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Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats of the Lower Columbia River, 2007–2010

FINAL REPORT

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March 2011

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Abstract

The tidal freshwater monitoring study reported here was part of the research, monitoring, and evaluation effort developed in response to obligations arising from the Endangered Species Act as a result of operation of the Federal Columbia River Power System. The project was funded by the Bonneville Power Administration and performed under the auspices of the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program. The research was a collaborative effort of the Pacific Northwest National Laboratory, the Oregon Department of Fish and Wildlife, the National Marine Fisheries Service, and the University of Washington. The study was designed to investigate the ecology and early life history of juvenile salmonids within shallow tidal freshwater habitats of the lower Columbia River and estuary. Sampling occurred in the vicinity of the Sandy River delta (river kilometers [rkm] 188–202) and in lower river reaches (rkm 110–141). This report provides a comprehensive synthesis of data covering the period from June 2007 through April 2010.

Summary

The tidal freshwater monitoring (TFM) study reported here was part of the research, monitoring, and evaluation effort developed by the Action Agencies (Bonneville Power Administration [BPA], the U.S. Army Corps of Engineers, and the U.S. Bureau of Reclamation) in response to obligations arising from the Endangered Species Act as a result of operation of the Federal Columbia River Power System (FCRPS). The project was funded by BPA and performed under the auspices of the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program (Project No. 2005-001-00). The research was a collaborative effort of the Pacific Northwest National Laboratory, the Oregon Department of Fish and Wildlife, the National Marine Fisheries Service, and the University of Washington.

Shallow-water habitats in the tidal freshwater portion of the lower Columbia River and estuary (LCRE) may be important for the growth and survival of both stream-type (yearling) and ocean-type (subyearling) salmon life histories. However, specific scientific knowledge addressing this point is sparse. The Independent Scientific Advisory Board and the Independent Scientific Review Panel recommended RME be conducted in the tidal freshwater area of the Columbia River. In the 2008 Biological Opinion on FCRPS operations, the National Oceanic and Atmospheric Administration (NOAA) Fisheries stated: "The Action Agencies will…evaluate migration through and use of a subset of various shallow-water habitats from Bonneville Dam to the mouth toward understanding specific habitat use and relative importance to juvenile salmonids...investigate the importance of early life history of salmon populations in tidal fresh water of the lower Columbia River."

The TFM study was designed to investigate the ecology and early life history of juvenile salmonids within shallow (<5 m) tidal freshwater habitats of the LCRE. We started collecting field data in June 2007. Since then, monthly sampling has occurred in the vicinity of the Sandy River delta (SRD; river kilometer [rkm] 188–202) and at other sites and times in lower river reaches (LRR) of tidal freshwater (rkm 110–141). This report provides a comprehensive synthesis of data covering the period from June 2007 through April 2010. The goal of the TFM study was to answer the following questions:

- In what types of habitats within the tidal freshwater area of the LCRE are juvenile salmonids found, when are they present, what are their densities, which stocks are present, and what are the fish community and environmental conditions they live in?
- What is the ecological importance of shallow (0–5 m) tidal freshwater habitats to the recovery of listed salmonid stocks, including Upper Columbia River Spring Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) and Snake River Fall Chinook salmon?

The research objectives, methods, results, and conclusions are described below for each chapter of the report. A synthesis of findings, management implications, and recommendations for future research is presented in the closing chapter.

S.1 Juvenile Salmon and Fish Community Characteristics (Chapter 2)

S.1.1 Objectives

The study objectives were to 1) describe juvenile salmon and fish community characteristics, including species composition, length-frequency distribution, average weights, density (#/m^2), and temporal and spatial distributions in the vicinity of the SRD and other tidal freshwater habitats within the lower Columbia River; 2) estimate through genetic stock identification the stock of origin for juvenile Chinook salmon captured at sampling sites; 3) characterize habitats, including vegetation composition and percent cover, conventional water quality, water-surface elevation, substrate composition, bathymetry, and beach slope, at the sites within the vicinity of the SRD; and 4) examine landscape-scale differences in fish community composition between two study areas of the LCRE.

S.1.2 Sampling Periods and Study Areas

Juvenile salmon and fish community characteristics were sampled monthly at the SRD during June 2007 through April 2010. At the LRR, data were collected during week-long samplings in January, February, May, August, and November 2009.

S.1.3 Methods

In the SRD, nine base sites were sampled. Habitat types included main channel, main-channel island, off-channel, off-channel island, confluence, and wetland. There were 35 monthly sampling events involving 256 site-samplings. During 2009, the study design was expanded to increase the spatial extent of our sampling effort within the tidal freshwater portion of the LCRE. In the LRR, we applied a landscape-scale stratified random sampling approach using six habitat strata: wetland channel, off-channel, main channel, confluence, main-channel island, and off-channel island. At all sampling sites, juvenile salmon were sampled with a beach seine (two sets per site per sampling). Individual fish in each catch were identified, measured, and weighed. The total number of fish in each species category was enumerated. Fin tissue samples from juvenile Chinook salmon were collected for genetic stock identification. Ancillary data on environmental and habitat conditions were obtained. The area seined was calculated and used to determine the primary response variable—fish density (#/m^2).

S.1.4 Results for Objective 1

The fish community in the shallow, tidal freshwater SRD study area was determined from over 500 beach seine hauls capturing over 200,000 fish. The total SRD catch was composed of 34 species, including 18 non-native species. Total catch abundance was composed of approximately 75% native fishes and 25% non-native fishes. Summer months yielded the highest densities of fish while the smallest densities of fish occurred during winter months. The overall mean lengths for common species captured at the SRD ranged from 39 to 54 mm. The most common fish was threespine stickleback (*Gasterosteus aculeatus*; 43% of total fish catch). This species exhibited a bimodal seasonal distribution with peaks occurring during late summer and winter months. The next most abundant fishes were banded killifish (*Fundulus diaphanous*; 18%), peamouth (*Mylocheilus caurinus*; 16%), and northern pikeminnow (*Ptychocheilus oregonensis*; 6%). Juvenile salmonid individuals composed about 4% of the total catch.

Seasonally, juvenile salmon density was highest in spring (mean ~0.01 fish/m^2). The season with the second highest density was winter (mean ~0.005 fish/m^2). Chinook and coho salmon were the only salmonid species encountered during every season. Chum salmon were captured during winter and spring months. Unmarked juvenile Chinook salmon were the most abundant salmonid captured (74% of the total salmonid catch), followed by chum (10%) and coho (8%) salmon and steelhead (<1%). Marked Chinook salmon composed 8% of the total salmonid catch. Densities were relatively low (mean <0.005 fish/m^2) at our sampling sites during summer and fall. The mean size of unmarked Chinook salmon was generally lowest during periods that corresponded to the highest densities of this species. After April, the size of unmarked Chinook salmon increased throughout the summer and fall months with the largest mean fork lengths of fish occurring in November and December. During winter months the length frequency distribution of unmarked Chinook salmon was bimodal with large numbers of small fish (e.g., <60 mm) and a smaller proportion of larger size classes (e.g., 90 to 120 mm). During spring months, small sized (e.g., <60 mm) fish continued to be predominant, but a greater number of fish occupied the 60- to 80-mm size range, and the larger sizes (e.g., 90 to 120 mm) of unmarked Chinook salmon were not captured. Summer months were dominated by fish ranging from 60 to 80 mm and fall months generally included juvenile Chinook salmon that ranged from 80 to 120 mm.

S.1.5 Results for Objective 2

Genetic stock identification analyses for 1242 unmarked Chinook salmon sampled in the SRD showed a majority of the fish were from the Spring Creek Group Tule Fall (35%) and the Upper Columbia Summer/Fall (33%) stock groups. Smaller proportions were estimated for the West Cascade Tributary Fall (15%) and Willamette River Spring (8%) groups. Snake River Fall (3%), Deschutes River Fall (3%), and West Cascade Tributary Spring (2%) fish were also present. Most of the marked, hatchery fish were also from the Spring Creek Group Tule Fall (69%) and Upper Columbia Summer/Fall (20%) stock groups. Genetic estimates for the Upper Columbia Summer/Fall stock include potential contributions of fish introduced in the lower Columbia River (above and below Bonneville Dam) in addition to native fish from the upper Columbia River. Within sites sampled in the LRR, the genetic stock composition differed from that at the SRD sampling sites for similar sampling dates. Unmarked Chinook salmon in the LRR were generally dominated by a single stock group—the West Cascade Tributary Fall stock (62% to 89% by month). Other stocks sampled in the LRR included Spring Creek Group Tule Fall fish in February 2010 (15%) and May 2009 (16%), and Willamette River Spring Chinook salmon in February 2009 (20%). As opposed to fall Chinook salmon, we found few spring Chinook salmon from the interior Columbia River Basin in our beach seine samples at the SRD or LRR study areas.

S.1.6 Results for Objective 3

Hydrology had the typical seasonal pattern for the contemporary Columbia River—lowest flows occurred late summer and early fall. Flows gradually began to increase through the winter months with the river reaching peak discharge in May and June. River discharge also demonstrated inter-annual fluctuations; during our study period June 2007 through April 2010, outflow at Bonneville Dam was lowest in September 2007 (~75 kcfs) and highest in June 2008 (>400 kcfs). Site-specific water-surface elevations generally followed annual, seasonal, weekly, and hourly patterns similar to those observed at Bonneville Dam; e.g., power peaking at Bonneville Dam caused corresponding rises in water level 40 km downstream at the SRD study area. Site-scale hydrodynamics were also influenced by topography and

lateral connectivity with the main channel. Water temperature peaked during August through October (~25 ºC) and gradually declined through the fall and winter months. While the overall seasonal patterns were similar, thermal conditions differed among sites. The emergent vegetation observed at the SRD and vicinity included a mixture of species indicative of various wetland communities with many sites dominated by creeping spikerush (*Eleocharis palustris*). Willow (*Salix* spp.) was the most common vegetation encountered during survey efforts. Topography ranged from gradually sloping, low-relief transitions from the uplands to steeply graded beach slopes. Substrate grain size ranged from sandy to silty.

S.1.7 Results for Objective 4

During the six time periods sampled for the landscape-scale comparison, we captured 25 fish species at the SRD study area and 27 species at the LRR sites. Seven species accounted for 1% or more of the total catch at both study areas with six of these species being common between the two areas. At times there were noticeable differences in fish communities between the SRD and LRR, but the patterns were not consistent through time. Across the SRD and LRR study areas, there were no consistent trends in the proportions of salmon, native non-salmon, and non-native species.

S.1.8 Summary, Conclusions, and Recommendations

We offer the following conclusions and recommendations regarding juvenile salmon and the fish communities of shallow tidal freshwater habitats:

- The presence of juvenile salmon in the catch year-round implies multiple life-history strategies are being expressed and, therefore, year-round sampling is necessary to obtain a holistic understanding of life-history strategies.
- Overall, recovery of listed species should benefit from efforts to restore shallow freshwater areas because juvenile fish, regardless of the rearing type, are captured in these habitats year-round.
- Seasonally, the highest Chinook salmon densities and the smallest average lengths were observed in spring. The second highest densities for Chinook were noted in winter, when there was a bimodal size distribution of Chinook salmon indicating temporal overlap of salmon life stages in tidal freshwater.
- Unmarked Chinook salmon far out-numbered catches of marked Chinook salmon, indicating unmarked fish use shallow tidal freshwater to a greater extent than marked fish. Length frequency distributions for unmarked and marked Chinook salmon had medians of 45 mm and 81 mm, respectively. Furthermore, unmarked fish were present year-round, whereas marked fish mostly appeared as a peak in spring. Although some unmarked fish (perhaps ~22%) originated in hatcheries, the size distribution and genetics data generally were indicative of naturally produced fish. Therefore, the data support restoration of shallow tidal freshwater habitats to aid recovery of wild fish populations.
- We encountered a diversity of stocks consistently throughout the year. In spring, the majority of the stock composition (68%) was composed of Spring Creek Fall Chinook salmon and Upper Columbia Summer/Fall Chinook salmon. However, stock groups from east and west of the Cascades were detected throughout the year, although in lower abundances. Because no single or group of stocks

predominated year-round, and assuming the various stocks have evolved differently, the potential for resource competition among co-existing stocks may be relaxed.

- Genetic stock composition for Chinook salmon varied depending on river reach; stock diversity was higher in our samples from SRD (rkm 188–202) compared to LRR (rkm 109–141). This indicates restoration strategies may need to consider longitudinal position (distance from the mouth) in the LCRE.
- Because not all hatchery Chinook salmon in the Columbia River basin are marked, it is almost certain our samples of unmarked fish contained unmarked hatchery fish. However, we found very different stock compositions in the unmarked and marked (known hatchery) juvenile populations, suggesting a strong signal from naturally produced fish. These results highlight the value of 100% marking of hatchery Chinook salmon for identifying naturally produced fish within the Columbia River basin.
- The SRD (rkm 188–202) and LRR (rkm 110–141) areas had the same six most common species and similar species richness (25 and 27 species, respectively). At times, however, there were noticeable differences in fish communities between the SRD and LRR, but the patterns were not consistent through time. Managers will need to consider the spatial and temporal variability in fish communities during restoration planning processes as well as during evaluation phases, e.g., action effectiveness monitoring and research.
- Fish size distributions for the six most common taxa, including Chinook salmon, suggest tidal freshwater habitats are used by juvenile life stages. Of these six taxa, threespine stickleback and banded killifish of multiple ages (e.g., juveniles to adults) use shallow tidal freshwater habitats year-round.

S.2 Juvenile Salmon Density and Habitat Attribute Associations (Chapter 3)

S.2.1 Objective

The study objective was to determine relationships between juvenile salmon density and macro-habitat features (e.g., sampling site, habitat stratum), environmental, and structural attributes.

S.2.2 Sampling Period and Study Areas

Associations between juvenile salmon density and habitat attributes were examined from beach siene and habitat samples collected in the SRD and LRR study areas during January, February, May, August, and November 2009.

S.2.3 Methods

Multiple regression analysis was used to assess relationships between observed salmon densities and selected habitat covariates measured at both the SRD and LRR sites. Covariates were selected based on professional judgment of the likelihood of a potential biological effect on salmon density. The covariates were temperature, dissolved oxygen, salinity, water velocity, mean depth, mean beach slope, habitat type

(see below), rapid habitat assessment (RHA) percentage emergent plants, and RHA dominant substrate type. Each covariate was individually regressed on the salmon densities.

S.2.4 Results

Juvenile salmonids were distributed spatially in many different types of habitat, including along the main river channel and in off-channel, tributary confluence (delta), and wetland areas. The habitat type with the highest density of juvenile salmon was variable; no single habitat type consistently had the most salmon. Consistent relationships between salmon density and macro-habitat features, environmental conditions, and structural attributes were not apparent.

S.2.5 Summary, Conclusions, and Recommendations

The following conclusions and recommendations arise from the analysis of habitat attributes and salmon density:

- Assuming salmon density indicates relative importance, no single or suite of macro-habitat features, environmental conditions, or structural attributes emerged in our analysis as being most important for juvenile salmon in shallow tidal freshwater.
- Habitat restoration should include a variety of habitat types to support variable use temporally and spatially by a diversity of life stages and species of juvenile salmon.
- Additional data obtained in 2010 after the analysis reported here was conducted should be analyzed. Furthermore, habitat attributes not included in the original analysis, such as RHA percentage sapling plants and bare ground, should be considered, as well as habitat categories from the Columbia River Estuary Ecosystem Classification System when the estuary-wide version is released in 2011.

S.3 Feeding Ecology (Chapter 4)

S.3.1 Objectives

The study objectives were to 1) quantify the diet composition of juvenile Chinook salmon; 2) assess the relative importance of prey organisms in the diet; and 3) evaluate foraging behavior, including prey selection. By characterizing diet and prey pool composition, and applying index models to empirical data, we examined the roles of various prey taxa in the diets of juvenile Chinook salmon and characterized feeding strategies in areas of the LCRE to draw conclusions about the ability of specific tidal freshwater habitats to support juvenile salmon.

S.3.2 Sampling Periods and Study Areas

Feeding ecology research was conducted in the SRD study area. Diet samples from juvenile salmon were obtained monthly from March 2008 through April 2010. Prey availability samples were collected during June, September, and December 2009 and March 2010.

S.3.3 Methods

We used gastric lavage to remove the stomach contents from juvenile Chinook salmon greater than or equal to 50-mm fork length. At each site, the contents from the digestive tracts of up to 20 Chinook salmon were flushed into individual polyethylene sample bottles using filtered river water at ambient temperature. To collect available prey, benthic samples were taken quarterly at each site using a standard ponar dredge (232 cm^2). Drifting invertebrates were collected with drift nets (363-µm mesh). The gear was oriented with openings facing upstream and, when possible (i.e., depending on water levels), approximately 3 m and 6 m from the existing waterline. Terrestrial or winged organisms were sampled using fallout traps. Duplicate traps were set parallel to the shore, downstream of drift nets for a period of 48 hours. In the laboratory, prey items in diet and prey availability samples were identified to the lowest classification practicable using standard taxonomic keys. To assess the importance of specific prey items in the diet, we calculated Index of Relative Importance (IRI) values. To evaluate the feeding behavior of juvenile Chinook salmon in specific tidal freshwater habitats, stomach content data and counts of prey in the environment were input into a selectivity coefficient model and subsequently standardized using a Relativized Electivity Index.

S.3.4 Results for Objective 1

The diets of juvenile Chinook salmon were generally dominated by dipterans (primarily chironomids and ceratopogonids), hemipterans, and malacostracans (Amphipoda and Mysidae). Dipterans consistently constituted large proportions of the gut content biomass, accounting for more than 20% of the diet during 86 of 109 (79%) sampling period-site combinations in which non-empty gut content samples were collected. Non-dipteran aquatic insects (e.g., Plecoptera and Ephemeroptera) periodically contributed appreciable proportions to the gut content biomass of juvenile Chinook salmon, but much less frequently than dipteran taxa, >20% of the diet in approximately 9% of sampling episodes. Although appreciable contributions of terrestrial insects (composed primarily of Formicidae and Aphididae) and non-malacostracan crustaceans (Cladocera, Copepoda, and Ostracoda) occurred infrequently (>20% of the diet in approximately 8% and 6% of sampling episodes, respectively), maximum proportions were large (0.63 and 0.50, respectively). The “Fish” category—composed of embryonic, larval, and juvenile life stages—was represented at most sites, restricted to few applicable sampling months at any one location. The largest biomass proportions of prey items included in the “Other” category (Annelida, Arachnida, Mollusca, Nemata, Nematomorpha, plant material, Platyhelminthes, Rotifera).

S.3.5 Results for Objective 2

Dipterans, hemipterans, amphipoda, and mysids were generally the most important prey taxa, representing a combined mean percent IRI (%IRI) value of 69.2% ranging from 3.2% to 100.0% over all sampling episodes. Of these taxa, dipterans typically were found to be most important; however, %IRI values varied considerably among sampling episodes. Hemipterans, amphipods, and mysids were associated with large %IRI values less frequently than the dipterans. Particularly during the late fall-winter months, aquatic/semiaquatic hemipterans were important components of the diet, whereas high %IRI values for amphipods and mysids appeared to be largely unrelated to sampling episode.

S.3.6 Results for Objective 3

For benthic prey, juvenile Chinook salmon selected against benthic dipterans and never consumed the prey item in proportion to its abundance in the environment. Benthic amphipods were a commonly preferred prey. For drifting prey, dipterans generally were selected against and not consumed in proportion to their abundance in the water column. Amphipods and mysids were commonly preferred drifting prey. For terrestrial and winged fallout prey, dipterans generally were selected against. Unlike electivity values calculated for either the benthos or drift, hemipterans in the fallout were largely selected for or consumed in proportion to their abundance in the environment.

S.3.7 Summary, Conclusions, and Recommendations

Based on our research on the feeding ecology of juvenile salmon in tidal freshwater, we offer the following conclusions and recommendations:

- In terms of the dipteran prey resource, given the large contribution of insects to the diets of juvenile salmon and their generally high densities in the benthos, drift and fallout across seasons, the sites sampled in this study appear to be well-suited energetically to support salmon production.
- Regardless of mechanisms that may affect the roles of large-bodied malacostracans and hemipterans in the diets of juvenile Chinook salmon in tidal freshwater habitats, even periodic or opportunistic consumption of these generally high-quality prey could contribute significantly to net energy gain.
- The underrepresentation of prey items such as microcrustaceans and fish in the diets of juvenile salmon may be related to factors including visual acuity, gape limitations, or low abundance of this prey in the water column. However, behaviors or morphological constraints that may act to dictate diet compositions in specific tidal freshwater habitats could be energetically advantageous.
- Our results generally suggest, under current conditions, that prey pools in tidal freshwater areas near the SRD likely provide useful forage for juvenile Chinook salmon. Given the importance of energy acquisition for young animals, we recommend restoration efforts in other areas of the LCRE adopt a food web perspective; i.e., managers should consider restoration strategies that promote the production of fish in addition to the prey they consume.
- Based on prey densities, modeled foraging behaviors, and diet compositions, it appears probable that intra-specific competition among juvenile Chinook salmon may be relatively weak. However, future research should seek to characterize factors that may promote or relax inter-specific competitive interactions.

S.4 Bioenergetics (Chapter 5)

S.4.1 Objectives

The study objectives were to 1) assess the influences of environmental (temperature) and dietary (consumed prey composition and quality) parameters on rates of consumption and growth for juvenile Chinook salmon in specific tidally influenced habitats in the LCRE, and 2) evaluate spatial and temporal variability in both consumption rates and growth.

S.4.2 Sampling Period and Study Areas

Bioenergetics modeling was based on data collected in the SRD study area from March 2008 through April 2010.

S.4.3 Methods

We used a modeling approach to investigate juvenile salmon bioenergetics in LCRE tidal freshwater. A bioenergetics model balances consumption with growth and losses from metabolic processes. We applied the Fish Bioenergetics 3.0 model parameterized for adult Chinook salmon to empirical data from this project and published values. Although this model was developed originally for adult Chinook salmon, previous research has found model-predicted estimates of consumption by juvenile salmon to be within 15% of field and laboratory estimates generated independently. The main model inputs were diet composition, prey energy, and thermal regime. The bioenergetics model predicted output based on species-specific physiological parameters and user input, including the initial and final mass of juvenile salmon. For each site, multiple cohorts were simulated over discrete time periods to represent the growth response of fish to environmental and dietary (i.e., prey quality and quantity) influences.

S.4.4 Results for Objective 1

The length-biomass regression models used to estimate initial and final fish weights were all found to be significant at $\alpha = 0.05$. Despite broad temperature fluctuations across cohorts, at most sites, mean predicted specific growth rates remained relatively consistent. Mean predicted specific growth rates for simulation cohorts were positive and varied little, except during sustained high temperature extremes.

S.4.5 Results for Objective 2

At each SRD sampling site, mean predicted specific growth rates for simulation cohorts generally were positive, indicating juvenile Chinook salmon typically gained biomass throughout residence periods. Feeding rates and estimates of gross conversion efficiency generally were moderate to high at the sampled sites. Over time, predicted growth was positive for most cohorts, and there were few instances during which a cohort lost biomass over a simulation period.

S.4.6 Summary, Conclusions, and Recommendations

The following conclusions may be drawn from and recommendations made based on the analysis of juvenile salmon bioenergetics in shallow tidal freshwater:

- Across sites, mean predicted specific growth rates for simulation cohorts were positive and varied little, except during sustained high temperature extremes. This model output suggests the integrated effects of prey composition and quality, thermal experience, and species-specific physiology will result in favorable growth for juvenile Chinook salmon at our sampling locations within shallow tidal freshwater LCRE habitats.
- Feeding rates (i.e., proportion of maximum consumption, *P*-value) for simulation cohorts of juvenile Chinook salmon at our sites generally were moderate to high. This suggests that prey pools exploited

by most cohorts were sufficient (in terms of the number of organisms, appropriate sizes, etc.) to allow juvenile Chinook salmon to feed close to their maximum daily ration.

- Gross conversion efficiency represents a measure of the ability of an organism to convert ingested food into new tissue given environmental conditions and prey quality and quantity. Our simulations suggest the prey base and thermal regime at sampling locations throughout the majority of our study allowed for the efficient allocation of energy to somatic growth—a critical factor for young, migratory fish.
- Consistently high *P*-values and gross conversion efficiencies at our sites suggest competition for prey resources may be weak.
- Our simulation scenarios were developed based on residence times estimated for the Columbia River estuary proper. To improve model output, future work should seek to estimate juvenile Chinook salmon residence times, throughout the year, specifically in tidal freshwater habitats.
- Results from growth simulations indicate there is a temperature maximum (~22 ^{o}C) at which juvenile salmon growth drops precipitously. Although this occurred infrequently at sampling locations during our study period, given the inter-annual uncertainty surrounding the thermal regime, this response should be considered when planning restoration efforts associated with listed salmon. Maintaining suitable flow regimes and overhanging riparian vegetation in tidal freshwater habitats are examples of actions that may help mitigate critical water temperatures.
- To help better inform management, future modeling syntheses should be conducted by coupling the bioenergetics model with a hydrologic model. A composite model of this type would allow researchers to better assess the potential impacts of variable river conditions on juvenile salmon.

S.5 Migration Pathways and Residence Times (Chapter 6)

S.5.1 Objectives

Two specific objectives were pursued under this study: 1) during spring and summer 2007 and 2008, use juvenile salmon tagged with acoustic transmitters and released upstream of Bonneville Dam as part of other studies to estimate migration pathways and residence times in the SRD study area; and 2) during winter 2010 (January 26, 27, and 29, 2010), capture, tag, and release juvenile Chinook salmon to estimate residence time and movement characteristics for these fish during winter and early spring months in a tidal freshwater, off-channel habitat of the LCRE.

S.5.2 Sampling Period and Study Areas

The acoustic-telemetry evaluation of migration pathways and residence times were conducted at the SRD study area during April through August 2008 and 2009 and January through April 2010.

S.5.3 Methods

We used the Juvenile Salmon Acoustic Telemetry System (JSATS) for this evaluation. During spring and summer 2007 and 2008, we deployed acoustic receivers to detect run-of-river juvenile Chinook salmon and steelhead (2008 only) tagged with JSATS transmitters and released at or upstream of

Bonneville Dam (rkm 233) as part of other studies. During winter 2010, we used a beach seine to capture juvenile Chinook salmon in the delta study area. Fifty-one fish (mean fork length [FL] = 103 mm) were tagged with JSATS transmitters, released, and detected on receivers in an off-channel area of the Columbia River near the SRD from January through April 2010.

S.5.4 Results for Objective 1

There were 575 and 981 unique detections in off-channel areas during 2007 and 2008, respectively. Coupled with data on main-channel detection rates from other studies, we determined 11% of the yearling and 4% of the subyearling Chinook salmon migrated through the SRD in off-channel habitats during 2007. During 2008, 8.4% of the tagged yearling Chinook salmon, 6.9% of the tagged subyearling Chinook salmon, and 3.1% of the tagged steelhead used SRD off-channel migration routes. Residence times were short, averaging <1 to 4 hours; steelhead times were the shortest and subyearling Chinook salmon times were the longest.

S.5.5 Results for Objective 2

During winter and early spring 2010, we detected 48 of 51 tagged fish released in the SRD study area. Individual tagged fish were detected starting on January 28, with the last detection of a tagged fish in the study area on April 15. Assuming the last detection of individual fish reflects movement out of the study area, exit timing was episodic during late January, February, and April, and protracted during March. Mean residence time was 34 days; the median was 26 days. While Chinook salmon originating from reaches above Bonneville Dam migrated quickly through off-channel tidal freshwater habitats during spring and summer, juvenile Chinook salmon remained in such habitats for prolonged time periods during late winter and early spring. One-quarter of the tagged fish were estimated to be fall Chinook salmon belonging to a diverse composition of stock groups, including Snake River, Spring Creek, Upper Columbia, and West Cascade groups.

S.5.6 Summary, Conclusions, and Recommendations

The acoustic-telemetry evaluations of migration pathways and residence times for tagged juvenile Chinook salmon and steelhead in the LCRE SRD and vicinity led to the following conclusions and recommendations:

- During spring and summer 2007 and 2008, a fraction (3–11%) of acoustic-tagged, run-of-river yearling and subyearling Chinook salmon and steelhead actively moving downstream from upriver sources migrated quickly (a few hours) through off-channel pathways compared to the main channel in the SRD and vicinity.
- Based on the telemetry (Chapter 6) and the fish community (Chapter 2) results, relatively large, actively migrating fish do not appear to use shallow off-channel habitats to the same extent as smaller size classes present in the area during the same spring and summer seasons.
- During winter to early spring 2010, residence time averaged 34 days for 48 juvenile Chinook salmon captured, tagged, released, and detected in the SRD. Sizes of these fish (mean fork length = 111 mm) were similar to those tagged for the 2007 and 2008 telemetry studies. However, residence times during winter to early spring indicated a direct association between the tagged juvenile Chinook

salmon and off-channel habitats compared to those for the spring and summer migrants from upriver. These data imply that the fish were residing and presumably feeding and growing in the off-channels areas and not actively migrating.

- Most fish (85%) captured, tagged, and released for the winter to early spring 2010 evaluation were from stocks originating west of the Cascade Mountains. However, genetic stock identification indicated a small portion of the tagged Chinook salmon originated from upriver sources (e.g., Snake River stock groups).
- One-quarter of the tagged fish were estimated to be fall Chinook salmon belonging to a diverse composition of stock groups, including Snake River, Spring Creek, Upper Columbia, and West Cascade groups. It appears these fish did not exhibit the general life-history pattern of fall Chinook salmon, which typically migrate downstream as subyearlings during late spring and summer months. Instead, it is likely they delayed migration and over-wintered in off-channel, tidal freshwater habitats.

S.6 Research Applications (Chapter 7)

We applied research results from the 2007–2010 TFM study to inform LCRE management decisions being made by the Action Agencies and federal and state fisheries resource agencies. Our results pertain to the federal LCRE habitat restoration program, recovery of endangered Columbia-basin salmonid Evolutionarily Significant Units, survival benefit units for proposed restoration actions, the FCRPS BiOp's Reasonable and Prudent Alternative, the Northwest Power and Conservation Council's Fish and Wildlife Program, the proposed dam removal restoration at the SRD, landscape-scale monitoring of juvenile salmon density, permitting of development activities, the Columbia River Crossing project, and other research in the LCRE. Particularly important management implications include the following:

- It is clear that juvenile salmon use shallow tidal freshwater habitats to feed and grow year-round, although such habitat use varies by season, stock of origin, life-history stage, and other factors. It is not clear, however, whether certain habitats are used more in comparison to others. Therefore, elucidating possible differences in juvenile salmon use among habitat types should be considered a high priority for ecosystem restoration and planning. In the meantime, the data support restoration of access to and quality of a variety of shallow tidal freshwater habitats.
- Habitat use as evidenced by salmon density and diet was highly variable. Juvenile salmon were present in all types of habitat sampled, from off-channel wetlands to main-channel areas. The results of the bioenergetics modeling suggest maintenance of adequate temperatures in tidally influenced shallow-water habitats is key for adequately supporting growth of juvenile salmon. Restoration actions focused on maintaining adequate flow and temperature regimes in these habitats will likely benefit juvenile salmon.
- Our data do not indicate a higher priority for one reach over another for restoration, although genetic stock identification data for Chinook salmon varied depending on longitudinal position in the LCRE and time of year. Conversely, we suspect lateral distance between off-channel habitats and the main channel influences conditions such as structural hydrologic connectivity, temperature, and bioenergetics growth potential; however, more research is warranted.
- Some fall Chinook salmon stock from east and west of the Cascade Mountains did not exhibit the typical life-history pattern to migrate downstream as subyearlings during late spring and summer

months. Rather, they delayed migration and over-wintered in off-channel, tidal freshwater habitats, presumably to their benefit.

- Feeding ecology and bioenergetics data showed the positive contribution shallow tidal freshwater habitats in the SRD are making to juvenile salmon growth and development.
- Ecosystem restoration in LCRE tidal freshwater should benefit listed salmon and steelhead and aid their recovery by facilitating expression of a diversity of life-history patterns in shallow-water habitats, such as over-wintering areas; providing prey year-round to sustain growth and improve the probability of survival in the ocean; exporting inorganic and organic materials from off-channel habitats to the main stem to support food webs for all migrants no matter their residence time within shallow water habitats; and supporting wild fish populations regardless of their watershed of origin.
- Based on findings to date, we recommend future research on remaining critical uncertainties and restoration action effectiveness. Critical uncertainties include juvenile salmon residence times and growth rates in tidal freshwater habitats and ecological interactions between juvenile salmon and threespine stickleback, between juvenile salmon and non-native plant and animal species, and between hatchery and unmarked salmon in tidal freshwater. Action effectiveness research is needed on juvenile salmon passage through culverts and tide gates placed under roads, tracks, levees, dikes, and other obstructions between restored sites and the LCRE; wintertime use of off-channel reference and restored areas in tidal freshwater; juvenile salmon density differences pre- versus post-restoration and restored versus reference or control site; landscape density estimates; and indices of survival benefits of restoration.

Preface

The tidal freshwater monitoring (TFM) study documented in this report is part of the research, monitoring, and evaluation (RME) effort developed by the Action Agencies (Bonneville Power Administration [BPA], U.S. Army Corps of Engineers [USACE], and U.S. Bureau of Reclamation) in response to obligations under the Endangered Species Act as a result of operation of the Federal Columbia River Power System. The project was performed under the auspices of the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program.

The Pacific Northwest National Laboratory (PNNL) led the multiyear study under contract with BPA (Project No. 2005-001-00; Contract No. 0026934). The study was a collaborative effort by PNNL, the Oregon Department of Fish and Wildlife (ODFW), the National Marine Fisheries Service (NMFS), and the University of Washington (UW). During 2010, the study was transferred from BPA to the USACE as part of provisions in the Memorandum of Agreement on estuary habitat restoration between the State of Washington and the Action Agencies.

This is the final deliverable for the TFM project under BPA funding. Electronic versions of all project reports may be found at www.efw.bpa.gov. The data reported herein are archived with Nikki Sather at the Marine Sciences Laboratory in Sequim, Washington. For additional information, please contact Ms. Sather at (360) 681-3688.

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Acronyms and Abbreviations

AFEP	Anadromous Fish Evaluation Program
BACI	before-after control-impact
BiOp	Biological Opinion
BPA	Bonneville Power Administration
C	degree(s) Centigrade or Celsius
cm	centimeter(s)
cm^2	square centimeter(s)
CV	coefficient of variation
d	day(s)
DART	Data Access in Real Time
ERTG	Expert Regional Technical Group
ESA	Endangered Species Act
ESU	Evolutionarily Significant Unit
FCRPS	Federal Columbia River Power System
FL	fork length
FWP	(NPCC's) Columbia Basin Fish and Wildlife Program
g	gram(s)
GCE	gross conversion efficiency (a measure of the ability of an organism to convert ingested food into new tissue given environmental conditions and prey quality and quantity)
GIS	geographical information system
GPS	global positioning system
h	hour(s)
h/d	hour(s) per day
%IRI	percent of Index of Relative Importance
IRI	Index of Relative Importance
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
kHz	kilohertz
km	kilometer(s)
L	liter(s)
LCRE	lower Columbia River and estuary
LCREP	Lower Columbia River and Estuary Partnership
LRR	lower river reaches

µm	micron(s)
m	meter(s)
m^3	cubic meter(s)
mg	milligram(s)
mg/L	milligram(s) per liter
mL	milliliter(s)
mm	millimeter(s)
MS-222	tricaine methanesulphonate
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
ODFW	Oregon Department of Fish and Wildlife
oz	ounce(s)
PC1	first principle component
PC2	second principle component
PCA	Principal Components Analysis
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
ppt	parts per thousand
PRI	pulse repetition interval
P-value	proportion value (in the context of bioenergetics modeling, a *P*-value is a derived figure representing the proportion of maximum consumption at which a cohort is feeding; a simulated consumption rate)
R^2	coefficient of determination
RHA	rapid habitat assessment
rkm	river kilometer(s)RME research, monitoring, and evaluation
RPA	Reasonable and Prudent Alternative
s	second(s)
SAV	submerged aquatic vegetation
s.e.	standard error
s.d.	standard deviation
SRD	Sandy River delta
TFM	tidal freshwater monitoring
UID	unidentified (taxa)
USACE	U.S. Army Corps of Engineers, Portland District
USGS	U.S. Geological Survey
UW	University of Washington

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1.0 Introduction

Prepared by Gary Johnson and Earl Dawley

The tidal freshwater monitoring (TFM) study reported here is part of the research, monitoring, and evaluation (RME) effort developed by the Action Agencies (Bonneville Power Administration [BPA], the U.S. Army Corps of Engineers, Portland District[USACE], and the U.S. Bureau of Reclamation) in response to obligations arising from the Endangered Species Act of 1973 (ESA) as a result of operation of the Federal Columbia River Power System (FCRPS) the 31 federally owned dams and associated transmission systems in the Columbia River basin. The obligations, outlined in the Reasonable and Prudent Alternative (RPA) of the 2008 FCRPS Biological Opinion (BiOp) (NOAA Fisheries 2008), include RME in the lower Columbia River and estuary (LCRE; Figure 1.1). As a part of this federal RME effort, the TFM study was conducted under the auspices of the Northwest Power and Conservation Council's (NPCC's) Columbia Basin Fish and Wildlife Program.

The TFM study was initiated in 2005 to investigate the ecology and early life history of juvenile salmonids within shallow (<5 m) tidal freshwater habitats of the LCRE. The project was a collaboration of the Oregon Department of Fish and Wildlife, the National Marine Fisheries Service, the University of Washington, and the Pacific Northwest National Laboratory (PNNL). We started collecting field data in June 2007. Since then, monthly sampling has occurred in the vicinity of the Sandy River delta (river kilometer [rkm] 188–202) and at other sites and times in LCRE tidal freshwater (rkm 110–141). Previously, Sobocinski et al. (2008) and Sather et al. (2009) reported TFM study data from June 2007 through December 2008 and 2009, respectively. This report provides a comprehensive synthesis of data covering June 2007 through April 2010, the field period for the study funded by BPA. The goal of the TFM study was to answer the following questions:

- In what types of habitats within the tidal freshwater area of the LCRE are juvenile salmonids found, when are they present, what are their densities, which stocks are present, and what are the fish community and environmental conditions they live in?
- What is the ecological importance of shallow (0–5 m) tidal freshwater habitats to the recovery of listed salmonid stocks, including Upper Columbia River Spring Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) and Snake River Fall Chinook salmon?

1.1 Background

Shallow-water habitats in the tidal freshwater portion of the LCRE may be important for the growth and survival of both stream-type (yearling) and ocean-type (subyearling) salmon life histories (Fresh et al. 2005). Scientific knowledge specifically addressing this point, however, is sparse (Johnson et al. 2008). The Independent Scientific Advisory Board (ISAB) and the Independent Scientific Review Panel (ISRP) recommended RME be conducted in the tidal freshwater area of the Columbia River (Bisson et al. 2000; ISRP 2004). As the ISRP stated in its review of fiscal year 2007–2009 proposals, "The Council should encourage innovative ecosystem-based research and monitoring in the estuary…." Furthermore, in the 2008 BiOp's RPA, the National Oceanic and Atmospheric Administration (NOAA) Fisheries (2008) states:

"The Action Agencies will… evaluate migration through and use of a subset of various shallow-water habitats from Bonneville Dam to the mouth toward understanding specific habitat use and relative importance to juvenile salmonids [RPA 59.4]…investigate the importance of early life history of salmon populations in tidal fresh water of the lower Columbia River [RPA 61.2]."

Figure 1.1. Map Showing the Lower Columbia River and Estuary. The tidal freshwater portion is approximately from rkm 56 to 234. Bonneville Dam is located at rkm 234.

The subyearling migrant, or ocean-type, life-history pattern (after Healey 1991) is characterized by downstream migration within the first days or months after emergence from natal stream gravels and subsequent residence in riverine and estuarine shallow-water habitats. Subyearling salmon have been found in shallow-water or nearshore habitats of the Fraser River estuary (Levy and Northcote 1982) and the Nanaimo River estuary (Healey 1978) in British Columbia, the nearshore waters of Puget Sound (Brennan et al. 2004; Beamer et al. 2005), the Sacramento-San Joaquin estuary (Kjelson et al. 1982), the Sixes and Coquille estuaries (Reimers et al. 1979), the Salmon River estuary (Bottom et al. 2005a), and Yaquina Bay (Meyers and Horton 1982) on the Oregon coast. Although specific linkages between fish and their habitats are not always evident, especially in highly migratory species such as Pacific salmon (Simenstad and Cordell 2000), it is likely that salmon with ocean-type life-history patterns depend on shallow tidal habitats for rearing and refuge (Fresh et al. 2005).

Alternatively, the yearling (river-type) life-history pattern generally is characterized by downstream migration after a period of 12 or more months spent rearing in the fish's natal watershed. Yearling fish typically migrate downriver faster (travel rate) than subyearling fish (Dawley et al. 1986). However, it is prudent to assume that the LCRE plays a greater role than serving as a simple migration conduit for yearling salmonids. The TFM study is intended to address the use of shallow-water habitat by both life-history types of Chinook salmon and well as other samonid species.

The basic habitat requirements of juvenile salmonids include provision of food, shelter, space, and suitable environmental conditions (Chapman 1966; Bjornn and Reiser 1991). Some habitat parameters of importance to juvenile salmonids are water temperature, depth, velocity, and cover (Healey 1980; Quinn 2005). In nature, juvenile salmonids must maximize energy intake while minimizing energy expenditure, and they must balance gains from feeding in profitable habitats with risk of predation (Fausch 1984; Harvey 1991). Parameters regulating this balance change with body size and therefore energetic demands, ability to detect and avoid predators, and the nature of suitable environmental conditions. Juvenile salmonids undergo an ontogenetic habitat shift into deeper, faster water (e.g., Healey 1980; Werner and Gilliam 1984) that occurs at specific size thresholds (Simenstad et al. 1980). Documentation of habitat use by subyearling and yearling upriver fall Chinook salmon in the tidal freshwater portion of the lower Columbia River is limited (Fresh et al. 2005) and it is also unknown how local populations of Chinook and coho (*O. kisutch*) salmon use off-channel areas. Because fall Chinook salmon display a wide range of life-history strategies (Healey 1991), and both yearling and subyearling arrivals in the estuary potentially could occur year-round (Connor et al. 2005), patterns of habitat use in the freshwater tidal estuary are certain to be complex, and consequently, much remains unknown.

Improved juvenile growth and survival in LCRE habitats can lead to increasing population size and stability and, therefore, aid recovery of fall Chinook salmon (Fresh et al. 2005). The availability of diverse shallow-water habitats, especially very shallow peripheral habitats, may be a limiting factor to the production and diversity of salmonids such as upriver fall Chinook salmon (Fresh et al. 2005; Quinn 2005). However, extensive tidal freshwater reaches such as those in the Columbia River (~180 km in length) are rare in rivers, so little information exists about the ecology of these ecosystems. For example, of 26 estuarine systems evaluated in Europe, only 7 had sizeable tidal freshwater habitats, and of those, none were over 40 km long (Pihl et al. 2002).

Downstream of Jones Beach (rkm 75) in the LCRE, the migration characteristics of juvenile salmon have been studied extensively (Dawley et al. 1986; Ledgerwood et al. 1991). Researchers have used nets, seines, traps, and trawls to examine migration timing, spatial distribution, abundance, relative survival, and feeding habits for various populations of salmon. Important research efforts include those of the following:

- U.S. Bureau of Fisheries (Rich 1920)
- Fish Commission of Oregon in 1963 (Reimers and Loeffel 1967)
- National Marine Fisheries Service (NMFS) from 1966 through 1972 (Craddock et al. 1976; Durkin 1982; Dawley et al. 1986)
- Northwest Regional Council and the BPA from 1977 through 1983 (Dawley et al. 1986; Kirn et al. 1986; Ledgerwood et al. 1991)
- Columbia River Estuary Data Development Program from 1978 through 1984 (McCabe et al. 1983; Bottom et al. 1984; Small 1990).
- USACE Anadromous Fish Evaluation Program from 1995 to the present (Ledgerwood et al. 2003; Roegner et al. 2004; Schreck et al. 2004)
- NPCC's Fish and Wildlife Program from 2001 to the present (Weitkamp 1994; Burke 2004; Bottom et al. 2005b; Fresh et al. 2005).

