

Residence Time

In 2004 and 2006, we estimated subyearling residence times to determine if restoration increased residence times compared to the Reference site. We used Calcein, a fluorochrome dye, to batch mark and subsequently release subyearlings in the Restoration and Reference sites (fig. 8). Calcein leaves a permanent mark on bony structures and scales and is easily seen using a specifically designed ultraviolet light detector, but is invisible to the naked eye. Large numbers of small salmon (<50 mm) can be batch marked while remaining in water with minimal handling. Calcein has been used successfully with Atlantic salmon fry, and laboratory trials indicated no adverse effects and no increased predation risk to marked fish (Mohler and others, 2002). We marked fish using osmotic induction whereby fish were placed in a 1.5- percent salt solution for 3.5 min and then in a 0.5-percent Calcein solution for 3.5 min (Mohler, 2003). Subyearlings were marked in batches of about 150 fish and allowed to recover in net pens overnight before release. After release at capture sites, fish were periodically recaptured using beach seines or fyke nets until the number of recaptured fish approached zero. Median residence times were calculated as the time at which 50 percent of the marked fish remained in the study areas, and were estimated once during May in both years (2004 and 2006).

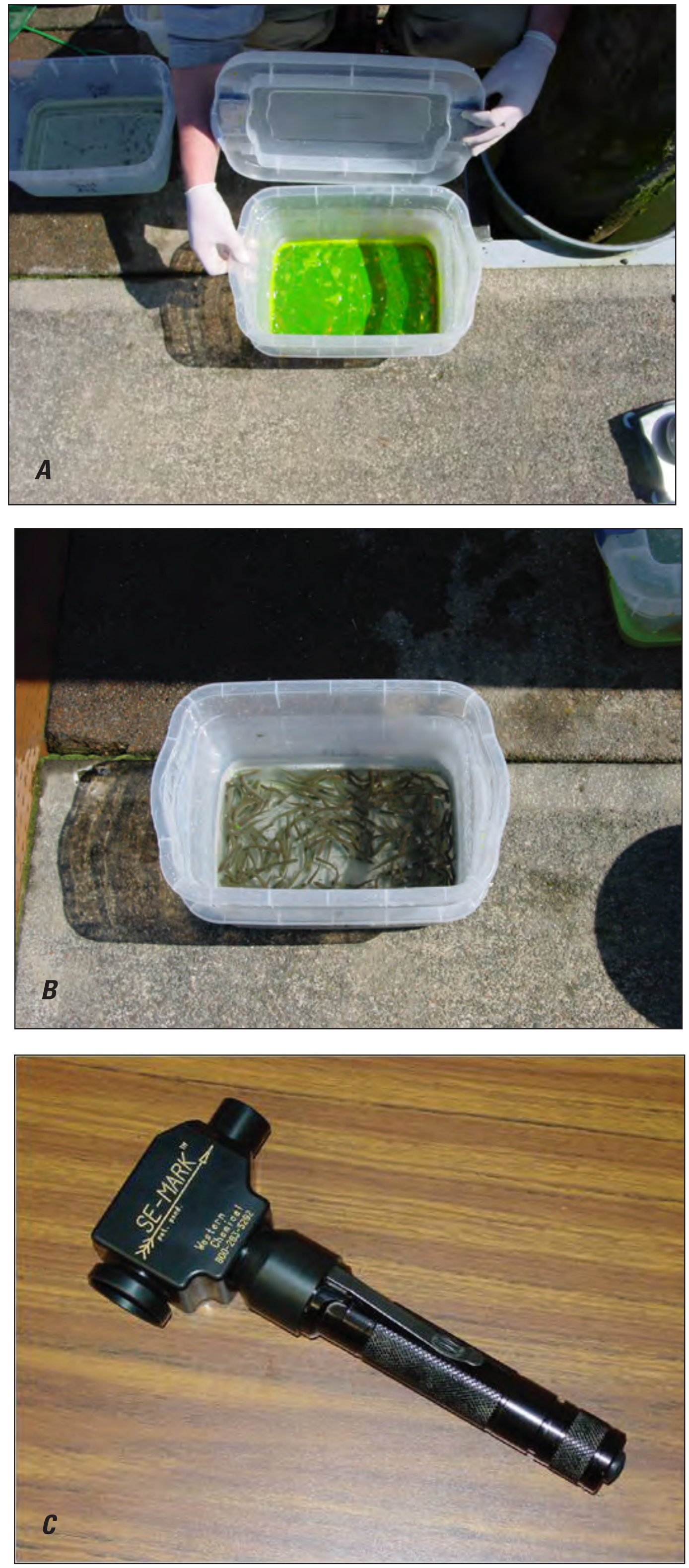

Figure 8. Subyearling Chinook immersed in Calcein solution, recovery after marking, and the Calcein detector. (Photographs taken by Ryan Koch, U.S. Geological Survey, April 22, 2004.)

Invertebrate Sampling and Processing

We sampled drift and benthic invertebrates at each study site to characterize the invertebrate community. Each year we collected monthly benthic invertebrate samples (10 replicates from each site) with a 174.6-cm^3 PVC coring device (McCabe and Hinton, 1996) to analyze abundance and diversity. Drift invertebrates were collected in three replicate neuston samples at each site with a metered 150-µm mesh drift net that had a rectangular opening of 35 × 50 cm. The sampling frame and net were towed through the water at a constant 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-percent ethanol for laboratory analysis.

In the laboratory, we identified invertebrates collected from benthic, drift, and stomach samples. Invertebrate samples were stained with rose bengal dye to aid in sorting. Invertebrates and plant matter were identified to the family level with a dissecting microscope. Identification of aquatic and terrestrial invertebrates followed Borror and White (1970) and Pennak (1989). After counting invertebrates, we recorded wet weights of taxonomic groups, dried groups for 24 h at 60ºC in a drying oven, and recorded dry weights. Organisms from fish stomachs were identified to the lowest practical taxon (generally family), counted, dried for 24 h, and weighed.

Water Temperature and Depth Monitoring

Water temperature and depth data were collected at the sampling sites to examine trends in fisheries data relative to these metrics. Discharge data were collected from a USGS gage (site #14246900) on the Columbia River located 1.1 km downstream of Crims Island to describe annual changes in river discharge. Collection of water temperature data 1.1 km downstream of Crims Island was discontinued in 2006; therefore, we used scroll case temperature data collected upstream at Bonneville Dam to describe annual changes in mainstem water temperatures (DART, 2010). We placed Sea-Bird® Model SBE-39 temperature and pressure recorders in the Restoration and Reference sites to develop a relation between water level recorded 1.1 km downstream of Crims Island and the backwater sampling sites. Water depth information also was 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 to record water temperature every 15 min at all beach seine and fyke net sites.

Carbon Sampling

We collected monthly soil and water samples at the Restoration and Reference sites in 2004, 2006, and 2008, to quantify the productive capacity of the sample sites post-restoration. Sediment samples were used to estimate total organic carbon (TOC) at the Restoration and Reference sites pre- and post-restoration. We also collected a single sediment sample from each site to determine median grain size and the percent sand, silt, and clay in 2004 and 2006. We assumed there would be no seasonal change in sediment grain size at sample sites (McCabe and others, 1997). Sediment samples for TOC analysis were collected with the same PVC corer used to collect benthic invertebrates. Single whole-water samples were collected at each site monthly to estimate TOC in the water. Sediment and water samples were analyzed by Test America Corporation, Beaverton, Oregon.

Plant Survey

On September 18 and October 11, 2006, we surveyed the plant community in newly restored habitat at the Restoration and Reference sites following Roegner and others (2008). We established linear baselines for quadrant sampling in the Reference and Restoration sites. Baselines were established perpendicular to the elevation gradient. Plants were identified following Hitchcock and Cronquist (1976) and Cooke (1997) and 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 completed a topographic and bathymetric survey of the Restoration and Reference sites pre- (2003) and post- (2006) restoration (fig. 9). The topography was surveyed with a Trimble® 5700 RTK GPS. We used an established control point on Crims Island and three rovers to collect geo-referenced elevation points at 1-s intervals. The RTK GPS has an advertised horizontal accuracy of ±1.45 cm and a vertical accuracy of ±2.45 cm. We collected bathymetric data in subtidal channels that were too deep to wade using a boat with a BioSonics©, Inc. DT-X series digital echo sounder and transducer with integrated RTK GPS. With these systems, we were able to collect more than 200,000 geo-referenced elevation points in the Restoration and Reference sites. The survey not only documented landscape changes resulting from restoration but also provided a benchmark to examine changes that will naturally occur over time.

Figure 9. RTK GPS instruments used for surveying the topography and bathymetry of the Restoration site pre- and post-restoration, Columbia River estuary, Oregon. (Photographs taken by John Olson and Craig Haskell, U.S. Geological Survey, October 11, 2006.)

Data Analysis

To analyze the change in the fish community resulting from restoration, we used two indexes to measure the similarity of fish assemblages between sites and years. The first was the percent similarity index or Renkonen index (Renkonen, 1938). The percent similarity index ranges from 0 to 100 percent with 0 indicating no similarity between fish assemblages and 100 percent indicating identical fish assemblages. It is defined as:

$$P_{jk} = \sum \text{minimum}\,(p_{ki}, p_{ji}),$$

where
- P = percent similarity of two fish assemblages j and k, and
- p = relative abundance of taxa i from assemblage k and j.

The second index was Morista's similarity index (Morista, 1959), which ranges from 0 to 1 with 1 being similar and 0 being dissimilar. It is defined as:

$$C_{jk} = \frac{2\sum X_{ij} X_{ik}}{(\lambda_j + \lambda_k) N_j N_k}, \text{ where}$$

$$\lambda_j = \frac{\sum [X_{ij}(X_{ij} - 1)]}{N_j (N_j - 1)}, \text{ and}$$

$$\lambda_k = \frac{\sum [X_{ik}(X_{ik} - 1)]}{N_k (N_k - 1)},$$

where
- C = similarity between assemblage j and k,
- X = number of individuals from taxa i, and
- N = total number of individuals from assemblage j and k.

We used the geo-rectified topographic and bathymetric survey information to expand beach seine densities in the Reference and Restoration sites and fyke net catches to the total amount of habitat (for example, marsh plain, subtidal channels) in the Restoration site. For annual comparisons of subyearling densities, we expanded beach seine densities per unit area to the total amount of existing marsh plain area to estimate the total numbers of subyearlings using the Restoration site in 2006, 2007, and 2008. We standardized the fyke net catches to compare subyearling catch pre-restoration

(2004) to post-restoration (2006) by multiplying mean CPUE (fish/h) by the total amount of channel habitat (m^2). Channel lengths (m), channel areas (m^2), and marsh plain areas (m^2) were quantified using geo-rectified digital imagery loaded into ArcMap software (ESRI, version 9.2). We could not use beach seines or quantify fish/unit area pre-restoration because existing steep sided-channels were not suitable for beach seining.

We used two community structure indexes to measure invertebrate diversity between sampling sites: the Shannon's index of diversity (H') and evenness (J'). Diversity is expressed as:

$$H' = \sum_{i=1}^{s} (p_i)(\log_e p_i),$$

where
H' = Shannon's index of diversity,
s = number of taxa, and
p_i = number of observations in a category/sample.

Shannon's index of diversity can range from 0 to 1, with 1 being the highest possible diversity given the total number of taxa present in the study area. The second index was evenness and is the proportion of the total possible diversity based on Shannon's index. The evenness index ranges from 0 to 1, and is expressed as:

$$J' = \frac{H'}{\log_e S}.$$

The number, weight, and frequency of occurrence of prey items were used to determine the importance of prey items to subyearling diets using the index of relative importance (IRI; Pinkas and others, 1971). The IRI is defined as:

$$(\%N_i + \%W_i)(\%O_i),$$

where
N = number of prey item i,
W = weight of prey item i, and
O = occurrence of prey item i.

High percentage of IRIs indicated greater importance of a food group among prey taxa. Because there is controversy over the use of combination indexes, including IRI (see Chipps and Garvey, 2007), we also present the individual diet indexes, separately.

Results

River Conditions

Annual discharge trends as measured 1.1 km downstream of Crims Island on the Columbia River mainstem generally were variable in relation to the 10-year average (2000–2009; fig. 10). During our sampling, discharge minimums were 2,687 m^3/s in 2004; 2,546 m^3/s in 2006; 2,475 m^3/s in 2007; 2,690 m^3/s in 2008; and 2,466 m^3/s in 2009. Discharge maximums were 11,327 m^3/s in 2004; 13,847 m^3/s in 2006; 10,477 m^3/s in 2007; 14,583 m^3/s in 2008; and 14,017 m^3/s in 2009. Annual discharge patterns were lower than average in 2004, higher than average in 2006 and 2008, and near the 10-year average in 2007 and 2009 (fig. 10). Water temperatures ranged from a low of 1.1ºC in January 2004 to a high of 23.9 ºC in early August 2009. Seasonal trends in water temperature generally were similar during the years that we sampled with peaks in late August and seasonal lows in early January.

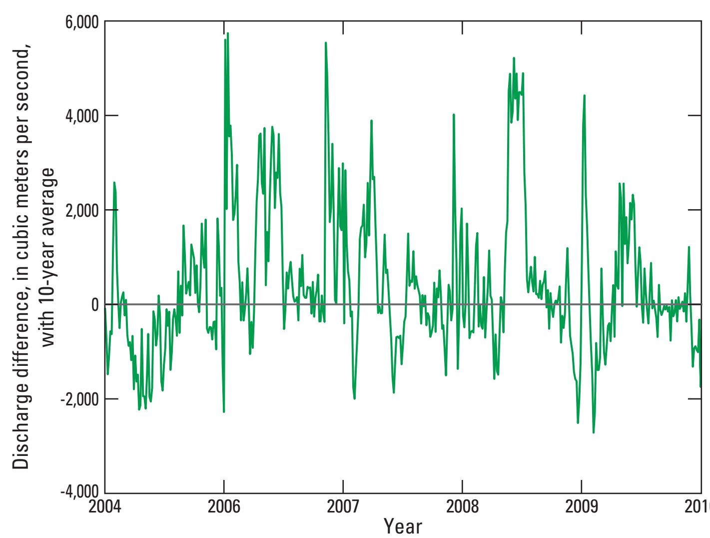

Figure 10. Annual trends in the difference between the mean daily discharge and the 10-year average (2000–2009) for that date as measured 1.1 km downstream of Crims Island, Columbia River estuary, Oregon, 2004 and 2006–09. Data does not include 2005 as the Restoration site was being excavated and no sampling occurred.

Fish Response

Community

We collected 25 species of fish from 13 taxonomic families from 2004 to 2008. The fish community primarily comprised threespine stickleback (*Gasterosteus aculeatus*, 58.4 percent), banded killifish (*Fundulus diaphanus*, 16.9 percent), peamouth chub (*Mylocheilus caurinus*, 13.4 percent), and subyearlings (9.1 percent; table A1). Subyearlings were the most common salmonid species and life history type collected so we focused most of our research and monitoring efforts at Crims Island on subyearlings. We captured 12,833 subyearlings, 221 chum salmon juveniles, 84 yearling Chinook salmon, and 5 coho salmon juveniles. Large piscivorous fish were virtually absent from fish collections pre- and post-restoration. The major predators of juvenile salmon in the Columbia River are northern pikeminnow (*Ptychocheilus oregonensis*), smallmouth bass (*Micropterus dolomieu*), and walleye (*Sander vitreus)* (Rieman and others, 1991; Vigg and others, 1991). All these fish were captured in small numbers during our sampling, however nearly all were too small to prey on juvenile salmonids.

The fish assemblage at the Restoration site varied within and among sites and years. We arbitrarily used the fish assemblage from the Restoration site in 2008 as a comparative baseline. The fish assemblage in the Reference site was most similar to the baseline assemblage across years, achieving high and consistent ranks in the percent similarity and Morista's index of similarity (table 2). The exception occurred in 2004 when the fish assemblage at the Reference site was less similar to the fish assemblage in 2006–08 and to the baseline. The fish assemblage in the Restoration site showed the most variation across years within the site and compared to the other sites. In the Restoration site, the fish assemblage in 2008 was most similar to fish assemblage in 2004, but showed the lowest similarity to fish assemblage in 2007 (table 2). The fish assemblage in the Restoration site in 2008 also was similar to fish assemblage in the Reference site from 2006 to 2008. As with the Restoration site, the similarity of the fish assemblage in the Mainstem site was variable across years and compared to the baseline (table 2). Percent similarity and Morista's index of similarity were ranked the same for the first seven fish assemblages.

Fourteen of the 25 fish taxa encountered were non-native (56 percent). However, without the inclusion of banded killifish, the main non-native fish we captured, non-native fish represented only 0.83 percent of the entire catch. It is noteworthy that we captured a single Amur goby (*Rhinogobius brunneus*) in a fyke net at the Restoration site on May 6, 2006.