Significant findings about yearling and subyearling salmon in the LCRE from these studies, with relevance to the research undertaken here, include the following:

- Sampling sites included shallow-water habitats in marine, estuarine, and freshwater areas mostly from the mouth to Jones Beach (rkm 75). The tidal freshwater reach from rkm 75 to Bonneville Dam (rkm 234) had been little studied.
- Compared to historical records, the diversity of life-history types in the LCRE has diminished (Burke 2004; Bottom et al. 2005b).
- The abundance of wild salmon in the LCRE is much lower than historically; the opposite is true for hatchery salmon (Bottom et al. 2005b).
- Subyearling salmon from watersheds below Bonneville Dam are more abundant in shallow-water habitats than subyearlings from upriver (Roegner et al. 2004).
- Peak abundance in shallow-water habitats in the vicinity of Jones Beach (rkm 75) is from April through August for subyearling Chinook salmon, April through mid-June for yearling Chinook salmon, and March through May for subyearling chum salmon (Dawley et al. 1986).
- Subyearling salmon may reside in estuarine waters for extended periods of time (weeks to months; e.g., Rich 1920; Campbell 2010), and smaller individuals using shallow-water habitats to feed spend more time in the LCRE than larger fish (Dawley et al. 1986). Some juvenile salmon over-winter in the LCRE (Dawley et al. 1986).
- Subyearlings sampled in shallow water near the shore are typically smaller than those from mid-river (Bottom et al. 1984; Dawley et al. 1986; McCabe et al. 1986). Fish at tidal freshwater sites are on average smaller than those at estuarine and marine sites (Roegner et al. 2004).
- Subyearling fish eat Corophium spp. and terrestrial insects in shallow-water habitats (Kirn et al. 1986; McCabe et al. 1986; Roegner et al. 2004). Average fork length tends to increase from spring to summer (Dawley et al. 1986; Roegner et al. 2004).
- Juvenile salmon migration characteristics in the LCRE are influenced by upriver forces, such as hydropower operations and hatchery practices (Weitkamp 1994; Bottom et al. 2005b).

The Upper Columbia River Basin Spring Chinook salmon and summer steelhead were listed as endangered in 1996 and 1999, respectively. As yearlings, these fish are thought to migrate downstream through the hydrosystem, generally from April through June, and reach the LCRE relatively quickly. Based on catches of marked wild and hatchery yearling outmigrants at Jones Beach (rkm 75), in the marine mixing zone (rkm 7–9), and near ocean areas (24 km seaward from the river mouth), almost all individuals used the estuary as a migration corridor and moved rapidly into the ocean (Dawley et al. 1986).

Snake River fall Chinook salmon were listed as threatened under the ESA in 1992 (NMFS 2004). This Evolutionarily Significant Unit (ESU) consists of fall Chinook salmon spawning populations in the Snake, Tucannon, Clearwater, Salmon, Imnaha, and Grande Ronde rivers. Subyearling fish, including Snake River fall Chinook salmon juveniles, generally migrate downstream through the hydrosystem from June through September. Snake River fall Chinook salmon were thought to primarily exhibit an ocean-type life history in which adults spawn in the fall, fry emerge the following spring, and juvenile fish emigrate seaward during late spring and summer to enter the ocean as subyearlings (Connor et al. 2002).

However, Connor et al. (2005) recently described an alternative life history for juvenile Snake River fall Chinook salmon that they named "reservoir-type" life history. Fish that adopt the "reservoir-type" life history delay their subyearling ocean entry, spend the winter in freshwater, and resume migration to the ocean the following year to enter the ocean as yearlings. Freshwater over-wintering areas could include the tidal freshwater portion of the LCRE (Connor et al. 2005). Fresh et al. (2005, p. xiii) concluded, "…upriver ESUs (e.g., Snake River fall Chinook salmon) will be more dependent on the tidally influenced shallow freshwater habitats between Bonneville Dam (their point of entry to the Columbia River estuarine system) and RM 40 [rkm 64]." Over-wintering and extended residence in estuarine habitats has been documented for fall Chinook salmon in the lower Columbia River tributaries and other watersheds (Dawley et al. 1986; Reimers and Loeffel 1967; Reimers 1968; Reimers 1973). As such, it is possible that a portion of Snake River fall Chinook salmon over-winter in the Columbia River estuary, including the tidal freshwater section within the TFM study area.

In the LCRE, the substantial loss (>75%) of shallow-water habitats (Thomas 1983) through diking, filling, dredging, and development is suggested as one important factor contributing to the decline of salmonids in the Columbia River basin (Bottom et al. 2005b). Fresh et al. (2005) offered that restoration of shallow-water habitat could result in enhanced performance (e.g., foraging success, growth), and thus, increased survival of juvenile salmonids. When the TFM field study began in 2007, there were limited data regarding habitat use in upstream LCRE reaches by juvenile salmonids that could contribute to an understanding of how restoration actions might enhance salmonid performance. Therefore, our study focused on supplying fundamental data to enhance general understanding of how juvenile salmonids use LCRE tidal freshwater habitats and to improve prioritization of strategic restoration efforts. Restoration is expensive and results can be uncertain in terms of functional performance and overall benefits to resources and the ecosystem (Thom 2000). Our study contributes directly to reducing uncertainty about yearling and subyearling salmon ecology in tidal freshwater habitats and, ultimately, the beneficial attributes of these habitats, thereby improving the likelihood of success for ecosystem-based restoration projects targeted at benefiting salmon.

1.2 Objectives

The overall and specific objectives for the 2007–2010 TFM study were as follows:

1. Describe the migration characteristics of juvenile salmon in tidal freshwater in the context of their habitats and fish communities by completing the following activities:
    a. Characterize the fish community and juvenile salmon migration, including species composition, length-frequency distribution, density (#/m^2), and temporal and spatial distributions in the vicinity of the Sandy River delta and other tidal freshwater habitats within the lower Columbia River, and apply the density data to contribute to the design a juvenile salmon monitoring program for the entire tidal freshwater segment (rkm 56–234).
    b. Estimate through genetic stock identification the stock of origin for juvenile Chinook salmon captured at sampling sites.
    c. Characterize vegetation composition and percent cover, conventional water quality, water-surface elevation, substrate composition, bathymetry, and beach slope at the sites within the vicinity of the Sandy River delta.

d. Examine landscape-scale differences in fish community composition between two study areas of the LCRE.

e. Determine the relationships between juvenile salmon density and macro-habitat features (i.e., sampling site, habitat stratum), environmental, and structural attributes.

2. Assess the ecological importance of tidal freshwater habitats to juvenile salmon in the vicinity of the Sandy River delta by completing the following activities:

   a. Quantify the diet composition of juvenile Chinook salmon, assess the relative importance of prey organisms in the Chinook salmon diet, and evaluate foraging behavior, including prey selection by Chinook salmon.

   b. Assess the influences of environmental (temperature) and dietary (consumed prey composition and quality) parameters on rates of consumption and growth for juvenile Chinook salmon in specific tidally influenced habitats in the LCRE, and evaluate spatial and temporal variability in both consumption rates and growth.

   c. Use juvenile salmon tagged with acoustic transmitters and released upstream of Bonneville Dam as part of other studies to estimate migration pathways and residence times in the Sandy River delta study area during spring and summer, and estimate residence times through mark-recapture of juvenile Chinook salmon collected from the Sandy River delta study area during winter months.

1.3 Study Area

Tidally influenced freshwater in the Columbia River occurs from approximately Tenasillahe Island to Bonneville Dam (rkm 56–234). The tidal freshwater area includes six hydrogeomorphic reaches below Bonneville Dam (Reaches C–H, Figure 1.2). It is characterized by a main channel maintained for navigation purposes, main stem islands, sloughs, wetlands, off-channel areas, and river confluences or deltas. Simenstad et al. (2005) provide the best available information about habitat classification in the tidal freshwater area. Major tributaries include the Sandy, Washougal, Willamette, Lewis, Kalama, and Cowlitz rivers. Dikes, levees, and armored shorelines are prevalent because lowland areas were disconnected from the river for purposes of economic development, resulting in the loss of shallow-water habitats (Thomas 1983; Kukulka and Jay 2003). The Lower Columbia River and Estuary Partnership (LCREP 1999) described the study area in detail.

The TFM study occurred in areas in the tidal freshwater portion of the Columbia River between Longview, Washington, and Bonneville Dam. Initially in June 2007, our sampling efforts were focused in the vicinity of the Sandy River delta (rkm 188–202 in Reach G; Figure 1.2). The Estuary/Ocean Subgroup for federal RME recommended the Sandy River delta and vicinity as a potential area for investigation because it is included within the tidal freshwater area of the LCRE hypothesized by Fresh et al. (2005) to be important to juvenile salmonids. This segment of the river is upstream of the Portland-Vancouver urban area and includes shallow-water habitats as well as ongoing and proposed habitat restoration activities. This region of the LCRE is dominated by the following habitat complexes: main stem channel, river confluence floodplains, wetlands, off-channel areas, and main stem islands. Prior to implementing our study in 2007, however, we considered study areas in other hydrogeomorphic reaches within the tidal freshwater portion of the LCRE. Sampling in the vicinity of the Sandy River delta was deemed most suitable, given proposed restoration activities as well as the dearth of existing data on fish

usage in LCRE tidal freshwater. However, during winter 2008-2009 and afterwards, we expanded the spatial extent of sampling sites in the study area to include sampling activities in Reaches D and E (rkm 110–141; Figure 1.2). This expansion increased the geographic breadth of the study, increasing the number of hydrogeomorphic reaches and sites sampled.

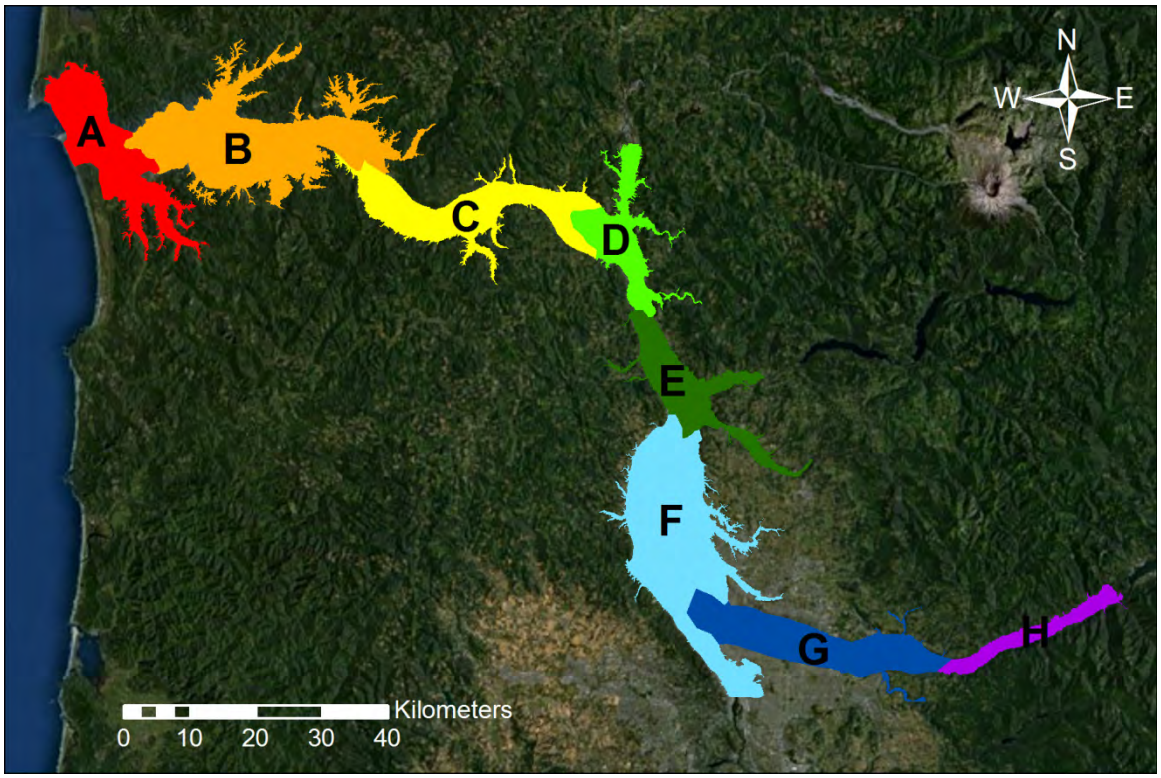

Figure 1.2. Map of the Lower Columbia River and Estuary Showing Hydrogeomorphic Reaches (modified from LCREP 2004). The tidal freshwater area of the river covers Reaches C through H, inclusive.

1.4 Organization of Report

This report contains seven main chapters and eight appendices that document the 2007–2010 TFM study in its entirety. Except for Chapters 1 and 7 and the appendices, the chapters are structured largely as stand-alone draft manuscripts intended for eventual publication in scientific journals. Following the introduction in Chapter 1, juvenile salmon and fish community characteristics are presented in Chapter 2 (Objectives 1a, b, c, d above). In Chapter 3, we describe the analysis of associations between juvenile salmon density and habitat attributes (Objective 1e). Juvenile salmon feeding ecology and bioenergetics are the focus for Chapters 4 and 5, respectively (Objectives 2a and b). The acoustic-telemetry evaluation of migration pathways and residence times is presented in Chapter 7 (Objective 2c). References for the literature cited in each chapter are listed in Chapter 8. Appendix A, Environmental Conditions; Appendix B, Habitat Characterizations; Appendix C, Photo Points; and Appendix D, Genetic Stock Identification, support Chapter 2. Appendix E, Relativized Electivity Indices, and Appendix F, Index of Relative Importance, are relevant to Chapter 4. Appendix G presents the diet data used for bioenergetics modeling in Chapter 5. Appendix H contains the landscape-scale monitoring design to meet this element of Objective 1a.

2.0 Juvenile Salmon and Fish Community Characteristics

Prepared by Nikki Sather, David Teel, Adam Storch, Gary Johnson, Erick Van Dyke, Earl Dawley, David Kuligowski, Tucker Jones, Amanda Bryson, and Katherine Sobocinski

The federal ESA listing of salmon and steelhead stocks within the Columbia River basin has resulted in a need to understand juvenile salmon ecology within tidal freshwater portions of the LCRE (NOAA Fisheries 2008). In the LCRE, the reduction of shallow-water habitats (Thomas 1983) has been attributed to the decline of Pacific salmon and steelhead in the basin (Bottom et al. 2005b). The rehabilitation of shallow tidal freshwater habitats, in part, may enhance the performance (e.g., foraging success and growth) of juvenile salmonids that use these habitats and, thus, increase their survival in freshwater (Fresh et al. 2005). Shallow-water habitats in tidally influenced areas of large rivers are believed to be important to the growth and survival of juvenile salmonids (Fresh et al. 2005). While the fundamental early life functions of many species of Pacific salmon and steelhead (*Oncorhynchus* spp.) have been described (Groot and Margolis 1991; Quinn 2005), empirical evidence associated with their use of shallow tidal freshwater habitats remains fragmented (Johnson et al. 2008). Bridging knowledge gaps associated with the important life functions of Pacific salmon and steelhead will require a comprehensive assessment of the relationships between these dynamic and ephemeral habitats and their temporal and spatial use by fish.

This investigation provides a characterization of the entire composition of fish found in the shallow tidal freshwater habitats we sampled in the LCRE, and includes temporal and spatial characterizations of important life functions associated with dispersal or migration behavior, length-frequency distribution, as well as estimates of the relative density of fish using shallow tidal freshwater habitats in the area. In addition, this investigation includes an assessment of stock of origin for Chinook salmon captured at sampling sites through genetic identification. The habitat assessment was complemented by characterizing vegetation composition and percent cover, conventional water quality, water-surface elevation, substrate composition, bathymetry, and beach slope at the sites within the tidally influenced freshwater habitats of the LCRE. The incorporation of these other ecological factors in the TFM study should help to shed additional light on the complexity of tidal freshwater habitats.

The goal of this research was to describe the migration characteristics of juvenile salmon in tidal freshwater in the context of their habitats and fish communities. Our research objectives were to 1) describe juvenile salmon and fish community characteristics, including species composition, length-frequency distribution, average weights, density (#/m^2), and temporal and spatial distributions in the vicinity of the Sandy River delta (SRD) and other tidal freshwater habitats within the lower Columbia River; 2) estimate through genetic stock identification the stock of origin for juvenile Chinook salmon captured at sampling sites; 3) characterize habitats, including vegetation composition and percent cover, conventional water quality, water-surface elevation, substrate composition, bathymetry, and beach slope, at the sites within the vicinity of the SRD; and 4) examine landscape-scale differences in fish community composition between two study areas of the LCRE.

2.1 Methods

Juvenile salmon and fish community characteristics were determined monthly at the SRD and vicinity during June 2007 through April 2010. At the sites in lower river reaches (LRR), data were collected

during week-long samplings in January, February, May, August, and November 2009. This section contains descriptions of the methods, including sampling sites and dates, fish sampling, environmental conditions, and statistical analysis.

2.1.1 Sampling Sites and Dates

Nine base sites were sampled monthly as part of the TFM study from 2007 through 2010. Site-selection criteria were based on common habitat attributes found within tidal freshwater reaches of the lower Columbia River. Habitat types included main channel, main-channel island, off-channel, off-channel island, confluence, and wetland. In addition, sites were considered based on sampling feasibility criteria such as boat access, net deployment, and retrieval. Sampling commenced in June 2007 at five sites at the SRD (Figure 2.1, Sites A, B, C, D, and N). After evaluating the five primary sites within the context of a before-after control-impact (BACI) design for the proposed SRD dam removal (Sobocinski et al. 2008), Site E was incorporated into the study during September 2007 to serve as a control site. To expand the spatial extent of sampling within tidal freshwater habitats and to incorporate greater diversity of habitat types within the study areas, three additional sites (F, H, and I) were added to the study during the fall of 2008 (Figure 2.1).

Figure 2.1. Sampling Sites in the SRD Study Area (rkm 188–202) from 2007 Through 2010

The SRD sampling sites were selected based on channel morphology type; e.g., main channel, off-channel, distributary and river confluence, and a wetland channel. Sites differed with regard to their levels of hydraulic connectivity to the main channel and the prominence of other habitat features such as vegetative cover, substrate grain size, and bathymetry. Thorough descriptions of the characteristics and habitat features encountered at each of the base sites were provided by Sobocinski et al. (2008) and Sather et al. (2009). Brief descriptions of the sites are provided below.

- **Site A**: Located on the north side of Reed Island State Park, this sampling location is broadly characterized by a fringing wetland with a gradually sloping beach face. Site A is an off-channel island sampling site (i.e., it is not directly connected to the main stem).
- **Site B**: On the southwest side of Chatham Island, this off-channel site maintains a steeply sloping beach face adjacent to a fairly deep channel. While the thalweg of the channel adjacent to Site B is fairly deep, the inlet and outlet to this channel maintain a higher elevation, making boat access to this site problematic during low-flow conditions.
- **Site C**: At the historic mouth of the Sandy River, this river confluence site maintains connection to a small channel from the remnant delta. The topography of this site is higher in elevation compared to the other sampling locations and is the only site that completely dewaters during periods of low flow (e.g., September and October).
- **Site D**: Located adjacent to and upstream from the current mouth of the Sandy River, this main-channel site is directly connected to the main stem of the Columbia River. The extensive sand flats at this site are likely related to the sedimentation and hydraulic interactions at the river confluence.
- **Site E**: On the west side of Gary Island, this off-channel site is similar to Site B in that it is adjacent to a channel that maintains deep water (>1.5 m) during periods of low flow. However, this site is characterized by a gradual sloping beach face, fine sediments, and fringing emergent vegetation.
- **Site F**: Located along the Oregon shore of the main stem Columbia River, upstream of the SRD, this site is bound at both upstream and downstream ends by pile dikes and coarse woody debris. Overall, this main-channel site is relatively shallow (<1.5 m) and dominated by sandy substrate with little emergent vegetation. The beach face is moderately vegetated above the high-water mark.
- **Site H**: Located in an off-channel along the southeastern shore of McGuire Island, downstream of the mouth of the Sandy River, this site is dominated by sandy substrate with minimal emergent vegetation. At the high-water mark, trees and emergent vegetation are abundant; however, below this point, steep sloping beaches support little ground cover.
- **Site I**: Located at the approximate mid-point of the north shore of Ackerman Island, this site is downstream of the mouth of the Sandy River. Ackerman Island is a main-channel island dominated by sandy substrate. Site I is generally shallow (<1.0 m) with little or no emergent vegetation. A relatively dense overstory of trees and shrubs exists above the high-water mark.
- **Site N**: Unlike any of the previously described sites, Site N is a wetland habitat located within the remnant SRD. Site N is within the upper extent of the remnant channel that drains to Site C, the former mouth of the Sandy River.

There were 35 monthly sampling events involving 256 site-samplings during the study from June 2007 through April 2010 (Table 2.1). On five occasions, Site C could not be sampled because there was no water at the site. Three times the water depth was too great to sample a site.

Table 2.1. Sampling Sites and Dates for the SRD Study Area

Dates	Site								
	A	B	C	D	E	F	H	I	N
June 5-6 and 26-27, 2007	--	✓	✓	✓	--	--	--	--	✓
July 11, 19, 2007	--	✓	✓	✓	--	--	--	--	✓
August 14-15, 2007	✓	✓	✓	✓	--	--	--	--	✓
September 11-12, 2007	✓	✓	✓	✓	✓	--	--	--	✓
October 16-17 2007	✓	✓	✓	✓	✓	--	--	--	✓
November 19-20, 2007	✓	✓	✓	✓	✓	--	--	--	✓
December 18-19, 2007	✓	✓	✓	✓	✓	--	--	--	✓
January 30-31, 2008	✓	✓	✓	✓	✓	--	--	--	✓
February 11, 2008	✓	✓	✓	✓	✓	--	--	--	✓
March 18-19, 2008	✓	✓	✓	✓	✓	--	--	--	✓
April 17-18, 2008	✓	✓	✓	✓	✓	--	--	--	✓
May 14-15, 2008	✓	✓	✓	✓	✓	--	--	--	✓
June 16-17, 2008	✓	✓	✓	✓	•	--	--	--	•
July 15-16, 2008	✓	✓	✓	✓	✓	--	--	--	✓
August 13-14, 2008	✓	✓	✓	✓	✓	--	--	--	✓
September 15-17, 2008	✓	✓	o	✓	✓	✓	✓	--	✓
October 20-22, 2008	✓	✓	o	✓	✓	✓	✓	✓	✓
November 18-21, 2008	✓	✓	✓	✓	✓	✓	✓	✓	✓
December 8-11, 2008	✓	✓	✓	✓	✓	✓	✓	✓	✓
January 20-22, 2009	✓	✓	✓	✓	✓	•	✓	✓	✓
February 17-19, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
March 17-19, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
April 13-14, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
May 19-21, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
June 15-19, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
July 14-16, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
August 18-20, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
September 21-24, 2009	✓	✓	o	✓	✓	✓	✓	✓	✓
October 20-22, 2009	✓	✓	o	✓	✓	✓	✓	✓	✓
November 16, 23-24, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
December 15-17, 2009	✓	✓	✓	✓	✓	✓	✓	✓	✓
January 25-29, 2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
February 16-18, 2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
March 23-26, 2010	✓	✓	✓	✓	✓	✓	✓	✓	✓
April 12-14, 2010	✓	✓	✓	✓	✓	✓	✓	✓	✓

√ = Sampled.
-- = Not sampled; site not included in study at that time.
o = Not sampled because no water at site.
• = Not sampled because the water depth was too great to sample the site.

During 2009, the study design was expanded to increase the spatial extent of our sampling effort within the tidal freshwater portion of the LCRE. This allowed us to compare fish community composition between the SRD and LRR within tidal freshwater. In the LRR between rkm 110 and 141 (Figure 2.2), we applied a landscape-scale stratified random sampling approach. Six habitat strata for the LRR were established: wetland channel, off-channel, main channel, confluence, main-channel island, and off-channel island.

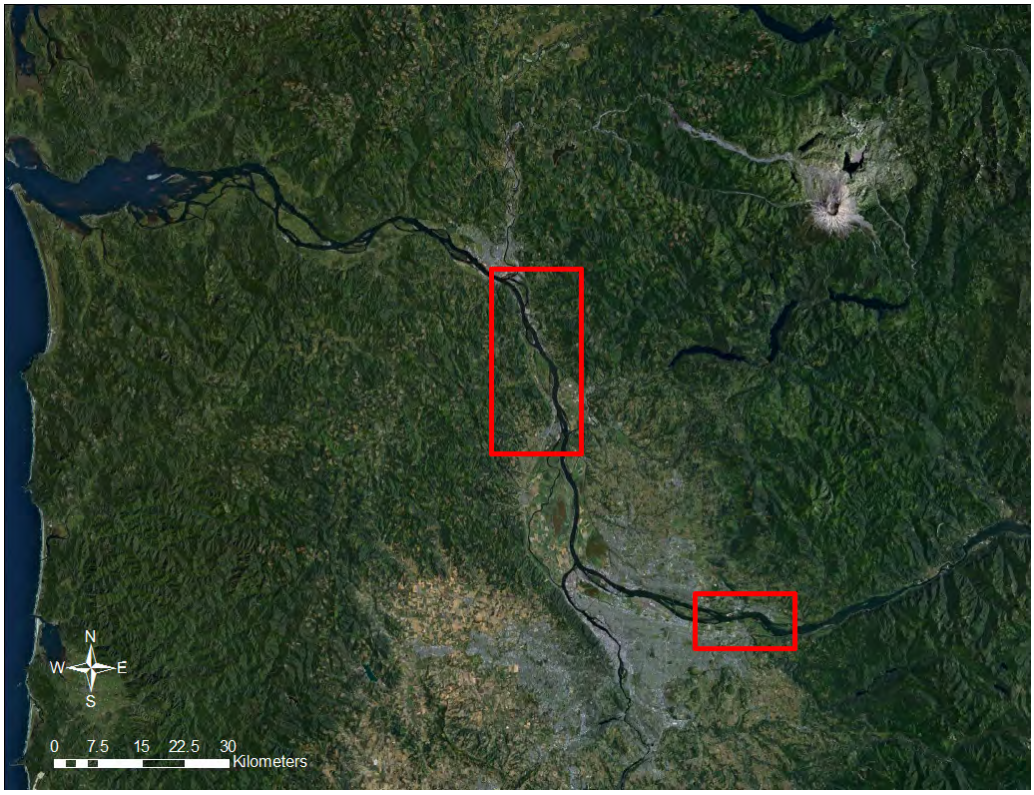

Figure 2.2. Location of the SRD (bottom rectangle; rkm 188–202) and LRR (top rectangle; rkm 110–141) Study Areas in the LCRE Tidal Freshwater

To implement the stratified random sampling approach, sampling sites were defined as 500-m linear segments along the shoreline within each of the six strata. Field reconnaissance supported the 500-m size criterion because most sites yielded little change in habitat features within this distance. Furthermore, a 500-m linear segment permitted adequate space for deploying a beach seine while providing flexibility in the event of unforeseen sampling impediments. Geographical information system (GIS) software was used to designate potential sites. Sites were excluded if they were deemed impossible to sample with a beach seine; e.g., there was heavy shoreline development, armoring, pile structures, or extremely shallow water. The site-designation process identified 156 potential sites within six habitat strata; this formed the sampling universe (Figure 2.3). During each sampling period within a given month, one to five sites were randomly selected from each of the six strata.

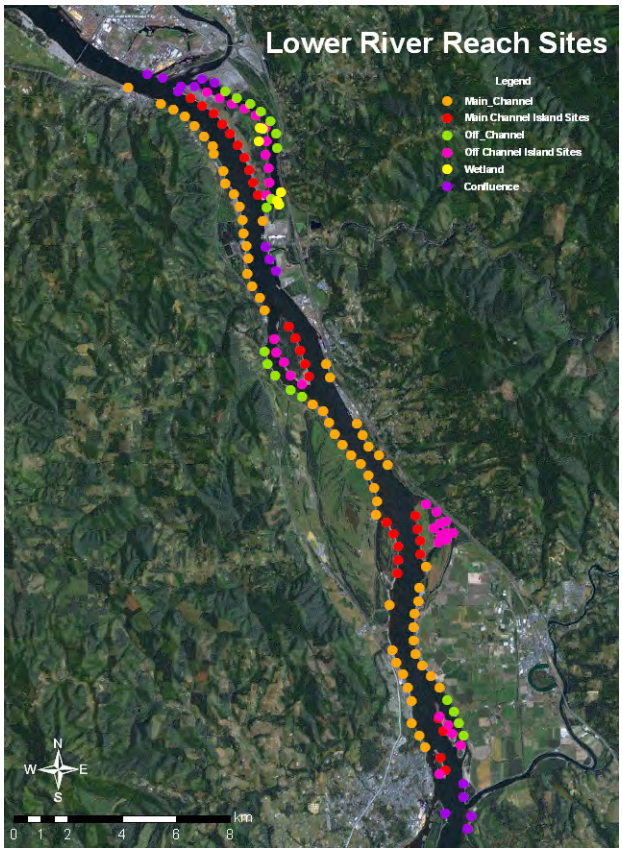

Figure 2.3. Stratified Sampling Universe Spanning Tidal Freshwater Habitats in the LRR (rkm 110–141). Six strata included wetland channel, off-channel, main channel, confluence, main-channel island, and off-channel island. The dots indicate the 500-m sampling units for beach seining.

2.1.2 Environmental Conditions

River conditions were described using outflow data from Bonneville Dam obtained from DART (Data Access in Realtime: http://www.cbr.washington.edu/dart/) and gage height at Vancouver, Washington, obtained from the U.S. Geological Survey (USGS; http://waterdata.usgs.gov/usa/nwis/). Site-scale water elevation was recorded using Onset Hobo water level loggers (Model U20-001-01). Site-specific water quality was documented in conjunction with monthly fish sampling. We evaluated water-quality parameters at each site during our monthly sampling efforts. Using a handheld YSI-85 or YSI-556 device (Yellow Springs Instruments, Yellow Springs, Ohio), we measured temperature (°C), salinity (ppt), and dissolved oxygen (mg/L). The analyst measuring water-quality properties waded into the water and suspended the probes approximately 0.3 m below the water's surface. Internal test verifications were performed regularly on water-quality instruments.

2.1.3 Fish Sampling

The following material explains fish-sampling methods regarding beach seining, fish handling, and genetics.

2.1.3.1 Beach Seines

Fish were sampled using one of two beach seines and/or set techniques. Two replicate, non-overlapping hauls were conducted at each site with the two hauls at least 30 minutes apart. Whenever possible, we deployed the beach seine by boat. However, when water elevation prevented motorized boat access, the net was moved and set by foot. Between June 2007 and April 2008, fish were sampled using a bagless beach seine, the KS-9 net, at the base sites near the SRD. Beginning in May 2008, a larger seine was used to sample all but Site N because this site was too confined to use the larger net. Regardless of seine type or set technique, the length (y) and width (x) of the deployed net were recorded for each set and catches were standardized by calculating fish density (#/m^2) for each sampling event.

The KS-9 net was constructed of 5-mm knotless mesh and measured 30.5 m long and 3 m deep. It was set by either boat or foot, depending on water elevation, at all sites from June 2007 through April 2008. The set technique we followed for the KS-9 net involved anchoring one end on the shore and deploying the remainder of the net into the water in a semi-circular pattern (Figure 2.4). Once both ends of the net were on the shore, the lead lines were evenly pulled toward shore, keeping the fish in the center of the net. However, the team ultimately thought the KS-9 net was not sufficient to adequately sample the sites. We concluded that this net, while providing useful data, could be improved upon in terms of length, shape, and bridle arrangement.

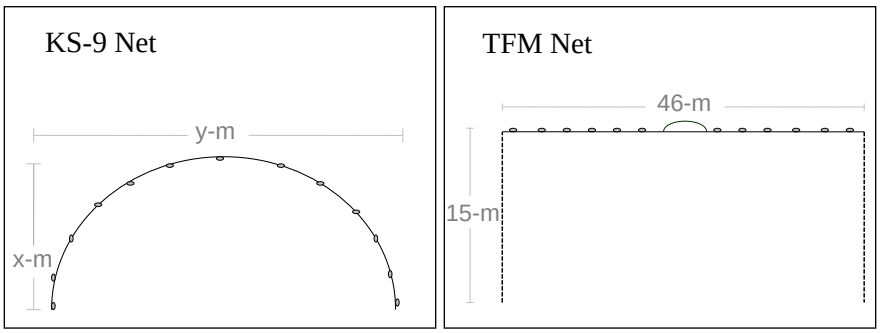

Figure 2.4. Seine Deployment Techniques Applied During the Tidal Freshwater Monitoring Study. The illustrations are not to scale.

The custom TFM net was designed specifically to sample within shallow-water habitats encountered in our study area. The TFM net is 46 m long and 3 m deep at the center with wings that taper to 1.5 m. The wings are constructed of 13-mm stretch black knotless netting. This seine is fit with a bag constructed of 3.2-mm knotless mesh (stretch measure) netting dyed green, and measures 2.4 m wide by 1.5 m deep. The seine is fitted with 17-oz buoyancy ethylene-vinyl acetate floats on 46-mm centers and a solid core lead line with a poly sleeve sewed to the base. A 15-m-long haul line was affixed to a bridle at the tapered ends of each wing. One end of the haul line was held to the shore while the boat moved toward the deep end of the channel. Once the end of the line was reached, the boat turned 90 degrees and began deploying the net (Figure 2.4). After the full length of the net had been set, the haul lines were used to bring the wings to the shore. Haul lines facilitated more consistent sets for the TFM net compared to the KS-9 net. We ceased using the KS-9 net for all sites in 2008, except for Site N where we continued to use the KS-9 net.

2.1.3.2 Fish Handling

After each haul, we removed fish from the net and placed them in holding buckets filled with river water at ambient temperature. All salmon were separated from the catch into buckets for immediate processing. Aerators were used to maintain adequate levels of dissolved oxygen in the holding water. When catches were large, we implemented a subsampling procedure that rapidly processed the catch while providing a means for estimating taxon composition for the set. After removing all salmon from the beach seine, the remaining catch was homogenized and one to two aliquots were removed using a standard aquarium net. This subsample was placed in holding buckets for further processing while the volume of the remaining catch was quantified by enumerating the aliquots required to remove all fish from the bag. While this approach introduced unknown bias in precision for quantifying taxa, it provided a standardized means for documenting thousands of fish over a short time period while reducing handling stress and mortalities. After the data were electronically entered, the subsampled catch was calculated as the product of the actual number of fish enumerated within each taxon and the number of scoops required to process the catch.

Catches were processed by enumerating all taxa and measuring to the nearest millimeter up to 20 individuals within each size class for a given species. Fish were identified to the lowest taxonomic level practical. In addition to enumeration and length measurements of salmon, a coded-wire tag wand and a passive integrated transponder (PIT) tag reader were used to help distinguish hatchery origins. On a subsample of Chinook salmon, fin tissues were taken for genetic stock identification and stomach contents were collected by lavage for diet composition. All salmon subjected to gastric lavage or tissue collection were anesthetized using a 40-mg/L tricaine methanesulphonate (MS-222) solution. After processing, anesthetized individuals were held in a recovery bucket filled with river water at ambient temperature. During recovery, dissolved oxygen was maintained in the bucket using aerators. We released fish processed from the first haul downstream of the sampling area to minimize potential contamination of the second sample; fish from the second haul were released at the site of capture. All observed mortalities were documented.

Data transfers from field to electronic datasheets were subjected to independent quality assurance/quality control review. Using the area swept for each beach seine haul, we calculated fish density as the number of individuals per square meter. Results summarizing individual species largely focused on those that represented greater than 1% of the catch.

2.1.3.3 Chinook Salmon Genetics

Fin clips on subsamples of Chinook salmon were preserved in ethanol for genetic mixture analysis. We used standard methods of genetic stock identification and individual assignment (reviewed by Manel et al. 2005). Chinook salmon were genotyped using the methods described by Teel et al. (2009). Data were collected for 13 microsatellite loci that have recently been standardized among several West Coast genetics laboratories (Seeb et al. 2007). The relative probability of stock origin for each sample was estimated using the genetic stock identification computer program ONCOR (Kalinowski et al. 2007). Confidence intervals of the mixture proportions were estimated using ONCOR by resampling mixture and baseline data 100 times. Population baseline data were from the multi-laboratory standardized Chinook salmon genetic database described by Seeb et al. (2007). Mixture proportions and assignment probabilities for individual baseline populations were summed to 10 Columbia River basin stock groups (Table 2.2).

Table 2.2. Genetic Stock Groups and Baseline Populations. Genetic data are from Seeb et al. (2007) except where noted.

Genetic Stock Group	Baseline Populations
West Cascade Tributary Fall	Cowlitz Hatchery, Lewis River, Sandy River
West Cascade Tributary Spring	Cowlitz Hatchery, Kalama Hatchery, Lewis Hatchery
Willamette River Spring	Mckenzie Hatchery and River,[(a)] North Santiam Hatchery and River[(a),] North Fork Clackamas River[(a)]
Spring Creek Group Tule Fall	Spring Creek Hatchery, Big Creek Hatchery,[(a)] Elochoman River,[(a)] Willamette River[(a)]
Deschutes River Fall	Lower Deschutes River, Upper Deschutes River[(b)]
Upper Columbia River Summer/Fall	Hanford Reach, Methow River, Wells Hatchery, Wenatchee River[(c)]
Mid and Upper Columbia River Spring	Carson Hatchery, John Day River, Upper Yakima River, Warm Springs Hatchery, Wenatchee Hatchery[(c)] and River
Snake River Fall	Lyons Ferry Hatchery
Snake River Spring	Imnaha River, Minam River, Rapid River Hatchery, Secech River, Tucannon Hatchery and River,[(c)] Newsome Creek,[(d)] West Fork Yankee Creek[(d)]
Rogue River	Cole Rivers Hatchery, Applegate River

(a) Northwest Fisheries Science Center, unpublished data.
(b) Narum et al. (2010).
(c) Washington Department of Fish and Wildlife, unpublished data.
(d) Narum et al. (2007).

Additional information about environmental conditions and habitat features was collected throughout the study areas. Photos were taken at each site during monthly sampling efforts throughout the 2007–2010 study period. To maintain a record of our actual sampling locations and visually depict our haul locations at a particular site throughout the study period, we used Trimble Geomatics Office to post-process the global positioning system (GPS) data that were collected in the field. These data were later exported into ArcGIS software for mapping. Physical habitat features, which included vegetation characterization, land and water-level elevation, and an analysis of substrate grain size, were collected following the protocols outlined by Roegner et al. (2009).

2.1.4 Statistical Analysis

We used principal component analysis (Cooley and Lohnes 1971) to examine differences in the fish community composition between the SRD and LRR study areas. Fish community composition was divided into three categories: salmon, native (excluding salmon), and non-native fishes. By transforming possibly correlated variables into fewer uncorrelated variables we can account for hierarchical levels of variability. Analysis of distance is a multidimensional extension of analysis of variance and was used to test for possible differences between LRR and SRD study areas. The significance tests were based on F-statistics adapted for the analysis of multidimensional data.

2.2 Results

Results are reported separately for 1) the site-scale, monthly sampling at the base sites in the SRD and vicinity from June 2007 through April 2010, and 2) the comparison across the tidal freshwater landscape-scale based on quarterly sampling at sites in the LRR during January, February, April, and November 2009 and February 2010. Supporting data are contained in appendices for water temperature and water surface elevation (Appendix A), habitat characterizations (Appendix B), photo points (Appendix C), and genetic stock estimates (Appendix D).

2.2.1 Sandy River Delta

2.2.1.1 Environmental Conditions

Hydrodynamics within the study areas varied seasonally. Lowest flows typically coincided with late summer and early fall. Flows gradually began to increase through the winter months with the river reaching peak discharge between April and June (Figure 2.5). In addition to seasonal patterns, variability in river discharge also demonstrates inter-annual fluctuations. Flow patterns measured as outfall at Bonneville Dam (DART; http://www.cbr.washington.edu/dart/river.html) and gage height (see http//waterdata.usgs.gov/nwis/) indicated peak discharge was lowest in 2007 and highest in 2008 (Figure 2.5). Site-specific water-surface elevations generally followed temporal patterns similar to those observed at Bonneville Dam and the gage at Vancouver (Appendix A). Power peaking at Bonneville Dam caused daily and weekly variation in river discharge and water-surface elevation at the SRD sites. Site-scale hydrodynamics (Appendix A) were also influenced by topography and lateral connectivity with the main channel. Scroll-case temperature measured at Bonneville Dam provided a baseline for riverine conditions and indicated consistent seasonal patterns. Water temperatures measured in conjunction with beach seine efforts at the SRD study area (Appendix A) followed the same seasonal patterns as those noted from the scroll case at Bonneville Dam. Temperatures peaked between July and September and gradually declined through the fall and winter months. While the overall seasonal patterns were similar, site-specific thermal conditions varied among sites (Figure 2.6).

Site-scale survey efforts demonstrated variability at temporal and site scales, as well as physical attributes that were common between sites. The emergent vegetation observed at the SRD and vicinity included a mixture of species indicative of various wetland communities with many sites dominated by creeping spikerush (*Eleocharis palustris*). Willow (*Salix* spp.) was the most common vegetation encountered during survey efforts (Appendix B). Topography ranged from gradually sloping, low-relief transitions from the uplands to steeply graded beach slopes. Substrate grain size ranged from sandy to silty (Appendix B). Photo points (Appendix C) and site-scale maps with geo-referenced beach seine haul locations visually depict temporal changes along the shoreline in the vicinity of the SRD. These changes were most dramatic during late spring and late summer to early fall when river discharge was highest and lowest, respectively (Appendix A).

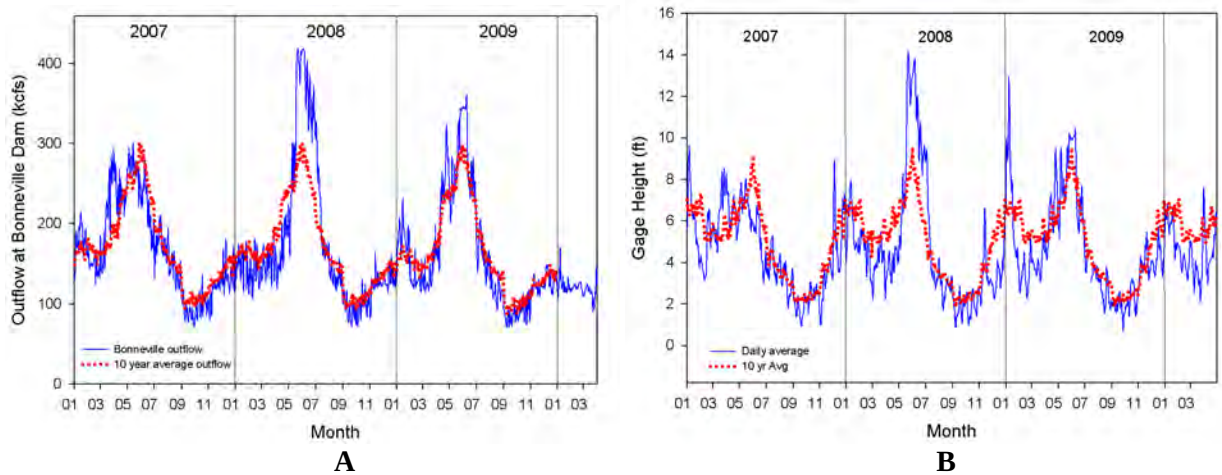

Figure 2.5. A) Outflow (solid blue line) Measured at Bonneville Dam, January 2007–April 2010. The 10-year average outflow is displayed as the dotted red line (data from Columbia River DART 2010). Bonneville Dam is approximately 40 rkm upstream from the SRD study area. B) USGS gage height at Vancouver, Washington, January 2007–April 2010. Daily average displayed in solid blue with 10-year average in dashed red line. The USGS gage at Vancouver is about 90 rkm downstream from the SRD study area.

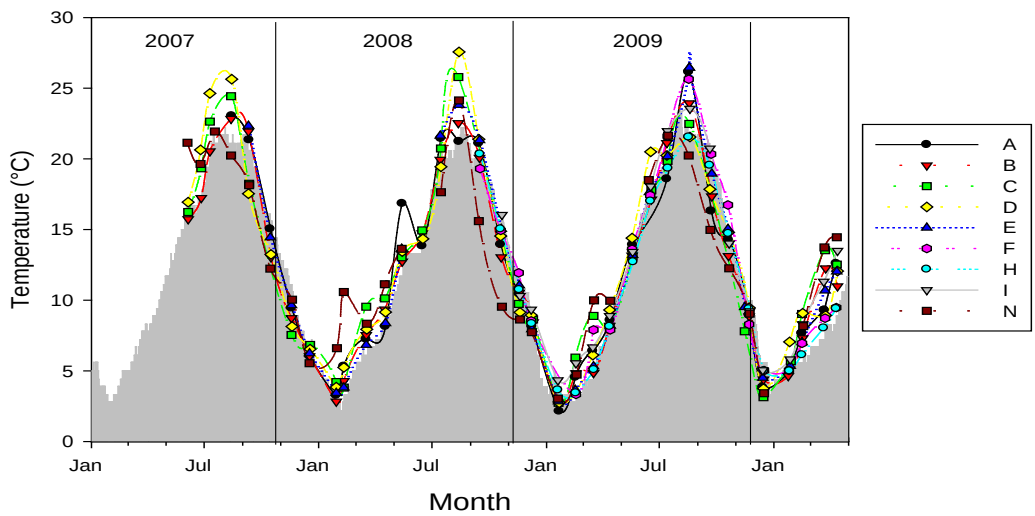

Figure 2.6. Instantaneous Water Temperature Measured During Beach Seine Sampling Efforts at the SRD Study Sites. The legend is for the site identification letters (see Figure 2.1). The gray shaded area denotes daily average river temperature measured at Bonneville Dam, January 2007–April 2010 (data from Columbia River DART 2010).