Table 2. Percent similarity index, rank of percent similarity index, Morista's index of similarity, and rank of Morista's index of similarity of fish assemblages between the Restoration site in 2008 (gray shading) and fish assemblages from the Restoration, Reference, and Mainstem sites in 2004 (pre-restoration) and from 2006 to 2008 (post-restoration), Columbia River estuary, Oregon.

Site	Year	Percent simmilarity		Morista's	
		Index	Rank	Similarity index	Rank
Restoration	2008	100.00	1	1.00	1
Restoration	2004	87.85	2	0.98	2
Reference	2007	85.94	3	0.97	3
Reference	2006	82.42	4	0.97	4
Reference	2008	80.62	5	0.94	5
Mainstem	2007	77.40	6	0.94	6
Mainstem	2008	76.66	7	0.94	7
Restoration	2006	74.41	8	0.92	8
Mainstem	2004	72.25	9	0.46	12
Reference	2004	66.36	10	0.77	10
Mainstem	2006	62.91	11	0.82	9
Restoration	2007	51.18	12	0.62	11

The fish, which is native to eastern Asia and named for the Amur River, was the first recorded collection in the Columbia River, although some had been collected previously in one of its tributaries—the East Fork Lewis River. The identity of the specimen was later verified, and since this first collection, other specimens have been found elsewhere in the Columbia River estuary (Sather and others, 2009).

Subyearling Total Numbers and Abundance

We captured many subyearlings in the Restoration site post-restoration. Peak yearly numbers extrapolated from beach seine catches from individual sampling trips ranged from 11,613 in 2008 to 13,962 in 2006 (fig. 11). In the Reference site, extrapolated numbers of subyearlings ranged from 404 in 2007 to 635 in 2006. Most subyearlings were captured from mid-March to late May. Numbers of subyearlings decreased during June and approached zero as mean daily water temperature exceeded 20ºC. However, small numbers of subyearlings persisted in subtidal channels and at the Mainstem site throughout the summer even though water temperature exceeded 22ºC. Our standardized fyke net CPUE indicated generally high densities of subyearlings in the Restoration site post-restoration (fig. 12) with similar seasonal peaks to beach seine catches.

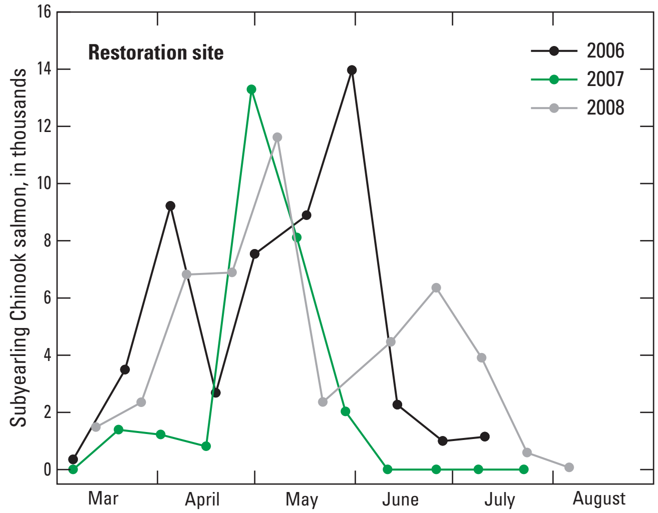

Figure 11. Seasonal change in the number of subyearling Chinook salmon in the Restoration site in 2006, 2007, and 2008, Columbia River estuary, Oregon. Numbers were calculated using beach seine densities extrapolated to the total area of available habitat as calculated using a GIS.

Subyearling densities in the Restoration site were highest in subtidal channels, intermediate in intertidal channels, and lowest in marsh plains (figs. 13 and 14). However, these differences were not significant (t = 1.88, P = 0.0832). Subyearling densities ranged from 0.005 to 0.323 fish/m^2 in subtidal channels and from 0.003 to 0.340 fish/m^2 in smaller intertidal channels (fig. 13). Overall, maximum densities in restored marsh plains were 0.048 fish/m^2 in 2006, 0.069 fish/m^2 in 2007, and 0.022 fish/m^2 in 2008. In 2008, maximum densities in restored marsh plains sampled with beach seines at high tide were 0.022 fish/m^2, whereas maximum densities in subtidal channels during low tide were 0.450 fish/m^2 (fig. 14). In the Reference site, maximum subyearling densities were consistent from year to year ranging from 0.159 fish/m^2 in 2004, 0.166 fish/m^2 in 2006, 0.106 fish/m^2 in 2007, and 0.107 fish/m^2 in 2008.

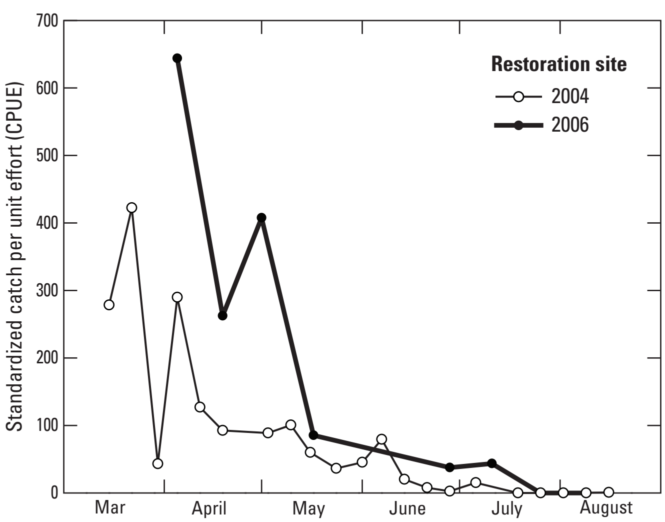

Figure 12. Seasonal change in mean catch per unit effort (CPUE) of subyearlings collected at the Restoration site in 2004 pre-restoration and in 2006 post-restoration, Columbia River estuary, Oregon.

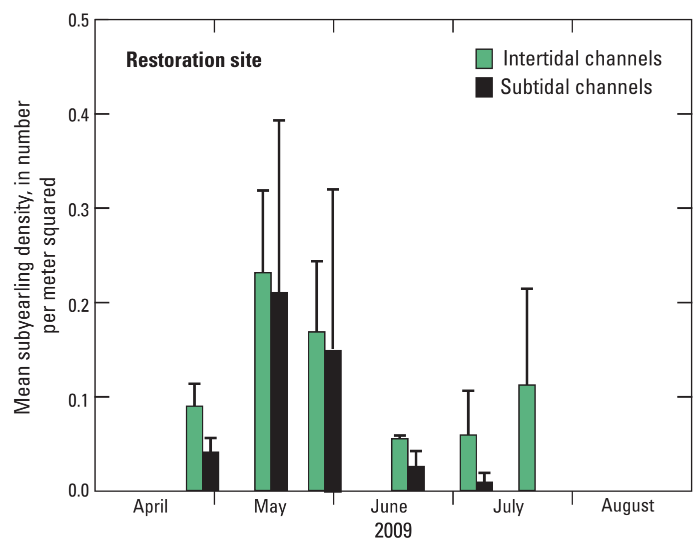

Figure 13. Mean density of subyearling Chinook salmon collected from subtidal and intertidal channels in the Restoration site, Columbia River estuary, Oregon, April 23, 2009–June 30, 2009. Error bars show standard error (SE).

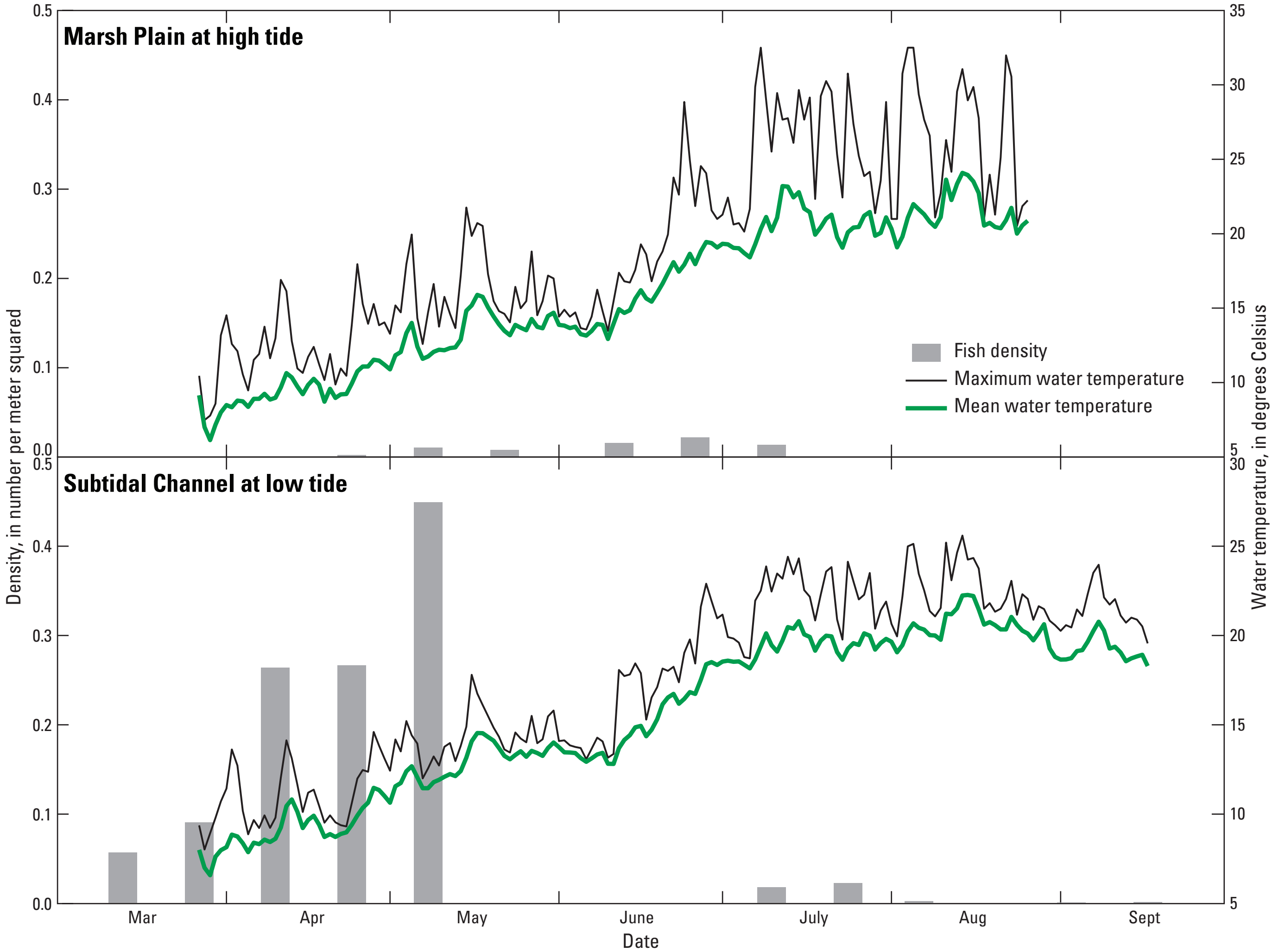

Figure 14. Seasonal change in subyearling Chinook salmon density, mean water temperature, and maximum daily water temperature collected at the Restoration site in marsh plain habitat at high tide and in subtidal channels at low tide Columbia River estuary, Oregon, 2008. High water precluded sampling in the subtidal channels from late May to early July.

Subyearling Size and Condition

Subyearlings were larger on average in the Restoration site post-restoration compared to pre-restoration. The grand mean fork length was 48.1 mm (SD=10.5) in 2004 and 59.3 mm (SD=16.3) from 2006 to 2008; this represented a significant difference (table 3; t = -2.89, P = 0.0071). Overall, fork lengths generally were greater in the Mainstem site than in the Restoration and Reference sites. Habitats farther away from the mainstem Columbia River contained smaller subyearlings than habitats closer to the mainstem. Subyearlings in intertidal channels were smaller (mean = 47.9 mm, SD = 8.7) than fish in larger subtidal channels (mean = 60.5 mm, SD = 15.8; fig. 15). The difference in mean fish size between these habitats was 12.6 mm and was significantly different (P < 0.05). Fish collected at the Mainstem site (grand mean = 60.0 mm) were significantly larger than fishes collected at the Reference (grand mean = 56.9 mm) and Restoration (grand mean = 55.7 mm) sites in all years (fig. 16). Although the grand means between the Reference and Restoration sites also were significantly different, we did not consider a difference of 0.8 mm to be biologically significant.

Table 3. Results of BACIPS *t*-tests examining the effect of restoration on subyearling Chinook salmon, benthic invertebrate, drift invertebrate, and total organic carbon response variables, Columbia River estuary, Oregon.

[BACIPS, before-after-control-impact paired series. Asterisk (*) denotes significance. <, less than]

Collection	Response variable	Years	Difference in means control-impact	Number of period means (pre- and post-restoration)	*t*	*P*
Subyearling Chinook	Condition factor*	2004, 2006–2008	–0.103	14, 19	–3.64	0.0019
	Fork length*	2004, 2006–2008	–7.671	13, 19	–2.89	0.0071
	Corrected prey weight	2004, 2006–2008	–0.117	8, 14	–1.49	0.1516
Benthic invertebrate	Abundance ($\log_{10}$)	2004, 2006–2008	–0.194	12, 30	–1.62	0.1126
	Diversity (*H*')	2004, 2006–2008	0.115	12, 30	1.90	0.0643
Drift invertebrate	Abundance ($\log_{10}$)	2004, 2006	–0.239	12, 6	–0.99	0.3357
	Diversity (*H*')*	2004, 2006	–0.596	12, 6	–6.88	<0.0001
Total organic carbon	Sediment*	2004, 2006, 2008	–60,288	5, 12	–3.12	0.0097
	Water*	2004, 2006, 2008	1.862	5, 12	6.16	<0.0001

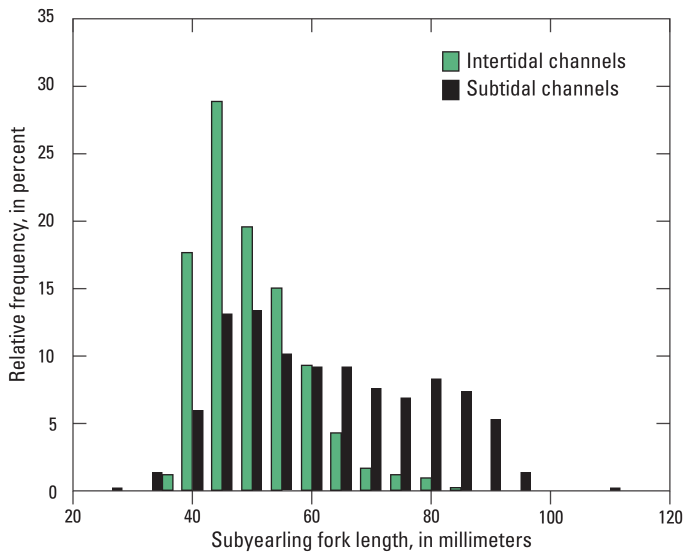

Figure 15. Relative frequency of subyearling Chinook salmon fork lengths collected in subtidal and intertidal channels at the Restoration site, Columbia River estuary, Oregon, April 23–June 30, 2009.