2.2.1.2 Fish Community Composition

From June 2007 through April 2010, we performed over 500 beach seine hauls and encountered over 200,000 fish at the SRD study area. The total catch during the 2007–2010 study period comprised 34 species (Figure 2.7), of which 18 were non-native fishes. Beach seine catches predominantly comprised native taxa; however, non-native species composed approximately 25% of the total catch. Summer months yielded the highest densities of fish while the smallest densities of fish occurred during winter months (Figure 2.8).

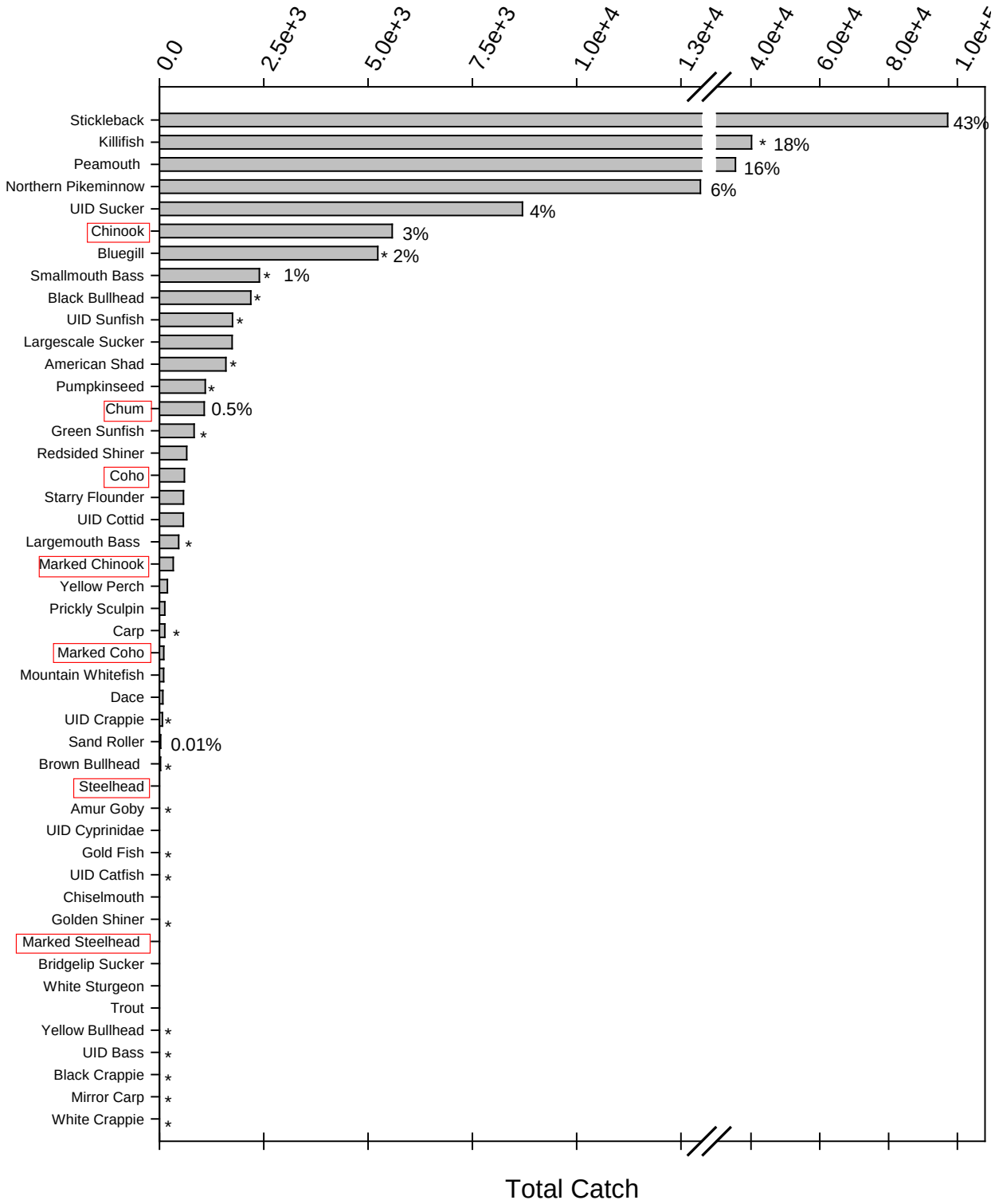

Figure 2.7. Combined Total Catch (# fish) for All SRD Sites During the 2007–2010 Study Period. Percentages were determined by the number of individuals of a species category divided by the total number of fish encountered during the 2007–2010 sampling period. Asterisk (*) indicates a non-native taxon. Red boxes indicate salmonids.

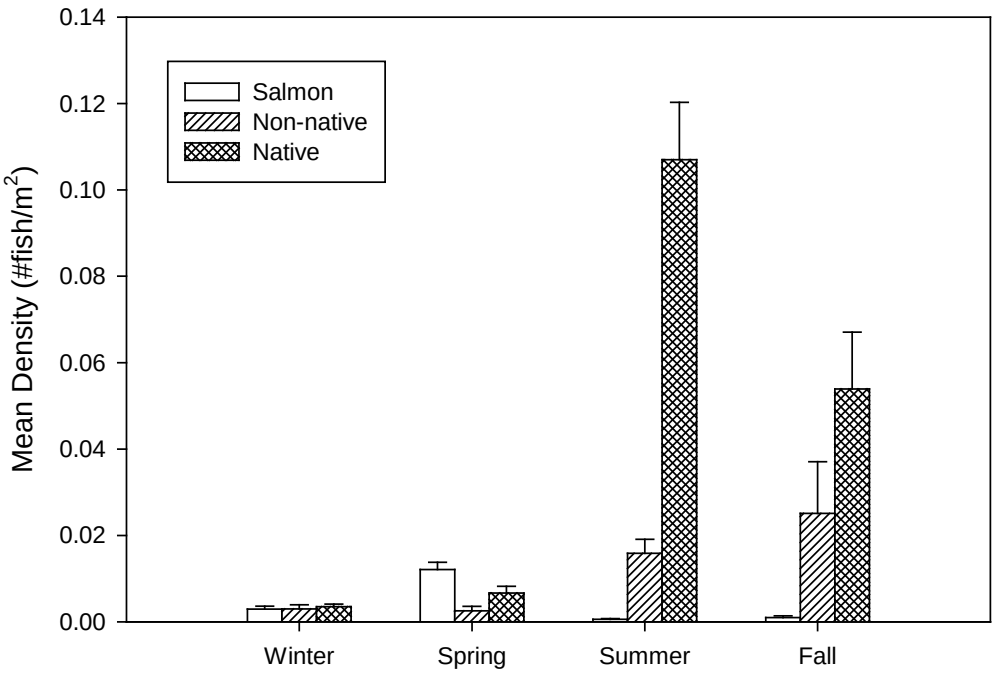

Figure 2.8. Mean Density for Salmon, Non-Native, and All Other Native (Non-Salmon) Taxa at All SRD Sites During the 2007–2010 Study Period. Error bars represent the standard error of the mean.

We identified eight species that were most common during the 2007–2010 sampling period. Of these species, five were native taxa and three were non-native taxa (Figure 2.9). Threespine stickleback (*Gasterosteus aculeatus*) were the most abundant species encountered in the SRD study area and exhibit a bimodal temporal distribution with peaks occurring in late summer as well as during winter months (Figure 2.9). Peamouth (*Mylocheilus caurinus*) and smallmouth bass (*Micropterus dolomieu*) catches peaked in summer months during all 3 years. Catches of unidentified sucker spp. (*Catostums* spp.) also peaked during summer months; however, there was greater variation in mean density across sample years for these species. Catches of northern pikeminnow (*Ptychocheilus oregonensis*) and banded killifish (*Fundulus diaphanous*) peaked from early fall through early winter during 2007 and 2009. In 2008, catches for these two species peaked during a similar time period, but overall densities were relatively lower. Mean densities and temporal distribution of bluegill (*Lepomis macrochirus*) showed patterns that were the most variable among the other common species.

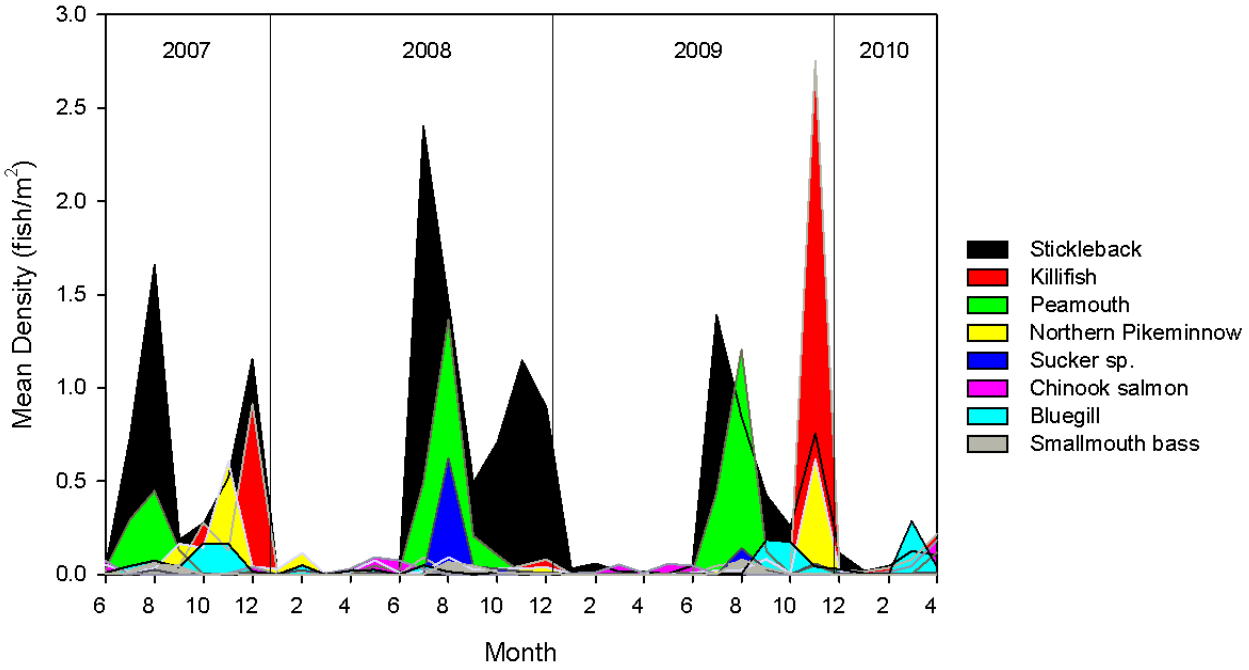

Figure 2.9. Temporal Distribution of the Most Abundant Species Encountered During the 2007–2010 Study Period in the SRD Study Area. The most abundant species were determined by species that accounted for >1% of the total combined catch (see Figure 2.7).

Within the SRD study area, combined 2007–2010 catches for common species were highest at Site C, the former mouth of the SRD. Sites D (the current mouth of the SRD) and Site I (Ackerman Island) yielded the lowest catches for the common fish species (Figure 2.10). Estimated mean densities of stickleback, killifish, northern pikeminnow, and sucker spp. were greatest at Site C during the 2007–2010 study period (Figure 2.11). Estimated mean densities of peamouth were greatest at Site E, Gary Island. Mean densities of Chinook salmon were highest at Site D, with Sites E and I yielding similar estimates. The largest estimated mean densities of bluegill were encountered at Sites N and B. Estimated mean densities of smallmouth bass were greatest at Site B; however, estimates for this species were similar at Sites A, D, and E.

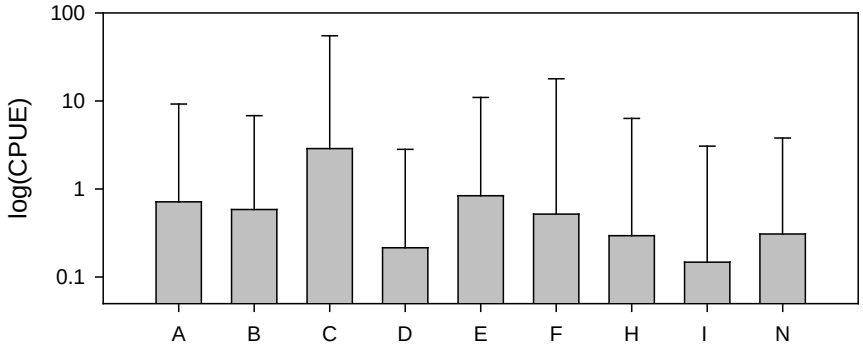

Figure 2.10. Catch per Unit Effort (# fish/beach seine haul) for the Eight Most Common Species Captured at the SRD Sites. Data are displayed on a logarithmic scale. Error bars represent the standard error.

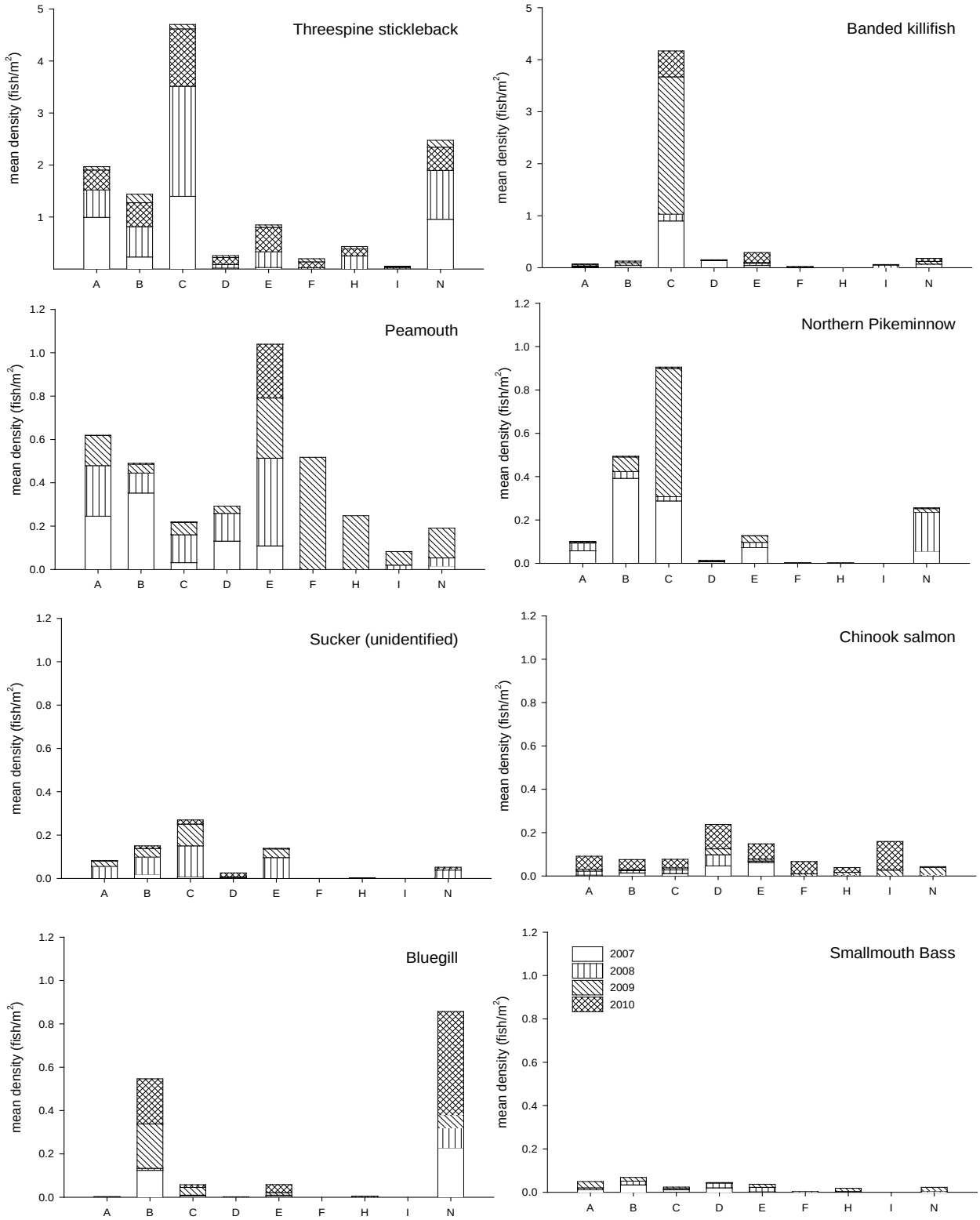

Figure 2.11. Mean Density of Fish (#/m^2) at Each SRD Site During the 2007–2010 Period

The overall mean lengths for common species captured at the SRD ranged from 39 to 54 mm (Table 2.3). The sizes of threespine stickleback, banded killifish, and bluegill are represented at mean

total length while mean fork length is used to represent sizes of peamouth, northern pikeminnow, Chinook salmon, and smallmouth bass. The smallest fish sizes (~10 mm) were observed for threespine stickleback, killifish, and northern pikeminnow. The largest fish captured was a northern pikeminnow (660 mm). The largest mean sizes of threespine stickleback, peamouth, sucker (unidentified), and smallmouth bass coincided with late spring months (Figure 2.12). Generally, the mean sizes of killifish and bluegill were largest during summer months. Northern pikeminnow were generally largest throughout summer months, except for catches of large pikeminnow during February and May 2009.

Table 2.3. Size Summary for the Most Common Species and Salmonid Species Captured in the SRD Study Area During the 2007–2010 Period. Sizes are expressed as fork lengths (mm). Marked salmon were those without adipose fins.

Taxon	Common Name	Median	Mean	Min	Max	Std. Error
	Common Species					
Gasterosteus aculeatus	Threespine stickleback	45	44	10	79	0.109
Fundulus diaphanous	Banded killifish	42	46	8	140	0.33
Mylocheilus caurinus	Peamouth	51	53	10	251	0.447
Ptychocheilus oregonensis	Northern pikeminnow	45	53	10	660	0.776
Catostomous sp.	Sucker sp.	48	51	13	149	0.639
Lepomis macrochirus	Bluegill	35	39	16	144	0.417
Micropterus dolomieu	Smallmouth bass	49	54	20	348	1.119
	Salmonid Species					
Oncorhynchus tshawytscha	Chinook salmon	45	51	38	377	0.295
O. tshawytscha	Chinook salmon (marked)	81	83	46	167	1.39
O. keta	Chum salmon	44	45	30	77	0.223
O. kisutch	Coho salmon	54	63	32	148	1.18
O. kisutch	Coho salmon (marked)	142	143	110	200	1.48
O. mykiss	Steelhead trout	184	211	155	400	18.8
O. mykiss	Steelhead trout (marked)	207	231	153	410	18.3

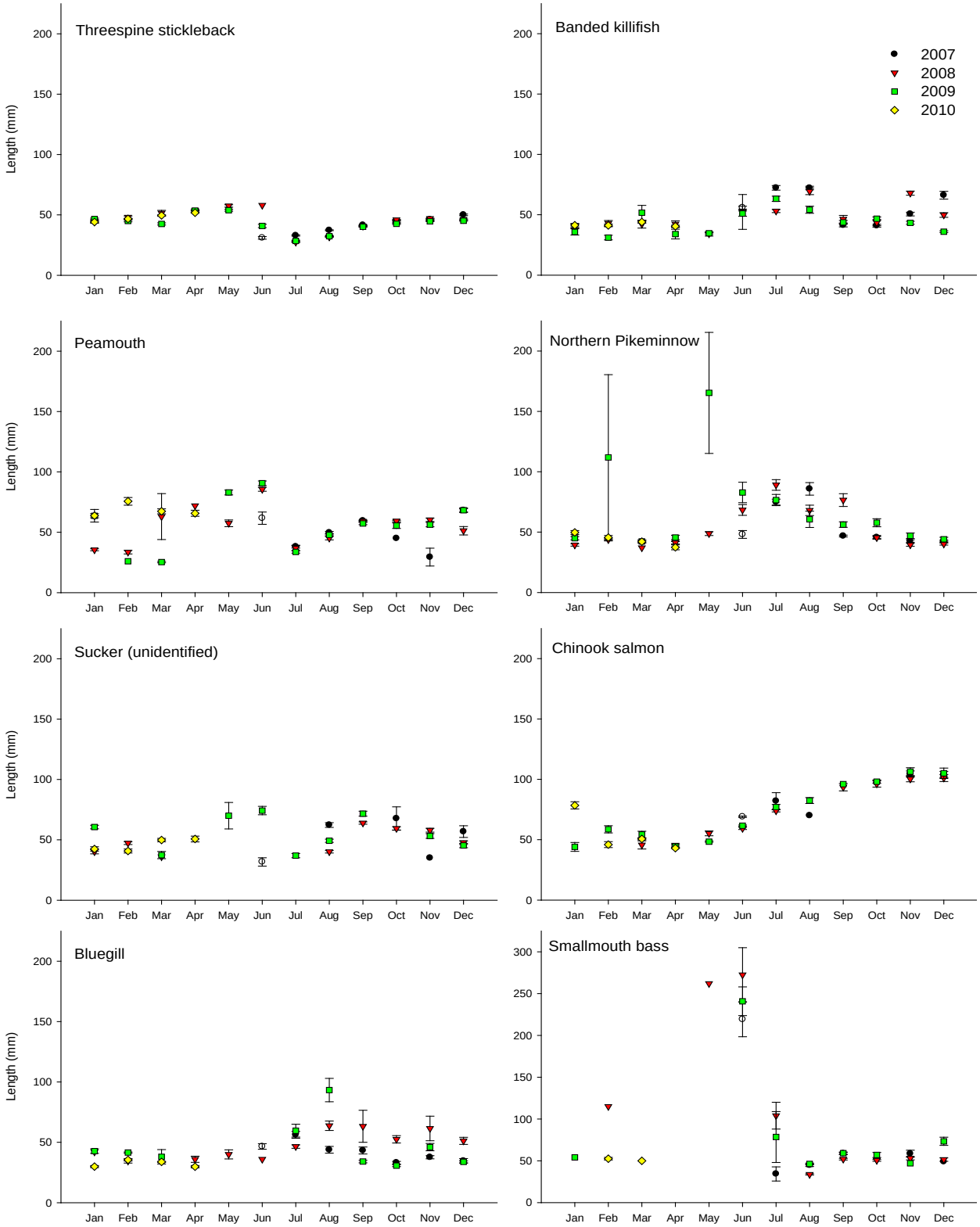

Figure 2.12. Mean Length of the Most Common Taxa Encountered at the SRD Study Area During the 2007–2010 Period. Error bars represent the standard error of the mean.

2.2.1.3 Salmon

Spring yielded the highest estimated mean densities for salmon and, of the six species of salmon and trout we observed during the 2007–2010 study period, spring was the only season in which all six species were captured. Winter ranked second in seasonal estimates for salmon species. Summer and fall yielded the lowest estimated mean densities for salmon in the SRD study area (Figure 2.13). Chinook and coho salmon were the only salmon species encountered during every season. Chum salmon (*O. keta*) were captured during winter and spring months. Marked coho, steelhead, and unmarked steelhead were captured during spring months and steelhead also were encountered during fall and winter time periods. The abundance of unmarked Chinook salmon within the SRD study area increased throughout the winter months and peaked during spring months each year of the study. With the exception of December 2007, the density of unmarked Chinook salmon was lowest during summer and fall months for all years sampled. Marked Chinook salmon dominated during spring months and were also captured during winter and summer time periods.

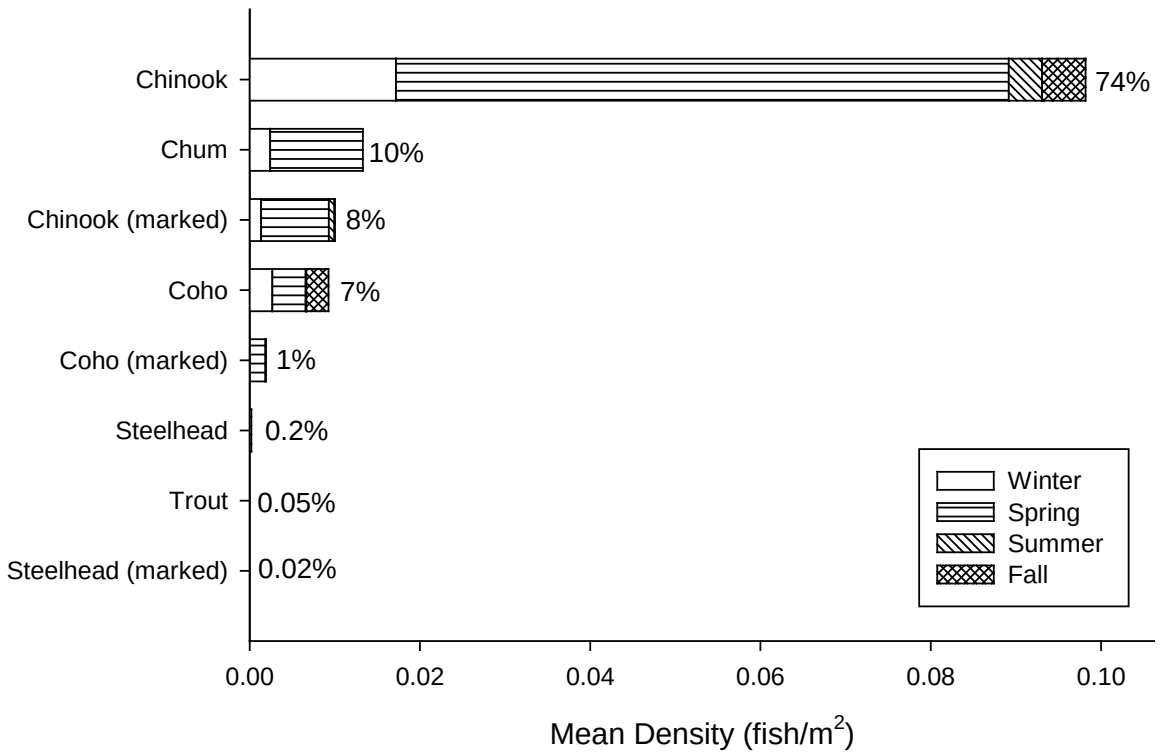

Figure 2.13. Mean Density for Salmonids at All SRD Sites During the 2007–2010 Study Period. The percentages for each taxa category represent the total salmonid density.

The mean size of unmarked Chinook salmon was generally lowest during periods that corresponded to the high densities of this species. After April, the size of unmarked Chinook salmon increased throughout the summer and fall months with the largest mean fork lengths of fish occurring in November and December (Figure 2.14). During winter months, the length frequency distribution of unmarked Chinook salmon was bimodal with large numbers of small fish (<60 mm) and a smaller proportion of larger size classes (90–120 mm). During spring months, small-sized (<60 mm) fish continued to be predominant, but a greater number of fish occupied the 60- to 80-mm size range, and the larger sizes (90–120 mm) of unmarked Chinook salmon were not captured. Summer months were dominated by fish ranging from 60 to 80 mm and fall months generally included 80- to 120-mm fish (Figure 2.15).

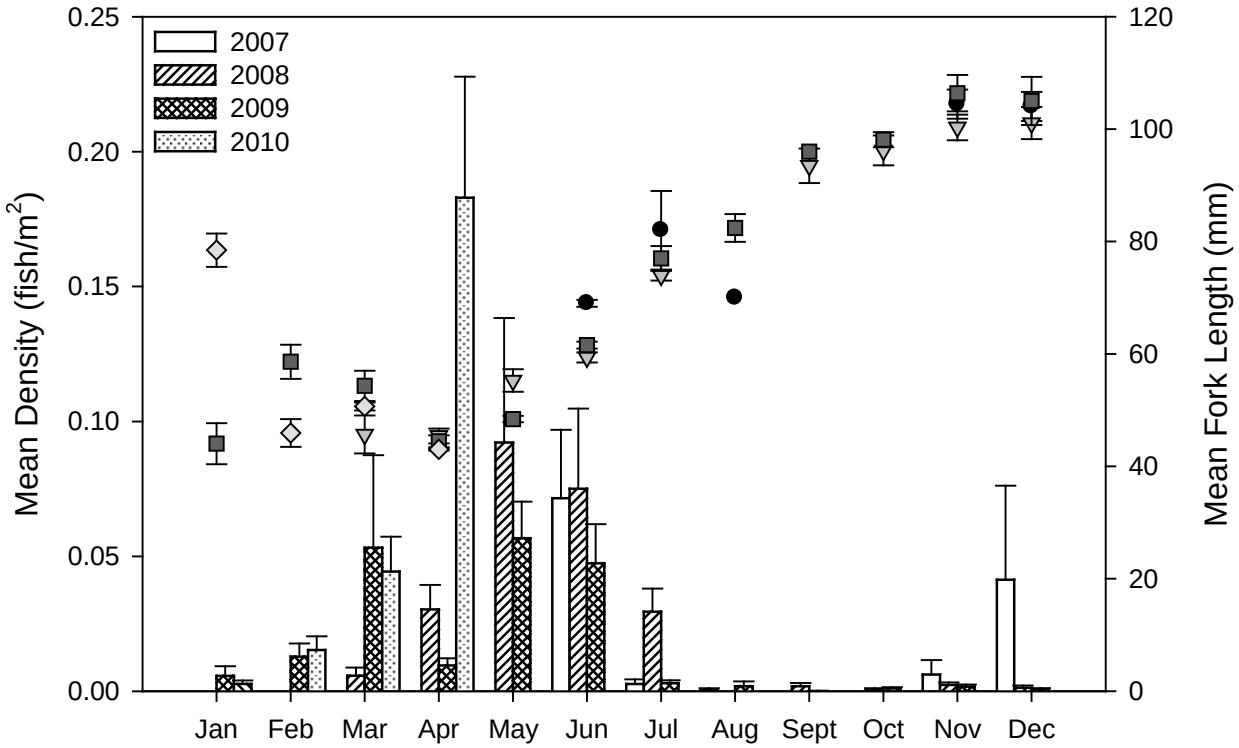

Figure 2.14. Mean Monthly Density of Unmarked Chinook Salmon Sampled at the SRD Study Area During the 2007–2010 Study Period and Average Fork Length for Unmarked Chinook Salmon During 2007 (circles), 2008 (triangles), 2009 (squares), and 2010 (diamonds). Error bars represent the standard error of the mean.

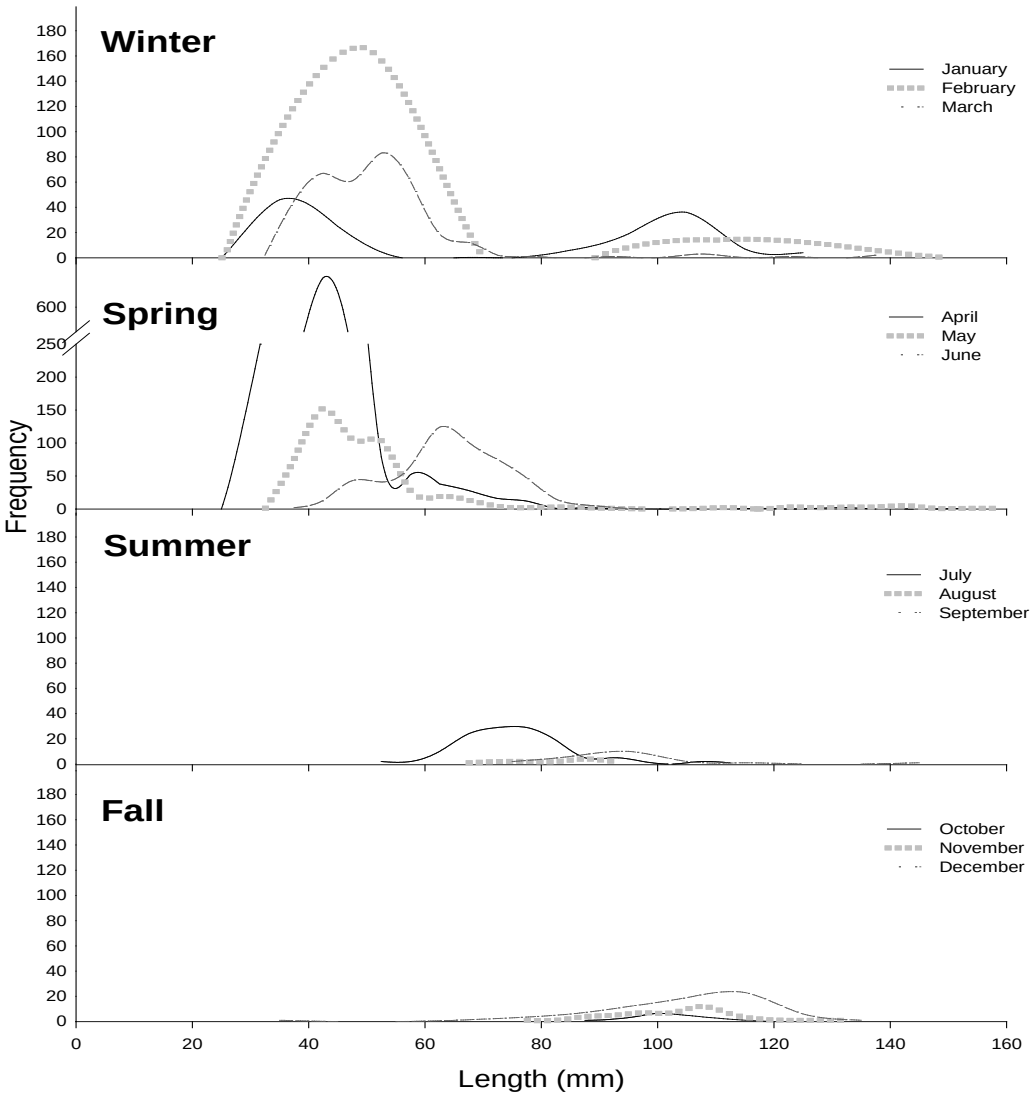

Figure 2.15. Seasonal Length Frequency Distribution for Unmarked Chinook Salmon Sampled at the SRD Study Area Between June 2007 and April 2010

2.2.1.4 Chinook Salmon Genetics

A total of 1401 Chinook salmon captured from in SRD were genotyped at 7 or more of the 13 microsatellite loci and used in genetic stock identification analysis. Stock composition estimates from the analysis of 1242 unmarked Chinook salmon sampled in the SRD are presented in Table 2.4. These samples may include both naturally produced and unmarked hatchery fish (Sather et al. 2009). The majority of the fish were from the Spring Creek Group Tule Fall (35%) and the Upper Columbia Summer/Fall (33%) stock groups. Smaller proportions were estimated for the West Cascade Tributary Fall (15%) and Willamette River Spring (8%) groups. Snake River Fall (3%), Deschutes River Fall (3%) and West Cascade Tributary Spring (2%) fish were also sampled. A total of 159 marked (known hatchery origin) Chinook salmon captured in the SRD region were analyzed genetically (Table 2.5). Most of the hatchery fish were also from the Spring Creek Group Tule Fall (69%) and Upper Columbia Summer/Fall (20%) stock groups. Four other stock groups contributed small proportions to the marked fish mixture

(2%–4%). One marked fish, captured in May 2008 was assigned to the Mid and Upper Columbia River Spring stock (*P*=1.00). However, overall we found little indication that spring Chinook salmon from the interior Columbia River basin or fish belonging to the introduced Rogue River stock (propagated in the lower Columbia River) contributed to any of the genetic samples in our study.

Table 2.4. Estimated Percentage Genetic Stock Group Composition and 95% Confidence Intervals of 1242 Unmarked Juvenile Chinook Salmon Sampled in the SRD from June 2007 Through April 2010

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	33.4	28.1	37.0
West Cascade Tributary Fall	15.3	13.0	19.0
Spring Creek Group Tule Fall	34.9	30.3	35.3
Snake River Fall	3.3	2.1	7.4
Willamette River Spring	7.7	5.5	8.7
Deschutes River Fall	3.2	1.8	5.6
West Cascade Tributary Spring	2.1	1.9	4.8
Mid and Upper Columbia River Spring	0.0	0.0	0.2
Snake River Spring	0.1	0.0	0.4
Rogue River	0.0	0.0	0.2

Table 2.5. Estimated Percentage Genetic Stock Group Composition and 95% Confidence Intervals of 159 Marked Juvenile Chinook Salmon Sampled in the SRD from June 2007 Through April 2010

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	19.6	10.5	25.2
West Cascade Tributary Fall	4.3	0.3	14.0
Spring Creek Group Tule Fall	68.7	56.1	73.6
Snake River Fall	2.4	0.0	7.5
Willamette River Spring	1.9	0.0	4.4
Deschutes River Fall	1.8	0.0	5.5
West Cascade Tributary Spring	0.6	0.0	4.7
Mid and Upper Columbia River Spring	0.6	0.0	1.9
Snake River Spring	0.0	0.0	0.6
Rogue River	0.0	0.0	0.0

Results from genetic stock identification analysis of samples grouped by survey are presented in Tables 2.4 and 2.5 and Figure 2.16. Marked and unmarked fish were analyzed separately. Because relatively few fish were analyzed from surveys conducted in late summer and autumn, unmarked samples collected during this period were pooled over years and samples from August, September, and October surveys were combined into a single mixture. Sample sizes of the mixtures ranged from 25 to 160 individuals. Stock proportions of unmarked Chinook salmon sampled in the SRD region showed a

strong seasonal pattern that was consistent across sampling years (Appendix D, Table D.1; Figure 2.16). Spring Creek Group Tule Fall fish contributed substantial proportions to samples collected from January (44%) through May (17% and 24%) with the largest values estimated for February 2010 (89%) and March 2009 (92%). The stock was largely absent in samples collected after May (0%–7%). The Upper Columbia Summer/Fall stock was a major contributor to catches in surveys conducted throughout much of the year. The largest proportion was estimated for July (73%), but the stock was also present in April (19% and 31%) and May (41% and 59%) and contributed 39% of the pooled August–October sample. The Upper Columbia Summer/Fall stock group was composed of only small proportions of some samples collected from January through March (0%–7%) and November through December (0% and 11%). The West Cascade Tributary Fall stock group appears to be present in the region throughout the year (2%–33%) and small proportions Snake River Fall fish were estimated in several surveys, particularly in May 2008 (10%) and in samples collected and in June and July (5%–8%). The pattern of estimates for the Deschutes River Fall stock was similar to that of the Snake River Fall stock, with the largest proportion in the June 2007 samples (16%). Spring Chinook salmon were present during several months, particularly from the Willamette River stock in January (38%) and February (40%) of 2009 and late in the year (August–October = 30%, November = 66%, December = 55%). Spring run fish from the West Cascade Tributary stock were evident in these same surveys with smaller estimated proportions for January (10%) and February of 2009 (13%) and late in the year (August–October = 8%, November = 9%, December = 16%).

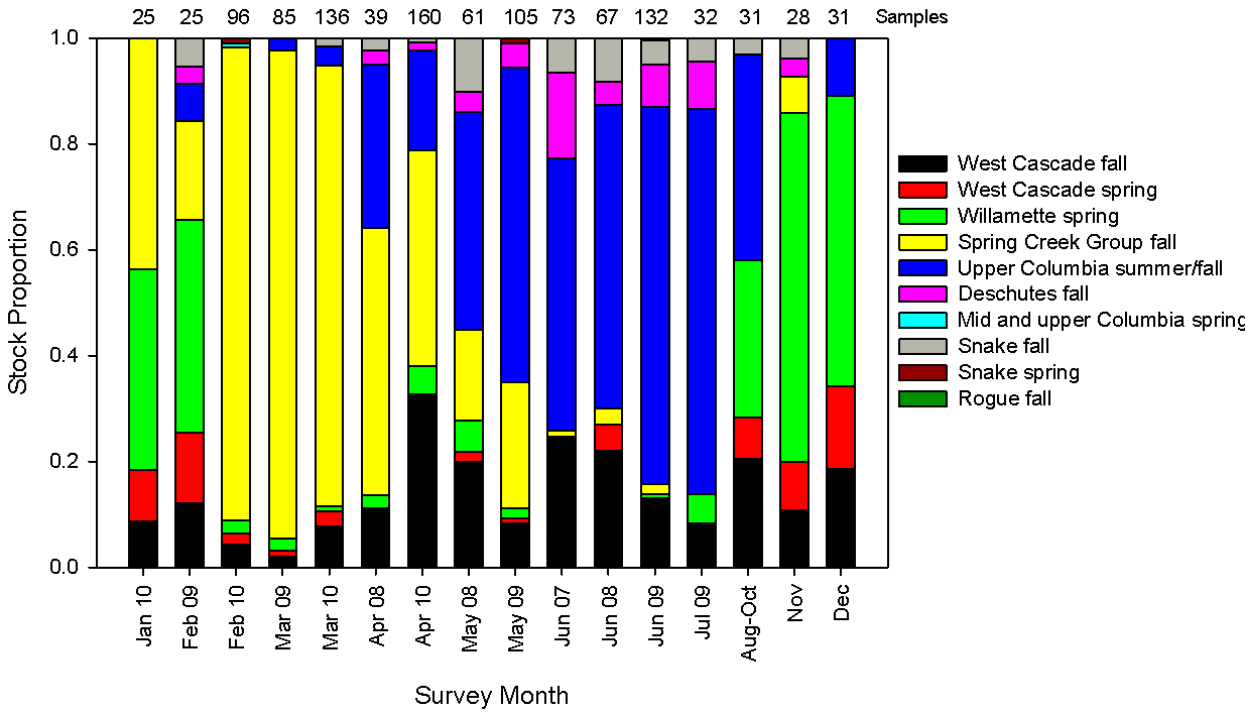

Figure 2.16. Estimated Stock Proportions and Sample Sizes of Unmarked Juvenile Chinook Salmon Sampled at SRD Sites, 2007–2010. Month and year of sampling are indicated. Samples collected in August through September were pooled from surveys conducted in 2007, 2008, and 2009. November and December samples were collected in 2007 and 2009.

2.2.2 Tidal Freshwater Landscape: Comparison of SRD and LRR Sites

2.2.2.1 Environmental Conditions

Although similar habitats were sampled during successive time periods, the water temperature and dissolved oxygen levels between the base sites at the SRD (rkm 188–202) and the LRR sites were significantly different ($P<0.05$) over sequential time periods during the 2009–2010 period (Figure 2.17). The median water temperatures were significantly different ($P<0.05$) between the two study areas for all time periods, except February 2009. Dissolved oxygen was significantly different ($P<0.05$) between the two study areas during half of the sampling events (May, August, and November 2009).

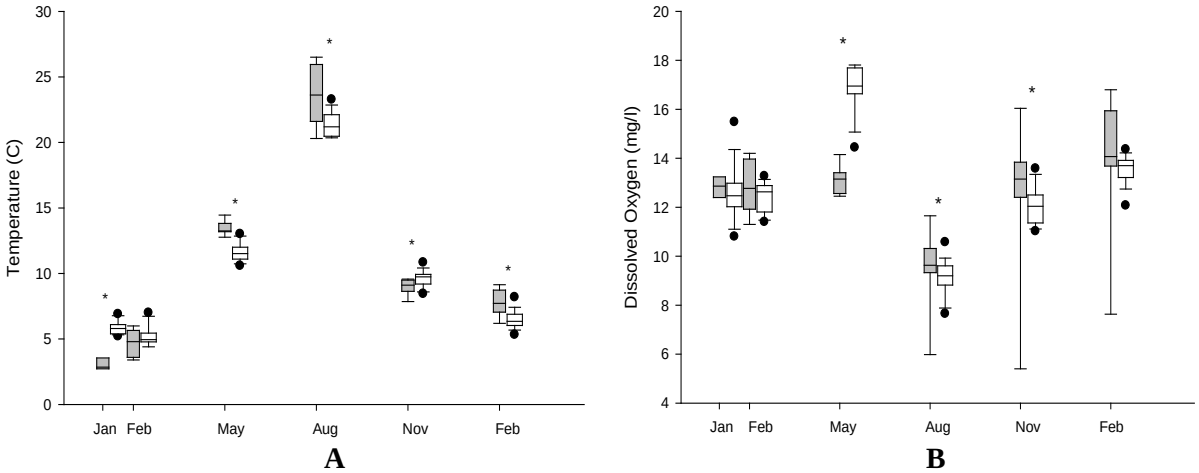

Figure 2.17. Comparison of Water Temperature (A) and Dissolved Oxygen (B) During 2009–2010 Beach Seine Efforts at SRD Study Sites (solid gray box) and LRR Sites (white shaded boxes). The box and whiskers are the 90th and 10th percentiles. Solid black lines within the boxes denote the median temperature during a given sample period and black dots denote sample outliers. An asterisk above a group indicates significant difference between sample regions during a given time period ($\alpha = 0.05$).