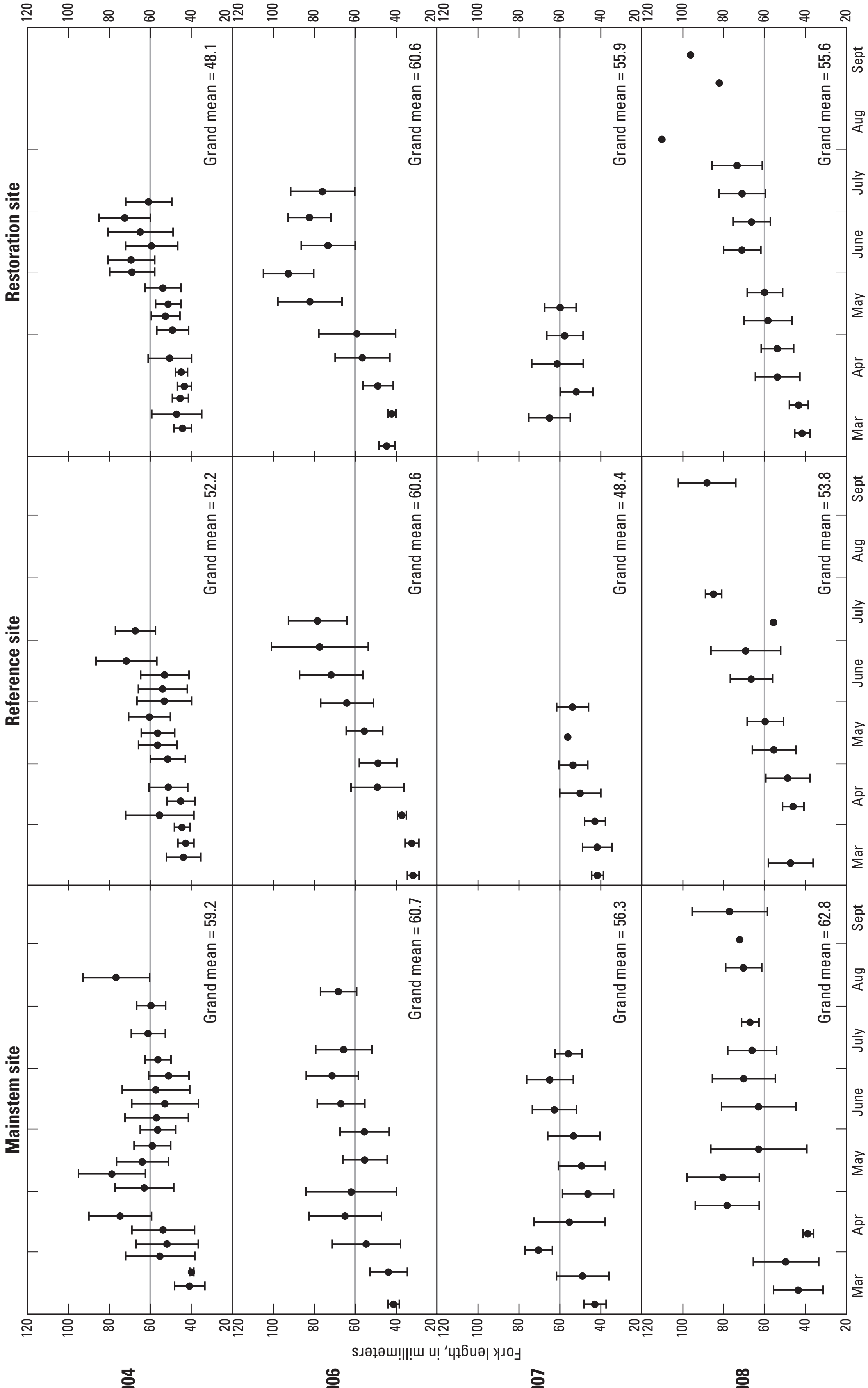

Figure 16. Seasonal variation in subyearling Chinook salmon mean (± SD) fork length collected at the Mainstem, Reference, and the Restoration sites in 2004 pre-restoration and post-restoration in 2006, 2007, and 2008, Columbia River estuary, Oregon. Reference line placed at 60 mm for site comparisons.

Mean condition factors were higher for fish in the Reference site than for fish in the Restoration site in 2004, 2006, and 2008, but the opposite was true in 2007. The mean condition factors at the Restoration site were 0.92 (SD = 0.15) in 2004, 1.04 (SD = 0.21) in 2006, 1.04 (SD = 0.11) in 2007, and 1.02 (SD = 0.18) in 2008. In the Reference site, the mean condition factors were 1.02 (SD = 0.16) in 2004, 1.09 (SD = 0.15) in 2006, 0.97 (SD = 0.14) in 2007, and 1.06 (SD = 0.20) in 2008. The differences in control versus impact period means were significantly different (t = -3.64, P = 0.0019; table 3) indicating that restoration resulted in a significant increase in the condition factor of subyearlings in the Restoration site compared to condition factors in the Reference site.

Subyearling Feeding

The diet of subyearlings varied between mainstem and backwater habitats. Subyearlings primarily preyed on *Corophium* spp. (amphipods) and *Daphnia* spp.(cladocerans) at the Mainstem site and on *Chironomus* spp. (aquatic dipterans larvae and pupae) in the Reference and Restoration sites (fig. 17). In 2004 pre-restoration, subyearlings ate dipterans almost exclusively in the Reference site, whereas the diet in the Restoration site also included a high percentage of dipterans but also included a small portion of *Daphnia* and *Corophium*. In 2004, subyearlings primarily fed on *Daphnia* at the Mainstem site followed by *Corophium* and relatively few dipterans. However, post-restoration, fish in the Restoration site consumed a much higher IRI percentage of dipterans in 2006 and 2007, which was very similar to IRI percentage of dipterans in the Reference site. In 2008, there was a substantial increase in the number of *Corophium* in stomachs of fish using the Restoration site, but this was not true for the Reference site. Percentage by number, a single component used in the calculation of the IRI, indicated that dipterans were the greatest prey in the Reference site and *Daphnia* were the greatest prey in the Mainstem and Restoration sites (table A3). Dipterans represented the highest percentage of prey by weight at the Reference and Restoration sites, but *Corophium* represented the highest percentage of prey by weight at the Mainstem site. There were two noteworthy changes in the percent IRI in our study. First, *Daphnia* accounted for a much larger percent IRI of food items at all sites in 2004 and 2006 compared to 2007 and 2008. Second, fish in the Restoration site had a much larger percent IRI of amphipods in 2008 than in 2004, 2006, and 2007.

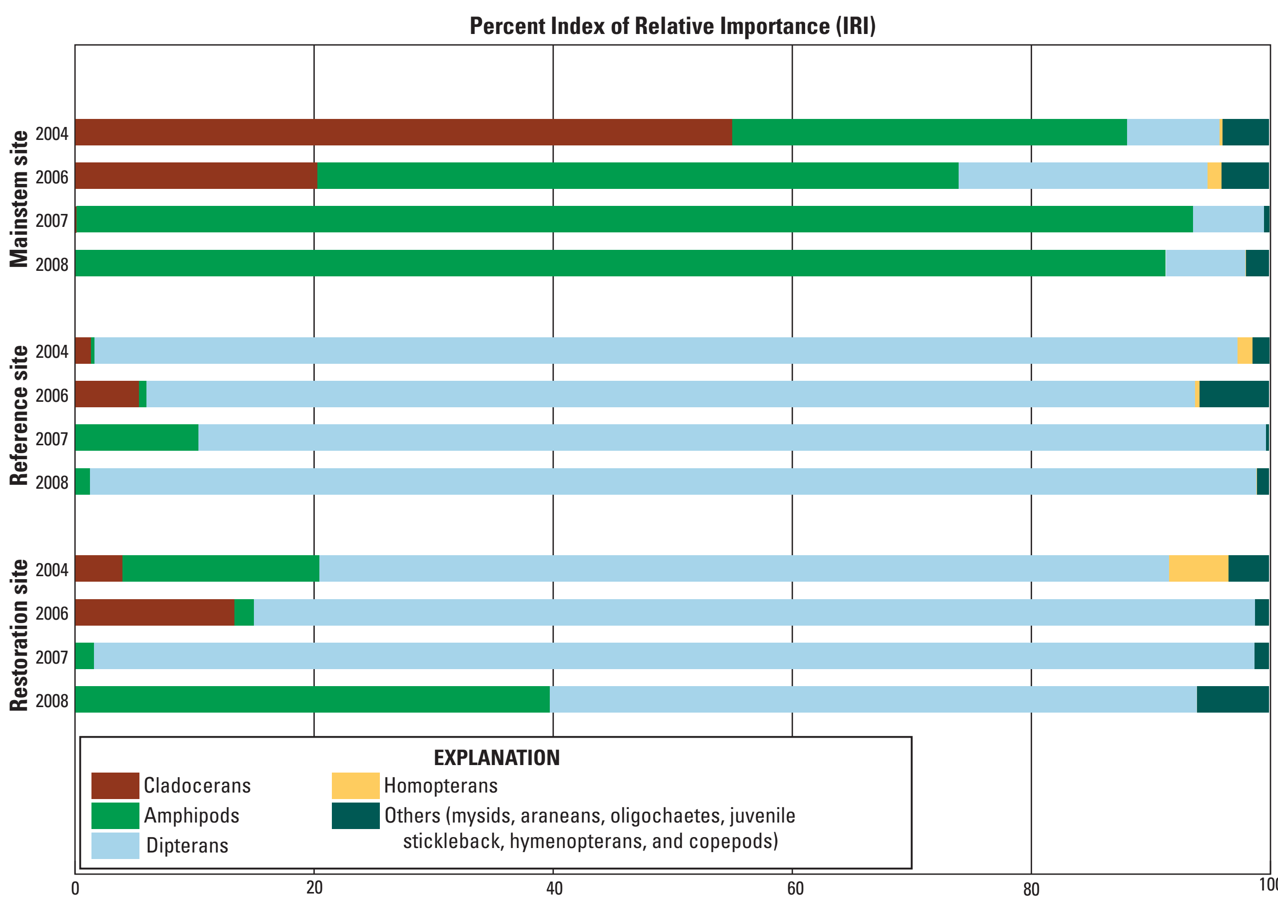

Figure 17. Percent Index of Relative Importance (IRI) of subyearling Chinook salmon prey collected at the Mainstem, Reference, and the Restoration sites pre-restoration in 2004 and post-restoration in 2006, 2007, and 2008, Columbia River estuary, Oregon.

The corrected prey weights of subyearlings indicated that fish in the Reference and Restoration sites had higher prey to body weight ratios than fish in the Mainstem site. Mean corrected prey weight was highest in the Reference site (grand mean = 0. 21, SD = 0.16) and lowest in the Mainstem site (grand mean = 0. 13, SD = 0.08). In the Restoration site, the mean corrected prey weight was virtually the same pre- (grand mean = 0. 21, SD = 0.13) restoration as post-restoration (grand mean = 0. 20, SD = 0.13). The mean corrected prey weight of subyearlings from the Restoration site in 2007 was highest (mean = 0.34) for any site during any year. Pre-restoration in 2004, subyearlings had a mean corrected prey weight of 0.21. Subyearlings exhibited corrected prey weights of 0.15 in 2006 and 0.16 in 2008. Subyearlings generally fed more intensively on Dipterans (mostly chironomid larvae) and less intensively on *Corophium* and *Daphnia*.

Subyearling Residence Time

We marked and released 447 subyearlings in the Reference site and 932 subyearlings in the Restoration site in 2006 to estimate site-specific residence times. Residence time of subyearlings at both sites was short and most fish left backwater areas within one or two tidal cycles. Median residence times of fish in the Restoration site in 2006 were longer post-restoration (50.2 h) than pre-restoration (12.7 h), but low sample sizes and variable effort between the 2 years precluded meaningful comparisons. In the Reference site, median residence time was substantially shorter (1 h) in 2004 than in 2006 (43.1 h; fig. 18).

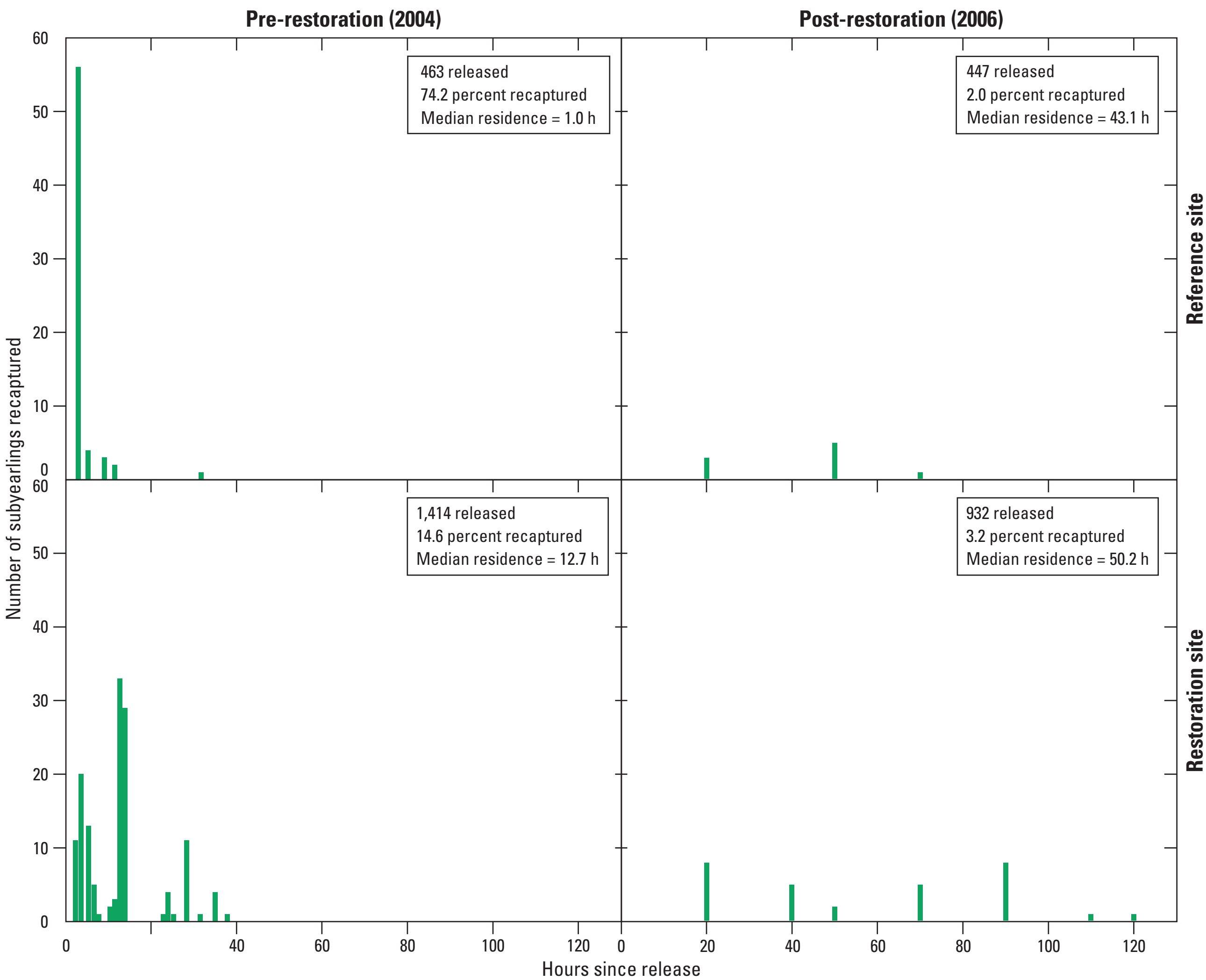

Figure 18. Residence time of marked subyearling Chinook salmon released into the Reference and Restoration sites pre-restoration in 2004 and post-restoration in 2006, Columbia River estuary, Oregon. In 2004, fish were individually marked using a panjet needless inoculator and monitored hourly after release. In 2006, fish were batch marked using the fluorochrome dye, Calcein, and monitored daily after release.

Invertebrate Response

Overall, dipterans were the primary invertebrate taxa collected in the Restoration and Reference sites, whereas *Corophium* was the dominant taxon at the Mainstem site. Pre-restoration, the benthic invertebrate community at the Restoration site primarily was composed of dipteran larvae (50.0 percent), *Corophium* (30.2 percent), and oligochaetes (11.9 percent; table A4). Post-restoration, the percentage of *Corophium* decreased (0 percent in 2006 and 2007, 0.9 percent in 2008), the percentage of dipterans generally remained the same, but the percentage of oligochaetes and nematodes increased. During all years, the benthic invertebrate community at the Reference site was represented by dipteran larvae, oligochaetes, and nematodes, whereas at the Mainstem site, the benthic invertebrate community was dominated by *Corophium*. The drift invertebrate community primarily was composed of dipterans at all sites during all years (table A6). The drift invertebrate community at the Restoration site was dominated by chironomids (33.5 percent), aphids (11.9 percent), and gastropods (6.0 percent) pre-restoration, but post-restoration, there was a higher percentage of chironomids (70.2 percent) and smaller percentages of aphids (6.9 percent) and gastropods (0.9 percent). Gastropods and immature stages of chironomids are aquatic in origin whereas aphids are only terrestrial.

Benthic invertebrate density was higher in backwater sites than in the Mainstem site and showed a general, although not significant, increase resulting from restoration. The benthic invertebrate density grand mean was 2,225 organisms/m^2 (range: 0–7,816/m^2) in the Mainstem site and 8,890 organisms/m^2 (range: 2,663–21,666/m^2) in the Reference site. In the Restoration site, invertebrate density was 2,462 organisms/m^2 (range: 1,203–4,639/m^2) pre-restoration but 9,254 organisms/m^2 (range: 945–34,961/m^2) post-restoration, however, due to the high variability, the difference between pre- and post-restoration abundances of benthic invertebrates was not significant (table 3, $P = 0.1126$).

Restoration generally had little effect on the abundance of the most common prey item of subyearlings—chironomid larvae. Pre-restoration, the overall density of chironomid larvae in the benthos was 2,677 larvae/m^2 in the Reference site and 1,059 larvae/m^2 in the Restoration site. Post-restoration, chironomid larvae density was 2,248 larvae/m^2 in the Reference site and 1,804 larvae/m^2 in the Restoration site. Adult chironomids were the predominant organisms found in the drift. Pre-restoration, adult chironomid densities were 0.194 adults/m^2 in the Reference site and 0.104 adults/m^2 in the Restoration site. Post-restoration, adult chironomid densities were 0.087 adults/m^2 in the Reference site and 0.116 adults/m^2 in the Restoration site.

Similar to benthic invertebrate densities, drift invertebrate densities were higher in the backwater sites than in the Mainstem site. Restoration resulted in a general decrease in drift invertebrate densities in the Restoration site. Overall, the grand mean of drift invertebrate density was 5,456/m^2 (range: 286–17,466/m^2) in the Mainstem site, and 48,119/m^2 (range: 8,876–134,574/m^2) in the Reference site. In the Restoration site, the grand mean drift invertebrate density was 55,285/m^2 (range: 6,586–111,382/m^2) pre-restoration and 36,507/m^2 (range: 15,175–67,287/m^2) post-restoration.

Although restoration had no significant effect on benthic or drift invertebrate densities, our *t*-test comparisons indicated that restoration resulted in significant decreases in invertebrate diversities. Benthic invertebrate diversity in the Restoration site significantly ($t = 3.46$, $P = 0.0032$) decreased in 2006, immediately post-restoration, but then increased in 2007 and 2008 to near 2004 levels when compared both within the Restoration site and between the Reference site (fig. 19). When data from 2007 and 2008 were considered along with 2006 data, the decrease in benthic invertebrate diversity post-restoration was not significant ($t = 1.90$, $P = 0.0643$). In the Reference site, benthic invertebrate diversity mean was 0.58 (range: 0.37–0.82) and evenness grand mean was 0.73 (range: 0.55–0.93). In the Restoration site pre-restoration, benthic invertebrate diversity was 0.52 (range: 0.29–0.71) and evenness grand mean was 0.71 (range: 0.49–0.96). Post- restoration, benthic invertebrate diversity mean in the Restoration site decreased to 0.49 (range: 0.10–0.76) and the evenness grand mean decreased to 0.65 (0.2–0.9) (table A5). Benthic invertebrate diversity and evenness means were lowest in the Mainstem site. In the Mainstem site, benthic invertebrate diversity mean was 0.30 (range: 0–0.67) and the evenness grand mean was 0.57 (range: 0–1.0).

Drift invertebrate diversity significantly decreased in the Restoration site compared to the Reference site ($t = -6.88$, $P < 0.0001$, table 3), however, the post-restoration drift invertebrate data were only collected in 2006, giving us only 1 year for comparison to pre-restoration conditions. In the Restoration site, drift invertebrate grand mean diversity was 1.015 (range: 0.60–1.23) and evenness was 0.74 (range: 0.57–0.90) pre-restoration, and post-restoration grand mean diversity was 0.52 (range: 0.2–1.08) and evenness was 0.48 (range: 0.18–0.86). In the Reference site, the drift invertebrate diversity and evenness grand means from all years combined were 0.62 (range: 0.28–1.07) and 0.55 (range: 0.27–0.81), respectively. In the Mainstem site, the drift invertebrate diversity and evenness grand means from all years combined were 0.52 (range: 0–0.86) and 0.77 (range: 0.43–0.96), respectively.

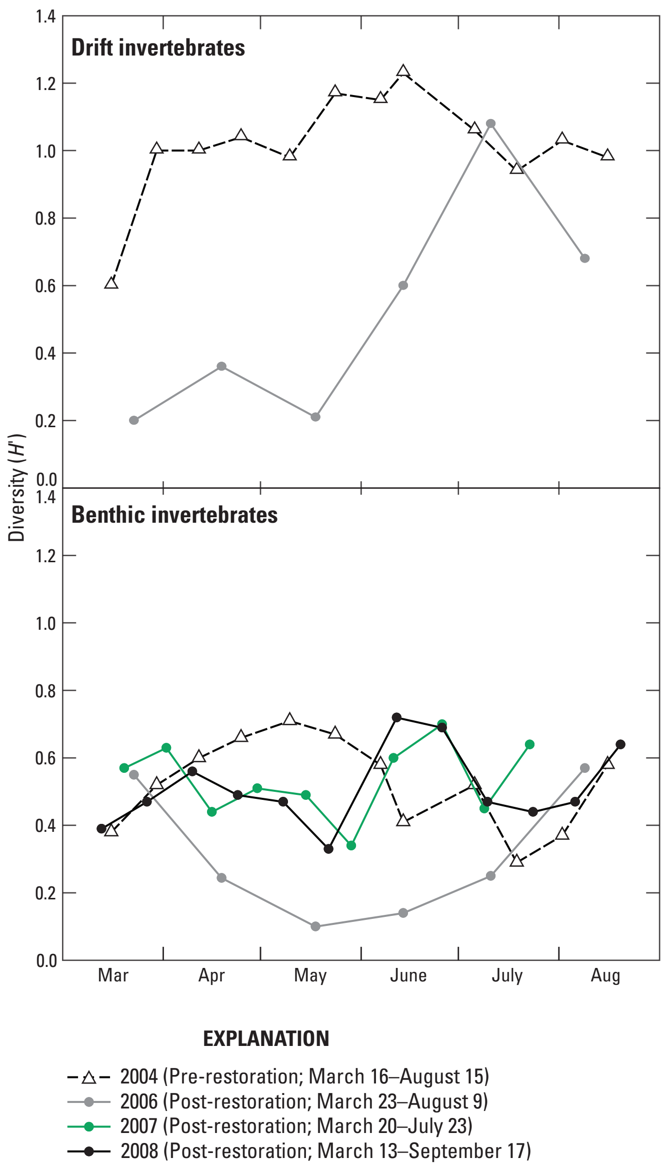

Figure 19. Seasonal change in drift and benthic invertebrate diversity (*H'*) at the Restoration site pre-restoration in 2004 and post-restoration in 2006, 2007, and 2008, Columbia River estuary, Oregon. Three replicate drift samples were collected at each site on a given date and ten replicate benthic invertebrate samples were collected at each site on a given date.

Sediment Characteristics

Restoration resulted in an increase in the median grain size and the percent sand in the sediments in the Restoration site, making the sediments more similar to the sediments in the Reference site (table 4). The percent sand increased from 1.6 percent in 2004 to 39.9 percent in 2006, and the median grain size increased from 0.008 to 0.037 mm, whereas the percentages of finer silt and clay decreased. However, the median grain size in the Reference site decreased from 0.160 to 0.087 mm and the percent sand decreased from 86.4 to 64.2 percent. Sediments at the Mainstem site were mostly larger grained sand and were similar between years.

Table 4. Median grain size, percent sand, percent silt, and percent clay from sediment samples collected pre-restoration on March 16, 2004, and post-restoration on March 23, 2006, at the Mainstem, Reference, and Restoration sites, Columbia River estuary, Oregon.

Sediment parameter	2004	2006
	Mainstem site	
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 site	
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

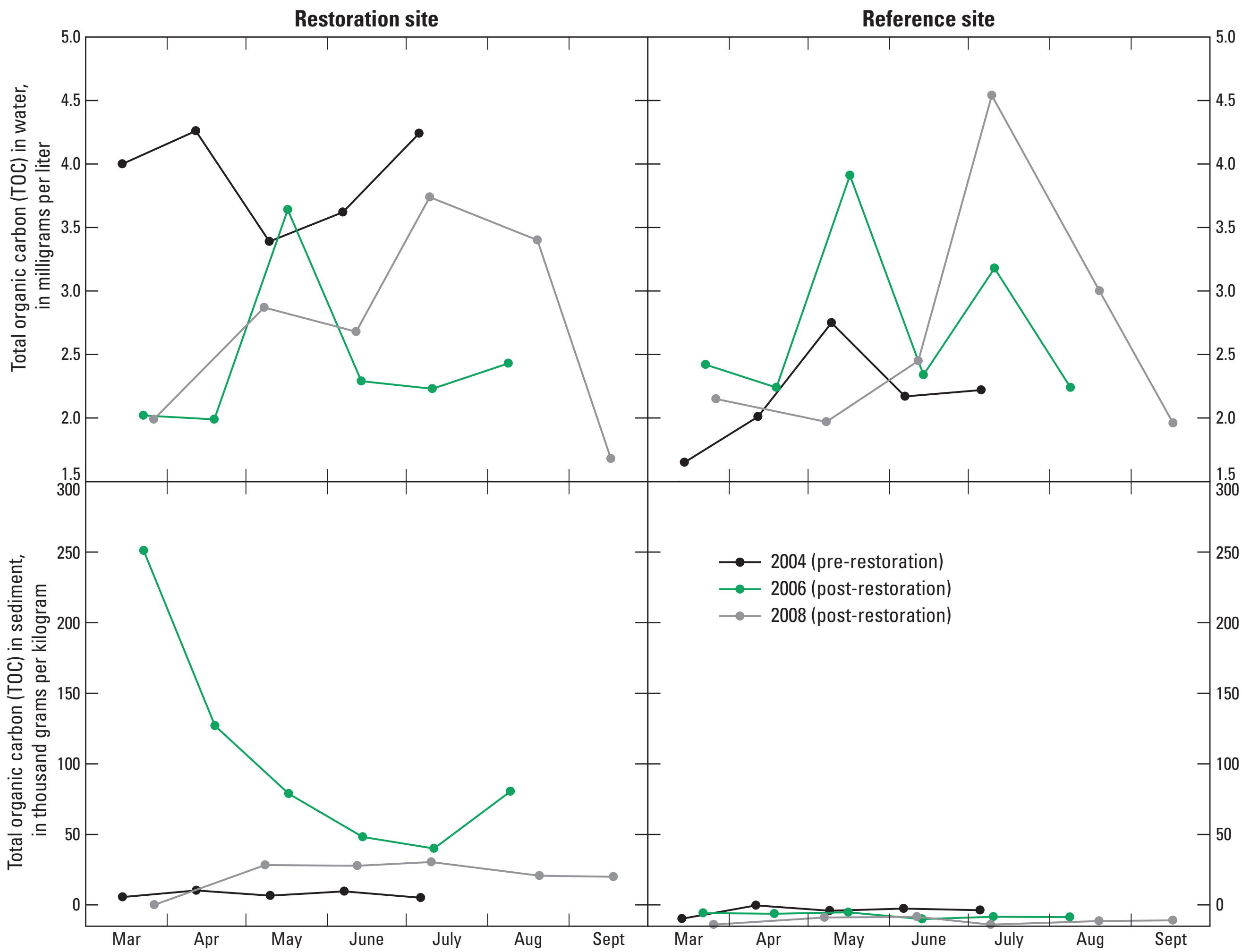

Figure 20. Seasonal change in total organic carbon (TOC) from water and sediment samples collected in the Restoration site and the Reference site pre-restoration in 2004 and post-restoration in 2006 and 2008, Columbia River estuary, Oregon.

In the Restoration site, productivity as measured by TOC increased by an order of magnitude post- restoration (fig. 20). Pre-restoration TOC values in sediments ranged from 5.1 to 10.2 g/ kg in the Restoration site and post-restoration TOC values ranged from 40.0 to 251.0 g/ kg. Sediment data collected in 2003 by the USACE at Crims Island showed that TOC values ranged from 5.4 to 36.6 g/kg (Sherman, 2004). Our *t*-test comparisons indicated a significant increase in TOC in sediment (t = -3.12, P = 0.0097) but also indicated a significant decrease in TOC in post-restoration water (t = 6.16, P < 0.0001) (table 3). TOC values in water and sediments generally were higher in the Reference site in 2006 than in 2004; however, in the Restoration site, TOC values decreased in post-restoration water. TOC values in water ranged from 3.4 to 4.3 mg/L pre-restoration and from 2.0 to 3.6 mg/L post-restoration. In the Mainstem site, TOC values in water and sediment were low and occasionally less than the detection limit.

Plant Survey

Post-restoration, the plant community in the Restoration site contained more total species and a slightly higher percentage of non-native species than the Reference site. During our survey, we found 38 species of plants in the Restoration site and 16 species of plants in the Reference site (table A8). Of the 38 species of plants collected in the Restoration site, five (13.2 percent) were non-native species including celery-leaved buttercup (*Ranunculus sceleratus*), purple loosestrife (*Lythrum salicaria*), threesquare tule (*Scirpus triqueter*), marsh cudweed (*Gnaphalium uliginosum*), and nodding beggar-ticks (*Bidens cernua*). In the Reference site, 2 of 16 (12.5 percent) species were non-native and included nodding beggar-ticks and birdsfoot-trefoil (*Lotus corniculatus*). The non-native reed canarygrass (*Phalaris arundinacea*), which was abundant pre- and post-restoration, generally was restricted to upland areas and not encountered in our surveys.

Topographic and Bathymetric Survey

We collected more than 200,000 geo-referenced elevation points at the Restoration site during our post-restoration topographic survey to document landscape changes that resulted from restoration and to provide a benchmark for future changes. Post-restoration topography clearly showed all the newly excavated channels resulting from restoration and showed that the elevation of the interior of the island had been reduced by 0.6 m as planned (fig. 21). Since our survey, we have found that the two entrances to the Restoration site are being widened and deepened by tidal action. Smaller, newly formed pilot channels in the interior of the island, were too small to be delineated by our survey, but were evident in many places. We also noticed that intertidal channel banks were sloughing as anticipated and smaller intertidal channels were filling with sediment. The looped channel system is also becoming filled with sediment at the upstream end. Over time, this single looped channel probably will become two separate channels connected to Bradbury Slough—an event that was anticipated during the planning of the restoration.

Discussion

Fish Assemblages

Restoration at Crims Island created juvenile salmon rearing habitat and appeared to improve ecosystem structure and function. Although the restoration dramatically changed the landscape, temporary disturbance quickly disappeared and the biotic community recovered. The resulting fish assemblage sampled in 2008 was most similar to the fish assemblage in the Reference site from 2006 to 2008. This shows that newly created habitats are quickly colonized by native and non-native fishes alike. There was concern that habitat restoration could create habitat for predators of juvenile salmonids, such as northern pikeminnow and smallmouth bass. However, we found only small numbers of juveniles of these species in backwaters at Crims Island, and none were large enough to prey upon juvenile salmon. Our catch results were similar to other studies in Columbia River tidal backwaters that show juvenile salmon comprise a relatively small percentage of fish assemblages that are dominated by native threespine stickleback, peamouth chub, and non-native banded killifish (Roegner and others, 2004; Sather and others, 2009).

Restoration primarily benefited subyearlings as they were the primary salmonid species we collected pre- and post-restoration. We also collected some chum salmon juveniles in March and April, but their relatively small numbers made it difficult to ascertain the benefit of restored habitats to them. Subyearlings were present in backwaters of the Restoration site when we began 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 largest numbers of subyearlings in the Restoration site were found in April and May. The seasonal variation in subyearling abundance probably is determined not only by the number of fish migrating through the river mainstem but by seasonal water temperatures that ultimately dictate salmon presence in backwaters. Subyearlings are found in warmer backwater areas in the spring when mainstem temperatures are cooler. This would optimize growth. However, as temperatures exceed 20ºC by summer, subyearlings are excluded from intertidal backwater habitats, yet a few subyearlings persist in subtidal channels of the Restoration site and in the Mainstem site in July and August.