2.2.2.2 Fish

During the six time periods sampled for the landscape-scale comparison we captured 25 fish species at the SRD study area and 27 species at the LRR sites. Seven species accounted for 1% or more of the total catch at both study areas with six of these species being common between the two areas. Redside shiner (*Richardsonius balteatus*) and smallmouth bass composed approximately 1% of the catch at the LRR and SRD sites, respectively (Table 2.6).

The proportions of salmon, native non-salmon, and non-native species in the fish community changed temporally across the landscape of tidal freshwater habitats (Table 2.6, Figure 2.18). During January 2009, the first principle component (PC1), which comprised native fish and salmon, accounted for 82% of the variation in the fish community proportions. The second principle component (PC2) accounted for 20% of the variation and was dominated by non-native fishes during January. Differences in fish community proportions between LRR and SRD sites were not significant (P=0.800). In February

2009, native fish and salmon accounted for 93% of the variation in the fish community. The proportions of these two groups were nearly equal contributors to PC1 (Table 2.7). PC2, which was dominated by the non-native proportion of the fish community, accounted for less than 10% of the variation in the data.

Differences between LRR and SRD sites in the proportions salmon, native non-salmon, and non-native species in the fish community were examined separately for each sampling month. During February 2009, SRD and LRR differences were not significant (P=0.966). In May 2009, 99% of the variation in the data was composed of native non-salmon fishes and salmon, which were equal contributors to PC1. Differences in the proportion of fish community between LRR and SRD sites were significant during May (P<0.001). LRR sites had a higher proportion of native (non-salmon) fishes and the SRD sites yielded a higher proportion of salmon species. During August, 99% of the variation in the fish community proportions was due to native and non-native fishes; proportions of each of these groups were nearly equal contributors to PC1. Differences in the fish community proportions between LRR and SRD sites during August were not significant (P=0.978). In November, differences in the fish community proportions between LRR and SRD sites during November were significant (P=0.010). Native and non-native groups composed 99% of the variation in the data and both groups were nearly equal contributors to PC1. LRR sites had a higher proportion of native fishes and the SRD sites yielded higher proportions of non-natives. In conclusion, among months and across the SRD and LLR study areas, there were no consistent trends in the proportions of salmon, native non-salmon, and non-native species.

Table 2.6. Percentages of Total Catch for Fish Encountered at the SRD Sites and LRR Sites. Catches were based on sampling efforts during January, February, May, August, November 2009 and February 2010. UID denotes unidentified taxa.

Common Name	Species	SRD	LRR
American shad	*Alosa sapidissima*	0.071	1.67
Amur goby	*Rhinogobius brunneus*	--	0.072
Banded killifish	*Fundulus diaphanus*	38.9	18.7
Black bullhead	*Ameiurus melas*	0.001	--
Black crappie	*Pomoxis nigromaculatus*	0.001	0.021
Bluegill	*Lepomis macrochirus*	0.809	0.235
Bridgelip sucker	*Catostomus columbianus*	0.003	0.008
Chinook salmon	*Oncorhynchus tshawytscha*	1.22	4.46
Chiselmouth	*Acrocheilus alutaceus*	0.006	--
Chum salmon	*Oncorhynchus keta*	--	0.125
Coho salmon	*Oncorhynchus kisutch*	0.080	0.196
Common carp	*Cyprinus carpio*	0.030	0.064
Dace	*Rhinichthys* spp.	0.012	0.001
Golden shiner	*Notemigonus crysoleucas*	0.003	0.296
Goldfish	*Carassius auratus*	0.003	0.015
Largemouth bass	*Micropterus salmoides*	0.017	0.007
Largescale sucker	*Catostomus macrocheilus*	0.227	0.578
Marked Chinook	*Oncorhynchus tshawytscha*	0.163	0.653
Marked coho	*Oncorhynchus kisutch*	0.068	0.467
Marked steelhead	*Oncorhynchus mykiss*	0.003	0.023

Table 2.6. (contd)

Common Name	Species	SRD	LRR
Mosquito fish	*Gambusia affinis*	--	0.003
Mountain whitefish	*Prosopium williamsoni*	0.005	0.031
Northern pikeminnow	*Ptychocheilus oregonensis*	10.3	4.61
Peamouth	*Mylocheilus caurinus*	18.2	1.54
Prickly sculpin	*Cottus asper*	0.089	0.197
Pumpkinseed	*Lepomis gibbosus*	0.685	0.080
Redside shiner	*Richardsonius balteatus*	0.015	1.07
Reticulate sculpin	*Cottus perplexus*	--	0.001
Sand roller	*Percopsis tranmontana*	0.021	0.001
Smallmouth bass	*Micropterus dolomieu*	1.14	0.093
Starry flounder	*Platichthys stellatus*	0.197	0.607
Steelhead	*Oncorhynchus mykiss*	0.006	0.005
Threespine stickleback	*Gasterosteus aculeatus*	23.6	62.2
UID bass	*Micropterus* spp.	--	0.166
UID catfish	*Ameiurus* spp.	--	0.004
UID crappie	*Pomoxis* spp.	--	0.165
UID minnow	*Cyprinidae*	--	0.029
UID sculpin	*Cottid* spp.	0.200	0.163
UID sucker	*Catostomus* spp.	3.23	0.947
UID sunfish	*Lepomis* spp.	0.715	0.234
White sturgeon	*Acipenser transmontanus*	--	0.028
Yellow bullhead	*Ameriurus natalis*	--	0.008
Yellow perch	*Perca flavescens*	0.041	0.254

Table 2.7. Loading Coefficients Resulting from Principal Components Analysis (PCA) of the Proportion of Fish Community Composition: Salmon, Native, and Non-Native

		Coefficients			
Month	PCA	Salmon	Native	Non-Native	Explanation
January	1	0.611	-0.774	0.163	native vs. salmon
	2	0.541	0.259	-0.800	non-native vs. other
February	1	0.691	-0.722	0.031	native vs. salmon
	2	-0.435	-0.381	0.816	non-native vs. other
May	1	0.707	-0.707	-0.001	native vs. salmon
	2	0.408	0.409	-0.816	non-native vs. other
August	1	-0.018	-0.698	0.716	native vs. non-native
	2	0.816	-0.423	-0.393	salmon vs. other
November	1	-0.014	-0.700	0.714	native vs. non-native
	2	0.816	-0.421	-0.396	salmon vs. other

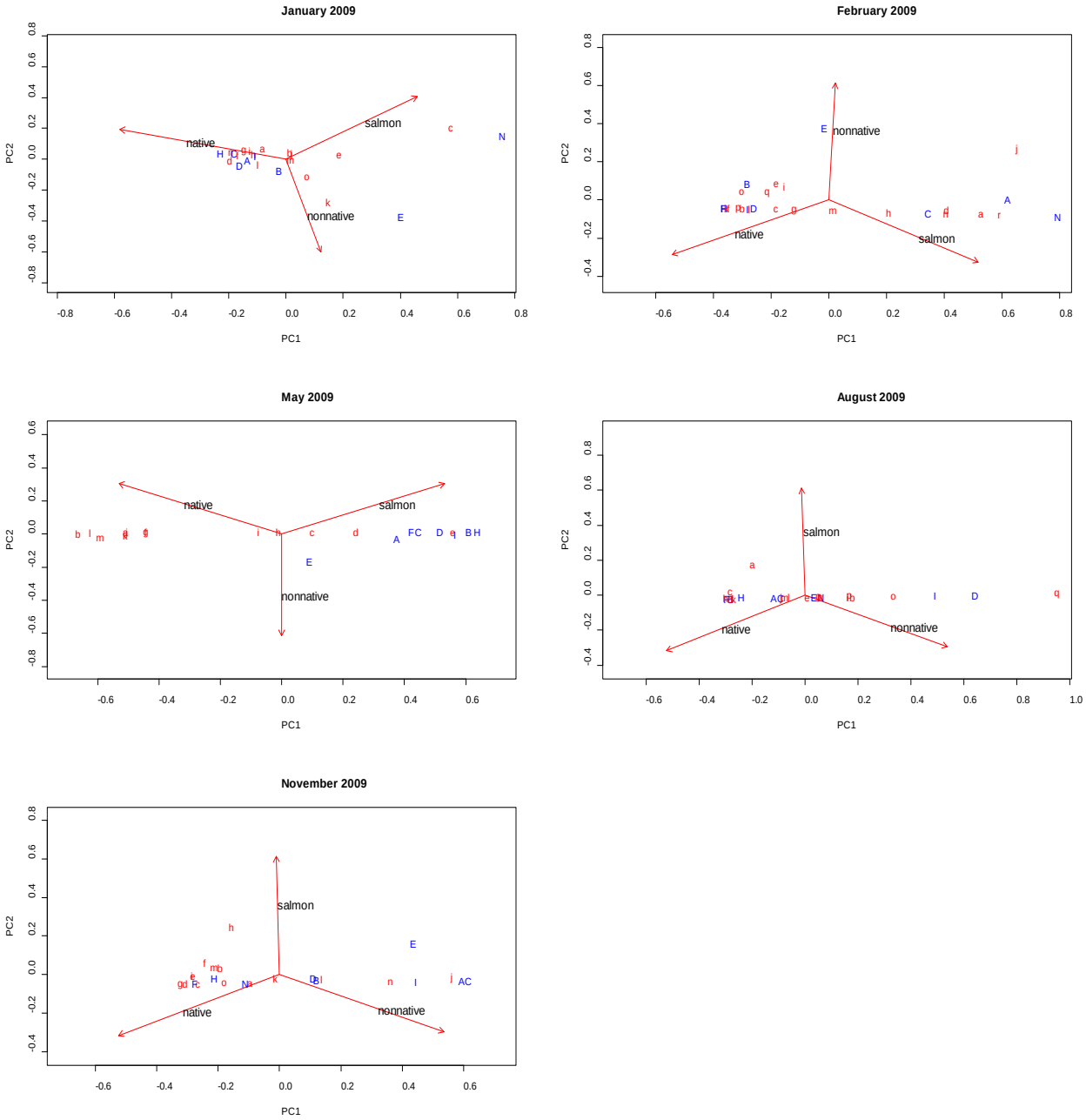

Figure 2.18. Plots with PC1 and PC2 as the X and Y Variables on the Proportions of Fish Community Composition for January, February, May, August, and November 2009. Lowercase letters (red) correspond to LRR sites. Capital letters (blue) correspond to fixed sites.

2.2.2.3 Chinook Salmon Genetics

Estimated stock proportions of unmarked Chinook salmon sampled in the LRR (n=362) are reported in Table 2.8. Most fish were estimated to be from the West Cascade Tributary Fall stock group (75%). Much smaller proportions were estimated for the Spring Creek Group Tule Fall (12%), West Cascade Tributary Spring (5%), and Willamette River Spring (4%) stocks. No other stock groups contributed more than 1%. The four stock groups composing the unmarked sample were also found in 54 marked fish captured in the region (Table 2.9). However, the largest proportion was from Spring Creek Group Tule Fall (57%) with smaller contributions from West Cascade Tributary Fall (24%), Willamette River Spring (14%), and West Cascade Tributary Spring (5%) stock groups.

Table 2.8. Estimated Percentage Genetic Stock Group Composition and 95% Confidence Intervals of 362 Unmarked Juvenile Chinook Salmon Sampled in the LRR from January 2009 Through February 2010

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	0.2	0.1	5.4
West Cascade Tributary Fall	75.4	65.2	76.7
Spring Creek Group Tule Fall	11.5	7.5	13.6
Snake River Fall	0.9	0.0	2.6
Willamette River Spring	4.4	1.8	6.0
Deschutes River Fall	0.3	0.0	1.6
West Cascade Tributary Spring	4.8	4.8	14.4
Mid and Upper Columbia River Spring	0.0	0.0	0.1
Snake River Spring	0.0	0.0	0.0
Rogue River	0.3	0.0	1.5

Table 2.9. Estimated Percentage Genetic Stock Group Composition and 95% Confidence Intervals of 54 Marked Juvenile Chinook Salmon Sampled in the LRR from January 2009 Through February 2010

Genetic Stock Group	Estimated Contribution (%)	95% Confidence Interval	
Upper Columbia River Summer/Fall	0.0	0.0	2.9
West Cascade Tributary Fall	24.4	11.0	37.5
Spring Creek Group Tule Fall	57.1	35.4	69.0
Snake River Fall	0.0	0.0	0.0
Willamette River Spring	13.6	4.6	22.3
Deschutes River Fall	0.0	0.0	1.8
West Cascade Tributary Spring	5.0	0.0	17.9
Mid and Upper Columbia River Spring	0.0	0.0	0.0
Snake River Spring	0.0	0.0	0.0
Rogue River	0.0	0.0	0.0

Marked fish from May 2009 in the LRR were entirely from the Spring Creek Tule Fall (88%) and West Cascade Tributary Fall (12%) stock groups (Appendix D, Table D.3; Figure 2.19). Marked fish collected in 2008 at the SRD were also largely from Spring Creek Tule Fall stock, particularly in March (96%) and April (98%). Samples from the SRD May survey were more diverse, with estimated proportions of 73% Spring Creek Tule Fall, 12% Upper Columbia Summer/Fall, and 8% Willamette River Spring fish.

Unmarked fish collected in the LRR were generally dominated by a single stock group, the West Cascade Tributary Fall stock (62%–89%) (Appendix D, Table D.2; Figure 2.20). Mixture proportions greater than 10% for other stocks sampled in the LRR included Spring Creek Group Tule Fall fish in February 2010 (15%) and May 2009 (16%), and Willamette River Spring Chinook salmon in February 2009 (20%).

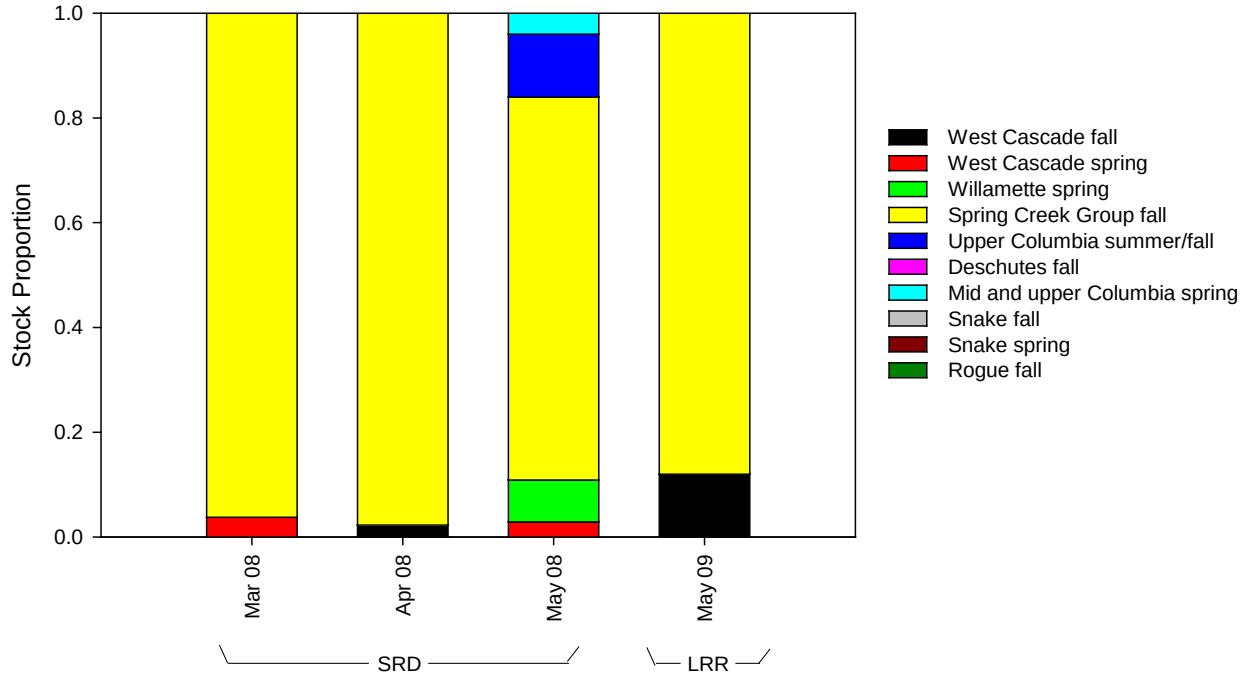

Figure 2.19. Estimated Stock Proportions and Sample Sizes of Adipose Fin-Clipped Juvenile Chinook Salmon Sampled in 2008 at SRD Sites and in 2009 at LRR Sites. Month and year of sampling are indicated.

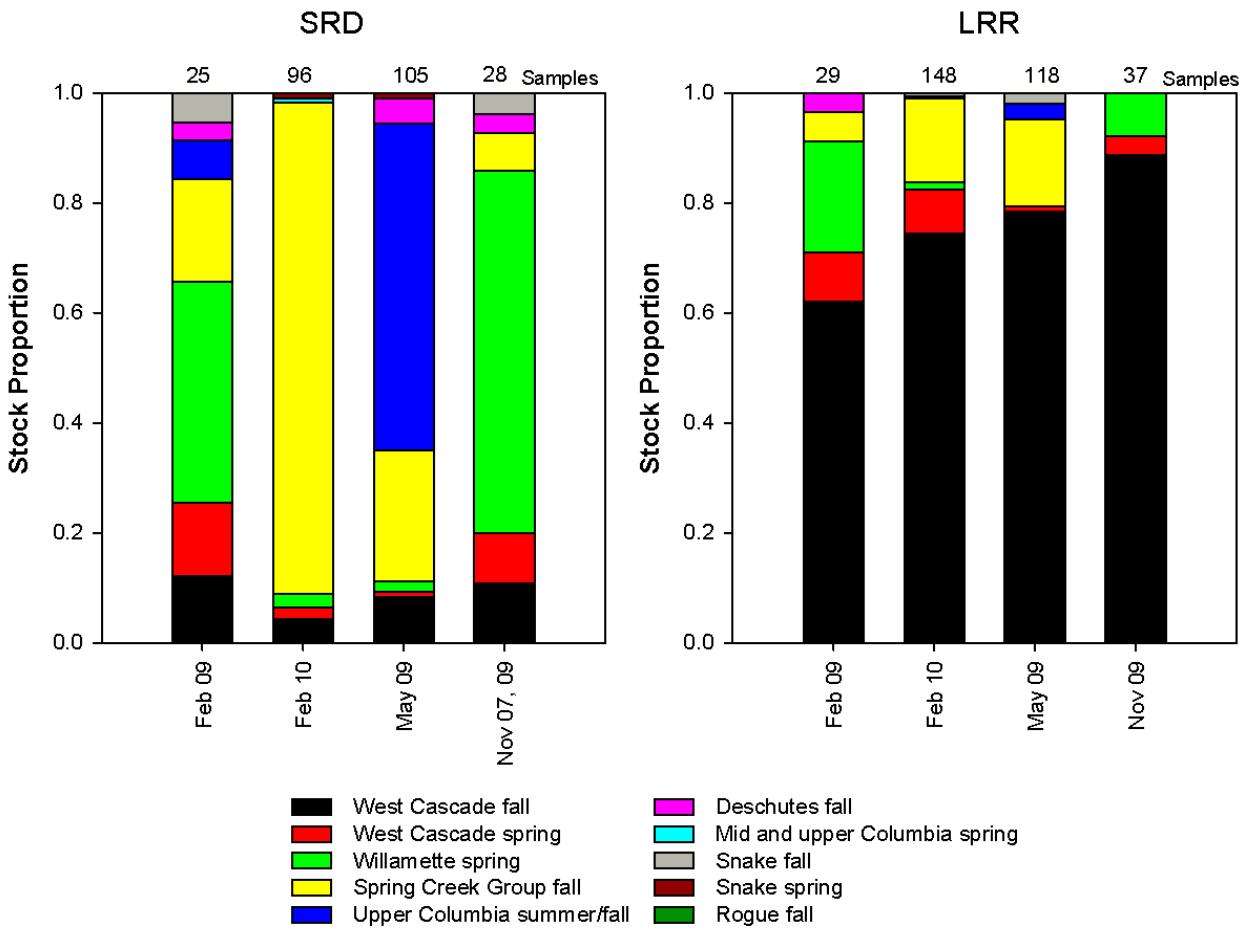

Figure 2.20. Estimated Stock Proportions and Sample Sizes of Unmarked Juvenile Chinook Salmon Sampled at Sites in the SRD (left panel) and LRR (right panel). Month and year of sampling are indicated.

2.3 Discussion

The discussion of juvenile salmon and fish communities in the shallow tidal freshwater of the LCRE is organized into sections for the general fish community at SRD, juvenile salmon characteristics, Chinook salmon genetic stock identification, and landscape considerations.

2.3.1 General SRD Fish Community

During the TFM sampling in the 2007–2010 period in the SRD (rkm 188–202), we captured a total of 34 fish taxa that included 18 non-native and 16 native fish species. Non-native taxa composed approximately 25% of total catch abundance. From 2002 through 2004, Roegner et al. (2008) captured a total of 42 fish taxa—6 non-native and 36 native fish species—in the Columbia River estuary proper (rkm 0–77). While these two studies report 17 common taxa, discrepancies between catches result from the large number of marine and estuarine taxa sampled in the estuary proper by Roegner et al. (2008), and the predominance of non-native taxa within the tidal freshwater sites sampled for the TFM study.

The fish community composition within the SRD exhibited strong temporal patterns. Mean densities of non-salmonid fishes were highest during summer and fall months. Winter yielded the lowest densities for all taxa. Temporal trends in abundance may be associated with biotic and abiotic factors. Spring and summer coincide with increased solar irradiance as well as increases in water temperatures (Small et al. 1990). Primary productivity within the LCRE is correlated with these seasonal changes, which are characterized by an increase in phytoplankton and above-ground biomass of vascular plants throughout the spring and summer months followed by decreases throughout the fall and winter (Small et al. 1990). Furthermore, shallow-water habitats within the LCRE exhibited higher concentrations of chlorophyll-a, particulate organic carbon, and suspended particles (inorganic and organic fractions) compared with main channel sites (Frey et al. 1984).

For the most common species encountered at the SRD sites, the mean sizes were generally highest during spring and summer months, the seasons with increased primary and/or secondary productivity. The mean sizes for most taxa were less than 100 mm and are typically representative of juvenile fishes (Wydoski and Whitney 2003). Following juvenile life phases, many of the taxa likely move from the shallow waters associated with the SRD sites. This emigration may be driven by factors such as changes in habitat requirements associated with increased size, the search for more profitable prey items, and/or relaxed threat of predation due to increased body size. Alternatively, the size distribution of the three-spine stickleback and banded killifish encountered at the SRD sites suggest these taxa complete their entire life cycles within the shallow-water habitats we sampled. Because threespine stickleback and banded killifish maintain a relatively small size range from juvenile to adult phases, the need for shifting among different habitats to support foraging and reproductive success is likely diminished. The life-history requirements for these fish appear to be fulfilled within the shallow tidal freshwater habitats we sampled.

Several factors should be considered when interpreting our data indicating predatory exotic species encountered at the TFM sites, including size-classes that may not impose predation risks to juvenile salmon. Gear biases may have led to underrepresentation of very small salmon able to be consumed by the predator species we encountered. Larger exotic predators, capable of consuming larger salmon, may also have been underrepresented in the catch. In addition, our sampling was conducted during the day, and, therefore, diel horizontal movement or crepuscular feeding habits of salmon predators were beyond the scope of our study. To appropriately evaluate predator-prey interaction between introduced and native fishes in tidal freshwater areas of the Columbia River, sampling techniques should consider predator movements and ontogenetic feeding variability.

2.3.2 Juvenile Salmon Characteristics

Salmon were encountered throughout all seasons during the 2007–2010 TFM sampling effort. Catches of salmonids were greatest during the spring followed by winter, and generally lowest during summer or fall months. Similar trends in abundance have been documented in the LCRE during historic (Dawley et al. 1986) as well as recent sampling efforts (Roegner et al. 2008). Chinook salmon were the most abundant of all salmonids captured and were the only species encountered during all seasons. Marked juvenile salmon and steelhead were typically lower in abundance when compared to their unmarked counterparts.

On average during the 2007–2010 period, 63 million hatchery Chinook salmon were released annually within the Columbia River basin (DART 2010). Approximately 88% of ESA-listed Chinook salmon below Bonneville Dam are hatchery reared fish (Ferguson 2009). We captured a disproportionately large number of unmarked Chinook salmon at the SRD study area (75% of the total salmon catch) compared with marked hatchery Chinook salmon (8% of the total catch). However, because we were unable to distinguish unmarked hatchery salmon from naturally produced salmonids and on average 22% of the hatchery Chinook salmon released above Bonneville Dam were unmarked during the 2007–2010 TFM study period, it is likely that our unmarked catches reflect a combination of natural and hatchery produced salmonids. Nonetheless, the large disparity between the abundance of unmarked and marked salmon in our catches suggests differences in the expression of early life-history patterns between these two groups.

In addition to differences in mean density between unmarked and marked Chinook salmon, there were differences in the mean size of these groups. Marked salmonids were larger compared to unmarked fish. It is likely larger salmon exhibit much different early life-history strategies than their smaller counterparts. The segregation between sizes and habitat use by juvenile salmonids has been noted in estuaries throughout the Pacific Northwest (e.g., Levings et al. 1986; Healey 1982). Similar to patterns noted elsewhere, smaller sizes of subyearling Chinook salmon occupied shallow nearshore habitats of the LCRE, whereas larger salmonids were more abundant in the main channel of the river, adjacent to shallow areas (Dawley et al. 1986; McCabe et al. 1986). Campbell (2010) found that approximately 50% of Chinook salmon sampled in the LCRE between 2004 and 2005 entered the estuary at sizes less than 60 mm. Smaller Chinook salmon also exhibited longer residence times compared with fish that entered the estuary at larger sizes.

These findings contrast with spring and summer tagging studies within the Columbia River that report juvenile Chinook and steelhead migrate from Bonneville Dam to the estuary in approximately 4 days (McComas 2009). Migration pathways and residence times in shallow tidal freshwater habitats during spring and summer confirmed rapid migration rates mostly in the main channel for tagged salmon (95-145 mm) from upriver (see Chapter 6). In contrast, large (>90 mm) Chinook salmon captured during winter at the SRD were found to exhibit a mean residence time of 34 days (see Chapter 6). The contrasting results centering on habitat selection and residence times of different sizes and origins of juvenile salmon support the concept of life-history diversity among and between salmon species exhibited in our beach seine data.

2.3.3 Chinook Salmon Genetic Stock Identification

The stock groupings we used in our genetic analysis are based on genetic lineages and correspond to life-history and geographic patterns (Waples et al. 2004; Narum et al. 2010). It is therefore possible to use genetic data to identify the genetic ancestry of fish in stock mixtures, and to use membership in a genetic group to make inferences about the life-history type (e.g., season of adult return) and region of origin. However, stock management activities have made it difficult to precisely identify the natal sources for several Columbia River Chinook salmon stocks. For example, early returning “tule” fall Chinook salmon originating in the Big White Salmon River in the Columbia River Gorge were used to develop the Spring Creek National Fish Hatchery stock in 1901 (Hymer et al. 1992). Over the next century, the Spring Creek National Fish Hatchery stock was then used to found a number of other hatchery populations and was also outplanted extensively in many Columbia River Gorge and lower river

tributaries (Myers et al. 2006). As a result, genetic data alone do not necessarily indicate that Spring Creek Group Tule Fall juveniles captured in our SRD sampling area originated in a Columbia River Gorge tributary. Other potential sources include rivers further downstream closer to our sampling area. Similarly, as a result of stock transfers and translocations, Chinook salmon in the Upper Columbia Summer/Fall stock, historically from the upper Columbia River east of the Cascade Mountains, are now also produced in Columbia River Gorge tributaries and hatcheries and in main stem spawning areas just below Bonneville Dam (see Sather et al. 2009 and references therein for additional information). A third example relevant to our study is that the Willamette River Spring stock was used for several decades to augment the spring Chinook salmon population in the Sandy River watershed, likely the cause of the high genetic similarity of the two populations (Myers et al. 2006). While identifying the natal source of the stock is therefore confounded, because of the proximity of our sampling area to the Sandy River and because the confluence of the Willamette River is further downstream, it is most likely that the Willamette River Spring stock fish sampled in our surveys originated in the Sandy River watershed.

The genetic stock composition estimates we present identify seven different genetic stock groups of Chinook salmon that occupy the shallow tidal freshwater habitats in the SRD and vicinity. These results are based on genetic samples collected in 28 surveys conducted over a period of nearly 3 years. And while most of the fish we analyzed were collected in spring and summer, samples were obtained in all months. The results reveal strikingly different patterns of seasonal use by several stocks. Fish from the Spring Creek Group Tule Fall stock were present in samples taken in our earliest surveys in the year (January) and were the predominate stock in the region throughout the spring, composing more than 80% of the Chinook salmon catches in our March surveys. After May, Spring Creek Group Tule Fall fish were rarely detected. Genetic analysis of estuarine samples taken near the Columbia River mouth reveal a similar pattern (Bottom et al. 2008), indicating a nearly complete seaward migration of the stock before summer. A very different pattern is shown for Upper Columbia River Summer/Fall fish. We observed substantial proportions of the stock in all surveys conducted from April through July (ranging from 19% to 73% monthly). Moreover, the Upper Columbia River Summer/Fall groups composed 39% of the pooled samples from September through October. The genetic estimates indicate a presence of these groups in some winter months as well (e.g., 7% in February 2009 and 11% of the pooled December samples). Although we found smaller contributions of the West Cascade Tributary, Deschutes River, and Snake River Fall run fish in our samples, these stocks also appear to use these habitats throughout much of the year. The pattern for spring Chinook salmon juveniles, particularly from the Willamette River Spring stock, was also quite different with the largest proportions of these fish found only in autumn and winter (ranging from 30% to 66%).

In contrast to our findings for the SRD study area, the genetic stock compositions of juvenile Chinook salmon in shallow tidal freshwater habitats in the LRR were predominately West Cascade Tributary Fall fish (75%). Although these estimates were from a less extensive set of samples (six LRR surveys) than the SRD, this pattern was consistent in winter, spring, and autumn sampling (range of 62% to 89%). No other stock group contributed more than 12% to the overall set of samples from the LRR area. One similarity in the results between the SRD and LRR areas was that spring run fish were a substantial proportion of the catch during surveys in February 2009. The major differences in the stock compositions of juveniles sampled at the same time in different estuarine regions illustrate that stock-specific habitat use varies at a landscape spatial scale as well as seasonally.

Because not all Columbia River basin hatchery Chinook salmon are marked, it is almost certain that our samples of unmarked fish contain some proportions of unmarked hatchery fish, as mentioned before.

However, we found very different stock compositions in the unmarked and marked (known hatchery) juvenile populations, suggesting a strong signal from naturally produced fish. Samples of hatchery fish were mostly from the Spring Creek Tule Fall stock (73%–96%), whereas unmarked samples taken in the same hauls were from much more diverse sources with proportions of several other stocks exceeding 20%. These results highlight the value of 100% marking of hatchery Chinook salmon for identifying naturally produced fish within the the Columbia River basin.

2.3.4 Landscape Considerations

Our landscape-scale investigation comparing juvenile salmon and fish community characteristics between the SRD and LRR study areas indicated species richness was similar between the two areas. However, there were differing temporal shifts in fish community composition possibly related to biotic conditions, abiotic factors, or likely a combination of both. Salmon and native proportions explained much of the variation in the data during winter and spring months at the SRD and LRR sites. This is likely related to the high densities of salmonids during the early part of the year. During summer and fall time periods, native and non-native groups explained most of the variation in the data. The dramatic decline in salmonids during summer and fall may be correlated with warmer water temperatures. Many of the non-native taxa captured during our efforts have higher thermal tolerances compared to salmonids (Eaton et al. 1995). Differences in water temperature and dissolved oxygen were significantly different between the SRD and LRR study areas, although differences were not consistent with sample region; i.e., the mean water temperature and/or dissolved oxygen in one area was not higher than the other area during all months. Likewise, differences between the SRD and LRR areas were not linked to successive sampling events, i.e., the temporal order in which regions where sampled.

The statistical evaluation of fish community composition within the SRD and LRR areas yielded significant spatial differences, although differences in the fish community composition between these areas were not consistent through time. In addition, site-scale habitat attributes, such as emergent vegetation, shrubs, trees, and bare ground, did not indicate structural differences between the two study areas. Few detectable differences among fish community composition and habitat attributes suggest homogeneity in the tidal freshwater sites we sampled. These findings are consistent with an analysis of plant community structure throughout the LCRE. Borde et al. (2009) reported few differences in vegetative community structure at sample sites within the SRD and LRR areas. However, differences in plant communities were noted over larger spatial scales and generally were linked to differences in hydrology, tidal and fluvial interactions, and salinity.

Despite the relatively large spatial segregation of our two study areas (~51 rkm), the metrics we measured did not yield differences in fish community composition. These findings contrast those noted by Roegner et al. (2008) with regard to spatial differences in fish community composition within the estuary proper. While these differences were noted over a more condensed longitudinal gradient (rkm 0–70) compared with our investigation, differences in fish community compositions noted by Roegner et al. (2008) may be attributed to environmental conditions such as salinity gradients (Roegner et al. 2008). Our results suggest little differences in fish communities and habitat attributes between the LRR (rkm 110–141) and SRD (rkm 188–202), but it is possible that the scale of our analysis was not sufficient to detect differences. Additionally, the inclusion of metrics that denote the functional attributes of habitats (e.g., prey resources, nutrient flux) may help confirm or refute our landscape-scale findings.

Because not all Columbia River Basin hatchery Chinook salmon are marked, it is almost certain that our samples of unmarked fish contain some proportions of unmarked hatchery fish, as mentioned before. However, we found very different stock compositions in the unmarked and marked (known hatchery) juvenile populations, suggesting a strong signal from naturally produced fish. Samples of hatchery fish were mostly from the Spring Creek Tule Fall stock (73%–96%), whereas unmarked samples taken in the same hauls were from much more diverse sources with proportions of several other stocks exceeding 20%. The unmarked fish were from multiple ESUs, demonstrating that juveniles representing significant Chinook salmon ecological/genetic diversity (Myers et al. 1998) occupy SRD and LRR habitats. Our samples included juveniles from the Lower Columbia River, Snake River Fall run, and Upper Willamette ESUs, which are considered threatened under the ESA (Good et al. 2005). These findings indicate that habitat improvements in tidal freshwater areas may provide direct benefits to populations in these ESUs.

2.4 Summary, Conclusions, and Recommendations

We offer the following conclusions and recommendations regarding juvenile salmon and the fish communities in shallow tidal freshwater habitats:

- The presence of juvenile salmon in the catch year-round implies multiple life-history strategies are being expressed and, therefore, year-round sampling is necessary to obtain a holistic understanding of life-history strategies.
- Overall, recovery of listed species should benefit from efforts to restore shallow freshwater areas because juvenile fish, regardless of the rearing type, are captured in these habitats year-round.
- Seasonally, the highest Chinook salmon densities and the smallest average lengths were observed in spring. The second highest densities for Chinook were noted in winter, when there was a bimodal size distribution of Chinook salmon indicating temporal overlap of salmon life stages in tidal freshwater.
- Unmarked Chinook salmon far out-numbered catches of marked Chinook salmon, indicating unmarked fish use shallow tidal freshwater to a greater extent than marked fish. Length frequency distributions for unmarked and marked Chinook salmon had medians of 45 mm and 81 mm, respectively. Furthermore, unmarked fish were present year-round, whereas marked fish mostly appeared as a peak in spring. Although some unmarked fish (perhaps ~22%) originated in hatcheries, the size distribution and genetics data generally were indicative of naturally produced fish. Therefore, the data support restoration of shallow tidal freshwater habitats to aid recovery of wild fish populations.
- We encountered a diversity of stocks consistently throughout the year. In spring, the majority of stock composition (68%) was composed of Spring Creek Fall Chinook salmon and Upper Columbia Summer/Fall Chinook salmon. However, stock groups from east and west of the Cascades were detected throughout the year, although in lower abundances. Because no single or group of stocks predominated year-round, and assuming the various stocks have evolved differently, the potential for resource competition among co-existing stocks may be relaxed.
- Genetic stock composition for Chinook salmon varied depending on river reach; stock diversity was higher in our samples from SRD (rkm 188–202) compared to LRR (rkm 109–141). This indicates restoration strategies may need to consider longitudinal position (distance from the mouth) in the LCRE.

- Because not all hatchery Chinook salmon in the Columbia River basin are marked, it is almost certain our samples of unmarked fish contained unmarked hatchery fish. However, we found very different stock compositions in the unmarked and marked (known hatchery) juvenile populations, suggesting a strong signal from naturally produced fish. These results highlight the value of 100% marking of hatchery Chinook salmon for identifying naturally produced fish within the Columbia River basin.
- The SRD (rkm 188–202) and LRR (rkm 110–141) areas had the same six most common species and similar species richness (25 and 27 species, respectively). At times, however, there were noticeable differences in fish communities between the SRD and LRR, but the patterns were not consistent through time. Managers will need to consider the spatial and temporal variability in fish communities during restoration planning processes as well as during evaluation phases, e.g., action effectiveness monitoring and research.
- Fish size distributions for the six most common taxa, including Chinook salmon, suggest tidal freshwater habitats are used by juvenile life stages. Of these six taxa, threespine stickleback and banded killifish of multiple ages (e.g., juveniles to adults) use shallow tidal freshwater habitats year-round.

3.0 Juvenile Salmon Density and Habitat Attribute Associations

Prepared by Nikki Sather, Gary Johnson, and John Skalski

During juvenile life stages, salmon occupy a gradient of habitats spanning tributary streams, rivers, and estuaries before entering the ocean to complete their life cycles (Quinn 2005). In freshwater ecosystems habitat types and complexity have been linked to growth, abundance, and survival of juvenile salmonids. Investigations centering on the association of juvenile salmon with freshwater habitats have occurred at multiple scales. In a comparison of macro-habitats, Jeffres et al. (2008) found vegetated ephemeral floodplain habitats provided more favorable rearing conditions for juvenile Chinook salmon than river-channel habitats. In the Sacramento River, juvenile Chinook salmon associated with off-channel habitats yielded larger daily otolith increment widths compared with fish from main-channel habitats (Limm and Marchetti 2009). In both studies, differences in growth were attributed to habitat disparities such as prey resources as well as environmental conditions. Micro-habitat attributes such as flow velocity and depth have also been linked to the abundance of juvenile salmon in freshwater streams. Beechie et al. (2005) found densities of juvenile salmonids were highest in backwater areas with low water velocity, but patterns differed among species and seasons. Habitat complexity offered by in-stream structures such as large woody debris has also been correlated with the abundance, size, and survival of juvenile salmonids in streams and rivers (Cederholm et al. 1997; Rosenfeld et al. 2000; Solazzi et al. 2000; Whiteway et al. 2010).

Much like habitat associations in freshwater environments, the habitat associations made by juvenile salmon in estuarine areas are dependent on species-specific requirements as well as environmental conditions. Juvenile salmon can be found in a range of nearshore and neritic habitats, salt marshes, and in association with benthic habitats such as eelgrass (Simenstad et al. 1982). In the Nanaimo River estuary, Healey (1980) noted the movement and distribution patterns of juvenile Chinook salmon during high and low tidal cycles were linked to habitat selection. At high tide schooling juveniles were distributed throughout the estuary, but during low tidal periods Chinook migrated to select nearshore locations. While there were apparent habitat associations across the estuarine landscape, patterns pertaining to site-specific attributes were not as clear. Healey (1980) encountered juvenile Chinook salmon at depths ranging from a few centimeters to over a meter and noted associations with a variety of habitat attributes (gravel, sand, mud, eelgrass). The use of intertidal channels by migrating juvenile salmonids has been noted in estuaries in the Pacific Northwest (e.g., Bottom et al. 2005a; Meyers and Horton 1982). The affinity for these habitat types is strongest for Chinook salmon compared with other salmonids and has been explained by high densities, long residence times, and subsequent growth rates within these habitat types (Quinn 2005:231–240).

The decline of wild populations of Pacific salmonids has resulted in an increased need to better understand linkages between life-history stages and environmental conditions. Understanding these linkages informs resource managers by providing empirical data that can be applied to making informed decisions about restoration and recovery of salmon stocks. Despite historical and present efforts to increase understanding of the driving factors in juvenile salmon ecology, the current breadth of knowledge is limited within tidal freshwater habitats of the LCRE (Bisson et al. 2000).

The intent of our research is to understand the habitat associations of juvenile salmon in tidal freshwater environments of the Columbia River. The Columbia River basin encompasses 78.5 hectares in seven states and two Canadian provinces. There are six species of anadromous salmon and trout representing 13 ESU that are listed as threatened or endangered under the ESA; seven ESUs originate from upriver sources and six are associated with the lower river below Bonneville Dam (NOAA Fisheries 2008). To date, research in the LCRE has revealed juvenile salmon use a variety of nearshore and wetland habitats (rkm 0–101). The abundance of juvenile salmon in the LCRE has been linked to the longitudinal gradient within the river, as well as particular habitat types and the life-history strategies of salmonids (Dawley et al. 1986; Bottom et al. 2008). The tidal freshwater portion of the LCRE extends 170 rkm to Bonneville Dam. Our research focused on two segments within this expanse: the LRR (rkm 110–141) and the SRD and vicinity (rkm 189–203) (Figure 3.1).

This research examined habitat attributes and the density of juvenile salmon encountered within the tidal freshwater landscape. The objective was to determine relationships between juvenile salmon density and macro-habitat features (e.g., sampling site, habitat stratum), environmental, and structural attributes.

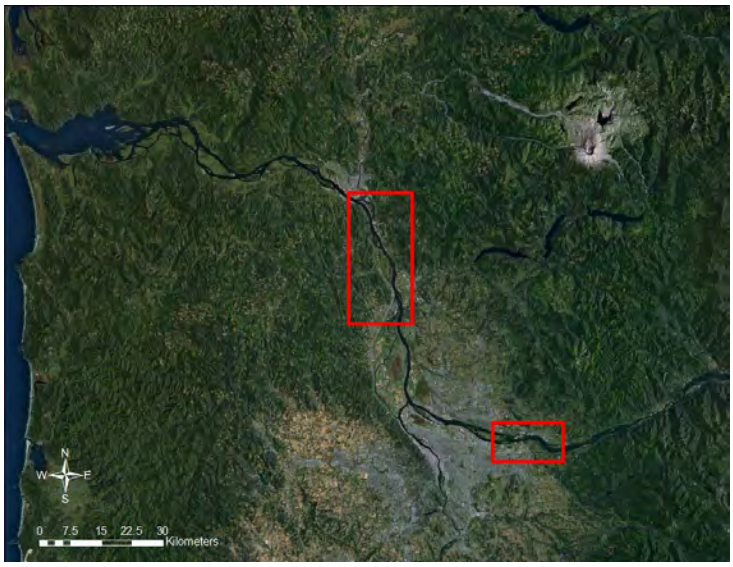

Figure 3.1. Location of the SRD (bottom rectangle; rkm 188–202) and LRR (top rectangle; rkm 110–141) Study Areas of the LCRE

3.1 Methods

The methods section contains information about the data collection and statistical analysis procedures we used to determine relationships between salmon density and habitat attributes.

3.1.1 Data Collection

Fish were sampled monthly from June 2007 through April 2010 at the SRD sites (see Chapter 2, Figure 2.1). Sites within the LRR were sampled during five week-long time periods during January, February, May, August, and November 2009. Methods pertaining to fish capture and site selection are described by Sather et al. in Chapter 2. The response variables were total, unmarked, and marked Chinook salmon densities (#/m^2).

Our multi-scale approach examined macro-habitat conditions as well as site-scale features (Table 3.1). Macro-habitat was characterized by habitat type, including main channel, main-channel island, off-channel, off-channel island, confluence, and wetland (see Chapter 2). Site locations and landscape connectivity level (defined by Diefenderfer et al. 2010) were also used to characterize macro-habitat. Site-scale characterization of the habitats included an evaluation of environmental and structural attributes. Environmental parameters such as water temperature, dissolved oxygen, salinity, velocity, and mean depth were collected coincident with fishing efforts using methods described by Sather et al. in Chapter 2. The cumulative change in water-surface elevation was calculated as the monthly change in water-surface elevation at each of the SRD sites using Onset Hobo water level loggers (Model U20-001-01). Structural attributes including mean beach slope, analytical dominant grain size, and percentage of emergent vegetation, saplings, and bare ground were evaluated using methods described by Sather et al. (2009). These characteristics were examined at the SRD sites during times that coincided with peak biomass and low-water conditions. In 2009, we adapted a rapid habitat assessment technique from Borde et al. (2009) to quantifying structural conditions at each site. This technique evaluates broad vegetative categories (emergent vegetation, shrubs, trees) and the connectedness of these features to the water's edge, as well as substrate conditions.