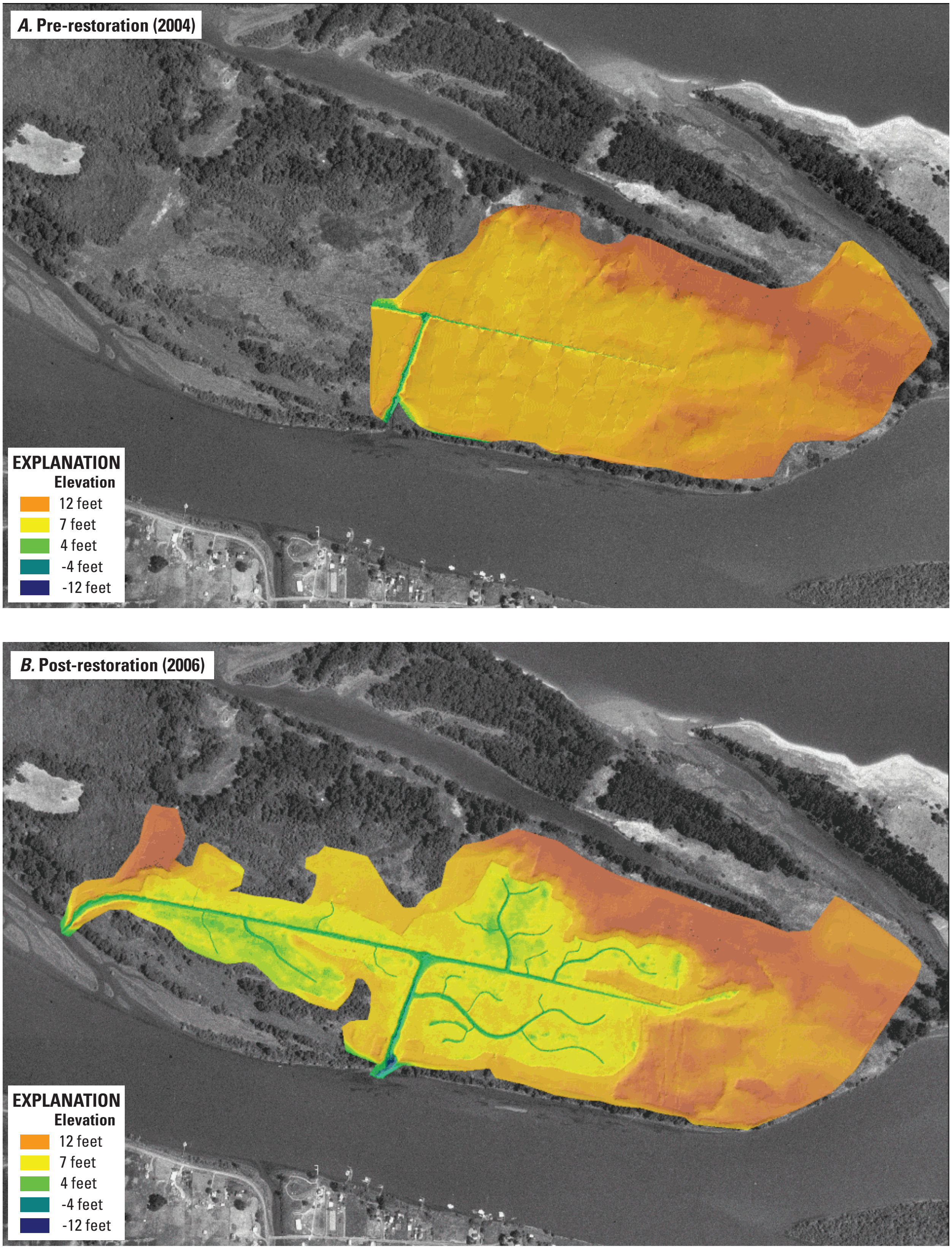

Figure 21. Geo-referenced elevation survey at the Restoration site conducted pre-restoration in 2004 and post-restoration in 2006, Columbia River estuary, Oregon. (Images from Thomas Batt, U.S. Geological Survey Digital Orthoquads, constructed in ARC GIS.)

Subyearling Abundance

It was necessary to change sampling gear during our study, and therefore we were unable to estimate absolute densities or total numbers of subyearlings in the Restoration site pre-restoration. Pre-restoration, existing habitat in the Restoration site was composed solely of deep subtidal channels that did not allow us to sample fish on an area basis (for example, using beach seines), and instead we sampled passively with fyke nets to estimate the number of fish/hour. Our fyke net catches, which were standardized by total channel area, indicated that more fish/hour were accessing habitat post-restoration. We estimated that substantial numbers of subyearlings, generally ranging from 11,000 to 13,000, used the Restoration site post-restoration. This greatly exceeded the number of fish that we estimated in the Reference site (range: 404–635), which was indicative of the greater area of the Restoration site relative to the Reference site. However, maximum subyearling densities were greater in the Restoration site during all years than in restored marsh plains but subtidal channel subyearling densities (sampled only in 2008) were greater in the Restoration site than in the Reference site. This indicates that the elevation of sample sites needs to be considered when selecting reference locations for future fish monitoring efforts. However, sites that have equal elevations would still need to be sampled simultaneously to have compatible water volumes given the fluctuation of the tide.

The effect of restoration on subyearling abundance can be examined by comparing fish densities in the Reference and Restoration sites because both were sampled with beach seines and can provide estimates of fish/area sampled. Post-restoration, the number of subyearlings using the Restoration site for feeding and growth increased but density was less in the Restoration site than in the Reference site. In the Reference site, we sampled a channel of low elevation where fish were concentrated at low tide, whereas in the Restoration site, we primarily sampled marsh plains of high elevation during inundation at high tide. Subtidal channels and low elevation wetlands concentrate fish resulting in high densities at low tide. Densities of subyearlings in the Restoration site probably will increase over time to levels similar to those of the Reference site as vegetation establishes and invertebrate density and diversity increase.

Restoration has provided subyearlings with marsh plain and intertidal channel habitat and increased subtidal channel habitat for rearing where little existed before. At high tide and during periods of high flow in the spring, subyearlings spread out and access marsh plains to feed and occupy warmer temperatures for growth. As the tide recedes, fish move back into subtidal channels. This is why we probably estimated lower densities of subyearlings in marsh plains than in subtidal channels. The new subtidal channels also provide fish with the opportunity to remain in the Restoration site at low tide thereby increasing overall residence time in productive backwaters.

Subyearling Feeding

The changes in habitat that accompanied restoration corresponded to changes in the invertebrate community and hence subyearling diets. We found that as newly created marsh plains became colonized with emergent vegetation in 2007 and 2008, the diversity of the invertebrate community increased. Subyearling access to inundated vegetation is important for feeding on a diverse prey base. Although the prey assemblage of subyearling diets changed after restoration, the intensity at which they fed remained similar to pre-restoration conditions as evidenced by corrected prey weights. Pre-restoration, subyearlings fed more intensively, and almost exclusively, on chironomids in the Reference site, but fed less intensively on a more diverse prey assemblage in unrestored habitats. Initially after restoration, subyearling diet in the Restoration site contained a higher percentage of dipterans and a lower percentage of amphipods than pre-restoration and generally was more similar to that of fish in the Reference site. However, *Corophium* became more important in the diet of subyearlings in 2008. This may be due to the fact that we collected more fish from subtidal channels in 2008 where *Corophium* may have been more abundant, whereas in 2007, we collected more fish from marsh plains where chironomids were more abundant. These differences reflect the diversity of the benthic community in the habitats where fish were collected. Subyearling diets in 2008 also coincided with a decrease in the ratio of prey to body mass and condition factor. However, it is difficult to attribute condition factors observed in the Restoration site to benefits derived there especially considering the short residence times we observed.

The feeding intensity was significantly lower in the Restoration site than in the Reference site, pre- and post-restoration, probably because invertebrate density was significantly lower in the Restoration site than in the Reference site. Chironomids were the most abundant invertebrate in the drift and the benthos at the Restoration and Reference sites, pre- and post-restoration. Many studies of subyearling diet in the Columbia River have shown the importance of aquatic insects, particularly chironomids, to subyearlings (Becker, 1973; McCabe and others, 1986; Muir and Emmett, 1988; Rondorf and others, 1990). Subyearlings can be opportunistic feeders and exploit a variety of food types. We found that subyearlings fed more intensively when primarily feeding on chironomids. Habitat restoration increased the overall density of chironomids for subyearlings because inundated emergent vegetation, more prevalent in restored habitats, is conducive to chironomid production (Stanford and others, 2005).

Subyearling Size and Stock

The restoration at Crims Island provided a diversity of habitats for a number of salmonid species and life stages, but the project primarily benefited Chinook salmon because of their subyearling life history. Juvenile coho salmon were not abundant at Crims Island because they usually spend their first year in tributaries, but some subyearling coho migrate into mainstem habitats (for example, Connor and others, 2001). This probably was the case for the few coho salmon we observed. Juvenile chum salmon also were not abundant at Crims Island probably because they spend relatively little time rearing in fresh water, but migrate directly to the estuary after emergence (Salo, 1991). In contrast, ocean-type Chinook salmon spend considerable time rearing in mainstem and off-channel habitats before entering the ocean as subyearlings (Healey, 1991). The subyearlings we collected at Crims Island were likely the progeny of natural fish that spawned in mainstem and tributary habitats downstream of Bonneville Dam and hatchery fish (Tule stock) from Spring Creek National Fish Hatchery (Dean Ballinger, Pacific States Marine Fisheries Commission, written commun., 2009). Sather and others (2009) classified 75 percent of adipose clipped fish that were sampled near the Sandy River Delta (rkm 194) as Spring Creek fall Chinook stock and 52 percent of unmarked Chinook salmon as upriver summer/fall Chinook stock. However, many of these unmarked fish likely were upriver stocks that were spawned downstream of Bonneville Dam (William Muir, NOAA Fisheries Service, oral commun., 2010). It is improbable that subyearlings from upriver production areas, such as the Hanford Reach and the Snake River, would use Crims Island habitats because they migrate later in the season (June–August) when water temperatures are too warm in backwaters.

The restoration design at Crims Island accommodated the different habitat needs of subyearlings of different sizes. We found that smaller subyearlings primarily used marsh plains and intertidal channels whereas larger subyearlings occupied larger subtidal channels. Similarly, McCabe and others (1986) found smaller subyearlings in intertidal areas and larger subyearlings in pelagic areas. The use of marsh plains and low-order slough channels by smaller subyearlings probably relates to the types of foods available to juvenile salmon and the growth opportunities in these habitats. In smaller channels, we mostly found insect prey (for example, Diptera) and higher temperatures for growth in the spring and early summer, but larger, mainstem habitat prey items primarily were pelagic zooplankton and benthic amphipods.

Overall, predation risk probably is less in Crims Island backwater habitats compared to mainstem habitats. Because we found no predators large enough to consume juvenile salmon in the Restoration site, juvenile salmon survival should be relatively high the longer fish can reside there. Predators could have avoided capture by the beach seines; however, they would not have avoided capture by fyke nets set to occlude the entire channel on an outgoing tide as channels dewatered. Juvenile salmon predation by smallmouth bass and northern pikeminnow generally occurs on larger subyearlings than are present in Crims Island backwaters and in closer proximity to higher velocity habitats (Zimmerman, 1999). Restored backwaters do not appear to provide juvenile rearing habitat for potential predators of juvenile salmon given the small numbers of northern pikeminnow, bass, and walleye juveniles that we collected.

Residence Time

Residence time of subyearlings in restored habitat at Crims Island was short, but the shallow-water habitat offered low predation risk and high growth opportunity. Juvenile salmon generally used shallow backwaters for one or two tidal cycles. Residence times were longer in the Restoration site than in the Reference site, but these differences were likely due to habitat type and site topography rather than the quality of the habitat. The Restoration site has more subtidal channels that make it more likely that fish will remain over successive tides. This is supported by the higher abundances of subyearlings in subtidal channels compared to intertidal channels. Fish living in the Reference site are forced to exit the site at low tide and generally do not re-enter on successive flood tides. Because parts of the Reference site drain directly to the mainstem Columbia River, there is little chance that fish exiting through this route will return on successive high tides. Yearly differences in median residence times in the Reference site were likely due to changes in our recapture methodology. In 2004, we released marked fish and then recaptured them hourly with a beach seine for 24 h, but in 2006, we recaptured marked fish with a beach seine once a day for a week. Short residence times and subyearling's requirement of extended rearing before ocean entry, underscore the need for a continuum of suitable, connected habitat in the Columbia River estuary. As fish continue moving downstream, they may reside longer in shallow-water habitats as they adjust physiologically to the saline environment before ocean entry. Our capture of newly emergent Chinook salmon fry indicates that backwaters at the Restoration site are likely among the first areas encountered by subyearlings that we captured. Restoration at Crims Island created additional rearing habitat and added to the continuum of rearing habitat for subyearlings in the Columbia River estuary.

Invertebrates, Sediments, and Productivity

Although invertebrate density did not change significantly post-restoration, invertebrate diversity significantly decreased in the benthos and the drift but began to rebound to pre-restoration levels by 2008. The excavation of the Restoration site was intended to reduce the elevation of the marsh plain and to remove non-native reed canarygrass, which was abundant. The temporary loss of emergent vegetation and benthic algae in the Restoration site probably contributed to the initial decrease in invertebrate diversity we observed. Tanner and others (2002) reported similar findings for a dike breach restoration project on Spencer Island in the Snohomish River estuary, Washington. In that study, a restored site had lower invertebrate diversity and fewer invertebrate taxa post-restoration than reference sites, but the numerical abundance of dipterans, the most important juvenile salmon prey, was similar. Tanner and others (2002) hypothesized that an increase in insect diversity was due to the stability of a non-tidal portion of the marsh relative to an unstable tidal portion. This hypothesis is inconsistent with the results reported here because the Reference and Restoration sites are tidal, and although the Reference site occasionally dewaters during low tide, it still has higher invertebrate diversity. With the continued establishment of the emergent vegetation community in the Restoration site invertebrate diversity and juvenile salmon feeding intensity probably will increase.

Restoration unexpectedly increased sediment productivity at Crims Island. Excavation unearthed a layer of highly productive sediment in newly restored habitat that may not have been available to plants and invertebrates before restoration. It also reduced the amount of finer sediments and increased the percent sand, making the sediments more similar to those in the Reference site. The increase in sediment TOC has facilitated the rapid return of emergent vegetation to the Restoration site. Over time, sediment TOC levels should decrease to a level similar to that of the Reference site yet continue to benefit the plant community and the lower Columbia River estuary in the form of exported detritus. Higher levels of TOC in water in the Reference site may indicate higher water column productivity than in the Restoration or Mainstem sites. However, it is difficult to attribute high water TOC levels to the site from which the water was collected. The established emergent marsh vegetation community in the Reference site provides a continual source of organic matter that after decomposition supplies carbon to both the water and sediments. TOC levels probably were lower in the Restoration site pre-restoration because terrestrial vegetation was inundated at high tide only in upper ends of the arms of the T-channel. Reduced elevations in the restoration area should promote establishment of an emergent vegetation community that will function more like the Reference site. Therefore, we expect the productive capacity as measured by TOC in water and invertebrate diversity of the Restoration site to increase over time.

Future Monitoring

Selecting representative reference sites is of critical importance to evaluating a habitat restoration project because it is the benchmark against which success is judged (National Research Council Academy of Sciences, 1992). We selected the Reference site on Gull Island because it served as the model for the design of Crims Island restoration. It represented what the USACE was trying to achieve both physically and biologically in terms of eventual ecosystem function. We believed that this site contained quality juvenile salmon habitat, and we observed many juvenile salmon feeding and using the site during our reconnaissance sampling in 2003. Certainly, this site was selected because of its proximity to the planned restoration area, and it lent itself to being the control site in our BACIPS analyses. We also selected the Mainstem site to provide a contrast with the backwater, tidal marsh habitats we sampled in the Reference and Restoration sites. Although the mainstem habitat that we sampled was physically and ecologically dissimilar to the Restoration and Reference sites, it represents the habitat that is available to many fish that do not find their way into off-channel habitats. Ideally, we would have selected more control sites given additional resources, but we selected control sites that were longitudinally in the same general area (downstream areas would have greater salinity influence, upstream areas would have less tidal influence) and that were logistically easier to sample. Underwood (1994) argued that sampling additional control sites at different temporal scales increases the power of analysis. Likewise, whether at differing temporal scales or not, future restoration projects would benefit from using more control sites for comparison to the Restoration site. Although available resources limit the number of control sites sampled, some spatial replication could be eliminated in favor of temporal replication where more reference sites are sampled, but at less frequent time intervals. Ultimately, BACI sampling designs with juvenile salmon metrics as a response variable require relatively small sampling intervals because their overall seasonal use of estuarine habitats can be short (Downes, 2002).

We believe that the restoration of Crims Island was successful insofar that it created additional habitat that was used by relatively large numbers of juvenile salmon, but our sampling was limited in scope in two ways. First, resources did not allow us to sample additional locations within the Restoration site or to sample additional control sites. Second, we were limited to only sampling for 3 years after the restoration was completed. The National Oceanic and Atmospheric Administration recommend a minimum of 5 years of monitoring to evaluate physical response and a longer period to evaluate ecological response of restoration activities (National Oceanic and Atmospheric Administration, 2004). For example, if we had only monitored invertebrate density and diversity for a single year after restoration, our results would have indicated significant decreases. Ultimately, evaluation of invertebrate response for an additional 2 years showed different results. Future sampling with similar effort constraints could sample every other year, for example, instead of the annual sampling conducted here. Although the restoration results generally were positive, there are likely changes or trends not captured in our sampling.

The most beneficial, cost-effective work to evaluate the long-term project success at Crims Island would be topographic surveys at periodic intervals to identify physical habitat changes over time. These low-cost, one time surveys could be completed at periodic intervals (for example, 5 years) and coupled with similarly low-effort fish, invertebrate, and plant surveys. As more restoration and monitoring data are collected in the Columbia River estuary, the need for intensive biological surveys to provide data for comparison should diminish.

We evaluated measures of fisheries and aquatic resources that were broad indicators of restoration success (for example, fish density, insect diversity, etc.), but higher-order indicators, such as survival, need to be incorporated into restoration evaluations. Our results suggest that habitat creation/manipulation at Crims Island was successful in creating ecologically functional habitat for juvenile salmonids. However, the metrics we examined were useful because they confirmed the presumed, general benefits of habitat restoration. For example, it is assumed, among other things, that restoration benefits fish if they use the restored habitat, if adequate food resources exist there, and if predation risk is low. This was certainly true for the Crims Island restoration. In contrast, if there had been relatively few fish, low invertebrate density and diversity, and high predation, then the value of the restoration would have been questionable. Ultimately, the real question is whether habitat restoration increases the survival of juvenile salmon. Estimating survival of fish that use restored habitat at a site like Crims Island may soon be possible. Recent advances in PIT-tag technology have led to 8.5 mm tags that can be used in fish as small as 50 mm and antennas that can be used in small channels. In addition, models specifically developed for estimating survival in wetlands (for example, Perry and Skalski, 2008) can measure the survival benefit of fish using restored habitat. We believe that estimating survival for smaller subyearling Chinook salmon, the fish that are the most likely to benefit from shallow-water restoration (fig. 22), will fill an information gap that can be used to plan future restoration projects in the lower Columbia River and estuary.

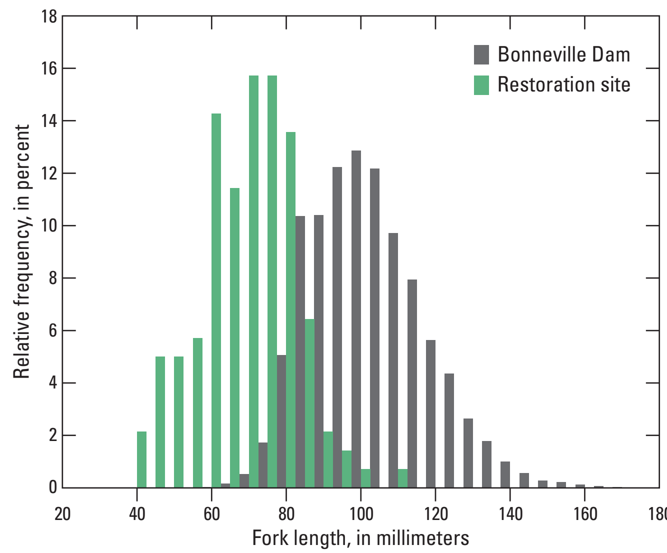

Figure 22. Comparison of the relative frequency of subyearling Chinook fork lengths collected at Bonneville Dam and the Restoration site, Columbia River estuary, Oregon, 2008.

Conclusions

1. Large numbers of subyearling Chinook salmon colonized newly created backwater habitats at Crims Island. Overall, numbers of subyearlings increased post-restoration as new habitat became available, but densities were less in the Restoration site than in the Reference site.

2. Diets of subyearling Chinook salmon contained mostly chiroinomid larvae and adults in backwater habitats. However, *Daphnia* and *Corophium* were important to diets in mainstem habitats. Restoration at Crims Island increased the density of chironomids and the overall diversity of invertebrates.

3. Small subyearling Chinook salmon occupied habitats farther from the Columbia River mainstem than large subyearlings. Similarly, small subyearlings used newly created intertidal channels whereas large subyearlings used subtidal channels. This underscores the need for small intertidal and subtidal channel habitats where juvenile salmon can reside when intertidal channels dewater at low tide and later in the juvenile salmon outmigration season.

4. Although the seasonal presence of subyearlings in backwaters is long, residence time of individuals is short. This underscores the need for a continuum of suitable habitats as subyearlings gradually move downstream during rearing.

5. Juvenile life stages of northern pikeminnow and smallmouth bass were present in small percentages in restored habitats, but predators large enough to prey on juvenile salmon were absent.

6. Overall, the fish community was dominated by threespine stickleback, banded killifish, peamouth chub, and subyearling Chinook salmon. Backwaters could potentially be important to juvenile chum salmon that also use Crims Island backwaters for feeding, but we captured too few to reach reasonable conclusions.

7. Water temperature largely dictates juvenile salmon presence in backwaters. Fish seek out warmer water in spring and early summer and avoid high temperatures in mid- to late summer.

8. Non-native banded killifish, which comprised a large percentage of the fish catch, use shallow backwaters to spawn in summer. Future work is needed to assess the relation between restored habitats and non-native fish, particularly banded killifish and the newly discovered Amur goby.

9. A diversity of habitats including marsh plains, intertidal channels, and subtidal channels need incorporation in future restoration designs as they are important to differing sizes of subyearlings.

10. Although the duration of our sampling was short in terms of ecological processes, we showed some ecological changes were moving toward equilibrium. The overall duration of monitoring of individual restoration projects should be increased to examine longer term ecological responses.

11. Monitoring would benefit from the selection of more control sites with which to compare biological responses in restored habitat.

12. Future monitoring efforts would benefit by incorporating higher order metrics, such as juvenile salmon survival and growth.

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Appendix A. Metrics of Fish, Subyearling Chinook Salmon Prey Items, Invertebrates, and Plants Sampled at Crims Island, Oregon, 2004–09

Table A1. Scientific name, common name, life stage, percentage of occurrence, and percentage of the total numbers of fishes collected with beach seines and fyke nets at Crims and Gull Islands, Columbia River estuary, 2004–08.

[–, no data]

Scientific name	Common name	Percentage of total			
		2004	2006	2007	2008
Catostomidae					
Catostomus macrocheilus	Largescale sucker	0.18	0.91	0.28	0.38
Centrarchidae					
Lepomis gibbosus[1]	Pumpkinseed	0.14	0.07	–	–
Lepomis macrochirus[1]	Bluegill	0.07	<0.01	–	–
Lepomis spp.[1]	Unidentified sunfishes	0.16	<0.01	–	0.01
Micropterus dolomieu[1]	Smallmouth bass	–	0.01	–	<0.01
Micropterus salmoides[1]	Largemouth bass	0.03	–	–	<0.01
Pomoxis nigromaculatus[1]	Black crappie	<0.01	0.06	–	<0.01
Clupeidae					
Alosa sapidissima[1]	American shad	0.13	0.19	<0.01	0.39
Cottidae					
Cottus asper	Prickly sculpin	0.10	0.02	–	0.04
Cyprinidae					
Cyprinus carpio[1]	Common carp	0.03	0.14	–	0.07
Ptychocheilus oregonensis	Northern pikeminnow	0.21	0.44	0.02	0.26
Mylocheilus caurinus	Peamouth chub	1.32	18.90	1.76	12.00
Fundulidae					
Fundulus diaphanus[1]	Banded killifish	17.19	7.35	42.63	16.49
Gambusidae					
Gambusia affinis[1]	Mosquitofish	0.01	<0.01	0.04	0.01
Gasterosteidae					
Gasterosteus aculeatus	Threespine stickleback	58.45	62.67	49.06	65.66
Gobiidae					
Rhinogobius brunneus[1,2]	Amur goby	–	<0.01	–	–
Ictaluridae					
Ameiurus spp.[1]	Bullhead	<0.01	–	–	–
Percidae					
Perca flavescens[1]	Yellow perch	–	0.70	–	–
Sander vitreus[1]	Walleye	–	<0.01	<0.01	–
Pleuronectidae					
Platichthys stellatus	Starry flounder	0.11	0.05	0.30	0.20
Salmonidae					
Oncorhynchus clarki	Cutthroat trout	<0.01	–	–	–
Oncorhynchus keta	Chum salmon	0.21	0.06	0.23	0.23
Oncorhynchus kisutch	Coho salmon	0.13	<0.01	<0.01	–
Oncorhynchus mykiss	Steelhead	<0.01	<0.01	–	<0.01
Oncorhynchus tshawytscha	Yearling Chinook salmon	0.11	0.02	0.01	0.06
Oncorhynchus tshawytscha	Subyearling Chinook salmon	22.46	8.39	5.64	4.18
Prosopium williamsoni	Mountain whitefish	0.03	–	–	–

[1]Non-native species.

[2]First record in the Columbia River.

Table A2. Species common name, number and percentage of fishes collected at unrestored primary channels, restored primary channels, restored secondary channels, restored marsh plains at the Restoration, Mainstem, and Reference sites, Columbia River estuary, Oregon.

[Fish were collected with beach seines and fyke nets from 2004 to 2008. #, number of fishes; %, percentage of fishes]

Species (common name)	Restoration site								Reference habitats				Total	Percentage of total
	Unrestored primary channel		Restored primary channel		Restored secondary channel		Restored tidal flat		Mainstem site		Reference site			
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
American shad[1]	0	0.00	0	0.00	0	0.00	1	0.00	245	1.00	63	0.13	309	0.22
Amur goby[1]	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	1	0.00
Banded killifish[1]	2,909	19.25	1,014	23.02	2,949	18.22	9,963	29.37	444	1.81	6,607	14.02	23,886	16.90
Black crappie[1]	12	0.08	0	0.00	34	0.21	7	0.02	2	0.01	7	0.01	62	0.04
Bluegill[1]	15	0.10	0	0.00	1	0.01	0	0.00	0	0.00	1	0.00	17	0.01
Brown bullhead[1]	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	1	0.00
Common carp[1]	7	0.05	0	0.00	70	0.43	12	0.04	12	0.05	38	0.08	139	0.10
Chinook salmon subyearling	2,328	15.40	579	13.14	528	3.26	994	2.93	2,995	12.19	5,409	11.48	12,833	9.08
Chinook salmon yearling	15	0.10	1	0.02	2	0.01	1	0.00	63	0.26	2	0.00	84	0.06
Chum salmon	5	0.03	52	1.18	9	0.06	35	0.10	78	0.32	42	0.09	221	0.16
Coho salmon	4	0.03	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	5	0.00
Cutthroat trout	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Largemouth bass[1]	7	0.05	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	8	0.01
Largescale sucker	0	0.00	0	0.00	574	3.55	78	0.23	8	0.03	24	0.05	684	0.48
Mosquitofish[1]	0	0.00	0	0.00	3	0.02	13	0.04	0	0.00	0	0.00	16	0.01
Mountain whitefish	0	0.00	0	0.00	0	0.00	0	0.00	13	0.05	0	0.00	13	0.01
Northern pikeminnow	36	0.24	3	0.07	326	2.01	5	0.01	0	0.00	103	0.22	473	0.33
Peamouth	87	0.58	338	7.67	8,758	54.12	1,142	3.37	4,121	16.77	4,452	9.45	18,898	13.37
Prickly sculpin	25	0.17	4	0.09	0	0.00	0	0.00	0	0.00	0	0.00	29	0.02
Pumpkinseed[1]	34	0.22	0	0.00	47	0.29	2	0.01	0	0.00	0	0.00	83	0.06
Smallmouth bass[1]	2	0.01	4	0.09	6	0.04	0	0.00	0	0.00	0	0.00	12	0.01
Starry flounder	0	0.00	0	0.00	0	0.00	2	0.01	181	0.74	6	0.01	189	0.13
Steelhead	0	0.00	0	0.00	0	0.00	0	0.00	3	0.01	0	0.00	3	0.00
Sunfishes[1]	0	0.00	1	0.02	3	0.02	1	0.00	0	0.00	1	0.00	6	0.00
Threespine stickleback	9,594	63.48	2,393	54.32	2,393	14.79	21,512	63.42	16,365	66.61	30,308	64.31	82,565	58.42
Unidentified suckers	32	0.21	12	0.27	0	0.00	132	0.39	5	0.02	49	0.10	230	0.16
Unidentified sculpin	0	0.00	4	0.09	9	0.06	5	0.01	4	0.02	4	0.01	26	0.02
Walleye[1]	0	0.00	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	2	0.00
Yellow perch[1]	0	0.00	0	0.00	471	2.91	17	0.05	27	0.11	7	0.01	522	0.37
Total	15,113		4,405		16,184		33,922		24,569		47,125		141,318	

[1]Non-native species.

Table A3. Percentage by number, percentage by weight, and percentage by occurrence of prey items collected from subyearling Chinook salmon in 2004 pre-restoration and in 2006, 2007, and 2008 post-restoration at the Reference, Mainstem, and Restoration sites, Columbia River estuary, Oregon.

[**Bolded** taxa and numbers represent those used for IRI analysis as shown in figure 17 with all unbolded combined into the 'Others' category]

Prey taxa	2004			2006			2007			2008		
	Reference site	Mainstem site	Restoration site—Pre-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration
	Percentage by number											
Amphipoda	**1.25**	**3.60**	**13.54**	**0.66**	**11.06**	**0.66**	**6.12**	**59.47**	**1.63**	**2.59**	**63.50**	**14.11**
Araneae	1.39	0.02	0.55	0.48	0.42	0.16	0.21	0.76	2.11	4.50	0.55	2.02
Cladocera	**15.94**	**92.56**	**35.98**	**9.77**	**71.31**	**49.97**	**0.84**	**10.61**	**0.00**	**0.08**	**5.89**	**0.13**
Coleoptera	0.20	0.00	0.14	0.04	0.51	0.09	0.00	0.00	0.00	0.23	1.10	0.00
Collembola	0.00	0.00	0.00	10.03	0.14	0.03	1.05	0.38	0.31	3.13	0.12	4.57
Copepoda	0.13	2.17	0.00	0.33	2.17	0.25	0.42	0.00	0.00	3.51	0.31	0.39
Decapoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Diptera	**75.30**	**1.51**	**31.87**	**75.09**	**12.82**	**48.05**	**89.45**	**23.23**	**93.75**	**83.22**	**16.81**	**69.24**
Ephemeroptera	0.00	0.00	0.00	0.00	0.09	0.00	0.21	0.38	0.00	0.23	0.98	0.00
Fish	0.40	0.00	1.09	0.26	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.07
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00	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	0.21	0.00	0.31	0.08	0.61	0.13
Homoptera	**2.37**	**0.03**	**13.68**	**1.43**	**0.28**	**0.13**	**0.00**	**0.00**	**0.31**	**0.15**	**1.04**	**0.26**
Hydracarina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.00	4.77
Hymenoptera	1.12	0.02	0.41	0.33	0.23	0.38	0.42	1.01	0.70	0.23	6.20	0.00
Isopoda	0.00	0.00	1.23	0.00	0.00	0.00	0.00	0.38	0.09	0.00	0.06	0.00
Lepidoptera	0.13	0.00	0.14	0.07	0.05	0.00	0.00	0.00	0.18	0.00	0.06	0.00
Megaloptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Mysidacea	0.07	0.02	0.68	0.77	0.32	0.09	0.00	0.13	0.00	0.00	1.17	1.63
Nematoda	1.38	0.00	0.00	0.59	0.00	0.00	0.63	0.63	0.18	0.31	0.12	0.59
Odonata	0.07	0.02	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.12	0.00
Oligochaeta	0.07	0.00	0.00	0.04	0.05	0.00	0.00	0.13	0.04	0.92	0.49	0.39
Plecoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.04	0.00	0.18	0.07
Pelecypoda	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Psocoptera	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanoptera	0.00	0.00	0.00	0.00	0.23	0.03	0.00	0.00	0.22	0.00	0.00	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.13	0.09	0.31	0.31	0.00
Unknown	1.25	3.60	13.54	0.66	11.06	0.66	0.00	0.00	0.00	0.00	0.00	0.00

Table A3. Percentage by number, percentage by weight, and percentage by occurrence of prey items collected from subyearling Chinook salmon in 2004 pre-restoration and in 2006, 2007, and 2008 post-restoration at the Reference, Mainstem, and Restoration sites, Columbia River estuary, Oregon.—Continued

[**Bolded** taxa and numbers represent those used for IRI analysis as shown in figure 17 with all unbolded combined into the 'Others' category]