Table 3.1. Habitat Covariates Available for TFM Study Sampling Sites (* indicates used as a covariate). RHA stands for rapid habitat assessment (after Borde et al. 2009).

Category	Attribute
Macro-Habitat	Stratum* (same as habitat type)
	Site
Environmental	Temperature (°C)*
	Dissolved oxygen (mg/L)*
	Salinity (ppt)*
	Velocity (m/s)*
	Mean depth (m)*
Structural	Mean beach slope (m)*
	Analytical dominant grain size
	Mean % emergent vegetation
	Mean % tree cover
	Mean % shrubs
	Mean % bare ground
	RHA % emergents*
	RHA % saplings
	RHA % bare ground
	RHA distance between vegetation and water edge
	RHA dominant substrate type*

3.1.2 Statistical Analysis

Multiple regression analysis was used to assess relationships between observed salmon densities and selected habitat covariates measured at the SRD and LRR sites. Covariates were selected based on professional judgment of the likelihood of a potential biological effect on salmon density. Each covariate

was individually regressed on the salmon densities for the week-long sampling episodes during January, February, May, August, and November 2009. Salmon density was estimated by summing the total salmon observed in each haul and dividing by the area swept (see Chapter 2).

3.2 Results

For each month, the results of the linear regression are presented for the continuous covariates found to be significant. For "type" covariates, the estimated densities for each category are provided. *P*-values are provided in Table 3.2 and R^2 values in Table 3.3. The results are described by month in the sections that follow. No covariates were significant (P>0.10) in May or August 2009.

Table 3.2. *P*-Values for Each Covariate Analyzed by Month. Significant *P*-values (P<0.10) are highlighted in gray.

Covariate	January	February	May	August	November
Temperature	0.854	0.181	0.202	0.463	0.027
Dissolved Oxygen	0.212	0.948	0.111	0.657	0.102
Salinity	0.867	0.573	0.881	0.923	0.809
Velocity	0.260	0.820	0.150	0.895	0.674
Mean Depth	0.649	0.071	0.835	0.694	0.959
Mean Beach Slope	0.497	0.027	0.416	0.159	0.380
Habitat Stratum	0.002	0.029	0.141	0.919	0.057
RHA % emergents	0.551	0.023	0.666	0.700	0.611
RHA dominant substrate type	0.085	0.018	0.512	0.796	0.376

Table 3.3. R^2 for Each Covariate Analyzed by Month. Noteworthy values (R^2>0.25) are highlighted in gray.

Covariate	January	February	May	August	November
Temperature	0.001	0.034	0.043	0.011	0.102
Dissolved Oxygen	0.035	0.000	0.066	0.004	0.057
Salinity	0.001	0.006	0.001	0.000	0.001
Velocity	0.029	0.001	0.062	0.000	0.004
Mean Depth	0.005	0.062	0.001	0.003	0.000
Mean Beach Slope	0.039	0.304	0.061	0.128	0.055
Habitat Stratum	0.374	0.223	0.209	0.030	0.219
RHA % emergents	0.008	0.096	0.005	0.003	0.006
RHA dominant substrate type	0.114	0.180	0.011	0.020	0.017

3.2.1 January 2009

Only habitat stratum (=type) was a significant (*P*=0.0016) covariate for January 2009 (Table 3.1, Figure 3.2). Estimated salmon density was highest (0.0108 fish/m^2) in the off-channel habitat category (Table 3.4).

Table 3.4. Estimate Salmon Density (#/m^2) by Habitat Stratum, January 2009

Habitat Stratum	Estimated Salmon Density (s.e.)
Confluence	0.0032 (0.0024)
Main channel	0.0071 (0.0031)
Main-channel island	0.0037 (0.0031)
Off-channel	0.0108 (0.0053)
Off-channel island	0.0031 (0.0017)
Wetland channel	0.0291 (0.0053)

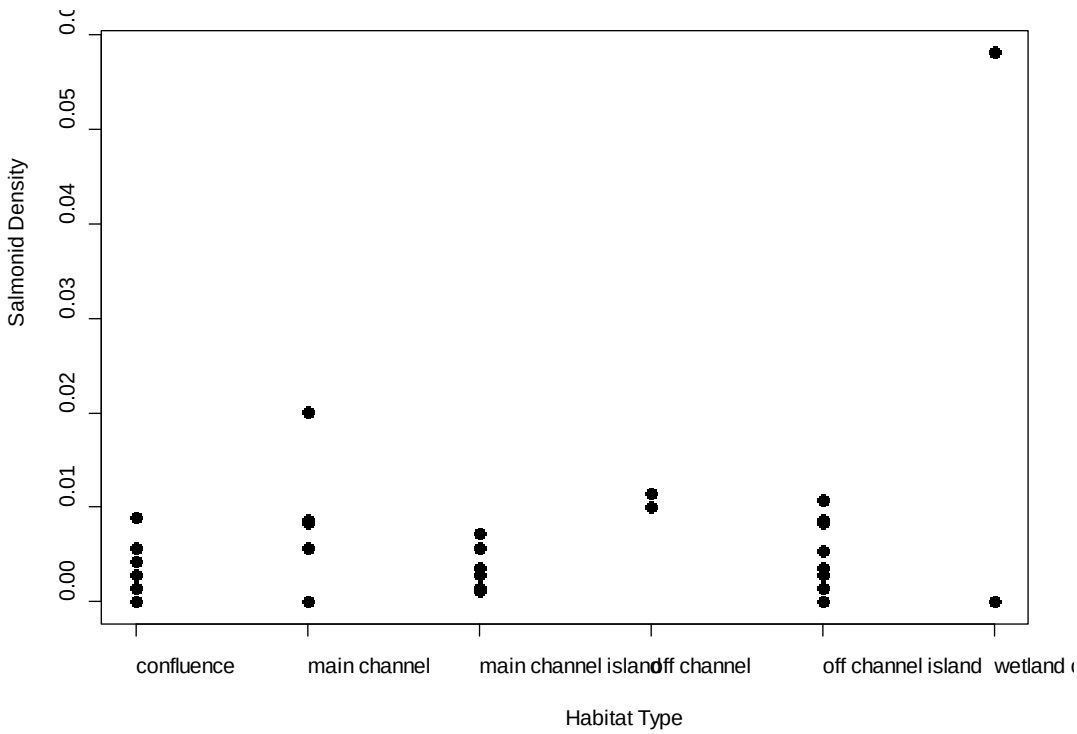

Figure 3.2. Plots of Significant Variables Against Density, January 2009

3.2.2 February 2009

Mean beach slope, habitat type, mean emergent vegetation, and quantitative dominate substrate type were all significant (*P*<0.10) covariates for February 2009 (Figure 3.3). The relationships for the significant continuous covariates, mean beach slope and mean emergent vegetation, were negative and positive, respectively (Table 3.5). Estimated salmon density was highest (0.0364 fish/m^2) in the wetland channel habitat type (Table 3.6) and highest (0.0366 fish/m^2) in the coarse substrate (Table 3.7).

Table 3.5. Regressions for Significant Continuous Covariates, February 2009

Continuous Covariate	Regression Result
Mean beach slope	$salmon.density = 0.0295\,(\widehat{s.e.} = 0.0076) - 0.2825\,(\widehat{s.e.} = 0.1143) * mean.beach.slope$
Mean emergent vegetation	$salmon.density = 0.0038\,(\widehat{s.e.} = 0.0032) - 0.0002\,(\widehat{s.e.} = 0.0001) * mean.emergent.veg$

Table 3.6. Estimated Salmon Density (fish/m^2) by Habitat Stratum, February 2009

Habitat Stratum	Estimated Salmon Density (s.e.)
Confluence	0.0158 (0.0042)
Main channel	0.0096 (0.0039)
Main-channel island	0.0023 (0.0047)
Off-channel	0.0158 (0.0095)
Off-channel island	0.0067 (0.0030)
Wetland channel	0.0364 (0.0095)

Table 3.7. Estimated Salmon Density (#/m^2) by Substrate Type, February 2009

Qualitative Dominate Substrate Type	Estimated Salmon Density (s.e.)
Coarse	0.0366 (0.0096)
Cobble	0.0065 (0.0096)
Fine	0.0145 (0.0039)
Sand	0.0071 (0.0022)

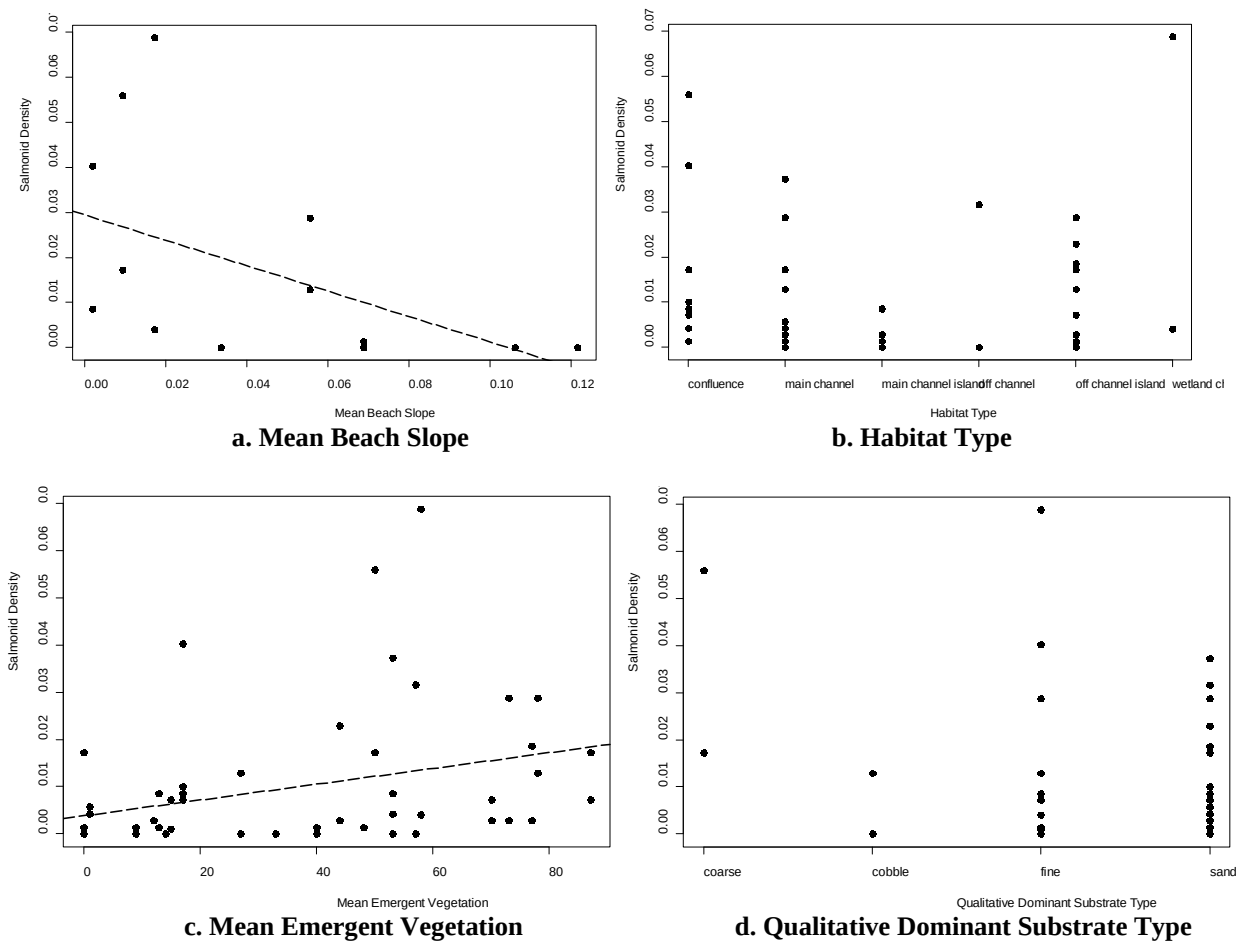

Figure 3.3. Plots of Significant Variables Against Salmon Density, February 2009. Linear regression results (dashed line) are included on plots that have continuous variables.

3.2.3 November 2009

Temperature was found to be the only significant (P<0.05) covariate for November 2009 (Figure 3.4). The relationship between the significant continuous covariate, water temperature, and juvenile salmon density was negative (Table 3.8).

Table 3.8. Regression for the Significant Continuous Covariate, November 2009

Continuous Covariate	Regression Result
Temperature	$salmon.density = 0.0409\,(\widehat{s.e.} = 0.0158) - 0.0038\,(\widehat{s.e.} = 0.0017)\,{*}temperature$

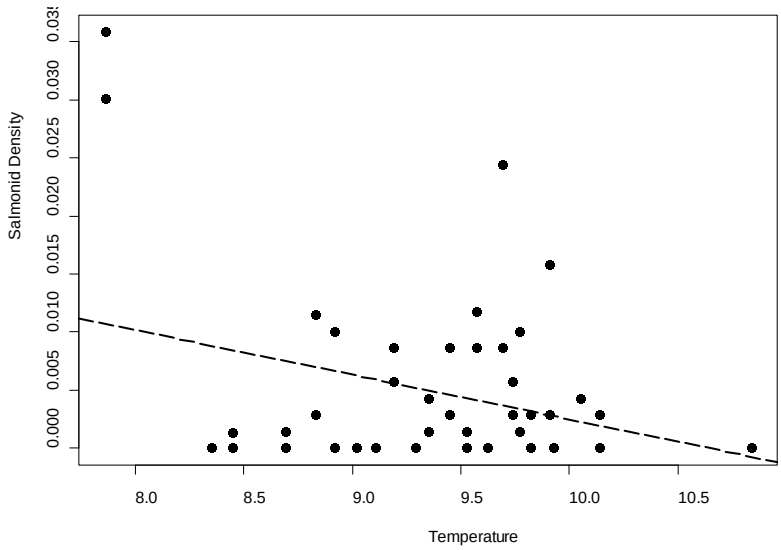

Figure 3.4. Plots of Significant Variables Against Salmon Density, November 2009

3.3 Discussion

The statistical approach to examining relationships between salmon density and habitat attributes did not reveal any consistent patterns. Plots of the significant covariates showed that, although significant, the relationship between salmon density and habitat conditions was tenuous with almost all statistically significant plots having a few outlying densities with large leverage and a high degree of variation. We had anticipated that expanding sampling into the LRR would diversify the data set and allow us to identify key habitats used by juvenile salmon. However, an analysis of salmon density variance conducted in 2009 indicated the within-site variability among replicate net sets was twice as large as the between-site variability with coefficients of variation of 1.514 vs. 0.731 (Sather et al. 2009). In other words, the within-site standard deviation between samples was 150% larger than the mean salmon density. This level of variability in salmon density can obscure between-site differences and relationships between salmon density and habitat attributes.

One approach to attempting to decrease variability is to increase sample size. Because the analysis reported here was limited to five sampling episodes (months) when data were collected at sites in both the SRD and LRR, data collected subsequently in February 2010 should be included in a new analysis. The LRR sites expanded the spatial extent and diversity of sampling sites. Therefore, all data from the LRR sites should be analyzed. Similarly, we now have 35 consecutive months of sampling at the SRD sites that has yet to be analyzed for salmon/habitat relationships.

Improvements in the analysis of salmon/habitat relationships could also be made in the independent variables. The habitat strata definitions, e.g., off-channel and wetland, are broad categories such that two sites under the same category could be ecologically different from each other. The report, *Columbia River Estuary Ecosystem Classification System* (Simenstad et al. In Review) will provide hierarchical

habitat categories[1] that could be applied to obtain tighter habitat categories than previously available. Water-surface elevation and temperature data downloaded from in situ loggers after the study period ended on April 30, 2010, are also available for future analyses. Diefenderfer et al. (2010) developed a habitat connectedness index for the extent to which a site is connected to the main LCRE channel that also could be an informative independent variable.

3.4 Summary, Conclusions, and Recommendations

The following conclusions and recommendations arise from the analysis of habitat attributes and salmon density data:

- Consistent relationships between salmon density and macro-habitat features, environmental conditions, and structural attributes were not apparent. Assuming salmon density indicates relative importance, no single or suite of macro-habitat features, environmental conditions, or structural attributes emerged in our analysis as most important for juvenile salmon in shallow tidal freshwater.
- Habitat restoration should include a variety of habitat types to support variable use temporally and spatially by a diversity of life stages and species of juvenile salmon.
- Additional data obtained in 2010 after the analysis reported here was conducted should be analyzed. Furthermore, habitat attributes not included in the original analysis, such as RHA percentage sapling plants and bare ground, should be considered, as well as habitat categories from the Columbia River Estuary Ecosystem Classification System when the estuary-wide version is released in 2011.

[1] Hydrogeomorphic ***reaches*** embody the formative geologic and tectonic processes that created the existing estuarine landscape and encompass the influence of the resulting physiography on interactions between fluvial and tidal hydrology and geomorphology across 230 km of estuary. Ecosystem ***complexes*** within each reach may include 18 or more classes of “patches” and “corridors” that form the estuarine mosaic, which was created predominantly by Holocene disturbance regimes and still actively modified by natural processes. Geomorphic ***catena*** are embedded within ecosystem complexes and represent distinct geomorphic structures, ecosystems, and habitats. These three components of the estuarine landscape are most likely to change over short time periods (after Simenstad et al. In Review).

4.0 Feeding Ecology

Prepared by Adam Storch and Nikki Sather

A growing body of evidence suggests shallow-water habitats in the tidal freshwater portion of the LCRE are crucial to salmon early life histories (Fresh et al. 2005; Sobocinski et al. 2008; Sather et al. 2009). Yet, a dearth of empirical data characterizing the feeding ecology of juvenile salmon in these areas remains. Understanding the roles of various prey resources in a consumer's diet and knowledge of the availability of prey in the environment are fundamental to elucidating factors that may constrain or promote growth and survival in certain habitats. For example, through comparisons of diet coupled with bioenergetics analysis, Madenjian et al. (1998) found lake trout in nearshore waters of Lake Michigan grow faster than those residing on an offshore reef due to differences in the availability of appropriate prey. Similarly, Richardson (1993) noted considerable evidence showing growth rates and densities of lotic salmonids are positively related to prey supply.

While the availability of high-quality prey resources in shallow tidal freshwater habitats of the LCRE is likely an important driver of biomass production dynamics for juvenile salmon, the adoption of feeding strategies that maximize net energy gain (i.e., optimal foraging strategy; Gerking 1994; Werner and Hall 1974) likely also contributes to favorable growth and survival. Graeb et al. (2004) found large larval yellow perch (*Perca flavescens*) that selected cladocerans and adult copepods over copepod nauplii experienced enhanced growth and survival. Miller et al. (1990), in a series of laboratory experiments, found that bloater (*Coregonus hoyi*) show greater preference for larger prey items with increasing size. The authors further identified reduced growth when bloaters were denied access (e.g., low prey availability) to larger-bodied zooplankton, suggesting the availability of appropriate sizes of prey could have substantial impacts on the growth of juvenile fish and subsequent recruitment. Thus, identifying general feeding behaviors—particularly related to consumer preference—in addition to quantifying the availability of important prey items, should help elucidate the suitability of tidal freshwater habitats in the LCRE for promoting growth and the ability of juvenile salmon in these areas to exploit high-quality prey resources.

The objectives of this work at LCRE sites near the SRD were to 1) quantify the diet composition of juvenile Chinook salmon; 2) assess the relative importance of prey organisms in the Chinook salmon diet; and 3) evaluate foraging behavior including prey selection. By characterizing diet and prey pool composition and applying index models to empirical data, we examined the roles of various prey taxa in the diets of juvenile Chinook salmon and characterized feeding strategies in areas of the LCRE to draw conclusions about the ability of specific tidal freshwater habitats to support juvenile salmon.

4.1 Methods

To characterize the diet composition of juvenile Chinook and prey availability in specific tidal freshwater habitats of the LCRE, data were collected at nine sites in the SRD from March 2008 through April 2010 (see Chapter 2, Figure 2.1). At the same SRD sites, prey availability samples were collected during June, September, and December 2009 and March 2010.

4.1.1 Field Sampling

When possible, juvenile Chinook salmon were collected monthly (March 2008–April 2010) at each site using either a 30.5-m beach seine (3-m depth; 5-mm knotless mesh) or a 46-m beach seine (3-m depth; 13-mm knotless mesh wings; 3-mm knotless mesh purse) (see Chapter 2). Typically, we deployed the seines by boat; however, if water depth was too low or site accessibility was poor at the time of sampling, nets were deployed by foot. After each haul, we removed fish from the net and placed them in holding buckets filled with river water at ambient temperature. Aerators were used to maintain adequate levels of dissolved oxygen in the holding water. To minimize handling stress, salmon were anaesthetized using a 40-mg/L MS-222 solution.

Lengths of captured salmon were measured to the nearest millimeter and, whenever possible, individuals were weighed (to the nearest 0.01 g). We used gastric lavage to remove stomach contents from juvenile Chinook salmon that were greater than or equal to 50-mm in fork length. Gastric lavage has been reported to be 99% effective at removing prey organisms from the stomachs of coho salmon with no impacts on their survival (Meehan and Miller 1978). At each site, contents from the digestive tracts of up to 20 Chinook salmon were flushed into individual polyethylene sample bottles using filtered river water at ambient temperature. Following lavage, samples were preserved in a 10% ethanol solution to slow degradation. Within 24 hours, all samples were preserved in a 70% ethanol solution for later analysis. After field processing, anaesthetized individuals were held in a container filled with river water at ambient temperature and dissolved oxygen until they fully recovered. Salmon were then released at or near their site of capture.

To characterize prey community compositions, we used a combination of benthic, drift, and terrestrial sampling methods. Benthic samples were collected quarterly at each site using a standard ponar dredge (232 cm^2). Duplicate samples were collected from each site at two points parallel to the shore. Upon retrieval, the contents of the dredge were emptied into a 1-L sample bottle, preserved with 70% ethanol, and labeled appropriately. All samples were stored in a cooler for transport.

Samples of drifting invertebrates were collected with drift nets (363-µm mesh) deployed at each site. Gear was oriented with openings facing upstream, and when possible (i.e., depending on water levels) approximately 3 m and 6 m from the existing waterline. Nets were set so that the bottom of the frame was positioned vertically at half the height of the water column. Because drift tends to vary throughout the day, with maximum drift occurring commonly at sunrise and sunset (Rabeni 1996), all nets were set for approximately 24 hours. After the effective sampling period had concluded, gear was retrieved and the mesh was rinsed with filtered river water to collect material in the cod end of the seine. Contents were then rinsed into a 1-L sample bottle, preserved with 70% ethanol, and labeled accordingly. As with the benthic samples, all samples were stored in a cooler for transport to the laboratory. Whenever possible, at both the beginning and the end of sampling periods, instantaneous flow readings were recorded at the mouth of each net.

Terrestrial or winged organisms were sampled using fallout traps. Traps measured 55 cm x 37 cm x 13 cm and were filled with a solution of filtered river water and liquid detergent/surfactant. Duplicate traps were set parallel to the shore downstream of drift nets for a period of 48 hours. Upon retrieval, the contents of each trap were poured through a 250-µm sieve and rinsed gently with filtered river water. Prey captured in the sieve were transferred to a 1-L sample bottle, preserved with 70% ethanol, and labeled.

4.1.2 Laboratory Procedures

In the laboratory, prey items in diet samples randomly selected from each site-sampling period combination (hereafter sampling episode) were identified to the lowest classification practicable using standard taxonomic keys (e.g., Merritt and Cummins 1996). Partially degraded organisms were identified based on paired or individual characteristic structures. Prey items of the same taxon and life-history stage were counted and placed in labeled centrifuge vials containing 70% ethanol solution. Subsequently, whole animals stored in the centrifuge vials were weighed (blotted dry), individually or as a group depending on size, to the nearest 0.001 g. Unidentifiable appendages or insect exuviae encountered in diet samples were not included in the prey counts.

Whenever possible, entire samples collected to characterize prey communities were enumerated with the aid of standard taxonomic keys (e.g., Merritt and Cummins 1996). However, when sample prey densities were large, subsampling procedures were used.

Benthic samples containing high densities of prey were subsampled according to procedures adapted from Boward and Friedman (2000). Prior to inspection, individual samples were poured through a 500-µm sieve held over a collection bucket to remove preservative and fine sediment. Sample contents remaining in the sieve were then rinsed gently with tap water to remove any residual preservative. Large debris, including sticks and leaves, was cleaned with a scrub brush to remove any clinging organisms. The contents of the sieve were rinsed into a sampling tray partitioned into 81 49-cm^2 cells. After each sample had been rinsed completely onto the tray, the contents were homogenized and spread evenly over an appropriate number of cells. One cell was selected at random, and the contents were then placed in a watch glass. Organisms transferred to the watch glass were identified and enumerated by taxon. If the total number of organisms encountered in the watch glass did not meet or exceed 120 organisms, further randomly selected cells were processed until the target number of organisms was met or the entire sample had been enumerated. The number of organisms within each taxon for the entire sample was then estimated based on subsample counts, the number of subsamples (i.e., cells) enumerated, and the total number of cells covered by the sample. Prey densities ($\#/m^2$) were estimated by dividing sample counts by the area of the ponar dredge opening.

Drift samples were subsampled according to published protocols (Mills et al. 1992; Storch et al. 2007). The contents of sample bottles were poured individually through a 60-µm sieve to remove preservative. The samples were then rinsed into a graduated beaker with filtered water and further diluted to a whole volume. Two 1-mL aliquots were withdrawn from the known-volume dilution of organisms and placed in separate watch glasses. Organisms in the two aliquots were identified and enumerated, after which counts were compared to ensure a difference equal to or less than 10%. If necessary, additional aliquots were removed until the 10% benchmark was achieved. The total numbers of prey items in the sample were then estimated by direct proportion. To estimate prey densities within drift samples, hydrographs for the lower Columbia River (i.e., below Bonneville Dam), recorded over the respective drift-sampling periods, were adjusted to beginning and ending instantaneous flow recordings and applied to estimate the total volume (m^3) of water flowing through each net.

When necessary, the subsampling procedure used for drift samples was applied to fallout samples. Prey densities were calculated by dividing sample counts by the area of the fallout trap. However, because sampling intervals varied among sampling episodes, densities were further standardized according to duration. The final unit of density for fallout samples was calculated as individuals per square meter per hour.

4.1.3 Data Analyses

Study data were analyzed to determine the relative importance of prey in the fish diet and prey selection patterns.

4.1.3.1 Relative Importance

To assess the importance of specific prey items in the diet, we calculated Index of Relative Importance (IRI) values (Pinkas et al. 1971; Eq. 4.1). These values were then standardized as percent IRI (%IRI) values (Cortés 1997) for each applicable sampling episode, to allow for direct comparisons among different food types. The IRI is a compound model combining information about a consumer's diet in terms of number, biomass, and frequency as follows:

$$\mathrm{IRI_i} = \%\mathrm{O_i}(\%\mathrm{W_i} + \%\mathrm{N_i}) \tag{4.1}$$

where

i = one of n different prey types

$\%\mathrm{O_i}$ = prey type i is frequency of occurrence (i.e., the proportion of the analyzed fish that held prey i)

$\%\mathrm{N_i}$ = proportion of prey item i by number

$\%\mathrm{W_i}$ = proportion of prey item i by mass.

To represent the diet of Chinook salmon in different tidal freshwater habitats in the SRD, IRI values were calculated by averaging the numbers and biomasses of individual prey found in gut contents during each sampling episode and then calculating a single composite score.

These composite IRI scores were then standardized to fall within a discrete scale (i.e., 0–100; Cortés 1997; Eq. [4.2]):

$$\%\mathrm{IRI_i} = \frac{100 * \mathrm{IRI_i}}{\sum_{i=1}^{n} \mathrm{IRI}_i} \tag{4.2}$$

Although %IRI values were calculated for all prey taxa encountered in diet samples (Appendix F), for simplicity, only taxa for which the weighted mean %IRI was ≥10% are presented in the results section below.

4.1.3.2 Prey Selection

We applied a stepwise approach for examining the feeding behavior of juvenile Chinook salmon in tidal freshwater habitats. The initial calculation, the selectivity coefficient (Eq. [4.3]; Vanderploeg and Scavia 1979a), summarizes the relative proportion of prey items within a particular site in relation to the

proportion of those prey items within Chinook salmon diets. The second calculation, the Relativized Electivity Index (Eq.[4.4]; Vanderploeg and Scavia 1979b), conveys the degree to which Chinook salmon are selecting or avoiding a particular prey item. The selectivity coefficient (W_i), derived from the Ivlev forage ratio ($E'_i = r_i/p_i$; Ivlev 1961), normalizes values so the sum of ratios for all prey types in a sample equals one. The coefficient reflects the consumer's perceived value of a food item in relation to the abundance of that prey item and the abundance of other available food (Lechowicz 1982) as follows:

$$W_i = \frac{r_i/p_i}{\sum_i^n r_i/p_i} \tag{4.3}$$

where p_i is the proportion of the total number of food type i in the environment and r_i is the proportion of the total biomass of food type i in the diet.

The Relativized Electivity Index (E*) standardizes W_i so that predator preference ranges from -1.0 to 1.0, where a value of -1 indicates complete avoidance of a particular prey item, 0.0 indicates that the prey item is consumed in proportion to its abundance in the environment, and 1.0 denotes complete selection for the prey type (Storch et al. 2007). The Relativized Electivity Index is calculated as follows:

$$E_i^* = \frac{W_i - (1/n)}{W_i + (1/n)} \tag{4.4}$$

where W_i is the selectivity coefficient (see Eq. [4.3]) and n is the number of taxonomic categories.

As for %IRI calculations, single electivity coefficients were calculated by averaging numbers of individual prey found in gut contents during each sampling episode to represent generalized foraging behavior (Storch et al. 2007). When a taxon was encountered in the diet but not in the environment, we assigned that prey item a count of one before calculating proportions (i.e., p_i in Eq. [4.3]). By doing this, we assumed there was at least one individual in the environment available for consumption; however, the taxon was sufficiently rare, thereby limiting the ability of our gear to sample that prey item effectively.

We collected samples to represent three potential sources of prey for juvenile Chinook salmon: benthos, drift, and fallout (i.e., terrestrial or winged prey). Because estimated prey densities necessarily have different units among the three prey pools (i.e., benthos, individuals/m^2; drift, individuals/m^3; fallout, individuals/m^2/hr), electivity index values were calculated for each prey source individually. To achieve this, based on the life stage of prey items and/or knowledge of its general behavior, diet data were coded according to where in the environment a particular prey item was most likely to be encountered by a juvenile salmon. For example, although it is possible that a predator could encounter *Daphnia* spp. in the benthos, because the crustacean is planktonic, the likelihood is greater that the invertebrate was consumed in the drift.

Many prey items encountered in gut content samples could not be easily assigned to a specific habitat. To account for the uncertainty associated with prey taxa that could be encountered by a fish either in the benthos or the drift (hereafter termed " ambiguous" taxa), the electivity model was applied to gut content data matrices where 1) 50% of ambiguous prey were attributed to foraging in the drift, 2) 50% of ambiguous prey were attributed to foraging in the benthos, 3) 100% of ambiguous prey were attributed to foraging in the drift, and 4) 100% of ambiguous prey were attributed to foraging in the benthos.

4.2 Results

Knowing the juvenile salmon diet composition, the relative importance of prey in the diet, and prey selection by juvenile salmon is essential for understanding the ecological importance to juvenile salmonids of tidal freshwater habitats in the LCRE. Basic prey electivity and %IRI data are presented in Appendices E and F, respectively.

Analyses of gut contents conducted on fish collected at sites near the SRD showed that throughout the year juvenile Chinook salmon foraged consistently on aquatic and terrestrial insects, and less commonly on crustaceans, worms, arachnids, and larval or juvenile fishes. Prey collected from the sampled environment consisted of benthic, drifting, and winged or terrestrial organisms. Benthic samples were composed primarily of several insect groups, mollusks, and large crustaceans including scuds and opossum shrimp. Drift samples were dominated by small crustaceans (e.g., water fleas, copepods, and seed shrimps), various insect groups, and arachnids. Although present, large crustaceans such as those found in the benthos were encountered infrequently in the drift. Samples collected using traps designed to help characterize winged or terrestrial prey items, consisted almost exclusively of insects. Spiders were also encountered in these samples, but constituted only small proportions.

4.2.1 Diet Composition

Across the nine sites sampled from March 2008 through April 2010, the diets of juvenile Chinook salmon were generally dominated by dipterans (primarily chironomids and ceratopogonids), hemipterans, and malacostracans (Amphipoda and Mysidae) (Figure 4.1). Of these taxa, dipterans consistently constituted large proportions of the gut content biomass, accounting for more than 20% of the diet during 86 of 109 (79%) sampling episodes in which non-empty gut content samples were collected. While no other single prey item contributed to juvenile Chinook salmon gut contents to the same extent as dipterans, periodically hemipterans and malacostracans combined to constitute large proportions of the gut content biomass (>20% of the diet during 36% of sampling episodes; Figure 4.1).

Non-dipteran aquatic insects (e.g., Plecoptera and Ephemeroptera) periodically contributed substantial proportions to the gut content biomass of juvenile Chinook salmon, but much less frequently than dipteran taxa (>20% of the diet in approximately 9% of sampling episodes). Although appreciable contributions of terrestrial insects (composed primarily of Formicidae and Aphididae) and non-malacostracan crustaceans (Cladocera, Copepoda, and Ostracoda) occurred infrequently (>20% of the diet in approximately 8% and 6% of sampling episodes, respectively), maximum proportions were large (0.63 and 0.50, respectively). The “Fish” category—composed of embryonic, larval, and juvenile life stages—was represented at most sites, restricted to few applicable sampling months at any one location. The largest biomass proportions of prey items included in the “Other” category (Annelida, Arachnida, Mollusca, Nemata, Nematomorpha, plant material, Platyhelminthes, Rotifera), were encountered during fall or early spring months, with the maximum proportion occurring at Site I (49%) (for a description of Site I, see Section 2.1.1 and Figure 2.1). Because of degradation resulting from digestive processes, some prey items found in gut content samples could be identified no further than class (i.e., Insecta). While biomass proportions of “Unidentified Insecta” were at times large, prey items included in the category were relatively rare and encountered typically when sample sizes were low (Figure 4.1).

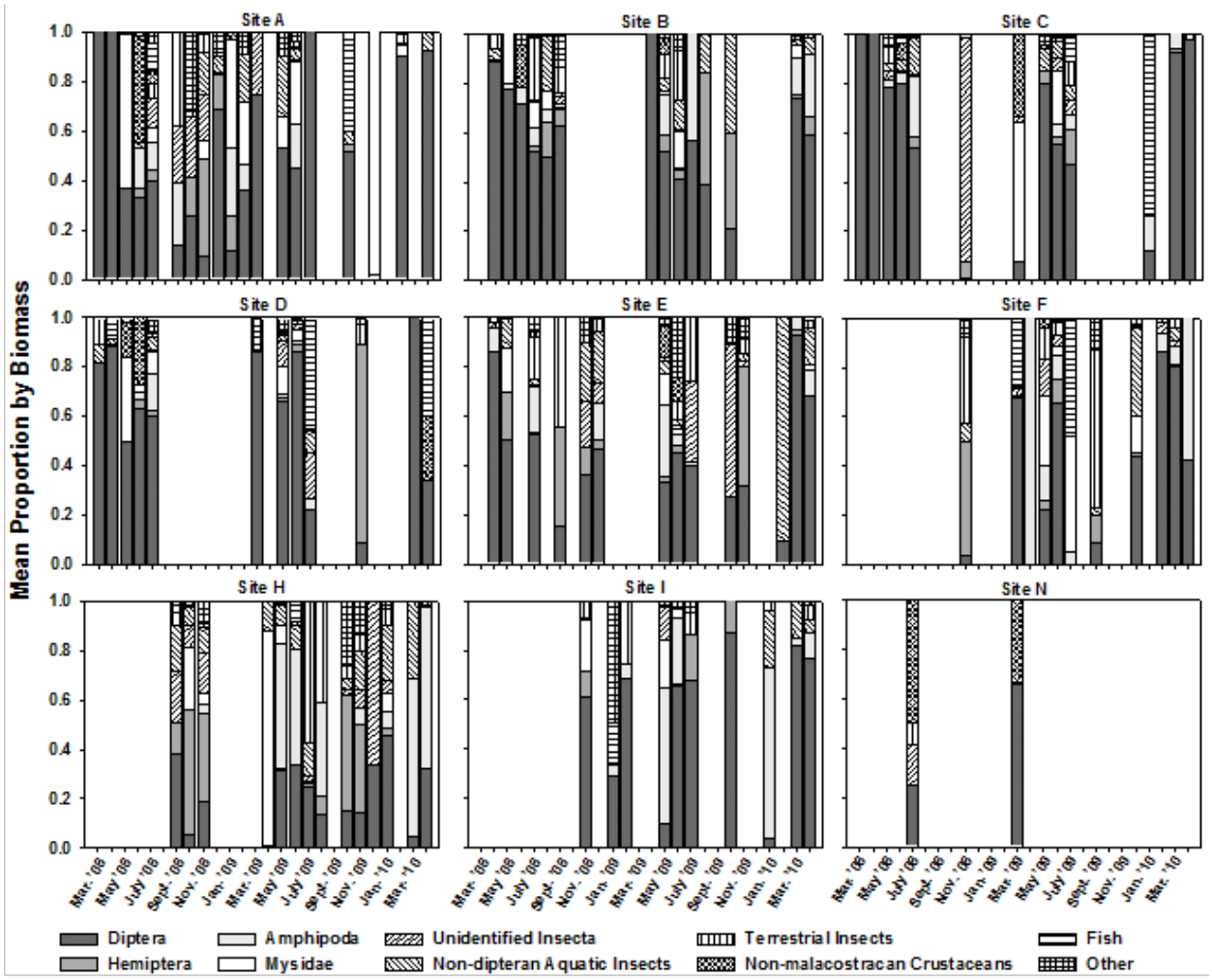

Figure 4.1. Distribution of Biomass Proportions of Major Prey Categories Found in the Gut Contents of Chinook Salmon. Missing data indicate episodes in which sampling was not conducted or no Chinook salmon of a size appropriate for gastric lavage were encountered.

4.2.2 Relative Importance

Trends in %IRI largely mirrored those described by biomass proportions (c.f., Figures 4.1 and 4.2). Dipterans, hemipterans, amphipoda, and mysids were generally the most important prey taxa, representing a combined mean %IRI value of 69.2% ± 24.9 s.d. with a range of 3.2% to 100.0% over all sampling episodes. Of these taxa, dipterans typically were found to be most important; however, %IRI values for dipterans varied considerably among sampling episodes (mean %IRI = 44.81% ± 30 s.d., range from 0.0% to 100.0%). Despite this variability, dipterans were associated with %IRI scores of 50% or greater during approximately 40% of all sampling episodes.

Hemipterans, amphipods, and mysids were associated with large %IRI values less frequently than the dipterans. Particularly during the late fall-winter months, aquatic/semiaquatic hemipterans were important components of the diet, whereas high %IRI values for amphipods and mysids appeared to be largely unrelated to sampling episode (Figure 4.2).

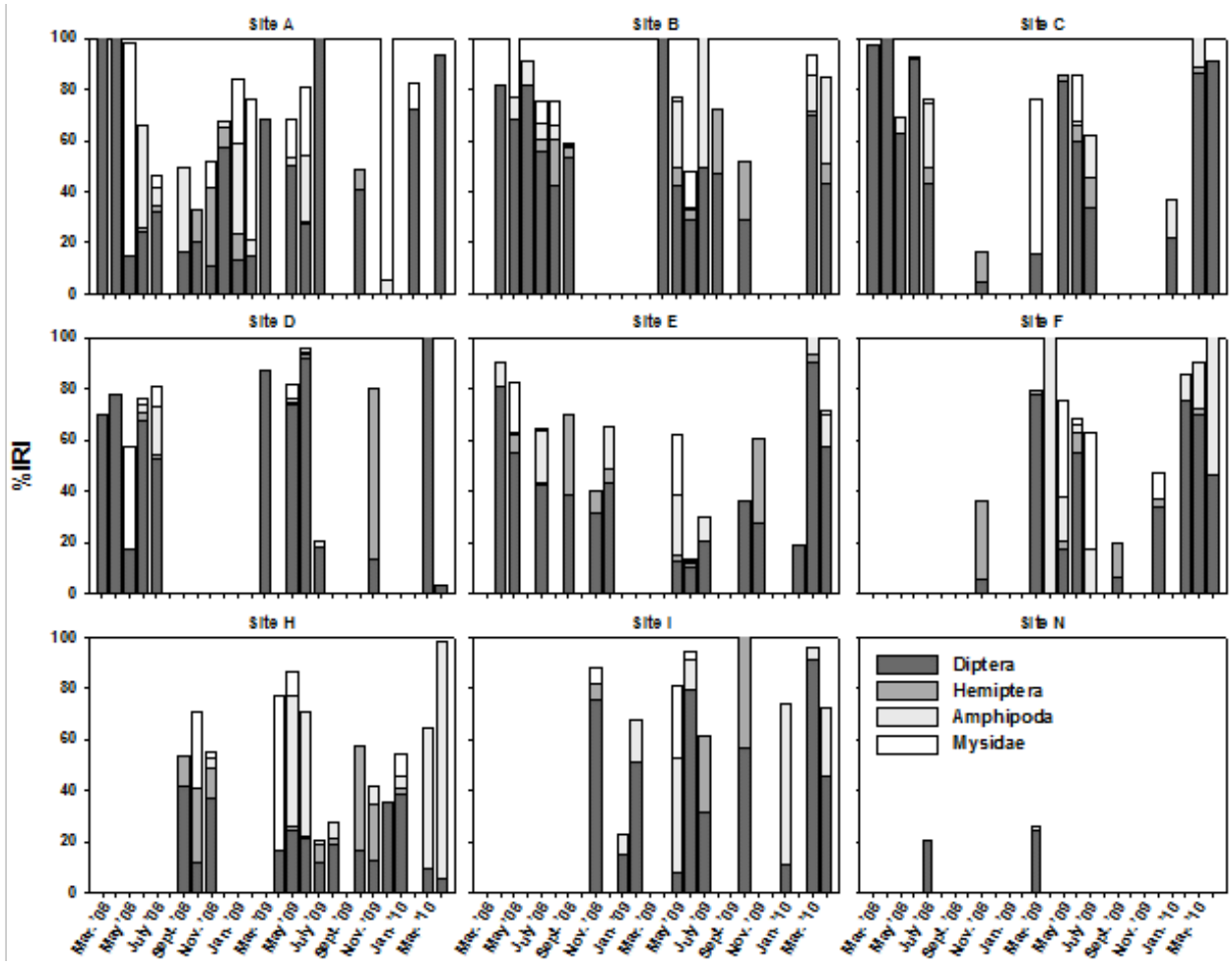

Figure 4.2. Distribution of %IRI Values for Major Prey Categories Found in the Gut Contents of Juvenile Chinook Salmon. Missing data indicate episodes in which sampling was not conducted or no Chinook salmon of a size appropriate for gastric lavage were encountered.

4.2.3 Prey Selection

Apportioning ambiguous diet items had little effect on calculated electivity values and consequently conclusions that may be drawn from model output. Thus, only instances in which this partitioning changed interpretation of a result are highlighted in the corresponding section. Because %IRI values identified four taxa generally to be most important across sampling episodes (Diptera, Hemiptera, Amphiopoda, and Mysidae; Figure 4.2), electivity values for only these prey items are discussed below.

4.2.3.1 Benthic Prey

In general, across most sites, juvenile Chinook salmon selected against *benthic* dipterans and did not consume the prey item in proportion to its abundance in the environment (i.e., $E^* = 0.0$) (Figure 4.3). Exceptions to the trend of negative selection for dipterans occurred at Site C during March, Sites D and I during both June and March, where the invertebrate was selected for. Alternatively, compared to electivity index values for dipterans, those calculated for hemipterans were less consistent both spatially and temporally. During June, aquatic/semiaquatic hemipterans were selected against at Sites A, B, and D,

and selected for at Site E. During months when amphipods and mysids were encountered in gut content and/or benthic samples, the malacostracans were generally a preferred prey item and were not consumed in proportion to their abundance in the environment. Amphipods were selected for during June at Sites A, C, D, and F, during December at Site A, and during March 2010 at Sites B, C, E, F, H, and I. Conversely, the prey item was selected against during June at Sites B, E, H, and I. Mysids, much like amphipods, were largely selected for in the benthos. The crustacean was preferred prey during June at Sites A, B, C, D, F and I, during December at Sites A and F, and during March at Site B. Selection against mysids occurred only during June at Site E (Figures 4.3 and 4.4).