Prey taxa	2004			2006			2007			2008		
	Reference site	Mainstem site	Restoration site—Pre-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration
	Percentage by weight											
Amphipoda	**2.55**	**64.55**	**29.77**	**3.81**	**63.64**	**5.04**	**28.26**	**83.59**	**4.70**	**6.15**	**81.09**	**30.15**
Araneae	1.57	0.26	0.32	2.55	1.49	0.48	0.04	0.15	2.46	1.98	0.43	1.80
Cladocera	**0.14**	**9.58**	**0.59**	**0.68**	**6.67**	**7.56**	**0.10**	**0.55**	**0.00**	**0.01**	**0.44**	**0.00**
Coleoptera	0.84	0.54	2.02	0.07	1.86	0.08	0.00	0.00	0.00	0.13	0.50	0.00
Collembola	0.09	0.00	0.91	3.76	0.11	0.02	0.26	0.08	0.19	2.22	0.07	1.73
Copepoda	0.11	5.10	1.26	0.03	0.22	0.04	0.04	0.00	0.00	0.78	0.03	0.07
Decapoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
Diptera	**82.78**	**15.22**	**43.76**	**59.79**	**11.08**	**78.47**	**68.96**	**6.23**	**90.07**	**84.07**	**5.76**	**29.89**
Ephemeroptera	0.00	0.00	0.00	0.00	0.53	0.00	0.31	0.90	0.00	0.27	1.61	0.00
Fish	1.71	0.00	6.53	11.55	0.00	5.04	0.00	0.00	0.00	0.00	0.00	26.16
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	0.54	0.08	2.71	0.72	0.12	0.00	1.56	0.00	0.56	0.18	0.34	0.53
Homoptera	**3.15**	**1.73**	**6.83**	**1.50**	**0.32**	**0.17**	**0.00**	**0.00**	**0.15**	**1.17**	**0.31**	**0.18**
Hydracarina	0.06	0.03	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.06	0.19
Hymenoptera	0.95	1.37	0.47	0.48	0.57	0.60	0.27	0.32	0.86	0.78	1.06	0.57
Isopoda	0.00	0.00	0.68	0.00	0.00	0.00	0.00	3.36	1.03	0.00	0.03	0.00
Lepidoptera	0.32	0.00	0.55	0.09	0.37	0.00	0.00	0.00	0.42	0.00	0.55	0.00
Megaloptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59	0.00	0.00	0.00
Mysidacea	0.85	0.92	3.06	13.57	9.16	2.43	0.00	1.47	0.00	0.00	6.70	4.81
Nematoda	1.62	0.20	0.36	0.73	0.00	0.00	0.61	0.24	0.12	0.39	0.01	0.15
Odonata	0.07	0.07	0.00	0.00	0.22	0.00	0.00	0.00	0.01	0.00	0.23	0.00
Oligochaeta	2.64	0.00	0.00	0.65	2.97	0.00	0.00	2.54	0.00	0.92	0.18	3.40
Pelecypoda	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Plecoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	0.03	0.00	0.08	0.38
Psocoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanoptera	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.01	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.00	0.00	3.05	0.07	0.12	0.81	0.20	0.00
Unknown	0.00	0.00	0.00	0.00	0.69	0.08	0.00	0.00	0.00	0.00	0.00	0.00

Table A3. Percentage by number, percentage by weight, and percentage by occurrence of prey items collected from subyearling Chinook salmon in 2004 pre-restoration and in 2006, 2007, and 2008 post-restoration at the Reference, Mainstem, and Restoration sites, Columbia River estuary, Oregon.—Continued

[**Bolded** taxa and numbers represent those used for IRI analysis as shown in figure 17 with all unbolded combined into the 'Others' category]

Prey taxa	2004			2006			2007			2008		
	Reference site	Mainstem site	Restoration site—Pre-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration	Reference site	Mainstem site	Restoration site—Post-restoration
	Percentage by occurrence											
Amphipoda	**11.90**	**54.37**	**29.76**	**15.00**	**68.85**	**21.15**	**26.42**	**82.14**	**30.19**	**17.65**	**73.91**	**51.96**
Araneae	14.29	6.80	5.95	20.00	11.48	9.62	1.89	7.14	30.19	14.71	8.70	13.73
Cladocera	**17.86**	**65.05**	**11.90**	**35.00**	**42.62**	**38.46**	**3.77**	**9.52**	**0.00**	**1.47**	**9.78**	**0.98**
Coleoptera	4.76	0.97	4.76	2.50	3.28	5.77	5.66	0.00	0.00	4.41	6.52	0.00
Collembola	4.76	0.0	7.14	17.50	3.28	1.92	1.89	3.57	11.32	11.76	2.17	14.71
Copepoda	11.90	33.01	9.52	10.00	18.03	9.62	0.00	0.00	0.00	10.29	3.26	0.98
Decapoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.09	0.00
Diptera	**94.05**	**48.54**	**63.10**	**100.00**	**63.93**	**82.69**	**92.45**	**66.67**	**90.57**	**92.65**	**73.91**	**69.61**
Ephemeroptera	0.00	0.00	0.00	2.50	3.28	0.00	1.89	3.57	0.00	1.47	11.96	0.00
Fish	1.19	0.00	2.38	0.00	0.00	1.92	0.00	0.00	0.00	0.00	0.00	5.88
Gastropoda	0.00	0.00	0.00	0.00	0.00	0.00	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	1.89	8.33	11.32	1.47	4.35	1.96
Homoptera	**25.00**	**12.62**	**20.24**	**30.00**	**9.84**	**7.69**	**0.00**	**0.00**	**7.55**	**2.94**	**7.61**	**2.94**
Hydracarina	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.41	3.26	4.90
Hymenoptera	17.86	5.83	7.14	15.00	6.56	7.69	3.77	2.38	18.87	4.41	11.96	5.88
Isopoda	0.00	0.00	3.57	0.0	0.00	0.00	0.00	2.38	1.89	0.00	1.09	0.00
Lepidoptera	1.19	0.00	1.19	2.50	1.64	0.00	0.00	0.00	5.66	0.00	1.09	0.00
Megaloptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00
Mysidacea	1.19	1.94	3.57	15.00	9.84	5.77	0.00	3.57	0.00	0.00	11.96	2.94
Nematoda	23.81	2.91	4.76	15.00	0.00	0.0	5.66	1.19	5.66	4.41	1.09	2.94
Odonata	1.19	0.97	0.00	0.00	3.28	0.0	0.00	0.00	0.00	0.00	1.09	0.00
Oligochaeta	1.19	0.00	0.00	2.50	1.64	0.0	0.00	9.52	1.89	4.41	3.26	0.98
Plecoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89	0.00	3.26	0.98
Pelecypoda	0.00	1.94	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00	0.00
Psocoptera	1.19	4.85	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Thysanoptera	0.00	0.00	1.19	0.00	1.64	0.00	0.00	0.00	7.55	0.00	1.09	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.00	0.00	3.77	1.19	3.77	2.94	1.09	0.00
Unknown	0.00	0.00	0.00	0.00	4.92	1.92	0.00	0.00	0.00	0.00	0.00	0.00

Table A4. Scientific name and percentage by number of total benthic invertebrates collected at the Restoration (REST), Reference (REF), and the Mainstem (MAIN) sites pre-restoration in 2004 and post-restoration in 2006, 2007, and 2008, Columbia River estuary, Oregon.

Scientific name	Percentage of total											
	2004			2006			2007			2008		
	REST	REF	MAIN	REST	REF	MAIN	REST	REF	MAIN	REST	REF	MAIN
Amphipoda											0.05	0.47
Corophiidae												
Corophium spp.	30.24	0.12	83.24		7.92	91.93		2.75	81.31	0.87	0.44	45.79
Copepoda							0.61	1.28	0.66	1.41	2.69	5.61
Coleoptera												
Elmidae	0.87											
Gammaridae												
Gammarus spp.	0.87									0.04		0.47
Diptera												
Ceratopogonidae	6.98	12.44	3.98	4.22	4.88		31.64	15.83	1.64	19.94	24.41	10.75
Chironomidae	43.02	46.52	3.41	75.90	26.43	1.18	15.39	30.68	8.20	42.43	29.29	6.07
Dolichopodidae							1.81	0.20			0.33	
Empidae											0.05	
Sciomyzidae			0.28	1.20								
Simulidae							0.24				0.05	
Tipulidae				1.81						0.14	0.11	
Unknown				0.60	0.17	0.59	0.12			0.09	0.05	
Diptera Total	**50.00**	**58.96**	**7.67**	**83.73**	**31.48**	**1.77**	**49.20**	**46.71**	**9.84**	**62.60**	**54.29**	**16.82**
Ephemeroptera	0.29						0.48			1.73	0.11	
Gastropoda	1.16	0.25	1.42		0.51	0.59		0.30	0.98	0.09		3.27
Hemiptera	0.58									0.09	0.44	
Hydracarina		0.12					0.12	0.49		1.37	0.82	
Isopoda										0.23		
Nematoda	0.87	17.54	0.85	6.63	16.50	1.18	7.88	12.09	2.30	11.59	16.29	14.95
Odanata		0.12									0.11	
Oligochaeta	11.92	19.78	2.84	9.04	40.74	3.55	40.36	32.94	1.97	14.87	23.04	9.35
Ostracoda		0.12							0.33	0.22	0.11	
Pelecypoda												
Corbiculidae												
Corbicula fluminea[1]	3.20	2.99	3.98		2.86	1.77	0.97	2.65	2.62	0.32	1.37	3.27
Trichoptera							0.36	0.10		0.14		

[1]Non-native species.

Table A5. Site, date, total number of invertebrates, mean density , standard deviation, number of taxa, diversity, and evenness of the benthic invertebrate community at the Mainstem, Reference, and Restoration sites pre-restoration (March 16–August 16, 2004) and post-restoration (March 23–August 9, 2006; March 20–July 23, 2007; and March 13–September 17, 2008), Columbia River estuary, Oregon.

[Ten replicates were collected at each site on a given date. Mean density in number per square meter (m^2)]

Site	Date	Total invertebrates	Mean density	Standard deviation	Taxa	Diversity (H')	Evenness (J')
Mainstem	3-16-04	2	171.80	362.20	2	0.30	1.00
Reference	3-16-04	60	5,153.90	1,718.00	4	0.37	0.61
Restoration	3-16-04	22	1,889.80	1,708.40	4	0.38	0.64
Mainstem	3-30-04	10	859.00	1,214.80	4	0.47	0.79
Reference	3-30-04	31	2,662.90	2,669.20	4	0.43	0.71
Restoration	3-30-04	44	3,779.60	3,167.8	6	0.52	0.67
Mainstem	4-12-04	–	0	0	–	–	–
Reference	4-12-04	49	4,209.00	2,575.40	4	0.52	0.86
Restoration	4-12-04	36	3,092.40	1,774.30	7	0.60	0.71
Mainstem	4-25-04	10	859.00	905.50	4	0.47	0.79
Reference	4-25-04	48	4,123.10	2,942.40	4	0.49	0.81
Restoration	4-25-04	31	2,662.90	2,932.60	6	0.66	0.84
Mainstem	5-10-04	18	1,546.20	1,755.70	3	0.30	0.62
Reference	5-10-04	53	4,552.60	4,189.60	4	0.47	0.78
Restoration	5-10-04	22	1,889.80	1,975.50	8	0.71	0.79
Mainstem	5-24-04	35	3,006.50	1,729.90	5	0.39	0.56
Reference	5-24-04	69	5,927.00	3,808.30	6	0.57	0.73
Restoration	5-24-04	54	4,638.50	3,392.70	9	0.67	0.71
Mainstem	6-07-04	2	171.80	362.20	2	0.30	1.00
Reference	6-07-04	94	8,074.50	2,111.90	6	0.63	0.81
Restoration	6-07-04	32	2,748.80	3,259.60	6	0.58	0.75
Mainstem	6-21-04	75	6,442.40	2,404.10	4	0.18	0.30
Reference	6-21-04	63	5,411.60	3,240.70	6	0.61	0.78
Restoration	6-21-04	15	1,288.50	1,231.60	5	0.41	0.59
Mainstem	7-06-04	91	7,816.80	2,270.90	4	0.14	0.24
Reference	7-06-04	109	9,363.00	5,775.80	7	0.56	0.67
Restoration	7-06-04	17	1,460.30	1,517.80	4	0.52	0.86
Mainstem	7-19-04	72	6,184.70	2,422.80	2	0.06	0.18
Reference	7-19-04	79	6,786.00	3,174.30	6	0.55	0.71
Restoration	7-19-04	27	2,319.30	2,664.80	4	0.29	0.49
Mainstem	8-02-04	1	85.90	271.60	1	0	-
Reference	8-02-04	103	8,847.60	5,896.60	5	0.45	0.64
Restoration	8-02-04	30	2,577.00	2,805.40	5	0.37	0.52
Mainstem	8-16-04	36	3,092.40	1,578.70	5	0.56	0.79
Reference	8-16-04	46	3,951.40	2,782.00	5	0.61	0.87
Restoration	8-16-04	14	1,202.60	1,355.20	4	0.58	0.96
Mainstem	3-23-06	67	5,755.22	2,219.75	3	0.31	0.65
Reference	3-24-06	51	4,380.84	4,589.32	6	0.61	0.78
Restoration	3-23-06	11	944.89	1,428.78	3	0.55	0.48
Mainstem	4-20-06	6	515.39	600.61	3	0.44	0.92
Reference	4-19-06	156	13,400.32	4,725.74	5	0.47	0.67
Restoration	4-19-06	12	1,030.79	2,135.03	2	0.244	0.81

Table A5. Site, date, total number of invertebrates, mean density , standard deviation, number of taxa, diversity, and evenness of the benthic invertebrate community at the Mainstem, Reference, and Restoration sites pre-restoration (March 16–August 16, 2004) and post-restoration (March 23–August 9, 2006; March 20–July 23, 2007; and March 13–September 17, 2008), Columbia River estuary, Oregon. —Continued

[Ten replicates were collected at each site on a given date. Mean density in number per square meter (m^2)]

Site	Date	Total invertebrates	Mean density	Standard deviation	Taxa	Diversity (H')	Evenness (J')
Mainstem	5-17-06	28	2,405.17	1,659.72	5	0.46	0.66
Reference	5-18-06	76	6,528.31	2,436.33	9	0.79	0.82
Restoration	5-18-06	43	3,693.65	2,656.85	3	0.10	0.20
Mainstem	6-14-06	17	1,460.28	1,720.36	2	0.10	0.32
Reference	6-15-06	142	12197.64	8,869.75	8	0.56	0.62
Restoration	6-14-06	64	5,497.53	5,870.80	4	0.14	0.24
Mainstem	7-11-06	34	2,920.56	1,159.55	4	0.33	0.55
Reference	7-11-06	80	6,871.91	3,862.80	8	0.70	0.78
Restoration	7-11-06	21	1,803.88	2,759.78	4	0.25	0.41
Mainstem	8-09-06	17	1,460.28	1,075.17	4	0.29	0.48
Reference	8-09-06	89	7,645.00	3,470.38	6	0.62	0.79
Restoration	8-09-06	15	1,288.48	1,581.31	6	0.57	0.74
Mainstem	3-20-07	0	0	0	0	0	0
Reference	3-20-07	67	9,592.04	10,992.59	7	0.56	0.67
Restoration	3-20-07	26	2,791.71	3,366.22	6	0.57	0.73
Mainstem	4-02-07	2	171.80	543.27	2	0.30	1.00
Reference	4-02-07	94	8,074.491	4,673.40	6	0.68	0.87
Restoration	4-02-07	63	5,411.63	3,667.92	5	0.63	0.90
Mainstem	4-16-07	9	773.09	633.82	2	0.15	0.50
Reference	4-16-07	111	9,534.77	7,825.233	6	0.52	0.67
Restoration	4-16-07	57	4,896.23	4,267.174	4	0.44	0.73
Mainstem	4-30-07	16	1,527.09	834.79	3	0.32	0.67
Reference	4-30-07	181	15,547.69	3,976.79	7	0.51	0.60
Restoration	4-30-07	95	9,067.10	11,684.38	5	0.51	0.73
Mainstem	5-15-07	8	687.19	887.16	1	0.00	
Reference	5-15-07	72	6,871.91	2,312.90	6	0.63	0.80
Restoration	5-15-07	94	8,074.49	10,568.62	5	0.49	0.70
Mainstem	5-29-07	35	3,006.46	2,982.50	6	0.53	0.68
Reference	5-29-07	79	6,786.01	4,462.51	7	0.78	0.93
Restoration	5-29-07	141	12,111.74	9,448.44	7	0.34	0.40
Mainstem	6-11-07	39	3,722.28	3,185.21	3	0.14	0.29
Reference	6-11-07	111	9,534.77	6,106.95	10	0.72	0.72
Restoration	6-11-07	137	13,075.71	16,262.91	7	0.60	0.71
Mainstem	6-26-07	84	7,215.50	2,150.33	5	0.24	0.34
Reference	6-26-07	130	11,166.85	12,461.09	8	0.66	0.73
Restoration	6-26-07	53	5,058.49	3,604.80	6	0.70	0.90
Mainstem	7-09-07	58	4,982.13	2,997.58	4	0.19	0.32
Reference	7-09-07	77	6,614.21	5,249.29	7	0.62	0.73
Restoration	7-09-07	76	7,253.68	6,299.25	4	0.45	0.75
Mainstem	7-23-07	54	5,153.93	3,982.97	5	0.40	0.57
Reference	7-23-07	91	7,816.80	7,260.02	6	0.55	0.71
Restoration	7-23-07	83	7,129.60	4,436.72	7	0.64	0.75

Table A5. Site, date, total number of invertebrates, mean density , standard deviation, number of taxa, diversity, and evenness of the benthic invertebrate community at the Mainstem, Reference, and Restoration sites pre-restoration (March 16–August 16, 2004) and post-restoration (March 23–August 9, 2006; March 20–July 23, 2007; and March 13–September 17, 2008), Columbia River estuary, Oregon. —Continued