4.2.3.2 Drifting Prey

Apportioning ambiguous prey affected model output in two instances of electivity calculations for drifting prey (c.f., Figures 4.5 and 4.6). At Site C during June, when 100% of the ambiguous prey was attributed to the drift prey pool, juvenile Chinook salmon preferred amphipods. When half of the ambiguous prey was attributed to foraging in the drift, there was a slight selection against the crustacean. However, the magnitude of this shift was relatively small (i.e., in both cases, E^* approached 0.0). Similarly, at Site F during December 2009, when 100% of ambiguous prey was attributed to foraging in the drift, mysids were selected for, whereas the malacostracan was consumed in proportion to its abundance in the environment when only 50% of the ambiguous prey consumed was assigned to drift. When considering the drift prey pool, there were few sampling episodes in which juvenile salmon selected for dipterans: during December at Sites C, D, and E. Otherwise, dipterans were selected against and never consumed in proportion to their abundance in the water column. When hemipterans were encountered in gut content and/or drift samples, they were selected against, except at Site B during June 2009, when the taxon appeared to be a preferred prey item. As in the benthos, amphipods were commonly preferred prey, selected for at Sites A, C, D, and H during June of 2009, Site A during December 2009, and Sites B, C, E, H, and I during March of 2010. The crustacean was selected against during June 2009 at Sites B, E, F, and I, and at Site F in September 2009 and March 2010, respectively. Mysids were largely a preferred prey item, and were never consumed in proportion to their abundance in the water column, except during June 2009 at Site E, and at Sites B and H during March 2010 when the malacostracan was selected against (Figures 4.5 and 4.6).

4.2.3.3 Terrestrial and Winged Prey

As in the benthos and the drift prey, winged and terrestrial dipterans generally were selected against. The single exception occurred during March 2010 when dipterans were a preferred prey item. Unlike electivity values calculated for either the benthos or drift, hemipterans in the fallout were largely selected for or consumed in proportion to their abundance in the environment. Both dipterans and hemipterans were consumed in proportion to their abundance in the environment during March 2010 at Sites D and F, respectively (Figure 4.7).

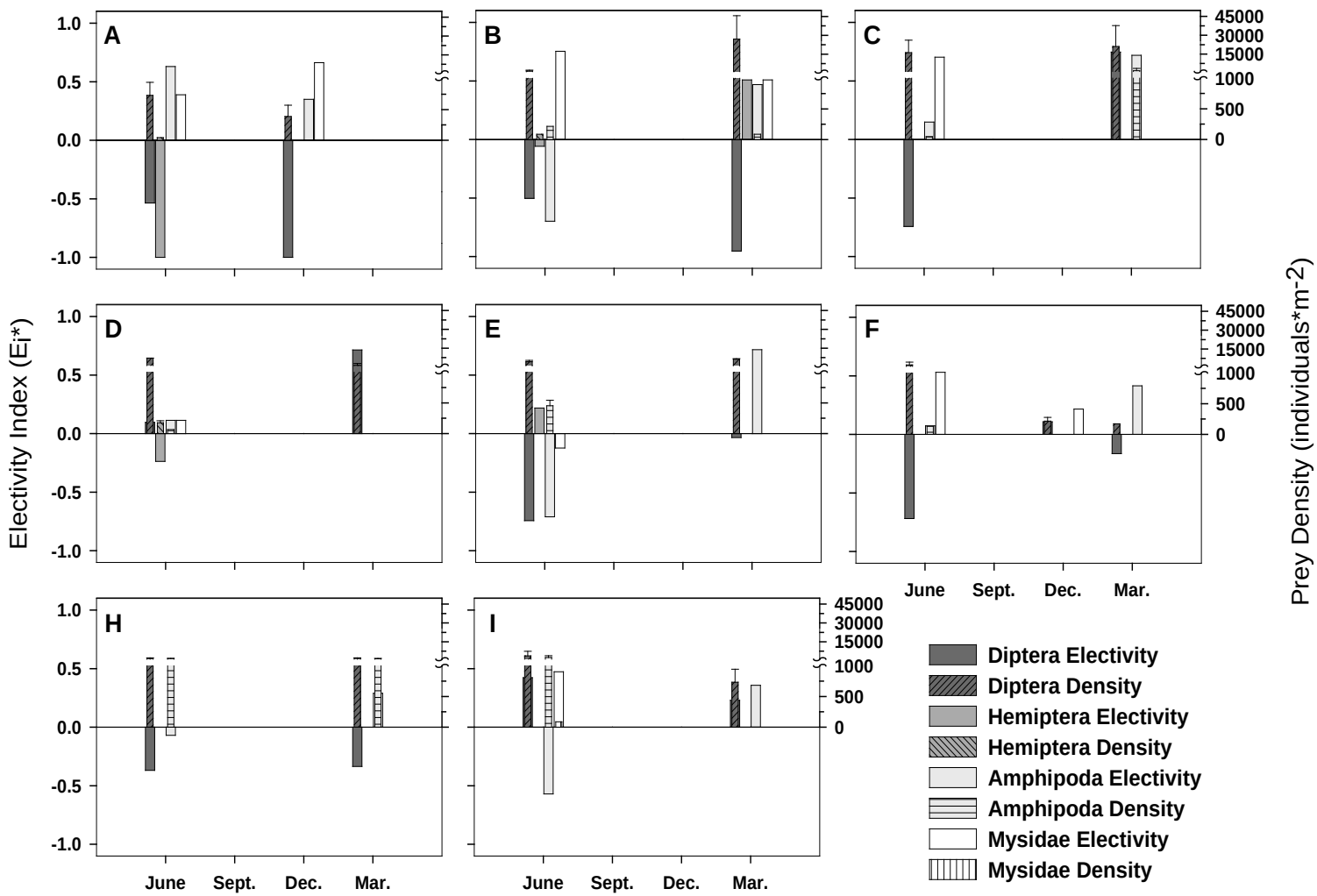

Figure 4.3. Relativized Electivity Index Values for Major Benthic Prey Items (100% Scenario). Values were calculated with 100% of the "ambiguous" prey items allocated to benthic production. Instances where a prey item was consumed in proportion to its abundance in the environment ($E^* = 0.0$) are identified in the text. Otherwise, see Appendix E for justifications of missing data.

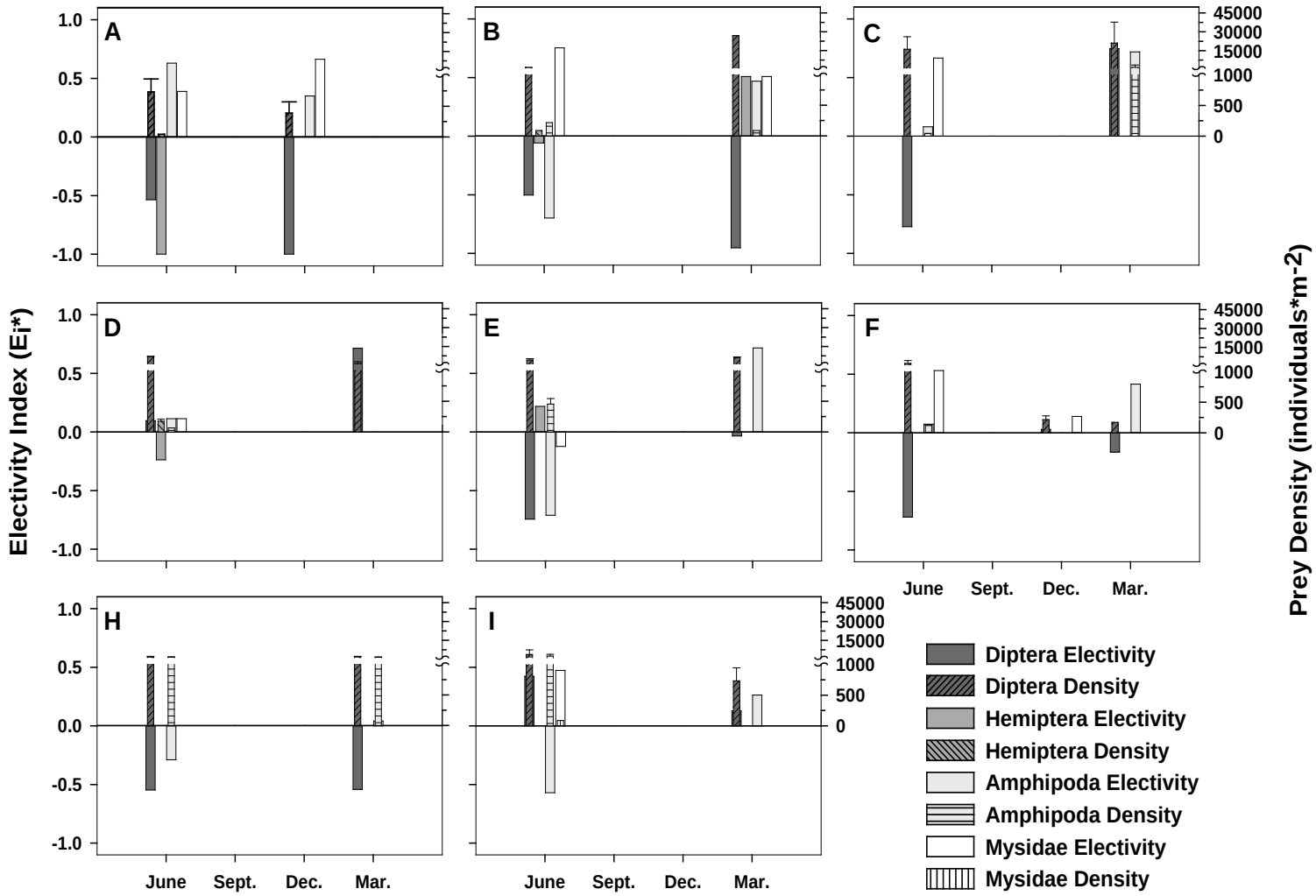

Figure 4.4. Relativized Electivity Index Values for Major Benthic Prey Items (50% Scenario). Values were calculated with 50% of the "ambiguous" prey items allocated to benthic production. Instances where a prey item was consumed in proportion to its abundance in the environment ($E^* = 0.0$) are identified in the text. Otherwise, see Appendix E for justifications of missing data.

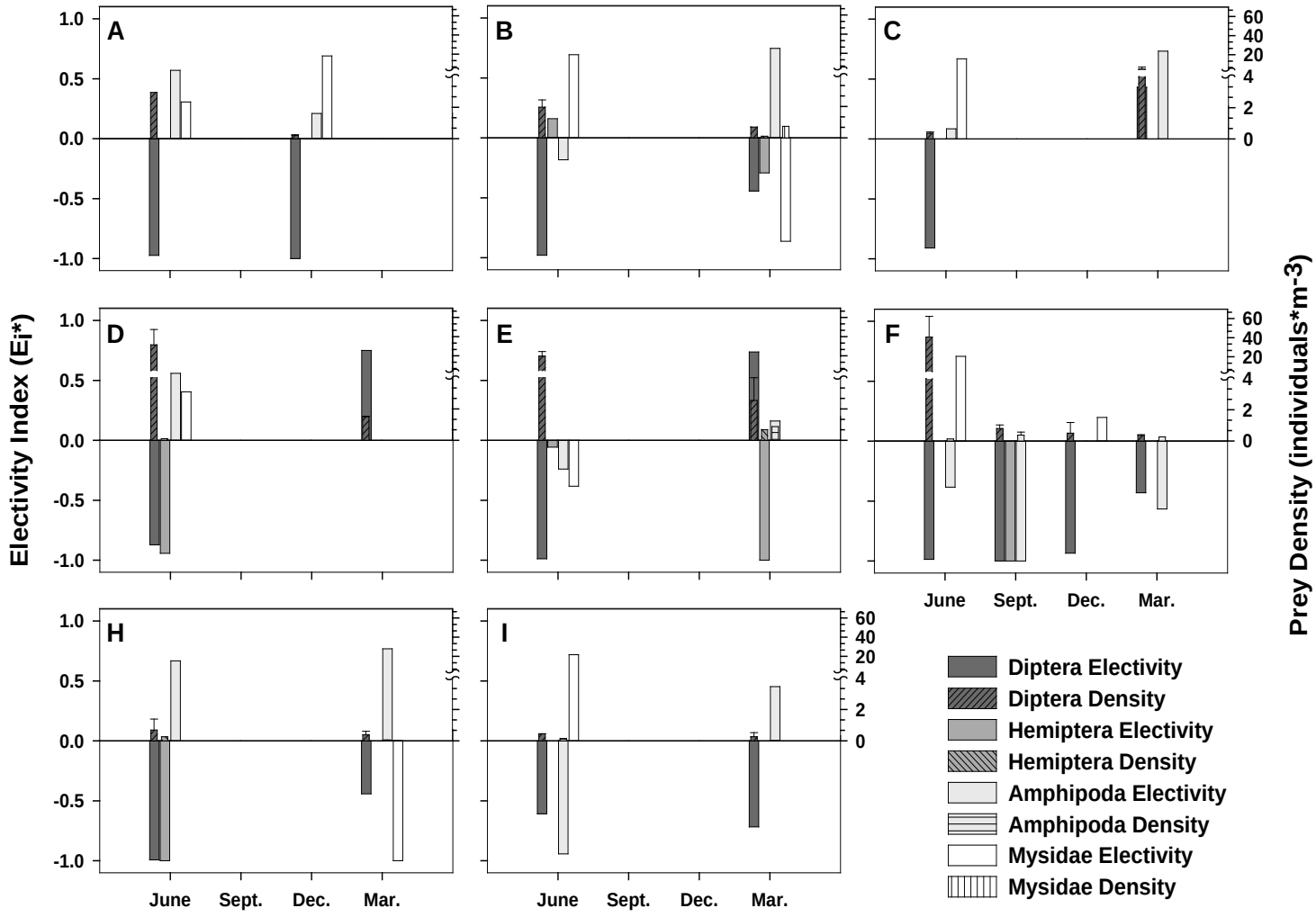

Figure 4.5. Relativized Electivity Index Values for Major Drifting Prey Items (100% Scenario). Values were calculated with 100% of the "ambiguous" prey items allocated to drift production. Instances where a prey item was consumed in proportion to its abundance in the environment ($E^* = 0.0$) are identified in the text. Otherwise, see Appendix E for justifications of missing data.

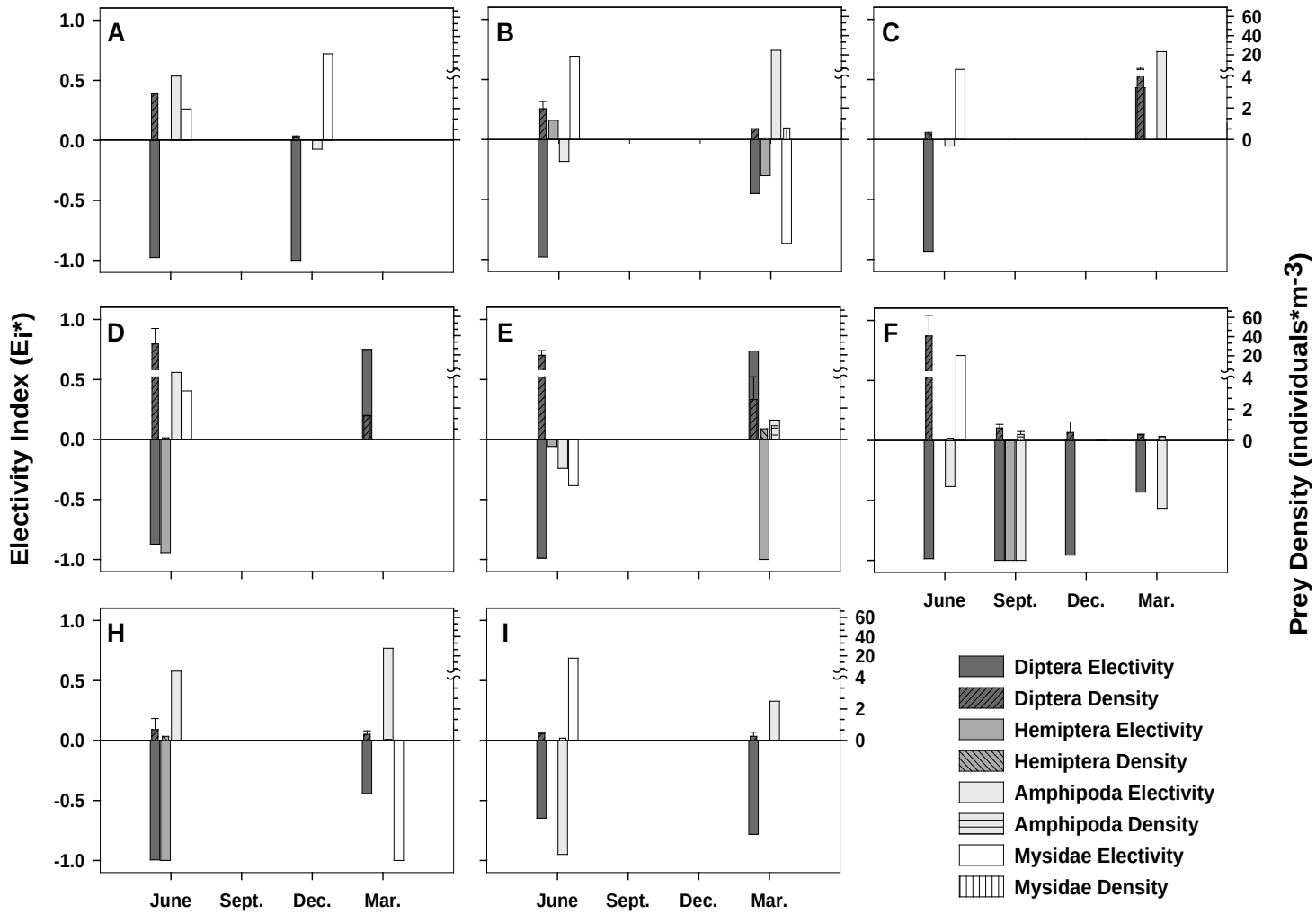

Figure 4.6. Relativized Electivity Index Values for Major Drifting Prey Items (50% Scenario). Values were calculated with 50% of the "ambiguous" prey items allocated to drift production. Instances where a prey item was consumed in proportion to its abundance in the environment ($E^* = 0.0$) are identified in the text. Otherwise, see Appendix E for justifications of missing data.

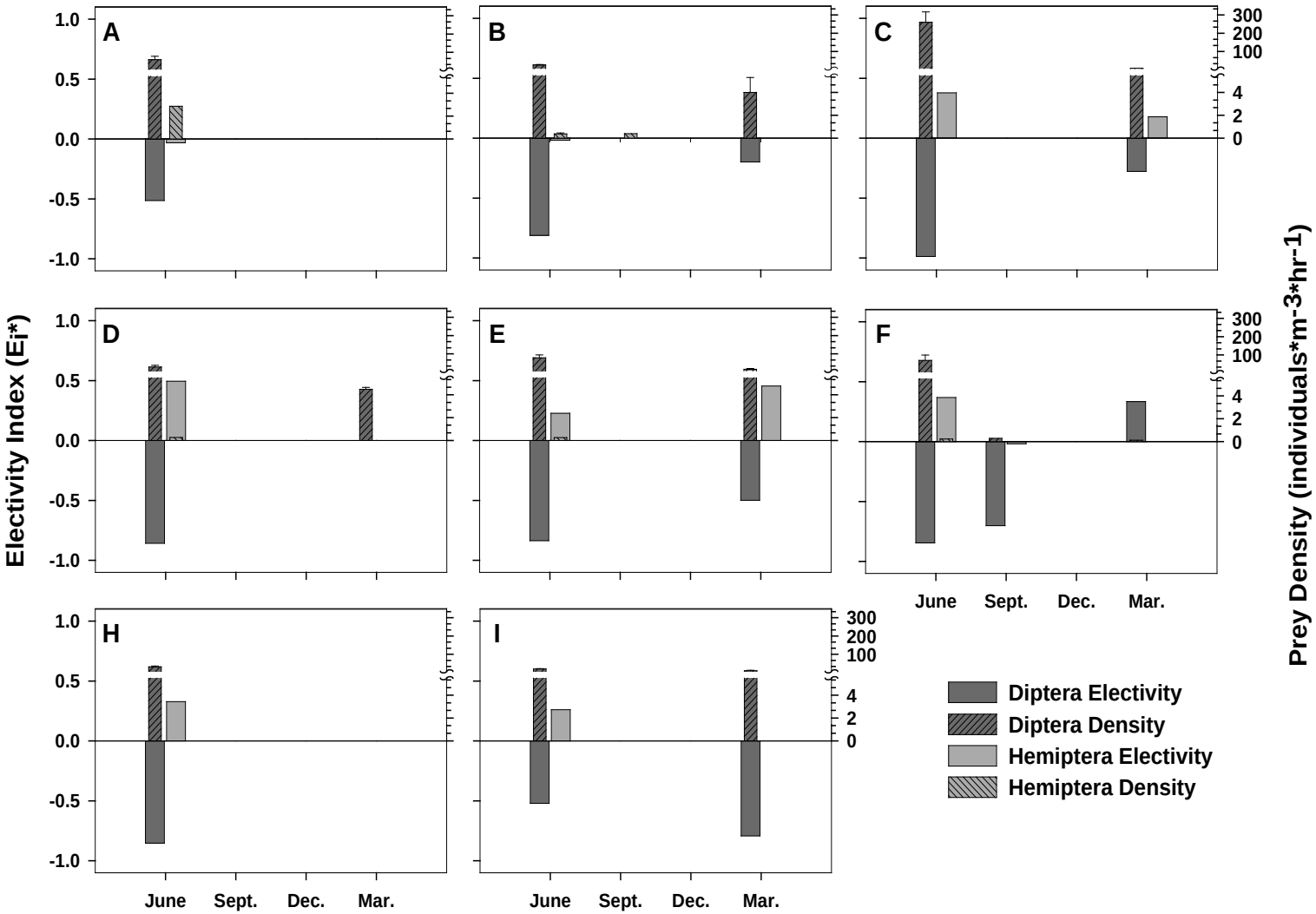

Figure 4.7. Relativized Electivity Index Values for Major Terrestrial or Winged Prey Items. Instances where a prey item was consumed in proportion to its abundance in the environment ($E^* = 0.0$) are identified in the text. Otherwise, see Appendix F for justifications of missing data.

4.3 Discussion

Understanding the roles of various prey items in the diet of a consumer and the foraging strategies used to optimize nutrition is important to elucidating factors that may regulate production dynamics in a particular habitat (Waters 1977). Although aspects of the general ecology of juvenile Chinook salmon in tidal freshwater areas of the LCRE are receiving more attention (e.g., Sobocinski et al. 2008; Sather et al. 2009), to our knowledge this study is the first to address the feeding ecology of juvenile salmonids by integrating analyses of diet composition and foraging strategy (i.e., prey selection) within discrete prey pools across a variety of habitat types within a tidal freshwater segment of the LCRE.

Both in terms of diet composition and relative importance (%IRI), dipterans, hemipterans, amphipods, and mysids generally contributed the most to the diets of juvenile Chinook at our sites. This trend generally was consistent in both space and time. Of these taxa, Diptera typically constituted the greatest proportion and were associated with large %IRI values. The substantial role of dipterans in the diets of juvenile salmon at our sites is not unprecedented in the LCRE. Characterizing the feeding ecology of juvenile Chinook salmon in wetland habitats, Lott (2004) found chironomids (Diptera, Chironomidae) dominated diet compositions and were among the most important prey taxa. Similarly, Bottom et al. (2008) identified dipterans (including emergent, larval, and unidentified life stages) typically to be the most important prey resource in emergent marsh, scrub-shrub, and forested wetlands in the Columbia River estuary proper.

Despite the significance of dipterans in salmon diets, juvenile Chinook salmon largely selected against the invertebrates in all three prey pools (i.e., drift, benthos, and fallout). The strong negative electivity index values associated with dipteran prey are likely an artifact of their large abundances in the environment. Although juvenile salmon consumed large quantities of dipterans at our sites, owing to the invertebrate's relatively high abundance in the environment, they did not appear to prefer dipterans over other prey. A similar conclusion was drawn by Storch et al. (2007) for alewife (*Alosa pseudoharengus*) consuming exotic zooplankton (*Cercopagis pengoi*) in three North American Great Lakes. In terms of the dipteran prey resource, considering the taxon's large contribution to the diets of juvenile salmon and their generally high densities in the benthos, drift, and fallout across seasons, the sites sampled in this study may be well suited to help sustain salmon populations.

Malacostracans (amphipods and mysids) were periodically important in the diet of juvenile Chinook salmon, as characterized by both %IRI and proportions by biomass. Bottom et al. (2008) identified a similar trend for salmon in the Columbia River estuary proper. Other studies have found that the malacostracan *Neomysis mercedis* is not a significant food for fish in the Columbia River estuary (Bottom et al. 1984; Simenstad et al. 1984). Despite the relatively sporadic contribution of these large crustaceans to the diets of juvenile salmon at our sites, when malacostracans were present in the diet or available in the environment, they frequently were characterized as a preferred prey item. This pattern may represent opportunistic exploitation of a profitable prey resource. As visual predators, fish often select large, easily attainable prey to maximize foraging efficiency (Gerking 1994). Preference for highly noticeable malacostracans over other prey, or supplementation for abundant but smaller items, may help optimize foraging efficiency—a strategy consistent with Optimal Foraging Theory (Pyke et al. 1977). Although energy densities can vary in both space and time, large-bodied mysids and amphipods are generally rich in energy (Cummins and Wuycheck 1971). Regardless of mechanisms, even periodic consumption of high-quality prey—including malacostracans—by juvenile Chinook salmon at our sites could help maximize net energy gain of juvenile salmon foraging in the SRD and vicinity of the LCRE.

Similar to malacostracans, the relative importance and contribution to the diet of hemipterans varied considerably across months. However, unlike amphipods and mysids, when hemipterans were present in the diet and/or the three prey pools, they largely were selected against. While we presented diet composition in terms of wet biomass, electivity calculations compare prey proportions in the diet relative to prey numbers in the environment. Hemipterans (e.g., corixids) encountered in our diet samples typically were large-bodied organisms. Therefore, in terms of biomass, the contribution of the taxon was large as shown in raw diet composition and %IRI. However, this biomass contribution comprised few organisms relative to the number found in the environment, at least partially explaining negative electivity index values. We chose to apply the Relativized Electivity Index (E^*_i) due to its favorable sampling properties. Like most electivity indices, unwanted model behavior is a necessary adjunct to positive properties (Lechowicz 1982). Lechowicz (1982) suggested preference indices are primarily useful in discerning feeding patterns, and when absolute levels of feeding on a particular prey item are of interest, direct measures of food consumption may be of greater use. In our study, we used measures of use and preference to support general conclusions about the suitability of specific habitats to sustain salmon populations. Thus, although juvenile salmon frequently selected against hemipterans, incidental consumption of the large invertebrates could be beneficial to juvenile salmon in terms of prey quality. Relative to many neopterans, hemipterans tend to be rich in energy (Cummins and Wuycheck 1971). So while hemipterans may not be sought or are consumed incidentally, they could be important contributors at times to the energy budgets of juvenile salmon residing in the SRD.

The contributions of other prey items to the diets of juvenile salmon at our sites varied considerably across space and time. Due largely to degradation, some individuals encountered were placed in an unidentified Insecta category. Given the prevalence of dipterans in our samples, it is likely that many of these unidentified items were actually dipterans. If this were true, our conclusions about the role of dipterans in the diet would be further substantiated. Non-dipteran aquatic insects (e.g., Ephemeroptera, Plecoptera, etc.) were encountered infrequently in our samples, but at times composed large proportions of the gut content biomass. Like hemipterans, these relatively large insects can represent high-quality prey (Cummins and Wuycheck 1971). Supplementing the diet with invertebrates such as mayfly larvae could prove to be beneficial in terms of the acquisition of energy and materials (e.g., essential molecules). Despite the fact that many of our sampling sites can be well vegetated (Appendix B), terrestrial insects were found infrequently in the diets of Chinook salmon. While there may be several factors leading to this result (e.g., low encounter rates between juvenile salmon and the invertebrates, avoidance of the prey due to factors including handling difficulty [Gerking 1994]), it appears that terrestrial insects contribute relatively little to the nutrition of juvenile Chinook salmon at our sites. The absence of non-malacostracan crustaceans (e.g., cladocerans) in the diets of juvenile salmon during most sampling periods is likely related to their size. Of the prey items encountered in both diet and availability samples, these crustaceans were among the smallest. For particulate feeders, visual acuity and prey size contribute to determining reactive distance, and consequently, encounter rates (Gerking 1994). Thus, it is not surprising that microcrustaceans were only periodically well-represented in the diet. Particularly given the diet compositions we observed, reduced encounter rates are not necessarily maladaptive, because prey such as crustacean zooplankton can be of relatively poor quality (Cummins and Wuycheck 1971; Storch 2007). The underrepresentation of fish in the diets of Chinook salmon at our sites may be due in large part to gape limitation. The sizes of Chinook salmon prey included in our analyses were relatively small (see Chapter 5 and Appendix G), likely constraining the maximum size of prey that could be handled

effectively. However, like other prey items encountered infrequently in our samples (e.g., non-dipteran insects), periodic consumption of vertebrate prey may contribute significantly to the energy budgets of juvenile Chinook salmon.

Regardless of specific mechanisms (e.g., prey availability, foraging strategies, gape limitations) that may dictate the roles of various prey items in the diets of juvenile salmon in tidal freshwater habitats, our results indicate that prey bases at the sites we sampled appear to be sufficient to support populations when the salmon prey demand is considered alone. Based on prey densities, modeled foraging behaviors, and diet compositions, it appears probable that intra-specific competition may be relatively weak. However, Chinook salmon do not forage in a vacuum. In this study we did not directly consider the role of inter-specific competitive interactions. The diets of other fish species commonly encountered at our sampling site have been found to overlap with juvenile salmon in other studies (Wydoski and Whitney 2003). Future work should seek to characterize the potential competitive interactions with non-salmoninae species to help expand knowledge of production potential and energy dynamics in tidal freshwater habitats.

4.4 Summary, Conclusions, and Recommendations

Based on our research on the feeding ecology of juvenile salmon in tidal freshwater, we offer the following conclusions and recommendations:

- In terms of the dipteran prey resource, given the large contribution of insects to the diets of juvenile salmon and their generally high densities in the benthos, drift, and fallout across seasons, the sites sampled in this study appear to be well-suited energetically to support salmon production.
- Regardless of mechanisms that may affect the roles of large-bodied malacostracans and hemipterans in the diets of juvenile Chinook salmon in tidal freshwater habitats, even periodic or opportunistic consumption of these generally high-quality prey could contribute significantly to net energy gain.
- The underrepresentation of prey items such as microcrustaceans and fish in the diets of juvenile salmon may be related to factors including visual acuity, gape limitations, or low abundance of this prey in the water column. However, behaviors or morphological constraints that may act to dictate diet compositions in specific tidal freshwater habitats could be energetically advantageous.
- Our results generally suggest, under current conditions, prey pools in tidal freshwater areas near the SRD likely provide useful forage for juvenile Chinook salmon. Given the importance of energy acquisition for young animals, we recommend that restoration efforts in other areas of the LCRE adopt a food web perspective; i.e., managers should consider restoration strategies that promote the production of fish in addition to the prey they consume.
- Based on prey densities, modeled foraging behaviors, and diet compositions, it appears probable that intra-specific competition among juvenile Chinook salmon may be relatively weak. However, future research should seek to characterize factors that may promote or relax inter-specific competitive interactions.

5.0 Bioenergetics

Prepared by Adam Storch

Throughout the LCRE, loss of shallow-water habitats (Thomas 1983) as a result of diking, filling, dredging, and development practices has been implicated in the decline of salmon populations (Bottom et al. 2005b). The ramifications of this habitat loss have led to mandates for restoration of shallow-water habitat (NOAA Fisheries 2008) intended to enhance juvenile salmon performance, such as foraging success, growth, and survival (Fresh et al. 2005). In response, and in light of insufficient supporting data, studies have been undertaken to provide improved understanding of how juvenile salmon use shallow habitats in the estuary (Bottom et al. 2008) and tidal freshwater (Sobocinski et al. 2008; Sather et al. 2009) of the LCRE. Although an important body of information documenting the use (e.g., presence, stock composition, density, etc.) of shallow tidal freshwater habitats in the LCRE by juvenile salmon is growing (see Chapter 2), little was known until recently about the feeding ecology of salmon in these areas (see Chapter 4). There remains an even greater lack of knowledge surrounding the energetic implications of residency in tidal freshwater habitats.

Understanding factors that may constrain or promote energy acquisition, and gaining insight into how juvenile fish partition consumed energy into metabolic pathways and growth under certain environmental conditions are critical to evaluating the roles of certain habitats in supporting fish populations (Adams and Breck 1990). To address the implications of energy dynamics in certain habitats, researchers have often applied a bioenergetics approach. For example, Koehler et al. (2006) used a bioenergetics model to show juvenile Chinook salmon were encountering ample food in littoral habitats of Lake Washington to meet energetic demands. The authors concluded managers should focus salmon recovery efforts in the Lake Washington basin on lacustrine habitats. Similarly, Luecke and MacKinnon (2008) applied a bioenergetics approach to examine the influences of landscape morphology on growth of Arctic grayling in paired watersheds. Their results suggested the presence of multiple lakes on the landscape acted to regulate summer temperatures, consequently influencing the ability of a given watershed to support fish production. These examples highlight the importance of understanding energy dynamics to assess the suitability of specific habitats to support fish growth and production. By integrating physiological and environmental parameters (Hanson et al. 1997), the bioenergetics approach should help assess the suitability of habitats for juvenile salmon growth in LCRE tidal freshwater areas.

The objectives of the research reported in this chapter were to 1) assess the influences of environmental (temperature) and dietary (consumed prey composition and quality) parameters on rates of consumption and growth for juvenile Chinook salmon in tidally influenced habitats in the LCRE, and 2) evaluate spatial and temporal variability in both consumption rates and growth. The implications of our findings will be discussed within the context of the ability of shallow tidal freshwater habitats to support populations of migrating juvenile salmon. By applying a bioenergetics model for Chinook salmon to empirical data, we assessed the integrated effects of variation in several critical variables across cohorts of Chinook salmon and among specific sites in the tidal freshwater region of the LCRE.

5.1 Methods

We applied a modeling approach to investigate juvenile salmon bioenergetics in LCRE tidal freshwater. The methods include a description of the bioenergetics model, model inputs, and model simulations. The bioenergetics modeling was based on data collected the SRD study area from March 2008 through April 2010.

5.1.1 Bioenergetics Model

To evaluate consumption, growth, and conversion efficiency by juvenile Chinook salmon in specific shallow tidal freshwater habitats in the SRD study area (see Chapter 2, Figure 2.1), we applied a species-specific bioenergetics model (Stewart and Ibarra 1991). The bioenergetics model balances consumption with growth and losses from metabolic processes as follows (Eq. 5.1):

$$G = C - (R + A + SDA) + (F + U) \tag{5.1}$$

where,

G = growth
C = consumption
R = standard respiration
A = active metabolism
SDA = specific dynamic action (the metabolic cost of digestion)
F = egestion
U = excretion.

In this modeling approach, based on species-specific physiological parameters, energy is allocated hierarchically to various compartments: consumed energy is first allocated to catabolism (maintenance and activity metabolism), then to losses from waste (urine, feces, and specific dynamic action), and lastly remaining energy is allocated to somatic storage (body growth and gonad development; Hanson et al. 1997). Given these parameters for energy allocation, by inputting observed diet, water temperature, and prey energy densities (see below), we evaluated the effects of variability in environmental parameters (i.e., diet and temperature) on several metrics (see Output Metrics) among discrete cohorts, across study sites (see Chapter 2, Figure 2.1) in shallow tidal freshwater areas of the Columbia River.

We applied the Fish Bioenergetics 3.0 model (Hanson et al. 1997), parameterized for adult Chinook salmon (Stewart and Iberra 1991), to both empirical data obtained from the TFM study as well as from published values. Although this model was developed originally for adult Chinook salmon, previous research has found model-predicted estimates of consumption by juvenile salmon to be within 10% of independently generated field and laboratory estimates (Beauchamp et al. 1989; Brodeur et al. 1992; Ruggerone and Rogers 1992). Thus, the model is appropriate for the analysis of juvenile Chinook salmon energetics.

5.1.2 Model Inputs

The primary model inputs included diet composition, prey energy, and thermal regime.

5.1.2.1 Diet Composition

Diet compositions (mg wet biomass) input to the bioenergetics model were characterized as part of a larger study to describe the feeding ecology of juvenile Chinook salmon in specific tidal freshwater habitats in the lower Columbia River. Details of sampling protocols and analytical methodologies are highlighted in Chapter 4. To better account for the variability in prey quality (i.e., energy density), where appropriate, diet data were grouped according to taxonomic classification and life stage and/or source (e.g., aquatic versus terrestrial; Appendix G).

5.1.2.2 Prey Energy

Energy density values of major prey items were obtained from the literature. Whenever necessary, prey caloric content was converted to joules using the ratio of 1 calorie:4.186 joules. Because the bioenergetics model calculates output in terms of wet biomass, all dry mass energy density values were converted to wet mass units (Waters 1977; Dumont et al. 1975; Vitousek at al. 1986) (Table 5.1).

5.1.2.3 Thermal Regime

The mean daily water temperatures input to the bioenergetics model for each site were primarily collected in situ using stationary Hobo data loggers (see Section 3.2.1). When necessary, linear interpolation was used to account for missing data. For instances in which linear interpolation could not be applied (e.g., when data were missing from the end of a simulation period), thermographs were supplemented with data from Columbia River DART (http://www.cbr.washington.edu/dart/dart.html) collected from the main stem Columbia River near Washougal, Washington.

Table 5.1. Prey Energy Densities (J·g wet mass^{-1}) Input into the Chinook Salmon Bioenergetics Model

Taxon	Energy Density	Primary Source(s)	Notes
Amphipoda	4429	Cummins and Wuycheck 1971	
Annelida	2700	Cummins and Wuycheck 1971	
Aquatic Diptera (adult)	4500	Beauchamp et al. 2004	Value for Chironomidae adult
Aquatic Diptera (larvae)	2478	Beauchamp et al. 2004	Value for Chironomidae larvae
Aquatic Diptera (pupae)	3400	Beauchamp et al. 2004	Value for Chironomidae pupae
Aquatic Diptera (unidentidied life stage)	2977	Cummins and Wuycheck 1971	Value for aquatic Diptera[a]
Aquatic Insecta	3422	Cummins and Wuycheck 1971	Mean of values for multiple taxa[a,b]
Arachnida	3366	Cummins and Wuycheck 1971	Mean of values for *Daphnia* spp.
Arthropoda	3494	Cummins and Wuycheck 1971	Mean of values for terrestrial and aquatic Arthropoda[a]
Cladocera	1907	Storch 2005	
Coleoptera	3937	Cummins and Wuycheck 1971	Mean of values for terrestrial and aquatic Coleoptera[a]
Collembola	3807	Cummins and Wuycheck 1971	Value for Collembola[a]
Copepoda	2302	Cummins and Wuycheck 1971	
Diptera (unidentified source and life stage)	3509	Cummins and Wuycheck 1971	Mean of values for terrestrial and aquatic Diptera[a]
Ephemeroptera	4705	Cummins and Wuycheck 1971;	Mean value for Ephemeroptera taxa
Fish (embryo, larvae and juvenile)	3698	Hanson et al. 1997	Mean value for larval fish
Hemiptera	3934	Cummins and Wuycheck 1971	Value for Cercopidae[a]
Hymenoptera	3230	Cummins and Wuycheck 1971	Value for terrestrial Hymenoptera[a]
Insecta (unidentified source and life stage)	3586	Cummins and Wuycheck 1971	Mean of values for terrestrial and aquatic Insecta[a]
Mysidae	3642	Cummins and Wuycheck 1971; Rudstam 1989	Mean value for mysids
Nemata/Nematomorpha	3887	Danovaro et al. 1999	Value for coastal nematode[c]
Odonata	3571	Cummins and Wuycheck 1971	Value for Odonata[a]
Other	2293	Cummins and Wuycheck 1971	Mean of values for multiple taxa[a,d]
Terrestrial Diptera	4035	Cummins and Wuycheck 1971	Value for terrestrial Diptera[a]
Terrestrial Insecta	3806	Cummins and Wuycheck 1971	Value for terrestrial Insecta[a]
Trichoptera	3488	Cummins and Wuycheck 1971	Value for Trichoptera[a]

(a) Converted to wet mass using Waters' (1977) convention (1 g dry mass ≈ 6 g wet mass ≈ 0.9 g ash-free dry mass)
(b) Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
(c) Converted to wet mass using the ratio 1 g dry mass:11 g wet mass (Dumont et al. 1975; Vitousek at al. 1986)
(d) Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada

5.1.3 Model Simulations

For each site, multiple cohorts were simulated over discrete time periods (hereafter, residence periods) to represent the growth response of fish to environmental and dietary (i.e., prey quality and quantity) influences. Simulations were conducted only for months in which diet data were collected (see Chapter 4). For the first cohort at each site, the initial simulation day (beginning from 1 Jan. 2008 = 1) was associated with the calendar day diet samples were actually collected in the field. For example, at Site A data characterizing diets for the first simulation cohort were collected on 18 March 2008. Thus, the first simulation day for that cohort was set to 78. Simulation periods for subsequent cohorts began on the first day of each month in which diet data were collected. Final simulation days were assigned based on mean lengths of fish included in diet analyses and data from Campbell (2010; Table 5.2).

The bioenergetics model predicts output based on species-specific physiological parameters and user input including initial and final mass (Hanson et al. 1997). Initial (Wt_i) and final (Wt_f) masses input into the model for each simulation cohort were estimated in two steps. First, period-specific growth rates from Campbell (2010) for juvenile Chinook salmon were applied to mean fork lengths of fish sampled for diet analyses (see Chapter 4). This step resulted in initial (observed) and final (predicted) lengths used in the model (Table 5.2). Second, temporally explicit length-biomass regression models (Table 5.3) were applied to the initial and final fork lengths that resulted in a predicted initial and final mass. Predictive models were developed using fork length and biomass data for all Chinook salmon encountered during sampling (Chapter 2) regardless of whether gut contents were removed for analysis. Regression analyses were conducted using SAS/STAT analysis software (SAS Institute 2004). To normalize the data and stabilize variances, data were log-transformed prior to analysis.

Table 5.2. Growth Rates and Residence Times Used to Develop Cohorts for Bioenergetics Simulations. Growth rates are means of estimates reported by Campbell (2010) for juvenile Chinook salmon in the Columbia River estuary from 2003 through 2005.

Period	Mean Growth Rate (mm/day)	Residence Size Class (mm)	Residence Time (days)
Jan.–Apr.	0.4	<45	52
		<60	54
		61–90	50
		>90	31
May–Aug.	0.42	<45	79
		<60	59
		61–90	46
		>90	45
Sept.–Dec.	0.42	61–90	33
		>90	20

Table 5.3. Parameters and Fit Statistics for Length-Biomass Regression Models Used to Estimate Initial and Final Masses for Bioenergetics Simulations. All data were log-transformed prior to analysis. Models were considered significant at $\alpha = 0.05$.

Model	RMSE	R^2	Model prob >F	ln (FL)	Intercept
Jan.	0.046	0.975	<0.0001	2.937	-11.224
Feb.	0.295	0.884	<0.0001	3.078	-11.720
Mar.	0.170	0.940	<0.0001	3.204	-12.219
May	0.155	0.960	<0.0001	3.014	-11.513
June	0.092	0.973	<0.0001	3.048	-11.582
Aug.	0.036	0.987	<0.0001	2.928	-11.064
Oct.	0.067	0.756	0.0110	2.968	-11.299
Nov.	0.048	0.984	<0.0001	3.164	-12.242
Dec.	0.054	0.981	<0.0001	2.825	-10.651
Combined	0.388	0.815	<0.0001	2.896	-11.037

RMSE = root-mean-square-error.
R^2 = coefficient of determination.
ln = natural logarithm.

The *P*-value is a derived figure representing the proportion of maximum consumption at which a cohort is feeding. This value is associated with a given fish size (i.e., initial and final mass) as well as other input parameters including thermal experience. The theoretical upper and lower bounds for fitted *P*-values are 0.0 and 1.0, respectively, where a value of 1.0 represents a fish feeding approximately at its maximum daily ration (Hanson et al. 1997). To evaluate the sensitivity of the bioenergetics model to changes in consumption rates, in addition to conducting simulations at fitted proportions of maximum consumption (i.e., baseline runs), the model was re-run for each cohort after perturbing fitted *P*-values ± 10%. In certain instances, simulated *P*-values exceeded the maximum theoretical consumption rate (e.g., at temperature extremes). For the relatively few simulation cohorts in which this occurred, *P*-values were scaled to 1.0, and the model was re-run. Under these circumstances, additional simulations were not conducted after perturbing P-values ± 10%.