[Ten replicates were collected at each site on a given date. Mean density in number per square meter (m^2)]

Site	Date	Total invertebrates	Mean density	Standard deviation	Taxa	Diversity (H')	Evenness (J')
Mainstem	3-13-08	30	2,863.29	6,695.15	5	0.39	0.56
Reference	3-13-08	142	12,197.64	5,549.18	7	0.53	0.62
Restoration	3-13-08	10	1,073.74	2,040.50	4	0.39	0.65
Mainstem	3-27-08	55	4,724.44	4,271.01	4	0.45	0.74
Reference	3-27-08	74	7,062.79	9,534.17	8	0.61	0.68
Restoration	3-27-08	64	5,497.53	4,476.27	6	0.47	0.61
Mainstem	4-10-08	12	1,145.32	1,214.79	4	0.47	0.78
Reference	4-10-08	57	4,896.23	4,774.93	5	0.53	0.76
Restoration	4-10-08	103	8,847.58	6,441.46	5	0.56	0.80
Mainstem	4-24-08	1	85.90	271.64	1	0.00	
Reference	4-24-08	129	12,312.17	8,536.03	6	0.43	0.55
Restoration	4-24-08	83	7,129.60	4,546.24	4	0.49	0.82
Mainstem	5-08-08	6	572.66	743.91	4	0.58	0.96
Reference	5-08-08	139	11,939.94	14,301.86	6	0.56	0.72
Restoration	5-08-08	178	15,289.99	12,400.41	7	0.47	0.55
Mainstem	5-22-08	0	0.00	0.00	0	0.00	0.00
Reference	5-22-08	60	5,153.93	4,109.60	7	0.56	0.66
Restoration	5-22-08	53	4,552.64	7,014.20	3	0.33	0.69
Mainstem	6-12-08	0	0.00	0.00	0	0.00	0.00
Reference	6-12-08	124	10,651.46	9,083.46	8	0.53	0.59
Restoration	6-12-08	69	5,927.02	3,398.77	9	0.72	0.76
Mainstem	6-26-08	4	343.60	600.61	2	0.24	0.81
Reference	6-26-08	107	10,498.75	6,352.71	6	0.63	0.81
Restoration	6-26-08	146	12,541.23	9,753.71	8	0.69	0.76
Mainstem	7-10-08	12	1,288.48	1,124.68	6	0.64	0.82
Reference	7-10-08	147	12,627.13	13,096.56	6	0.58	0.74
Restoration	7-10-08	382	32,813.36	24,683.53	7	0.47	0.56
Mainstem	7-24-08	-	-	-	-	-	-
Reference	7-24-08	226	21,665.60	13,498.54	6	0.49	0.63
Restoration	7-24-08	276	23,708.08	13,881.52	7	0.44	0.52
Mainstem	8-06-08	16	1,527.09	1,861.14	5	0.57	0.82
Reference	8-06-08	124	10,651.46	11,575.65	7	0.60	0.70
Restoration	8-06-08	65	5,583.42	4,674.28	5	0.47	0.67
Mainstem	8-20-08	0	0.00	0.00	0	0.00	0.00
Reference	8-20-08	217	18,640.05	10,598.45	10	0.68	0.68
Restoration	8-20-08	406	34,960.83	17,431.09	10	0.64	0.64
Mainstem	9-03-08	31	2,662.86	3,275.94	4	0.45	0.74
Reference	9-03-08	166	14,259.21	13,376.22	8	0.65	0.72
Restoration	9-03-08	228	19,670.84	12,750.18	12	0.76	0.70
Mainstem	9-17-08	47	4,037.25	2,219.75	7	0.67	0.79
Reference	9-17-08	107	9,191.18	6,006.78	12	0.82	0.76
Restoration	9-17-08	124	10,909.15	7,904.46	9	0.69	0.72

Table A6. Scientific name and percentage by number of drift invertebrates collected at the Restoration (REST), Reference (REST), and Mainstem (MAIN) sites pre-restoration in 2004 and post-restoration in 2006, Columbia River estuary, Oregon.

Taxa	Percentage of total					
	2004			2006		
	REST	REF	MAIN	REST	REF	MAIN
Amphipoda						
Corophiidae						
Corophium spp.	2.11	0.30		0.39	0.41	0.63
Gammaridae						
Gammarus spp.	4.66	0.48				
Araneae	1.94	2.34	3.80	1.05	0.58	5.03
Coleoptera						
Cantharidae	0.04					
Chrysomelidae	0.43		0.54			
Coccinellidae	0.30					
Curculionidae	0.35				0.08	
Dytiscidae	0.13	0.12				
Elateridae	0.04					
Elmidae	1.60	0.12	1.09	0.13	0.25	0.63
Gyrinidae					0.08	
Haliplidae	0.30				0.08	
Hydraenidae						1.26
Hydrophilidae	0.04	0.12				
Limnebiidae						
Ptilodactylidae	0.04					
Scarabaeidae	0.04	0.18	0.54			
Staphylinidae	1.38	1.08		0.39	0.33	
Unknown	0.86	0.96	2.17	0.39	0.08	4.40
Collembola						
Entomobryidae	1.90	0.84		1.44	30.50	2.52
Hypogastruridae	0.52	0.06	1.63		0.41	
Sminthuridae	0.13	0.06			0.25	
Unknown		0.06				
Decapoda						
Astacidae						
Pacifasticus connectens	0.04					
Dermaptera						
Forficulidae	0.04					
Diplopoda	0.04					
Diptera						
Canaceidae				0.52	0.41	3.77
Ceratopogonidae		0.12		3.66	9.65	13.21
Chironomidae	33.45	59.50	57.07	70.20	31.57	40.25
Culicidae	0.04					
Dixidae	4.57	3.49	7.61			
Dolichopodidae					0.33	
Dryomyzidae				1.31	1.57	
Empidae				0.13	0.08	
Ephydridae				0.52	0.33	
Sciomyzidae	2.55	1.08	0.54	0.39	0.41	
Simulidae				0.26		
Syrphidae	0.04					0.63
Tachnidae	0.04					
Tipulidae	0.09	0.36		0.92	0.16	
Unknown	0.39	0.54		0.26	0.41	1.26

Table A6. Scientific name and percentage by number of drift invertebrates collected at the Restoration (REST), Reference (REST), and Mainstem (MAIN) sites pre-restoration in 2004 and post-restoration in 2006, Columbia River estuary, Oregon.—Continued.

Taxa	Percentage of total					
	2004			2006		
	REST	REF	MAIN	REST	REF	MAIN
Ephemeroptera	0.09					
Gastropoda	6.04	7.51	0.54	0.92	1.48	
Hemiptera						
Belostomatidae	0.26					
Corixidae	5.44	0.18		0.78	0.16	
Gerridae	0.09					
Miridae	0.26	0.12				
Saldidae	0.78	0.90	0.54		1.24	
Tingidae	0.47					
Unknown	0.35			0.13	0.41	
Homoptera						
Aphididae	11.87	10.46	6.52	6.93	11.13	1.89
Cicadellidae	1.68	0.42	1.09		0.08	0.63
Delphacidae					0.08	
Unknown		0.06				0.63
Hydracarina	2.00	0.12	0.54			
Hymenoptera		2.46	2.17			
Apidae	0.40	0.06		0.13		
Braconidae	1.64	1.14	2.17	1.96	3.05	0.63
Cynipidae						0.63
Diapriidae	0.04					
Eucoilidae				0.52	0.08	3.15
Eulophidae	0.09			0.26	0.16	0.63
Formicidae	0.82					
Mymaridae	0.04	0.06				
Pompilidae					0.08	
Pteromalidae	0.04					
Scelionidae	0.56			0.13	1.40	2.52
Unknown	3.45			0.52		
Isopoda						
Asellidae		0.12				
Unknown	0.04					
Lepidoptera						
Noctuidae						0.63
Tortricidae					0.08	
Unknown	0.43	0.12	0.54			
Mysidacea						
Mysidae						
Neomysis mercedis	0.26				0.16	
Nematoda						0.63
Neuroptera						
Sisyridae					0.08	0.63
Odonata						
Coenagrionidae	0.39	0.78	0.54		0.25	
Unknown	0.09					0.63
Oligochaeta	0.04	0.06	0.54	1.57	0.82	3.77
Ostracoda	0.17	2.52				
Pelecypoda						
Corbicula fluminea	0.04	0.42				

Table A6. Scientific name and percentage by number of drift invertebrates collected at the Restoration (REST), Reference (REST), and Mainstem (MAIN) sites pre-restoration in 2004 and post-restoration in 2006, Columbia River estuary, Oregon.—Continued.

Taxa	Percentage of total					
	2004			2006		
	REST	REF	MAIN	REST	REF	MAIN
Psocoptera						
Liposcelidae			0.54			
Pseudocaeciliidae				0.13	0.16	
Psocidae	0.82	0.18	1.63	0.52		
Unknown						1.26
Thysanoptera						
Phloeothripidae					0.08	
Thripidae	1.86	0.30	7.07	0.65	0.41	6.92
Trichoptera						
Chloroperlidae					0.08	
Hydroptilidae	0.09					
Limnephilidae		0.06				
Perlodidae				0.13		
Unknown	1.25	0.12		0.26		
Unknown					0.41	0.63

Table A7. Site, date, total number of invertebrates, mean, standard deviation, number of taxa, diversity, and evenness of the drift invertebrate community at the Mainstem, Reference, and Restoration sites, Columbia River estuary, Oregon, March 16–August 15, 2004.

[Three replicates were collected at each site. Mean density in number per square meter (m^2). –, no data]

Site	Date	Total	Mean	Standard deviation	Taxa	Diversity (H')	Evenness (J')
Mainstem	3-16-04	11	3,149.6	2,161.7	2	0.13	0.43
Reference	3-16-04	219	62,706.2	7,730.9	11	0.28	0.27
Restoration	3-16-04	51	14,602.8	9,291.4	11	0.60	0.57
Mainstem	3-30-04	13	3,722.3	3,471.6	3	0.23	0.49
Reference	3-30-04	132	37,795.5	16,920.1	14	0.56	0.48
Restoration	3-30-04	23	6,585.58	4,884.4	13	1.00	0.90
Mainstem	4-12-04	44	12,598.5	12,516.9	7	0.43	0.51
Reference	4-12-04	469	134,288.5	74,837.2	21	0.52	0.39
Restoration	4-12-04	264	75,591.0	16,455.9	33	1.00	0.65
Mainstem	4-25-04	5	1,431.7	1,312.1	4	0.58	0.96
Reference	4-25-04	74	63,565.2	-	10	0.50	0.50
Restoration	4-25-04	201	57,552.2	16,898.3	27	1.04	0.73
Mainstem	5-10-04	6	1,718.0	859.0	4	0.58	0.96
Reference	5-10-04	139	39,799.8	7,305.6	10	0.46	0.46
Restoration	5-10-04	42	12,025.8	9,756.2	14	0.98	0.86
Mainstem	5-24-04	42	12,025.8	2,577.0	8	0.71	0.78
Reference	5-24-04	164	46,958.0	16,215.0	11	0.35	0.34
Restoration	5-24-04	257	73,586.7	15,588.5	33	1.17	0.77
Mainstem	6-07-04	15	4,294.9	4,545.3	8	0.78	0.87
Reference	6-07-04	33	9,448.9	5,364.4	9	0.71	0.75
Restoration	6-07-04	71	20,329.4	5,719.4	21	1.15	0.87
Mainstem	6-14-04	5	1,431.7	1,312.1	4	0.58	0.96
Reference	6-14-04	68	19,470.4	2,161.7	10	0.60	0.60
Restoration	6-14-04	163	46,671.7	6,094.2	30	1.23	0.83
Mainstem	7-06-04	13	3,722.3	2,761.3	4	0.41	0.68
Reference	7-06-04	114	32,641.6	17,372.0	16	0.74	0.61
Restoration	7-06-04	340	97,352.0	30,664.0	28	1.06	0.74
Mainstem	7-19-04	13	3,722.3	495.9	3	0.37	0.78
Reference	7-19-04	121	34,645.9	5,522.5	19	0.72	0.56
Restoration	7-19-04	389	111,382.2	12,516.9	31	0.94	0.63
Mainstem	8-02-04	16	4,581.3	2,624.3	6	0.65	0.83
Reference	8-02-04	100	28,633.0	9,461.9	14	0.80	0.70
Restoration	8-02-04	268	76,736.3	13,371.9	35	1.03	0.67
Mainstem	8-16-04	1	286.3	495.9	1	0	-
Reference	8-16-04	31	8,876.2	5,248.5	8	0.73	0.80
Restoration	8-16-04	248	71,009.7	4,408.0	30	0.98	0.66
Mainstem	3-23-06	41	11,739.51	6,504.16	10	0.83	0.83
Reference	3-24-06	470	134,574.86	62,984.03	11	0.32	0.31
Restoration	3-23-06	99	28,346.62	15,768.93	7	0.20	0.24

Table A7. Site, date, total number of invertebrates, mean, standard deviation, number of taxa, diversity, and evenness of the drift invertebrate community at the Mainstem, Reference, and Restoration sites, Columbia River estuary, Oregon, March 16–August 15, 2004.—Continued

[Three replicates were collected at each site. Mean density in number per square meter (m^2). –, no data]

Site	Date	Total	Mean	Standard deviation	Taxa	Diversity (H')	Evenness (J')
Mainstem	4-20-06	35	10,021.53	9,184.89	8	0.62	0.68
Reference	4-19-06	225	64,424.13	5,632.76	16	0.53	0.44
Restoration	4-19-06	219	62,706.16	8,460.06	14	0.36	0.31
Mainstem	5-17-06	5	1,431.65	1,788.13	3	0.41	0.86
Reference	5-18-06	98	28,060.29	13,752.76	16	0.67	0.55
Restoration	5-18-06	235	67,287.43	8,774.03	13	0.21	0.18
Mainstem	6-14-06	10	2,863.30	1,312.13	5	0.64	0.91
Reference	6-14-06	48	13,743.82	6,708.91	11	0.71	0.68
Restoration	6-14-06	53	15,175.46	3,576.25	9	0.60	0.63
Mainstem	7-11-06	61	17,466.10	6,560.63	14	0.86	0.75
Reference	7-11-06	107	30,637.25	10,248.04	21	1.07	0.81
Restoration	7-11-06	68	19,470.40	4,884.42	18	1.08	0.86
Mainstem	8-09-06	7	2,004.31	495.94	4	0.50	0.83
Reference	8-09-06	265	75,877.31	21,116.68	23	0.80	0.59
Restoration	8-09-06	91	26,055.98	1,788.13	12	0.68	0.63

Table A8. Scientific name, common name, presence in the Restoration and Reference sites, and wetland classification of plants surveyed at Crims and Gull Islands, Columbia River estuary, Oregon, September 18 and October 11, 2006.

[**Wetland class**: FAC, facultative wetland species; FACU, facultative upland species; FACW, facultative wet wetland species; OBL, obligate wetland species]

Scientific name	Common name	Restoration site (Crims Island)	Reference site (Gull Island)	Wetland class
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
Ranunculaceae				
Ranunculus sceleratus[1]	Celery-leaved buttercup	x		OBL
Salicaceae				
Salix spp.	Willow	x	x	

Table A8. Scientific name, common name, presence in the Restoration and Reference sites, and wetland classification of plants surveyed at Crims and Gull Islands, Columbia River estuary, Oregon, September 18 and October 11, 2006.—Continued

[**Wetland class**: FAC, facultative wetland species; FACU, facultative upland species; FACW, facultative wet wetland species; OBL, obligate wetland species]

Scientific name	Common name	Restoration site (Crims Island)	Reference site (Gull Island)	Wetland class
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]Non-native species.

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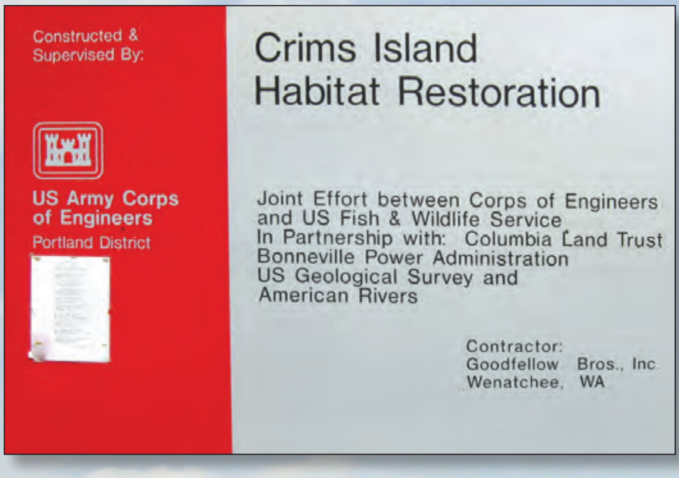

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