5.1.4 Output Metrics

Growth (mean specific growth rate, $\overline{SGR}$) and consumption (proportion of maximum consumption, *P*-value) rates output from the bioenergetics model were compared among simulation cohorts and sites. In addition, we calculated gross conversion efficiency (GCE) as follows:

$$GCE = \left(\frac{\Delta G}{\Delta I}\right) \cdot 100 \tag{5.2}$$

where,

ΔG = grams of growth in total weight gain throughout a defined period (i.e., residence periods)

ΔI = grams of prey consumed during the residence period.

Gross conversion efficiency provides a complementary metric that evaluates an organism's ability to convert ingested food into new biomass (i.e., somatic growth) given the integrated effects of food quality (energy density), diet composition, and temperature-dependent effects on metabolism (Koehler et al. 2006; Mateo 2007).

5.2 Results

The results of the bioenergetics modeling for juvenile salmon in tidal freshwater habitats are presented for initial and final body mass, growth, and conversion. The juvenile salmon diet data used in the bioenergetics modeling are presented in Appendix G.

5.2.1 Initial and Final Body Mass

The length-biomass regression models used to estimate initial (Wt_i) and final (Wt_f) mass (Tables 5.4 through 5.7) input to the bioenergetics model were all found to be significant at $\alpha = 0.05$. All models, including the combined, fit the data well, with the coefficient of determination (R^2) ranging from 0.756 to 0.987 (Table 5.3). Although a model was also developed using July data, the analysis suffered from outliers of unknown origin. Thus, Wt_i or Wt_f values for July and other months in which data were not available (see Table 5.3) were estimated using the combined model.

5.2.2 Growth

Simulated *P*-values exceeded the upper theoretical limit (i.e., 1.0), typically when water temperatures were above approximately 21°C or below 5°C (Tables 5.4–5.7, Figures 5.1 and 5.2). For these simulation cohorts, the Chinook salmon bioenergetics model was run at *P*-value = 1. Predicted $\overline{SGR}$ for these simulation cohorts commonly were less than, or approximately equal to, zero. Exceptions to this result occurred for the following:

- Site A; cohorts 11 (residence period = 1 Jan. 2009 – 1 Feb. 2009, $\overline{SGR}$ = 0.007 g·g-1·d-1) and 12 (residence period = 1 Feb. 2009 – 4 Mar. 2009, $\overline{SGR}$ = 0.005 g·g-1·d-1)
- Site F; cohort 13 (residence period = 1 Mar. 2009 – 1 Apr. 2009, $\overline{SGR}$ = 0.011 g·g-1·d-1), and cohorts 11 (residence period = 1 Jan. 2009 – 1 Feb. 2009, $\overline{SGR}$ = 0.005 g·g-1·d-1)
- at Site I; cohort 12 (residence period = 1 Feb. 2009 – 4 Mar. 2009, $\overline{SGR}$ = 0.005 g·g-1·d-1) (Figures 5.1 and 5.2).

Similarly, $\overline{SGR}$ for the single cohort modeled at Site N was positive (residence period = 16 July 2008 – 31 Aug. 2008, $\overline{SGR}$ = 0.009 g·g-1·d-1), despite being associated with a *P*-value artificially scaled to the upper theoretical limit.

Regardless of site, predicted $\overline{SGR}$ values for the cohorts where simulated *P*-values did not exceed 1 were positive. This was true even when simulations were conducted after perturbing the simulated *P*-value by -10%. For these simulations, growth rates fell between approximately 0.008 $g \cdot g^{-1} \cdot d^{-1}$and

0.022 $g \cdot g^{-1} \cdot d^{-1}$, with the maximum baseline $\overline{SGR}$ occurring at Site D (simulation cohort = 25, residence period = 1 Mar. 2010 – 3 Apr. 2010, $\overline{SGR}$ = 0.022 $g \cdot g^{-1} \cdot d^{-1}$) and the minimum at Site F (simulation cohort = 14, residence period = 1 Apr. 2009 – 25 May. 2009, $\overline{SGR}$ = 0.008 $g \cdot g^{-1} \cdot d^{-1}$).

5.2.3 Consumption and Gross Conversion Efficiency

Simulated consumption rates (*P*-values) for cohorts modeled at Site A generally were moderate (mean = 0.61 ± 0.19 s.d., range = 0.41–1.00) and had no apparent relationship with initial estimated body size (W_{ti}; Spearman rank-order, r = 0.19, *P* = 0.4274) or temperature (r = 0.19, *P* = 0.4274). Gross conversion efficiencies varied considerably among simulation cohorts (mean = 16% ± 6.96, range = -10–22%), and like consumption rates, the parameter was not correlated with W_{ti} (r = -0.04, *P* = 0.8692). Alternatively, GCE appeared to be inversely related to mean temperature (r = -0.80, *P* < 0.0001; Table 5.4). Among those cohorts for which simulated baseline *P*-values exceeded 1.0, only during the residence period lasting from 1 July 2009 through 6 August 2009 (simulation cohort 17) was the GCE negative (i.e., fish were predicted to lose body mass due to integrated effects of food quality and quantity and temperature dependence; see Table 5.4).

Consumption rates simulated for cohorts modeled at Site B largely were moderate (mean = 0.66±0.25 s.d., range = 0.40–1.00) and had no statistically significant relationship with Wt_i (r = 0.47, *P* = 0.0930) or temperature (r = 0.52, *P* = 0.0558). At Site A, GCE was not correlated with Wt_i (r = -0.52, *P* = 0.0558), but was correlated negatively with temperature (r = -0.96, *P*<0.0001) and varied widely among simulation cohorts (mean =9%±8.71, range =-22%–23%). For the four cohorts in which simulated baseline *P*-values exceeded 1.0, all displayed negative GCEs (Table 5.4).

Simulated rates of consumption at Site C were, on average, less than those at Sites A and B and varied among cohorts to a much smaller degree (mean = 0.50 ± 0.07 s.d., range = 0.39–0.65). Consumption rates at this site were correlated neither with Wt_i (r = 0.18, *P* = 0.5522) or temperature (r = -0.21, *P* = 0.4908). Gross conversion efficiency was relatively invariable at Site C, ranging from 12% to 44% (mean = 21% ± 8.28) and related significantly to Wt_i (r = 0.63, *P* = 0.0225) and temperature (r = 0.66, *P* = 0.0135). Fitted *P* -values did not exceed the upper theoretical limit during any residence period at Site C (Table 5.4).

Fitted *P*-values at Site D were similar to those at Site A, both in terms of mean value and range (mean = 0.60 ± 0.17, range = 0.42–1.00). As was found for Sites A, B, and C, *P* -value was not correlated significantly with either Wt_i (r = -0.16520, *P* = 0.6079) or temperature (r = 0.49, *P* = 0.1077). The GCE and associated variation at Site D were generally comparable to those at Site A (mean = 16% ± 8.86, range = -7%–28%). While temperature and GCE showed a strong negative correlation (r = -0.96, *P* < 0.0001) at this site, no significant relationship was identified between GCE and Wt_i (r = -0.28, *P* = 0.3813). Only for simulation cohort 17 (residence period = 1 July 2009–16 Aug. 2009) did fitted *P*-values exceed 1.0; resulting in a GCE less than zero (Table 5.4).

As was found at other sites, simulated rates of consumption at Site E were largely moderate (mean = 0.57 ± 0.19, range = 0.40–1.00), and not correlated with Wt_i (r = -0.049, *P* = 0.8693). However, a significant positive relationship existed between *P*-value and temperature (r = 0.54, *P* = 0.0486). Gross conversion efficiency at Site E (mean = 16% ± 8.64, range = -10%–25%) was similar to that estimated at Sites A and D, and displayed a strong negative correlation with water temperature (r = -0.98, *P* < 0.0001),

but no significant relationship with initial body mass (r = -0.27, *P* = 0.3442). For simulations conducted at Site E, fitted *P* -values exceeded the upper theoretical limit only during the residence period spanning 1 July 2009–16 Aug. 2009 (simulation cohort 17; Table 5.4).

At Site F, fitted consumption rates varied considerably around a moderate average value (mean = 0.62 ± 0.26, range = 0.39–1.00) and were not correlated significantly with either Wt_i (r = -0.08736, *P* = 0.7984) or temperature (r = 0.18, *P* = 0.6074). Cohorts simulated at Site F generally displayed high GCEs with large variability among simulations (mean = 17% ± 7.57, range = -1%–27%). While GCE showed a strong negative correlation with temperature (r = -0.82, *P* = 0.0019), no significant relationship was found between the metric and initial body size (r = 0.06, *P* = 0.8519). Of the two cohorts where simulated baseline *P*-values exceeded 1.0 (simulation cohorts 13 and 17), a negative GCE value was calculated only for cohort 17 (residence period = 1 July 2009 – 16 Aug. 2009; Table 5.4).

The mean of *P* -values for simulation cohorts modeled at Site H was similar to that calculated at other sites and varied markedly among residence periods (mean = 0.59 ± 0.22 s.d., range = 0.37–1.00). As at other sites, consumption rate was correlated neither with Wt_i (r = -0.35, p = 0.2222) nor temperature (r = 0.34, *P* = 0.2414). Gross conversion efficiencies at this site commonly were high, and like consumption estimates, showed a high degree of dispersion (mean = 15% ± 10.40, range = -12%–25%). At Site H, fitted consumption rates exceeded 1.0 for simulation cohorts 17 (residence period = 1 July 2009–16 Aug. 2009) and 18 (residence period = 1 Aug. 2009–16 Sept. 2009), resulting in both instances in a negative GCE (Table 5.4).

Across simulation cohorts, predicted rates of consumption at Site I were similar to those modeled at Site B (mean = 0.67 ± 0.27 s.d., range = 0.40–1.00). Like most other sites, *P*-values for Site I were not correlated with Wt_i (r = 0.34, *P* = 0.3338) or temperature (r = -0.30444, *P* = 0.3924). Gross conversion efficiencies estimated at Site I were among the highest at any site and displayed high variability (mean = 18% ± 8.50, range = -3%–26%). No statistically significant correlation was found between GCE at Site I and either Wt_i (r = 0.01, *P* = 0.9867) or temperature (r = -0.56, *P* = 0.0897). Although simulated *P* -values exceeded the upper theoretical limit during three residence periods, estimated GCE was negative only for cohort 17 (residence period = 1 July 2009–16 Aug. 2009; Table 5.4).

For the single cohort modeled at Site N, the simulated *P*-value exceeded the upper theoretical limit. Thus, the Chinook salmon bioenergetics model was run assuming a consumption rate of 1.00. This resulted in a relatively low GCE (10%), yet the cohort was not predicted to lose body mass during the simulation period (Table 5.4).

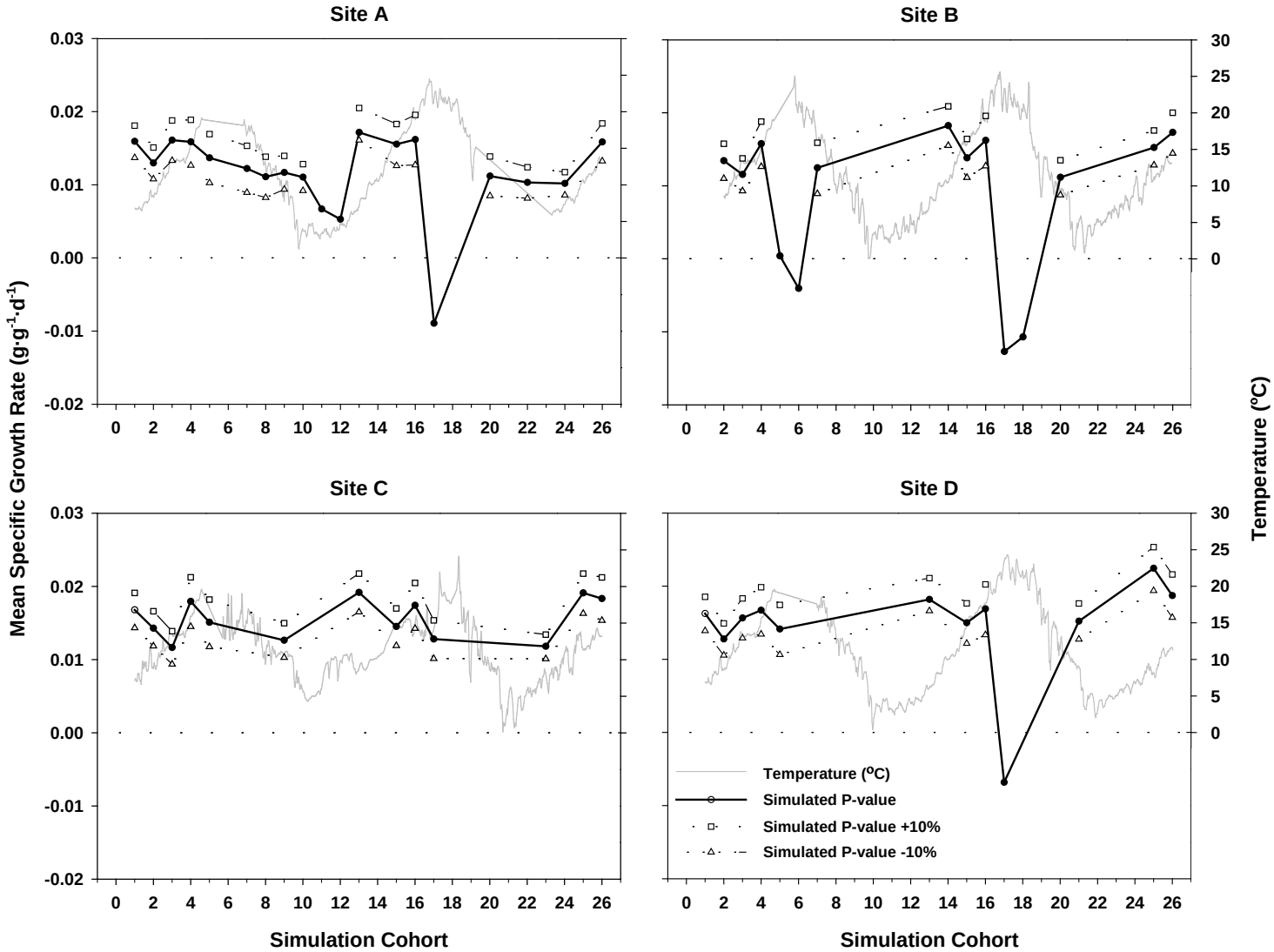

Figure 5.1. Mean Predicted Specific Growth Rates ($g \cdot g^{-1} \cdot d^{-1}$) for Juvenile Chinook Salmon Cohorts at Sites A, B, C, and D. Values without 10% upper and lower bounds are for simulation cohorts where initial simulated *P*-value exceeded the maximum theoretical limit and were therefore scaled to 1.0.

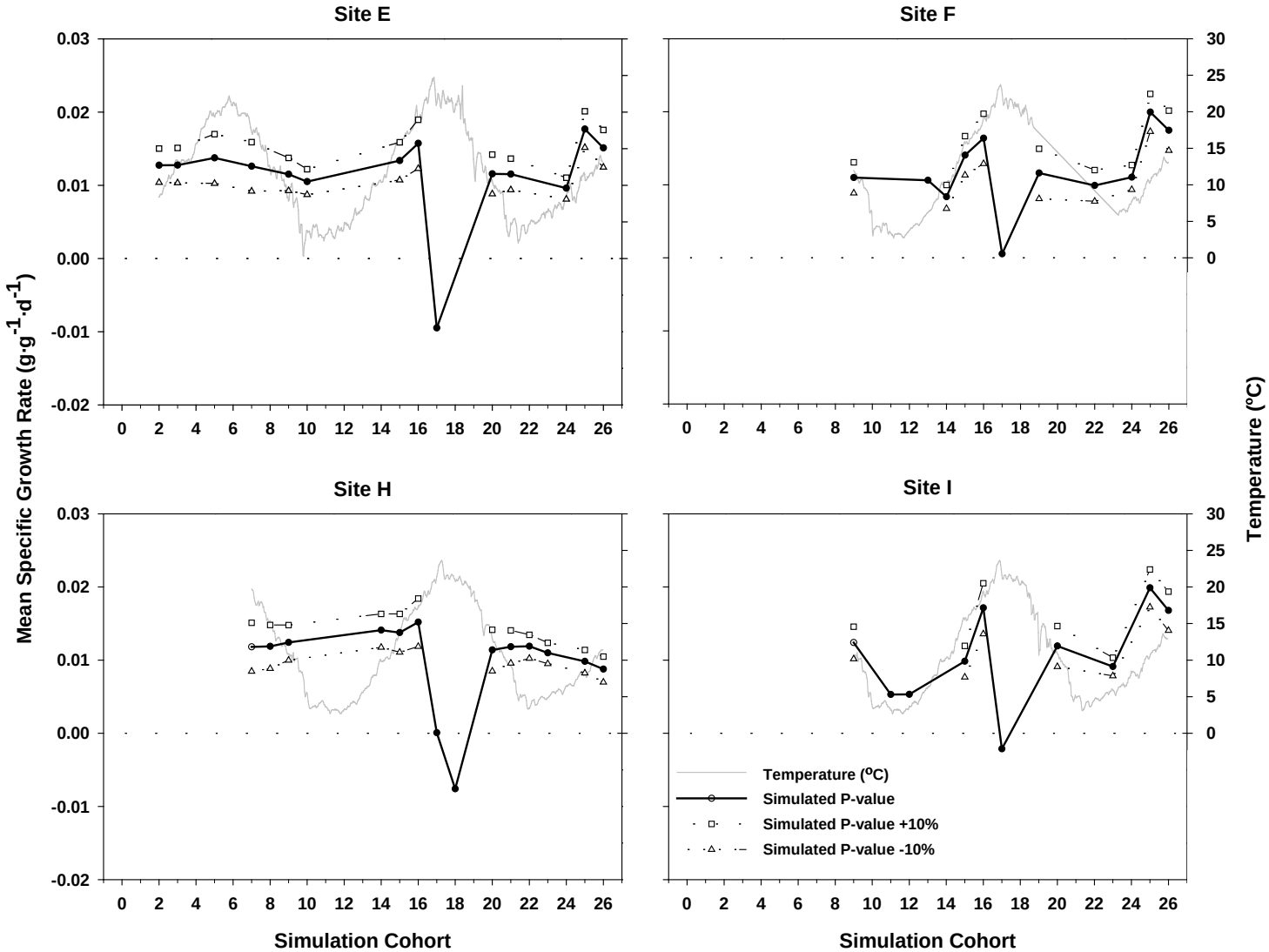

Figure 5.2. Mean Predicted Specific Growth Rates ($g \cdot g^{-1} \cdot d^{-1}$) for Juvenile Chinook Salmon Cohorts at Sites E, F, H, and I. Values without 10% upper and lower bounds are for simulation cohorts where the initial simulated *P*-value exceeded the maximum theoretical limit and were therefore scaled to 1.0.

Table 5.4. Simulation Cohorts, Habitat Parameters, Fish Size, Bioenergetics Model Output, and Gross Conversion Efficiency for Juvenile Chinook Salmon from March 2008 to May 2010 at Sites A, B, C, D, E, F, H, I, and N. Asterisks indicate cohorts where a proportion of maximum consumption of 1.00 was assumed for bioenergetics simulations because fitted values exceeded the maximum theoretical *P*-value (i.e., 1.00).

Site	Simulation Cohort	Residence Period	Simulation Period (days)	Mean Temperature (°C; s.d.)	Mean Fork Length (mm; s.d.)	Wt_i (g)	Wt_f (g)	*P* - value	C (g)	GCE (%)
A	1	18 Mar. 08 – 7 May 08	78 – 128	8.38 (1.48)	69.3 (1.5)	4.0	8.8	0.63	25.2	19
	2	1 Apr. 08 – 21 May 08	92 – 142	9.91 (1.91)	78.0	4.9	9.3	0.52	25.5	17
	3	1 May 08 – 16 June 08	122 – 168	12.69 (1.05)	67.8 (12.8)	3.4	7.0	0.49	21.4	17
	4	1 June 08 – 17 July 08	153 – 199	15.98 (2.24)	69.8 (15.3)	4.0	8.2	0.61	30.5	14
	5	1 July 08 – 16 Aug. 08	183 – 229	18.62 (0.33)	77.7 (13.0)	4.9	9.1	0.62	32.9	13
	7	1 Sept. 08 – 4 Oct. 08	245 – 278	18.00 (0.46)	90.0	7.4	11.1	0.57	28.2	13
	8	1 Oct. 08 – 21 Oct. 08	275 – 295	15.99 (1.2)	103.0	11.8	14.7	0.54	21.4	14
	9	1 Nov. 08 – 21 Nov. 08	306 – 326	11.66 (0.87)	104 (9.3)	11.7	14.8	0.42	15.8	20
	10	1 Dec. 08 – 21 Dec. 08	336 – 356	6.90 (2.41)	98.2 (13.8)	10.2	12.6	0.53	10.9	22
	11*	1 Jan. 09 – 1 Feb. 09	367 – 398	3.64 (0.61)	115.0	15.2	18.6	1.00	17.9	19
	12*	1 Feb. 09 – 4 Mar. 09	398 – 429	3.72 (0.48)	118 (6.9)	19.5	23.0	1.00	21.5	16
	13	1 Mar. 09 – 24 Apr. 09	426 – 480	6.73 (1.89)	58.5 (2.6)	2.3	6.2	0.75	17.6	22
	15	1 May 09 – 16 June 09	487 – 533	13.76 (2.22)	70.5 (10.2)	3.8	7.7	0.46	21.7	18
	16	1 June 09 – 17 July 09	518 – 564	17.76 (1.58)	68.5 (7.9)	3.8	7.8	0.60	29.0	14
	17*	1 July 09 – 16 Aug. 09	548 – 594	21.34 (1.68)	85.0	6.5	4.0	1.00	24.1	-10
	20	1 Oct. 09 – 21 Oct. 09	640 – 660	15.04 (2.13)	102.1 (2.7)	11.4	14.3	0.50	19.4	15
	22	1 Dec. 09 – 21 Dec. 09	701 – 721	11.35 (0.44)	105.6 (15.3)	12.4	15.3	0.41	15.6	18
	24	1 Feb. 10 – 4 Mar. 10	763 – 794	6.66 (0.51)	110.8 (0.6)	16.2	22.1	0.63	27.7	21
	26	1 Apr. 10 – 21 May 10	822 – 872	10.75 (1.76)	62.1 (5.4)	2.5	5.6	0.41	14.6	21

Table 5.4. (contd)

Site	Simulation Cohort	Residence Period	Simulation Period (days)	Mean Temperature (°C; s.d.)	Mean Fork Length (mm; s.d.)	Wt_i (g)	Wt_f (g)	*P* - value	C (g)	GCE (%)
B	2	17 Apr. 08 – 6 June 08	108 – 158	11.59 (1.79)	75.0 (6.8)	4.4	8.5	0.46	24.3	17
	3	1 May 08 – 15 June 08	122 – 167	12.68 (1.04)	98.0	10.2	17.0	0.52	45.0	15
	4	1 June 08 – 17 July 08	153 – 199	15.99 (2.29)	70.4 (7.1)	4.1	8.4	0.64	33.0	13
	5*	1 July 08 – 16 Aug 08	183 – 229	20.58 (1.86)	74.2 (5.2)	4.4	4.2	1.00	28.4	-1
	6*	1 Aug. 08 – 16 Sept. 08	214 – 260	21.13 (1.68)	87.0 (11.7)	7.3	6.1	1.00	19.2	-7
	7	1 Sept. 08 – 24 Sept. 08	245 – 268	19.10 (1.26)	89.0 (4.7)	7.2	9.5	0.77	21.1	11
	14	1 Apr. 09 – 25 May 09	457 – 511	10.20 (1.98)	55.0	1.8	4.8	0.44	13.4	22
	15	1 May 09 – 16 June 09	487 – 533	13.71 (2.26)	80.3 (11.7)	5.6	10.5	0.46	28.2	17
	16	1 June 09 – 17 July 09	518 – 564	17.86 (1.76)	68.6 (10.5)	3.8	7.8	0.63	30.0	13
	17*	1 July 09 – 15 Aug. 09	548 – 593	21.83 (2.04)	95.0	8.9	4.7	1.00	23.4	-18
	18*	1 Aug. 09 – 15 Sept. 09	579 – 624	21.77 (1.65)	92.0	8.6	5.3	1.00	15.2	-22
	20	1 Oct 09 – 21 Oct. 09	640 – 660	12.76 (2.17)	102.0	11.4	14.3	0.44	16.3	18
	25	1 Mar. 10 – 20 Apr. 10	791 – 841	9.30 (1.83)	64.9 (15.6)	2.9	6.2	0.43	14.5	23
	26	1 Apr. 10 – 25 May 10	822 – 876	11.60 (1.64)	55.6 (7.1)	1.9	4.7	0.40	13.6	21
C	1	18 Mar. 08 – 7 May 08	78 – 128	9.30 (1.51)	65.3 (3.8)	3.3	7.6	0.58	21.0	20
	2	1 Apr. 08 – 21 May 08	92 – 142	10.67 (1.65)	70.0	3.6	7.3	0.48	22.3	17
	3	1 May 08 – 15 June 08	122 – 167	12.88 (0.98)	97.2 (17.3)	9.9	16.7	0.51	44.0	15
	4	1 June 08 – 17 July 08	153 – 199	16.13 (2.25)	60.8 (8.0)	2.6	5.9	0.59	22.5	15
	5	1 July 08 – 16 Aug. 08	183 – 229	16.65 (1.95)	69.8 (11.1)	3.5	7.1	0.50	21.3	17
	9	1 Nov. 08 – 21 Nov. 08	306 – 326	11.00 (0.75)	95.6 (7.3)	9.0	11.6	0.43	13.0	20
	13	1 Mar. 09 – 24 Apr. 09	426 – 480	9.48 (0.83)	55.7 (1.2)	2.0	5.5	0.52	16.9	21
	15	1 May 09 – 16 June 09	487 – 533	12.45 (1.72)	76.1 (6.8)	4.8	9.2	0.51	27.0	17
	16	1 June 09 – 17 July 09	518 – 564	14.67 (0.66)	62.9 (8.8)	2.9	6.4	0.49	19.7	18
	17	1 July 09 – 16 Aug. 09	548 – 594	14.22 (1.04)	83.6 (6.9)	6.0	10.8	0.46	28.6	17
	23	1 Jan. 10 – 20 Feb. 10	732 – 782	5.81 (1.39)	88.0 (5.3)	6.9	12.5	0.65	22.8	24
	25	1 Mar. 10 – 24 Apr. 10	791 – 845	10.20 (1.89)	55.8 (3.5)	2.0	5.5	0.42	14.1	25
	26	1 Apr. 10 – 25 May 10	822 – 876	12.11 (1.55)	52 (1.5)	1.5	4.1	0.39	12.3	21

Table 5.4. (contd)

Site	Simulation Cohort	Residence Period	Simulation Period (days)	Mean Temperature (°C; s.d.)	Mean Fork Length (mm; s.d.)	Wt_i (g)	Wt_f (g)	*P* - value	C (g)	GCE (%)
D	1	19 Mar. 08 – 8 May 08	79 – 129	8.77 (1.51)	67.7 (2.3)	3.7	8.3	0.52	20.6	22
	2	1 Apr. 08 – 21 May 08	92 – 142	10.20 (1.81)	79.2 (3.5)	5.1	9.7	0.46	28.0	16
	3	1 May 08 – 16 June 08	122 – 168	12.79 (1.01)	70.0 (0.0)	3.7	7.6	0.52	24.1	16
	4	1 June 08 – 17 July 08	153 – 199	16.14 (2.36)	65.9 (7.1)	3.4	7.1	0.64	28.8	13
	5	1 July 08 – 16 Aug. 08	183 – 229	18.8 (0.42)	75.0 (9.0)	4.4	8.4	0.66	32.4	12
	13	1 Mar. 09 – 24 Apr. 09	426 – 480	6.64 (1.87)	56.4 (1.6)	2.0	5.7	0.76	16.5	22
	15	1 May 09 – 16 June 09	487 – 533	13.68 (2.27)	73.3 (10.1)	4.3	8.4	0.57	29.1	14
	16	1 June 09 – 17 July 09	518 – 564	17.76 (1.6)	65.2 (4.2)	3.3	7.0	0.70	29.7	12
	17*	1 July 09 – 16 Aug. 09	548 – 594	21.31 (1.67)	71.0 (11.8)	3.8	2.6	1.00	16.8	-7
	21	1 Nov. 09 – 4 Dec. 09	671 – 704	9.68 (1.38)	78.0	4.8	7.8	0.42	12.9	24
	25	1 Mar. 10 – 3 Apr. 10	791 – 824	7.72 (0.87)	49.3 (0.5)	1.3	2.8	0.48	5.2	28
	26	1 Apr. 10 – 4 May 10	822 – 855	10.18 (1.33)	53.8 (3.1)	1.7	3.1	0.46	7.3	19
E	2	18 Apr. 08 – 7 June 08	109 – 159	11.63 (1.77)	79.6 (3.1)	5.2	9.8	0.43	25.3	18
	3	1 May 08 – 16 June 08	122 – 168	12.68 (1.08)	87.7 (7.6)	7.3	13.0	0.46	32.3	18
	5	1 July 08 – 16 Aug. 08	183 – 229	19.75 (1.03)	78.1 (4.7)	5.1	9.2	0.92	43.2	10
	7	1 Sept. 08 – 4 Oct. 08	245 – 278	18.79 (1.08)	87.0	6.7	10.2	0.68	27.8	12
	9	1 Nov. 08 – 21 Nov. 08	306 – 326	11.46 (0.8)	105.2 (6.6)	12.2	15.3	0.44	16.6	19
	10	1 Dec 08 – 21 Dec 08	336 – 356	6.82 (2.32)	103.3 (9.1)	11.8	14.4	0.53	11.9	22
	15	1 May 09 – 16 June 09	487 – 533	13.64 (2.26)	83.4 (21.5)	6.3	11.5	0.48	31.8	16
	16	1 June 09 – 17 July 09	518 – 564	17.73 (1.61)	70.7 (7.4)	4.2	8.4	0.65	33.1	13
	17*	1 July 09 – 16 Aug. 09	548 – 594	21.39 (1.74)	74.7 (10.2)	4.5	2.7	1.00	18.0	-10
	20	1 Oct. 09 – 21 Oct. 09	640 – 660	14.68 (1.97)	98.0	10.1	12.8	0.48	17.1	16
	21	1 Nov. 09 – 21 Nov. 09	671 – 691	10.41 (0.73)	105.6 (10.6)	12.3	15.5	0.42	15.1	21
	24	1 Feb. 10 – 4 Mar. 10	763 – 794	6.25 (0.56)	118.0	19.5	26.4	0.66	30.2	23
	25	1 Mar. 10 – 20 Apr. 10	791 – 841	8.75 (1.5)	61.6 (4.8)	2.7	6.5	0.46	15.1	25
	26	1 Apr. 10 – 21 May 10	822 – 872	11.22 (1.64)	65.8 (6.8)	3.0	6.3	0.40	16.2	21

Table 5.4. (contd)

Site	Simulation Cohort	Residence Period	Simulation Period (days)	Mean Temperature (°C; s.d.)	Mean Fork Length (mm; s.d.)	Wt_i (g)	Wt_f (g)	*P* - value	C (g)	GCE (%)
F	9	18 Nov. 08 – 8 Dec. 08	323 – 343	10.75 (0.74)	111.0	14.4	17.9	0.43	17.8	20
	13*	1 Mar. 09 – 1 Apr. 09	426 – 457	5.17 (0.75)	104.3 (7.6)	14.6	20.3	1.00	28.5	20
	14	1 Apr. 09 – 25 May 09	457 – 488	8.7 (1.41)	128.0	20.4	26.5	0.39	27.1	23
	15	1 May 09 – 16 June 09	487 – 533	13.65 (2.28)	78.9 (9.3)	5.3	10.0	0.46	27.3	17
	16	1 June 09 – 17 July 09	518 – 564	17.59 (1.39)	67.4 (6)	3.6	7.5	0.57	27.1	14
	17*	1 July 09 – 16 Aug. 09	548 – 594	20.86 (1.55)	78.0 (4.6)	5.1	4.9	1.00	27.5	-1
	19	1 Sept. 09 – 21 Sept. 09	610 – 630	20.07 (0.67)	96.0	8.8	11.3	1.00	22.7	11
	22	1 Dec. 09 – 21 Dec. 09	701 – 721	12.05 (0.5)	109.4 (7.5)	13.7	16.7	0.45	19.1	16
	24	1 Feb. 10 – 4 Mar. 10	763 – 794	6.74 (0.59)	102.0	12.6	17.6	0.60	22.7	22
	25	1 Mar. 10 – 24 Apr. 10	791 – 845	8.07 (1.38)	53.1 (2.6)	1.7	4.9	0.49	12.1	27
	26	1 Apr. 10 – 25 May 10	822 – 876	10.92 (1.8)	55.0 (6.3)	1.8	4.6	0.39	12.7	22
H	7	17 Sept. 08 – 7 Oct. 08	261 – 281	18.08 (0.77)	93.8 (9.7)	8.3	10.6	0.56	16.8	14
	8	1 Oct. 08 – 21 Oct. 08	275 – 295	16.28 (1.12)	95.7 (5.2)	9.5	12.0	0.49	16.8	15
	9	1 Nov. 08 – 21 Nov. 08	306 – 326	11.79 (0.84)	97.5 (11.5)	9.6	12.3	0.42	13.7	20
	14	1 Apr. 09 – 21 May 09	457 – 507	9.62 (1.76)	71.0	3.7	7.5	0.41	16.7	23
	15	1 May 09 – 16 June 09	487 – 533	13.49 (2.32)	80.6 (9.3)	5.7	10.6	0.43	26.1	19
	16	1 June 09 – 17 July 09	518 – 564	17.48 (1.4)	73.4 (14.8)	4.7	9.2	0.56	31.9	14
	17*	1 July 09 – 16 Aug. 09	548 – 594	20.81 (1.56)	76.3 (6.8)	4.8	4.5	1.00	26.5	-1
	18*	1 Aug. 09 – 16 Sept. 09	579 – 625	21.32 (0.85)	83.6 (9.2)	6.4	4.6	1.00	14.7	-12
	20	1 Oct. 09 – 21 Oct. 09	640 – 660	15.74 (1.57)	99.5 (2.9)	10.6	13.3	0.48	17.8	15
	21	1 Nov. 09 – 21 Nov. 09	671 – 691	11.02 (0.71)	102.8 (4.7)	11.3	14.3	0.42	14.9	20
	22	1 Dec 09 – 3 Jan. 10	701 – 734	5.11 (1.34)	90.0	8.1	11.7	0.75	15.1	24
	23	1 Jan. 10 – 21 Jan. 10	732 – 752	4.45 (0.39)	97.6 (9.3)	9.4	11.7	0.90	9.5	24
	25	1 Mar. 10 – 1 Apr. 10	791 – 822	7.24 (0.7)	120.0	22.9	31.0	0.51	32.1	25
	26	1 Apr. 10 – 2 May 10	822 – 853	9.72 (1.29)	121.3 (52.5)	17.5	23.0	0.37	25.5	21

Table 5.4. (contd)

Site	Simulation Cohort	Residence Period	Simulation Period (days)	Mean Temperature (°C; s.d.)	Mean Fork Length (mm; s.d.)	Wt_i (g)	Wt_f (g)	*P* - value	C (g)	GCE (%)
I	9	20 Nov. 08 – 10 Dec. 08	325 – 345	9.81 (0.9)	97.5 (9.3)	9.6	12.3	0.40	11.8	23
	11*	1 Jan. 09 – 1 Feb. 09	367 – 398	3.66 (0.48)	102.5 (0.5)	10.8	12.7	1.00	13.8	14
	12*	1 Feb. 09 – 4 Mar. 09	398 – 429	3.28 (0.36)	121.0	21.0	24.9	1.00	19.3	20
	15	1 May 09 – 15 June 09	487 – 532	13.41 (2.29)	116.2 (34.8)	17.0	26.3	0.46	57.1	16
	16	1 June 09 – 17 July 09	518 – 564	17.48 (1.4)	64.2 (9.9)	3.1	6.7	0.62	27.3	13
	17*	1 July 09 – 16 Aug. 09	548 – 594	20.81 (1.56)	71.0	3.9	3.3	1.00	22.0	-3
	20	1 Oct. 09 – 21 Oct. 09	640 – 660	14.77 (1.87)	95.0	9.2	11.8	0.40	13.3	19
	23	1 Jan. 10 – 1 Feb. 10	732 – 763	4.4 (0.38)	118.0	16.4	21.7	0.85	20.7	26
	25	1 Mar. 10 – 24 Apr. 10	791 – 845	8.14 (1.36)	53.3 (4.4)	1.7	5.0	0.52	12.9	25
	26	1 Apr. 10 – 25 May 10	822 – 876	10.86 (1.72)	57.6 (4.5)	2.0	5.0	0.40	13.9	22
N	5	16 July 08 – 31 Aug. 08	198 – 244	18.26 (2.14)	65.0	3.0	6.3	1.00	33.8	10

5.3 Discussion

Although the body of research seeking to elucidate the importance of shallow, tidally influenced freshwater habitats for juvenile salmon in the LCRE is expanding (e.g., Sobocinski et al. 2008; Sather et al. 2009), to our knowledge no investigations have been undertaken to characterize energy dynamics for juvenile salmon in these areas. Optimal energy acquisition is a key component in an animal's quest for nutrition, promoting organismal functions such as maintenance and development (Wiegert 1968). Thus, it stands to reason that identifying potential energetic constraints within particular habitats is vital when assessing the suitability of specific areas to support salmon. To help elucidate the energetic consequences of salmon residence in tidal freshwater habitats in the LCRE, we applied a bioenergetics model (Stewart and Ibarra 1991) to field-collected data. Our results suggest that certain tidal freshwater habitats in the LCRE generally provide suitable forage and environmental conditions to support the energetic requirements of juvenile Chinook salmon.

At each SRD sampling site, mean predicted specific growth rates for simulation cohorts generally were positive, indicating juvenile Chinook salmon typically gained biomass throughout residence periods. While it is difficult to separate factors that may be most important in regulating growth in certain habitats—due largely to interactive effects—our results suggest that the availability and consumption of high-quality prey was an important determinant of favorable growth. Despite broad temperature fluctuations across cohorts, at most sites mean predicted specific growth rates remained relatively consistent (Figures 5.1 and 5.2), indicating that within a certain range the model was relatively insensitive to temperature. Thus, with certain exceptions, it seems plausible that the changes in modeled growth we observed among cohorts resulted largely from changes in diet composition and consequently the amount of energy consumed. Given the consistent positive growth that was predicted from the model, we conclude prey pools at our sites are largely suitable to support juvenile Chinook salmon growth.

While predicted growth was positive for most cohorts, there were few instances during which a cohort lost biomass over a simulation period. The equations used to describe physiological processes in the Chinook salmon bioenergetics model include temperature dependence functions (Hanson et al. 1997). For growth, as for other components of the energy budget, the specific rate drops precipitously when a certain temperature maximum is reached. This relationship between growth and temperature is not only a theoretical construct, but has been well-documented for salmonid species (e.g., Brett 1956; O'Connor et al. 1981; Thyrel et al. 1999). During our simulations, across sites the temperature maximum (~22 °C) was reached infrequently and did not always result in loss of biomass for the respective cohort. Our model output suggests that, in the tidal freshwater habitats we sampled, negative growth does not necessarily result solely from a specific temperature being reached, but rather when that temperature is sustained for a period of time. Selong et al. (2001) suggested the development of thermal protection standards for juvenile salmon is critical to protecting and recovering salmonid populations, particularly given the vulnerability of this life stage to natural and anthropogenic warming. Results from our analyses support the consideration of thermal standards, including both absolute temperature and duration, in tidal freshwater habitats in the LCRE.

Feeding rates and estimates of GCE generally were moderate to high at our sites (c.f., Koehler et al. 2006), suggesting simulation cohorts were encountering a sufficient number of prey (number of organisms, appropriate sizes, high energy content, etc.) at appropriate sizes and that conditions were

favorable to meet to meet energetic requirements and allow for the allocation of energy to somatic growth requirements for the allocation of energy to somatic growth. Koehler et al. (2006) drew similar conclusions based on bioenergetics model output for juvenile Chinook salmon residing in Lake Washington. Gross conversion efficiency represents a measure of growth performance in response to the integrated effects of food quality, food quantity, and environmental conditions of the habitat (Hewett and Johnson 1992; Hanson et al. 1997). Like simulated growth, GCE in our study declined drastically when a certain threshold was reached. For these cohorts, diet composition and, thus, energy consumption, were similar to cohorts that experienced favorable GCE. Our simulations suggest dramatic reductions in GCE appear to be more closely related to a thermal maximum than variability in diet composition, highlighting the importance of applying restoration strategies that minimize high water temperatures in shallow tidal habitats.

Like most modeling applications, our analyses were dependent on specific assumptions. We applied a model for Chinook salmon originally developed for the adult life stage. Although the physiological response of a salmon is known to vary with ontogeny (Brett 1995), we feel the application of this model is appropriate. Previous research has found model-predicted estimates of consumption by juvenile salmon to be within 10% of field and laboratory estimates derived independently (Beauchamp et al. 1989; Brodeur et al. 1992; Ruggerone and Rogers 1992).

Our simulations cohorts were developed based on residence times and estimated for the Columbia River estuary proper (e.g., Campbell 2010). While residence times for juvenile Chinook salmon may differ between saline portions of the LCRE sampled by Campbell (2010) and tidal freshwater areas sampled in our study, our goal was to assess the general suitability of tidal freshwater habitats for juvenile salmon, and not to predict the specific fate of groups of fish. Thus, we think this approach is tenable. For use in evaluating more directed hypotheses (e.g., run success), site- and life-stage-specific estimates are necessary to minimize bias (Koehler et al. 2006). Although we believe our approach is justified, to refine model output and relax assumptions, future work should seek to estimate residence times specifically in tidal freshwater habitats throughout the year.

As for residence times, to estimate initial and final weights, and ultimately simulate proportions of maximum consumption, we relied on estimated growth rates obtained from juvenile Chinook salmon in the saline portion of Columbia River estuary (Campbell 2010). While not ideal, given our objectives, we believe the application of these growth rates was appropriate. When considering predicted growth, we were interested not in absolute values, but whether growth was positive, negative, or maintenance (i.e., zero), to provide for inferences about the suitability of tidal freshwater habitats for juvenile salmon. Given this argument and the dearth of growth information that exists for juvenile Chinook salmon residing in tidal freshwater regions of the LCRE, we are justified in our approach. However, future work should seek to estimate in situ growth rates to allow for more precise inferences.

In this study, diet data were collected on a monthly basis from SRD tidal freshwater sites. While periodic temporal resolution is common in diet studies (e.g., Koehler et al. 2006; Bottom et al. 2008), our data represent a snapshot of the most recently consumed prey items. To better capture within-month variability in diet composition, one alternative is to sample more frequently, an undertaking that can be extremely time and labor intensive. Stable carbon isotopes are being used more commonly to characterize time-integrated diet and corroborate information gained from traditional gut content analysis (e.g., Hobson and Clark 1992; Vander Zanden et al. 1998). For example, Storch et al. (2007) applied an isotope-mixing model to observed stable carbon isotope values of various prey items to corroborate the

gut content data and provide a time-integrated description of the roles of invasive zooplankton in the diets of alewife in the Great Lakes. Approaches such as this should be considered in the future to help reinforce conclusions drawn from gut content analyses and bioenergetics simulations.

Identifying biotic (e.g., prey base) and abiotic (e.g., temperature) factors that may promote or constrain the flow of energy through food webs is an important step in understanding observed production dynamics of secondary consumers (Lindeman 1942). In this study, we applied an energy balance (Hanson et al. 1997) to field-collected data to assess the suitability of specific tidal freshwater habitats to support juvenile Chinook salmon and elucidate factors that may regulate production. Modeled growth and feeding rates and resulting GCEs suggest that, under certain conditions, the tidal freshwater habitats we considered support favorable salmon production. With the federal listing status of several salmonid stocks within the Columbia River basin (NOAA Fisheries 2008), our results underscore the importance of maintaining shallow tidal freshwater habitats in the LCRE. While model simulations showed positive growth and moderate-to-high feeding rates and conversion efficiencies during most simulation periods, we did identify a thermal limit at which growth declined precipitously. In light of this constraint, thermal protection standards should be considered, and steps—including maintaining water masses, restoring hyporheic flows, and extending riparian vegetation—should be taken to help minimize drastic temperature fluctuations and maximums.

5.4 Summary, Conclusions, and Recommendations

The following conclusions were drawn from and recommendations were made based on the analysis of juvenile salmon bioenergetics in shallow tidal freshwater:

- Across sites, mean predicted specific growth rates for simulation cohorts were positive and varied little, except during sustained high temperature extremes. This model output suggests the integrated effects of prey composition and quality, thermal experience, and species-specific physiology will result in favorable growth for juvenile Chinook salmon at our sampling locations within shallow tidal freshwater LCRE habitats.
- Feeding rates (i.e., proportion of maximum consumption, *P*-value) for simulation cohorts of juvenile Chinook salmon at our sites generally were moderate to high. This suggests that prey pools exploited by most cohorts were sufficient (in terms of the number of organisms, appropriate sizes, etc.) to allow juvenile Chinook salmon to feed close to their maximum daily ration.
- Gross conversion efficiency represents a measure of the ability of an organism to convert ingested food into new tissue given environmental conditions and prey quality and quantity. Our simulations suggest the prey base and thermal regime at sampling locations throughout the majority of our study allowed for the efficient allocation of energy to somatic growth—a critical factor for young, migratory fish.
- Consistently high *P*-values and GCEs at our sites suggest competition for prey resources may be weak.
- Our simulation scenarios were developed based on residence times estimated for the Columbia River estuary proper. To improve model output, future work should seek to estimate juvenile Chinook salmon residence times, throughout the year, specifically in tidal freshwater habitats.

- Results from growth simulations indicate there is a temperature maximum (~22 ^{o}C) at which juvenile salmon growth drops precipitously. Although this occurred infrequently at sampling locations during our study period, given the inter-annual uncertainty surrounding the thermal regime, this response should be considered when planning restoration efforts associated with listed salmon. Maintaining suitable flow regimes and overhanging riparian vegetation in tidal freshwater habitats are examples of actions that may help mitigate critical water temperatures.
- To help better inform management, future modeling syntheses should be conducted by coupling the bioenergetics model with a hydrologic model. A composite model of this type would allow researchers to better assess the potential impacts of variable river conditions on juvenile salmon.

6.0 Migration Pathways and Residence Times

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The listings of salmonids in the Columbia River basin under the ESA have prompted increased interest in the ecology of the LCRE. All migratory salmonid stocks in the basin that rear in the ocean must travel downstream through the LCRE. Habitats within the 235-km stretch of river and estuary between Bonneville Dam and the ocean function as migration pathways, locations for feeding and growth, refuge from predators, and areas for physiological adjustment from freshwater to saltwater (Bottom et al. 2005b; Fresh et al. 2004). BiOps on operation of the FCRPS have included LCRE habitat restoration and supporting research, monitoring, and evaluation as a means to avoid jeopardizing the existence of ESA-listed stocks (NMFS 2000, 2004; NOAA Fisheries 2008). Because salmon can display a wide range of life-history strategies (Healey 1991), and both yearling and subyearling fishes in the estuary potentially occur year-round (Connor et al. 2005), patterns of habitat use in freshwater tidal reaches are certain to be complex, and consequently, much remains unknown. Fisheries and FCRPS managers are asking: In what types of habitats within the tidal freshwater area of the Columbia River are juvenile salmonids found, when are they present, and under what environmental conditions? What is the ecological role of shallow (0–5 m) tidal freshwater habitats to the recovery of ESA-listed salmonids in the Columbia River basin? Addressing these questions requires, in part, understanding of migration pathways and residence times in the LCRE.

Juvenile salmonid migration characteristics, especially in the estuary and lower river below rkm 75, were studied in the 1970s and 1980s. Sims and Durkin (reported by Dawley et al. 1986) noted movement of hatchery subyearling Chinook salmon through the estuary was generally rapid. Marked fish began entering the ocean within 6 days after reaching the tidal freshwater zone at Jones Beach, Oregon (rkm 75). Duration of estuarine residence was linked to size of fish, timing of release, and location of natal stream. Fish migrating at smaller sizes during early release periods (mid-April) and from tributaries closest to the mouth of the LCRE yielded greatest estuarine residence times. Dawley et al. (1986) marked and recaptured over 100,000 juvenile salmon and found that smaller subyearling salmon (<120 mm) using shallow-water habitats tended to spend more time in the LCRE than larger juvenile migrants (>120 mm). Generally, the largest fish within hatchery and wild groups migrated the fastest from natal stream/release site to the estuary. Conversely, smaller fish had protracted migrations and thus used the habitats and food resources along the migration route more extensively. Average movement rates through the estuary (rkm 75–16) from 1978 through 1980 were similar to upriver movement rates (13, 19, 23, and 44 km/d, respectively, for hatchery subyearling and yearling Chinook salmon, coho salmon, and steelhead). Movement rates to and through the estuary generally increased in relation to greater migration distance, higher river flows, greater body size, and level of smoltification. However, residence time in the estuary was substantial (up to 90 days) for some fish migrating from locations upstream from Bonneville Dam and Willamette Falls, regardless of fish size. Subyearling Chinook salmon originating from lower river tributaries and sporadic groups of yearling Chinook and coho salmon displayed protracted residence in the estuary—up to 103 days, 90 days, and 32 days, respectively. Dawley et al. (1986) also noted some juvenile salmon over-wintered in the LCRE.

In the last decade, telemetry technologies have been used to examine migration rates and pathways. Schreck et al. (2004), using radio and acoustic telemetry, monitored tagged Snake River-origin juvenile salmonids to and through the estuary. They found yearling steelhead and subyearling Chinook salmon

migrated rapidly to and through the freshwater portion of the estuary, averaging from 2.7 to 3.4 km/h for the slowest subyearling Chinook migrants to 4.1 km/h for the fastest steelhead migrants. Harnish et al. (In Review) studied migration pathways below rkm 85 and found 21% to 33% of acoustic-tagged yearling and subyearling Chinook salmon and steelhead smolts were detected migrating through off-channel areas below rkm 85 during 2008. Median travel times were similar for all species or run types and migration pathways examined, ranging from 1 to 2 days.

Information, however, is lacking on migration pathways and residence times in the off-channel habitats in the tidal freshwater of the Columbia River. Accordingly, we applied acoustic-telemetry technology similar to that described by Harnish et al. (In Review) and McMichael et al. (2010). Two specific objectives were pursued: 1) during spring and summer 2007 and 2008, use juvenile salmon tagged with acoustic transmitters and released upstream of Bonneville Dam as part of other studies to estimate migration pathways and residence times in the SRD study area; and 2) during winter 2010 (January 26, 27, and 29, 2010), capture, tag, and release juvenile Chinook salmon to estimate residence time and movement characteristics for these fish during winter and early spring months in a tidal freshwater, off-channel habitat of the LCRE.

6.1 Methods

A basic acoustic-telemetry system consists of a tag (the transmitter), a hydrophone (the receiving transducer or node), a signal processor, and processing and analysis software. Such a system can be used to detect the presence of a tagged animal in an area of interest. The micro-acoustic tags used in this study transmitted 417 kHz of sound. The equipment—the Juvenile Salmon Acoustic Telemetry System (JSATS)—provided the smallest acoustic tag available to meet the need to tag subyearling Chinook salmon (McMichael et al. 2010). Figure 6.1 shows a JSATS transmitter and a PIT tag. The methods for this research are summarized in Table 6.1.

Figure 6.1. Photograph of a JSATS Acoustic Tag and a PIT Tag

Acoustic tags were surgically implanted in fish using methods described by McMichael et al. (2010). During 2007 and 2008, we monitored fish migrating through the SRD study area that had been tagged at upriver locations as part of other studies. Autonomous receivers (called nodes) were deployed in relatively deep areas of off-channel habitats in the study area to maximize signal detectability (Figure 6.2). The detection range for JSATS transmitters is about 300 m in open water (McMichael et al. 2010). Nodes deployed for other studies were also used in 2007 and 2008. The nodes were operational 24 h/d to receive signals from tagged fish, except during servicing to replace batteries and data media.

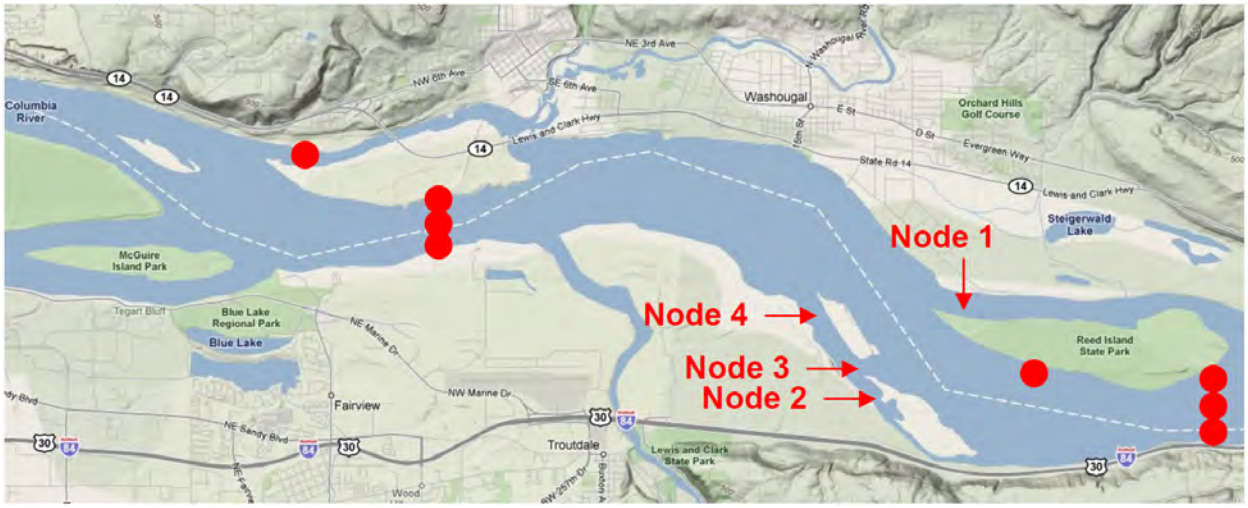

Figure 6.2. Acoustic Receiver (node) Locations During 2008. The red dots represent receiver arrays deployed for other studies that provided useful information for our study. Node 1 was located in the side channel behind Reed Island and Nodes 2–4 were placed in side channels behind a group of islands termed "delta islands." Receiver locations during the 2007 study were similar, except Nodes 2 and 4 were placed slightly further upstream and downstream, respectively, and in shallower water than in 2008.

During 2010, we used a beach seine to capture juvenile Chinook salmon in the vicinity of the SRD behind Gary Island ~2 km upstream of the mouth of the Sandy River, and near McGuire Island ~7 km downstream of the mouth of the Sandy River. A total of 51 fish greater than 86 mm in length were tagged with JSATS transmitters. The fish to be tagged were anaesthetized using fresh river water and MS-222 (tricaine methanesulfonate; 80 to 100 mg/L). Each fish was weighed and measured before tagging. Fin tissues from individual juvenile Chinook salmon were collected for genetic stock identification described by Teel et al. (2009), which included genetic mixture analysis and the relative probability of stock origin of each sample as estimated using the genetic stock identification computer program ONCOR (Kalinowski et al. 2007). During surgery, each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The dilution of the "maintenance" anesthesia was 40 mg/L. Using a surgical blade, a 6- to 8-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. An acoustic tag was inserted in the body cavity toward the anterior end of the fish. The incision was closed using 5-0 Monocryl suture. After closing the incision, each fish was placed in a dark 18.9-L transport bucket filled with aerated river water. Fish were held in these buckets for 18 to 24 hours before being transported for release into the river. Fish were tagged on January 26, 27, and 29, 2010, and released 24 hours later. All tagged fish were released near Node 7085 behind Gary Island (Figure 6.3). Five autonomous acoustic receiving nodes were deployed in the off-channel area behind Flag and Gary islands in the SRD study area (Figure 6.3).

Table 6.1. Summary of Methods for Acoustic Telemetry Research for the Tidal Freshwater Monitoring Study, 2007–2010

Factor	2007	2008	2010
Study Period	April 27 to August 18	April 26 to July 25	January 27 to April 23
Tag Manufacturer	Sonic Concepts	Advanced Telemetry Systems (ATS)	ATS
Tag Weight in Air (g)	0.63	0.43	0.43
Tag Dimensions (mm; wide x high x long))	5.5 x 4.8 x 19	5.21 x 3.8 x 12	5.21 x 3.8 x 12
Species Tagged[(a)]	CH1 and CH0	CH1, CH0, STH	CH
Source of Tagged Fish	Upriver studies	Upriver studies	*In situ* beach seine
Marked/Unmarked	Marked	Marked	Unmarked
Mean Fish Fork Lengths (mm)	CH1 = 145; CH0 = 105[(b)]	CH1 = 144; CH0 = 115; STH = 215[(c)]	CH = 103
Genetic Stock Estimate	No	No	Yes
Number of Tagged Fish Potentially Available for Detection	>23,000	23,340	51
Number of Release Sites	(2) Lower Granite and Bonneville dams	(6) Lower Granite Dam, Arlington, John Day Dam, The Dalles Dam, Bonneville Dam, and Skamania	(1) Sandy River delta (SRD) vicinity
TFM Detection Sites	(4) in vicinity of SRD plus arrays nearby up- and downstream as part of other studies	(4) in vicinity of SRD plus arrays nearby up- and downstream as part of other studies	(5) SRD vicinity

(a) CH1 = yearling Chinook salmon, STH = steelhead, CH0 = subyearling Chinook salmon; CH = juvenile Chinook salmon.
(b) Fish length data for 2007 are from the Post-FCRPS study (McComas et al. 2009). These fish lengths are representative of tagged fish from other studies that also migrated through the SRD study area.
(c) Fish length data obtained from Harnish et al. (In Review).

Acoustic data were downloaded from the nodes once a month during the yearly study periods. Tag life for the transmitter and pulse repetition rate of one pulse every 7 seconds was not measured for the 2010 tagging effort. We approximated tag life of at least 60 days based on data from tag-life studies for transmitters with 3-s and 5-s repetition rates (personal communication with G. McMichael, September 30, 2010).

For data analysis, a detection event was primarily defined by at least four valid acoustic signal receptions with a pulse-repetition interval (PRI) matching the temporal pattern of a properly functioning JSATS tag within a time window that also was defined by the PRI specific to each tag. The window duration was 47.8 s for 3-s tags (2008), 79 s for 5-s tags (2007), 110.2 s for 7-s tags (2010), and 157 s for 10 -s tags (Snake River fish tagging 2008). We matched detected fish with release codes and developed time-of-detection histories. The primary results from the analysis of the acoustic data were the species of tagged fish, time of first detection event, time of last detection event, location(s) (i.e., nodes where valid detection events occurred), and total number of valid detection events. For brevity, in the remainder of Chapter 6 the term “detection” refers to a valid detection event.

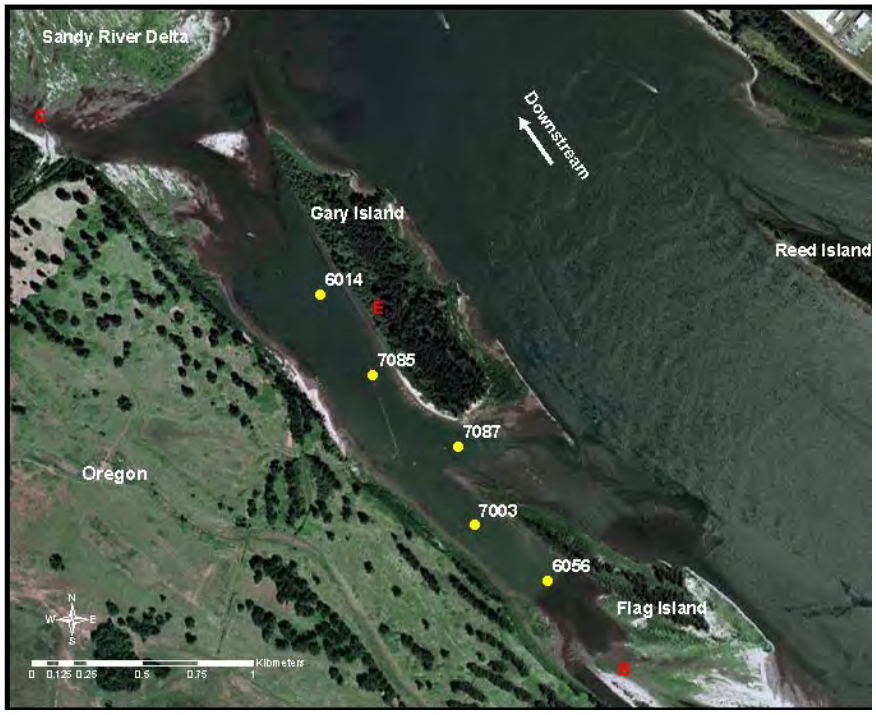

Figure 6.3. JSATS Autonomous Receiver Node Locations (yellow dots) During 2010. The numbers are the node identifiers. The red dots are the locations of beach seine sites as part of other research in the SRD (see Chapter 2). Node 7087 was located at rkm 200.

To determine migration pathways during 2007 and 2008, we tallied the numbers of acoustic-tagged fish using particular pathways through the SRD study area: 1) counts for the main channel are for acoustic-tagged fish with detections on both arrays upstream and downstream of the SRD to maximize the likelihood of correctly categorizing fish that migrated downstream in the main channel; and 2) counts for the SRD and vicinity are for acoustic-tagged fish with valid detection events on any of the nodes in the (Figure 6.2), including detections behind Reed Island (Node 1) and the delta islands (Nodes 2, 3, and 4). During 2007, residence time was estimated by the time difference between first and last detection on a given node, because only 5 of 575 tagged fish observed in the study area were detected on more than one node. During 2008 and early 2010, however, residence time was estimated by the mean duration between first and last detections for the suite of nodes as a whole, i.e., the duration between first and last detections in the study area no matter which node because most fish were detected on multiple nodes.

6.2 Results

The results are presented in two sections. First, we describe data on 2007–2008 migration characteristics in the SRD and vicinity using thousands of tagged fish released at and above Bonneville Dam for the purpose of other studies. Second, we convey the January–April 2010 residence time data from fish we captured, tagged, released, and monitored in the SRD and vicinity.

6.2.1 2007 and 2008 Migration Characteristics

Hundreds of acoustic-tagged fish were detected on receiving nodes in the SRD study area (Table 6.2). During 2007, a total of 575 yearling and subyearling Chinook salmon, approximately 3% of the total

number of fish implanted with JSATS transmitters, had valid detections. During 2008, approximately 4% (981 fish) of the total number of tagged fish detected by SRD and main-channel nodes were detected on SRD nodes.

Table 6.2. Numbers of Acoustic-Tagged Fish with at Least One Detection on the Receivers in the SRD and Vicinity and the Nearby Main Channel (MC)

Year	Receivers	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon	Total
2007	SRD	392	NA	183	575
	MC	3,210	NA	4,832	8,042
2008	SRD	500	66	415	981
	MC	5,454	2,031	5,578	13,063

NA = Not applicable.

The detection histories during the 2007 study indicate that the majority of the acoustic-tagged Chinook salmon—89% of the yearlings and 96% of the subyearlings—migrated through the study area via the main channel of the Columbia River (Table 6.3). Conversely, 11% of the yearling and 4% of the subyearling Chinook salmon migrated through the SRD and vicinity in off-channel habitats. A greater percentage of acoustic-tagged yearling and subyearling Chinook salmon used the route between Reed Island and the Washington shore (8.6% and 3.4%, respectively) than the route along the Oregon shore at the delta islands (2.3% and 0.3%, respectively). No fish were observed to have crossed over between the Reed Island and SRD pathways during 2007.

During the 2008 study, the majority of the acoustic-tagged fish in the SRD study area used the main river channel as a migration pathway—91.6% for yearling Chinook salmon, 96.9% for steelhead, and 93.1% for subyearling Chinook salmon (Table 6.3). Conversely, depending on species, 3.1% to 8.4% of the acoustic-tagged fish migrating from upriver release sites were present in off-channel habitats in the study area. Similar to 2007, more fish migrated in the channel behind Reed Island than behind the delta islands (Table 6.3). Sequential detections by the SRD nodes indicated movement patterns were primarily downstream within the study area. Because only two acoustic-tagged fish (subyearling Chinook salmon) were first detected on Node 2 (Figure 6.2), it appeared the outermost migration pathway along the Oregon shore (e.g., behind Chatham Island) was seldom used. Three acoustic-tagged yearling Chinook salmon crossed the main channel from behind Reed Island to the off-channel areas behind the delta islands.

Table 6.3. Migration Pathways for Tagged Yearling and Subyearling Chinook Salmon and Steelhead During 2007 and 2008. Pathways are defined below the table.

		Yearling Chinook Salmon		Steelhead		Subyearling Chinook Salmon	
	Pathways[a]	Freq.	Percentage	Freq.	Percentage	Freq.	Percentage
2007	Main Channel[b]	3,210	89.1%	NA	NA	4,832	96.3%
	Reed Island[c]	309	8.6%	NA	NA	170	3.4%
	Delta Islands[d]	83	2.3%	NA	NA	13	0.3%

Table 6.3. (contd)

		Yearling Chinook Salmon		Steelhead		Subyearling Chinook Salmon	
	Pathways[(a)]	Freq.	Percentage	Freq.	Percentage	Freq.	Percentage
2008	Main Channel	5,454	91.6%	2,031	96.9%	5,578	93.1%
	Reed Island	357	6.0%	38	1.8%	355	5.9%
	Delta Islands	143	2.4%	28	1.3%	60	1.0%

(a) Includes fish detected at nodes deployed in the Sandy River Delta (SRD) and vicinity for migration pathway studies and the nearby main channel for other studies during 2007 and 2008.
(b) Main Channel = fish detected on main-channel arrays upstream and downstream, but not any of the SRD migration pathway nodes.
(c) Reed Island = fish detected on the Reed Island node, but not the nodes behind Gary Island near the SRD.
(d) Delta Islands = fish detected on the nodes behind Gary and Flag islands near the SRD, but not the Reed Island node.
NA = Not applicable.

Residence times for acoustic-tagged fish migrating through the study area during spring and summer 2007 and 2008 were short (<4 h) (Table 6.4). A few yearling and subyearling fish did have extended time in the study area at hundreds of hours. For example, examination of species-specific frequency distributions for 2008 revealed median residence times of 0.05, 0.06, and 0.06 hours for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively.

Table 6.4. Residence Times (hours) for Yearling and Subyearling Chinook Salmon and Steelhead Tagged with Acoustic Transmitters and Detected at Nodes in the SRD and Vicinity During 2007 and 2008. The sample sizes for residence time estimates for 2007 were 26 fish less than total unique detections (Table 6.2) because the receiving node at the old Sandy River channel was removed by well-meaning citizens during the course of data collection.

Year	Statistic	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2007	n	366	NA	153
	Mean (h)	0.78	NA	3.69
	Minimum (h)	<0.01	NA	<0.01
	Maximum (h)	109	NA	335
2008	n	500	66	415
	Mean (h)	1.71	0.07	1.56
	Minimum (h)	<0.01	<0.01	<0.01
	Maximum (h)	179	0.36	522

NA = Not applicable.

6.2.2 Early 2010 Residence Time

Genetic stock identification provides context for the early 2010 residence time results. For the acoustic-tagged fish, 30 of 51 fish were from the Willamette River Spring Chinook salmon stock (Table 6.5). This stock is known to have been transferred to the Sandy River drainage (Sobocinski et al. 2008). The West Cascades stocks, which can originate in watersheds of the Washougal, Lewis, Kalama, Cowlitz, and other rivers in the lower Columbia River region, accounted for one-quarter of the tagged fish. The two Snake River fish did not have strong stock identification probabilities. The 103-mm mean length of the tagged fish indicates a yearling life-history pattern with emigration to the ocean typically during spring. All but 1 of the 51 tagged fish was unmarked; i.e., they had no adipose fin clip or coded wire tag.

Table 6.5. Best Stock Estimates from Genetic Stock-Identification of Chinook Salmon

Location	Spring Creek	Snake	Snake	Upper Columbia River	West Cascades	West Cascades	Willamette River
Stock	Fall	Fall	Spring	Summer/Fall	Fall	Spring	Spring
Number	1	1	1	5	6	7	30
Proportion	0.02	0.02	0.02	0.10	0.12	0.14	0.59

During the 2010 SRD study, 48 of 51 acoustic-tagged fish yielded at least one valid detection event. All 48 fish were first detected on Node 7085, the node nearest the post-tagging release point. Only one-quarter of the tagged fish were detected in the most upstream portion of the monitoring area, Node 6056. Nearly all fish (92%) were detected at least once on the most-downstream node, Node 6014. Most fish (85%) were detected on three or more nodes during the January–April monitoring period (Table 6.6), indicating movement in the study area behind Gary Island.

Table 6.6. Multiple Detection Events for the Individual Tagged-Fish Detected in the Study Area (n=48: 1 node, any two nodes, any three nodes, etc.)

#Nodes	1	2	3	4	5
#Fish	3	4	19	9	13

Nearly half of the tagged fish (48%) were detected last on Node 7085 behind Gary Island (Figure 6.4). Eleven (23%) and ten (20%) fish were last seen on the other two nodes near Gary Island, Nodes 6014 and 7087, respectively. Only one fish was detected last on Node 6056, the most upstream node in the study. Individual tagged fish were last detected starting on January 28; the last detection of a tagged fish in the study area was on April 15 (Figure 6.5). Exit timing was episodic during late January, February, and April. During March, last detections were protracted. Exit rates ranged from 0 to 3 tagged fish/d with 3 fish/d observed on 2 days in both February and April (Figure 6.6). Exit rates during March did not exceed 1 fish/d. Exit timing was not related to fish length or weight (Figures 6.7 and 6.8).

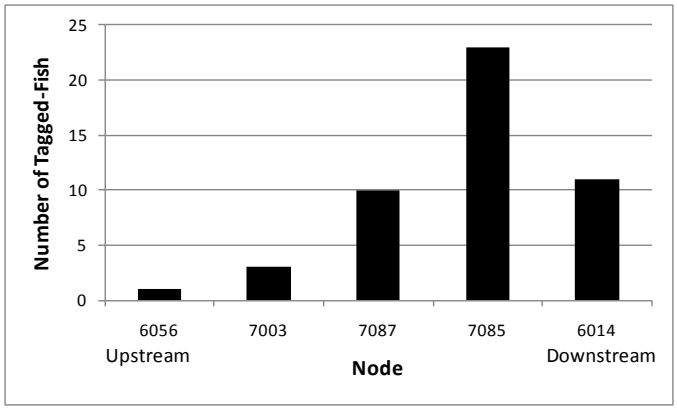

Figure 6.4. Number of Last Detection Events by Node

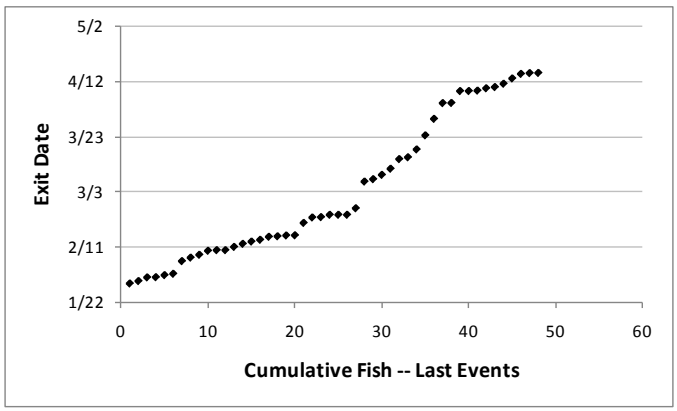

Figure 6.5. Date Sequence for Last Valid Detection Event for the 48 Tagged Fish Detected at the SRD Nodes from January Through April 2010

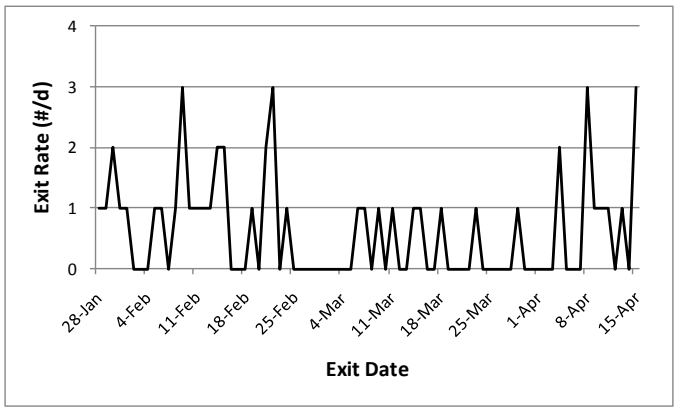

Figure 6.6. Daily Exit Rates for Last Valid Detection Events for the 48 Tagged Fish Detected at the SRD Nodes from January Through April 2010

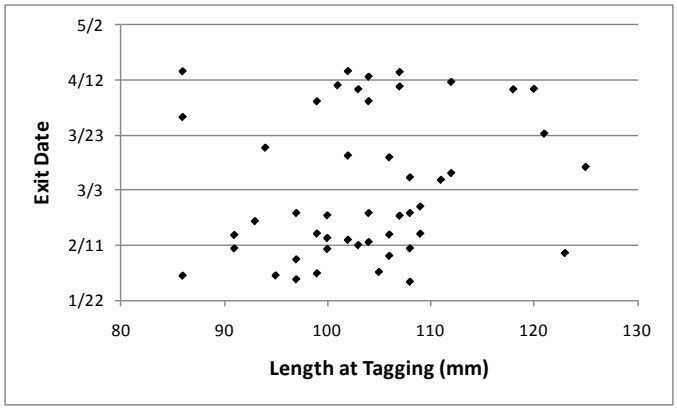

Figure 6.7. Relationship Between Length at Tagging (mm) and Exit Date

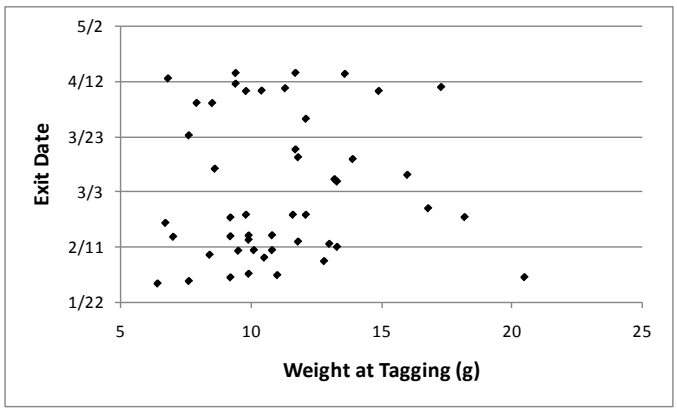

Figure 6.8. Relationship Between Weight at Tagging (g) and Exit Date

During the acoustic-telemetry study conducted from winter to early spring 2010, mean and median residence times for juvenile Chinook salmon were 34 days and 26 days, respectively (Table 6.7). Residence times were somewhat bimodal with peaks around 20 and 80 days (Figure 6.9). These estimates are conservative because last detection could have been due to tag battery depletion, not necessarily emigration out of the SRD study area.

Table 6.7. Residence Time (d) Statistics During Early 2010

Statistic	Value
n	48
Minimum (d)	1.11
Maximum (d)	78.39
Mean (d)	34.25
Median (d)	26.31

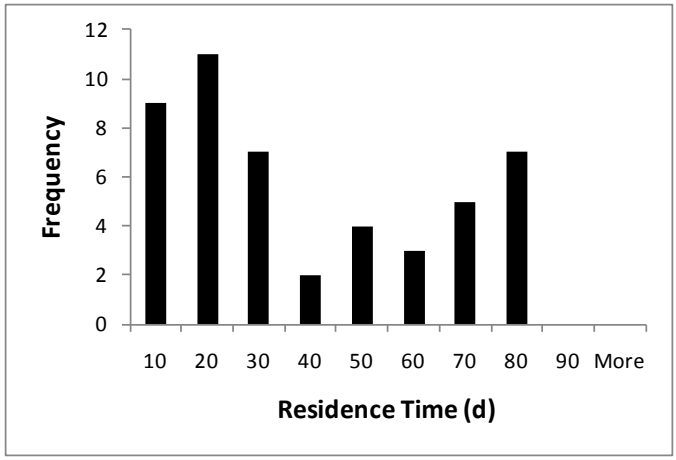

Figure 6.9. Frequency Distribution of Residence Times During Early 2010

6.3 Discussion

The two phases of this investigation revealed contrasting behavioral patterns for tagged juvenile salmonids in tidal freshwater, off-channel habitats of the lower Columbia River near the SRD. During spring and summer 2007 and 2008 when run-of-river fish were tagged and released upstream as part of other studies, a portion of the tagged population (3%–11%) used off-channel routes in the vicinity of the SRD, although the bulk of the tagged fish migrated in the main channel of the river. This is consistent with findings downstream of Puget Island (rkm 67) in the Columbia River where tagged fish were detected in side-channel routes in Cathlamet and Grays bays (Harnish et al. In Review). The off-channel distribution may also reflect density-dependent allocation of available space and resources given the millions of juvenile salmon entering the LCRE during spring and summer each year. The rapid movement (i.e., hours) through off-channel habitats of tagged run-of-river fish suggests active migration toward the ocean. This pattern of migration for run-of-river fish during spring and summer months contrasts the patterns we observed for juvenile Chinook salmon that were captured, tagged, released, and detected at the SRD during winter to early spring of 2010. Mean fork length (FL) for the 51 SRD tagged fish was 103 mm, and most were from the spring run Willamette stock group (59%). These tagged fish resided in the SRD vicinity for an average of 34 days over the period January 28 to April 15, 2010. This estimate of residence time is conservative because tagged fish could have continued to reside in the study area after the tag ceased transmitting when its battery was depleted. The contrast in behavioral patterns between the spring and summer 2007–2008 run-of-river juvenile salmonids and the early 2010 juvenile Chinook salmon revealed different strategies for juvenile salmon in the LCRE.

Differences in the life-history strategies for juvenile Chinook salmon stem from two broad characterizations: “stream type” (e.g., yearlings) and “ocean type” (e.g., subyearlings) (Healey 1991). During 2009, acoustic-tagged yearling and subyearling Chinook salmon exhibited rapid migration rates between Bonneville Dam and the mouth of the Columbia River; mean travel time was 3.4 days and 4.1 days, respectively (McMichael et al. 2010). Similarly, the fish we detected in the off-channel areas of the SRD demonstrated a rapid rate of migration with little to no residualization. While the tagged group of Chinook salmon monitored during the spring and summer months for our study represented two contrasting life-history strategies (e.g., stream- and ocean-type), both groups demonstrated similar migration patterns. The likely explanation for these patterns stems from location of release, as well as the

sizes of the tagged fish. Dawley et al. (1986) noted salmon released from upriver locations had faster migration rates toward the estuary compared with fish released from hatcheries within the lower river. In addition, the size of migrating fish was correlated with rates of migration as well as lateral dispersal. Larger salmon had higher migration rates and were more closely associated with the main channel of the river (Dawley et al. 1986). Our findings of rapid migration during spring and summer 2007 and 2008 by tagged large-sized salmon from upriver sources through off-channel habitats support the observations made by Dawley et al. (1986) in the lower river.

While rapid migration rates noted by McMichael et al. (2010) may be applied to the broad categorization of life-history groups, decades of research on juvenile salmon indicate many species of salmonids exhibit delayed rearing in freshwater and estuarine habitats. Characterization of these early life-history strategies for juvenile salmon often focuses on attributes such as migration timing, size of fish during migration, residence time in discrete habitats, and genetic stock lineage. In the Snake River basin, Connor et al. (2002, 2005) identified two strategies of fall Chinook salmon. The first strategy was akin to an ocean type strategy with migrants leaving natal streams soon after emergence, and the second strategy was described as a "reservoir-type" whereby fall Chinook salmon over-wintered in reservoir habitats prior to making spring migrations as yearlings. It was postulated that some fish exhibiting the reservoir strategy in the Snake River basin over-wintered in tidal freshwater habitats of the lower Columbia River (Connor et al. 2005). While some of the fish tagged for our winter residence time study were from upriver sources, more than 80% of the tagged fish originated from stocks that are commonly associated with the lower river (e.g., West Cascade and Willamette stock groups). Additionally, 25% of the tagged fish were fall Chinook salmon, a group that typically migrates to the ocean as subyearlings. During a period from 1966 to 1972, Dawley et al. (1986) noted that while the majority of juvenile fall Chinook salmon entered the estuary from April through September some fish migrated during later time periods or over-wintered in the lower river and migrated out during the following spring. In both studies, residualization was coupled with fall Chinook salmon that migrated later at smaller sizes (Dawley et al. 1986; Connor et al. 2002).

Most of the Chinook salmon we tagged during the winter 2010 study period were likely yearling migrants from lower river stock groups. However, a portion of the tagged fish apparently was fall Chinook salmon that demonstrated a late winter and early spring residence in tidal freshwater habitats of the Columbia River. We have no knowledge of rearing conditions prior to the initial capture and we found no difference in size between the spring and fall groups. To minimize handling and stress, the tagged fish were not lavaged to retrieve stomach contents. However, concurrent investigations in the study area indicate dipterans and hemipterans are important components of the winter diet of Chinook salmon at the SRD (see Chapter 4, Figures 4.1 and 4.2).

The migration pathways and movement patterns we observed for acoustic-tagged fish in the SRD and vicinity have implications for fish access to and restoration of off-channel, shallow-water habitats for rearing. Lateral connectivity and access to shallow, off-channel habitats is fundamental to the mechanism for juvenile salmon to derive benefits from such habitats (Simenstad and Cordell 2000). In the LCRE, improving access (also called opportunity) is an important strategy for habitat restoration (Johnson et al. 2003). In our study area, access into the side channel between Chatham Island and the Oregon shore (Figure 6.1; southeast of Node 2) is inhibited by an extensive network of pile structures at the upstream end of the island. Besides reducing the amount of river flow into that side channel, a linear array of piling can also act like a louver array, which can act as a fish guidance device (Odeh and Orvis 1998). During the spring-summer monitoring period we detected few tagged fish moving downstream in the channel

behind Chatham and Flag islands into the area behind Gary Island (Table 6.3). However, many tagged fish migrated downstream through the side channel behind Reed Island (Table 6.3). This area is likely more accessible than the channel behind Chatham Island, because the upstream connection to the main channel is not blocked by pile structures and its lateral connection to the main channel is closer compared with Chatham Island. The removal of pile structures at the upstream end of Chatham Island may be implemented as a restoration technique aimed at improving access for juvenile salmonids to off-channel habitats in tidal freshwater.

The migration characteristics we observed are not representative of all juvenile salmon populations present in the LCRE. Currently, the transmitter size associated with the JSATS acoustic tag technology limits the breadth of research pertaining to broader life-history strategies of migrating juvenile salmon. The size of the transmitter restricts the group of fish that could be reliably tagged to those greater than 95 mm FL. While salmon of this size may be representative of one life-history strategy, the majority of juvenile salmon encountered during a concurrent study within the SRD were made up of smaller size classes (overall mean FL = 65 mm). The size distribution for Chinook salmon encountered via beach seine efforts at our study sites ranged from 33 to 158 mm (see Chapter 2). To gain an appreciable understanding of salmon ecology in shallow tidal freshwater habitats, using acoustic telemetry, the tag size will need to be reduced to accommodate tagging smaller fish (>50 mm) with minimal tag effects.

Tag effects are a concern with any methodology where an object is surgically implanted in an animal. We do not know how the implanted tag may have affected its behavior. Hockersmith et al. (2008), researching tag effects studies for the same types of transmitters and species of fish we studied, reported that travel times in most reaches were not significantly different between fish tagged with JSATS transmitters and fish tagged with PIT tags. Furthermore, laboratory experiments by Hockersmith et al. (2008) showed low mortalities (<4.5%) of yearling Chinook salmon for both tag types. For subyearling Chinook salmon, mortality among control and PIT-tag treatments ranged up to 7.7%, while integrated and nonintegrated treatments had slightly higher rates (up to 8.3% and 7.9%, respectively). Tag effects must be accounted for during research using acoustic telemetry.

Acoustic telemetry has the potential to provide useful data about temporal distributions, residence times, and migration pathways to evaluate habitat use and assess the effectiveness of restoration actions in the LCRE. However, the current technology remains limited by transmitter size (tagged fish must be >95 mm), receiving capability in shallow water (<3 m), and transmitter life. Besides downsizing the existing acoustic tags, the size limitation could be addressed by developing a “pinger” tag that transmits an uncoded acoustic signal instead of the coded pulse currently used to obtain a unique identifier. Because the pinger signal would not be unique, new statistical approaches similar to those used in analysis of batch mark data in fisheries, would be necessary. To overcome the limitations of shallow water, we recommend comparing the performance of the omni-directional hydrophone we used to the performance of a directional (e.g., 30 deg) hydrophone to support development of design guidelines for the optimum acoustic transmitter/receiving system for shallow water. Moreover, the transmitters we used lasted for ~2 months. A long-life (~1 year) tag would be useful for over-wintering studies in LCRE tidal freshwater. Radio-frequency transmitters are another option worth considering for use in shallow water. Receiving antennas could be placed onshore with fewer logistical constraints than would be the case with underwater acoustic receivers. All tagging studies should include measurements of transmitter life. As tagging technologies evolve and improve, they should be considered for application to action effectiveness research in the LCRE. Objectives could include mark-recapture for juvenile salmon

residence time, abundance and distribution relative to pile structures, and alternatives assessment and field tests of acoustic-telemetry methods for survival estimation at restoration sites.

In conclusion, the acoustic-telemetry research revealed stark differences in residence times between active migrants during spring and summer and inactive migrants during winter and early spring sampled in shallow, off-channel habitats in tidal freshwater. Over-wintering in tidal freshwater may provide important opportunities for feeding and growth that could ultimately translate into increased fitness and survival during migration to, in, and from the ocean.

6.4 Summary, Conclusions, and Recommendations

The acoustic-telemetry evaluations of migration pathways and residence times for tagged juvenile Chinook salmon and steelhead in the LCRE SRD and vicinity lead to the following conclusions and recommendations:

- During spring and summer 2007 and 2008, a fraction (3–11%) of acoustic-tagged, run-of-river yearling and subyearling Chinook salmon and steelhead actively moving downstream from upriver sources migrates quickly (a few hours) through off-channel pathways compared to the main channel in the SRD and vicinity.
- Based on the telemetry (Chapter 6) and the fish community (Chapter 2) results, relatively large, actively migrating fish do not appear to use shallow off-channel habitats to the same extent as smaller size classes present in the area during the same spring and summer seasons.
- During winter to early spring 2010, residence time averaged 34 days for 48 juvenile Chinook salmon captured, tagged, released, and detected in the SRD. Sizes of these fish (mean FL = 111 mm) were similar to those tagged for the 2007 and 2008 telemetry studies. However, residence times during winter to early spring indicated a direct association between the tagged juvenile Chinook salmon and off-channel habitats compared to those for the spring and summer migrants from upriver. These data imply the fish were residing and presumably feeding and growing in the off-channels areas and not actively migrating.
- Most fish (85%) captured, tagged, and released for the winter to early spring 2010 evaluation were from stocks originating west of the Cascade Mountains. However, genetic stock identification indicated a small portion of the tagged Chinook salmon originated from upriver sources (e.g., Snake River stock groups).
- One-quarter of the tagged fish were estimated to be fall Chinook salmon belonging to a diverse composition of stock groups, including Snake River, Spring Creek, Upper Columbia, and West Cascade groups. It appears these fish did not exhibit the general life-history pattern of fall Chinook salmon, which typically migrate downstream as subyearlings during late spring and summer months. Instead, it is likely they delayed migration and over-wintered in off-channel, tidal freshwater habitats (e.g., Dawley et al. 1986; Connor et al. 2005).

7.0 Research Applications

Prepared by Gary Johnson and Christine Mallette

The purpose of this chapter is to apply research results from the 2007–2010 TFM study to inform LCRE management decisions being made by the Action Agencies and federal and state fisheries resource agencies. A primary management concern for the LCRE is ecologically productive, cost-effective habitat restoration to support the fitness and increase production and survival of Columbia River basin salmon populations. This concern was institutionalized in the 2000, 2004, and 2008 FCRPS BiOps (NMFS 2000, 2004; NOAA Fisheries 2008). At the time, though, the availability of information pertaining to the ecology of juvenile salmon in tidal freshwater of the Columbia River was sparse (Fresh et al. 2005; Williams 2007). Our study on juvenile salmon ecology in tidal freshwater habitats was undertaken to alleviate critical uncertainties and apply the results to habitat restoration program management. Results were obtained from sampling a diversity of shallow tidal freshwater water habitats in the SRD and vicinity (rkm 188–202) and lower river reaches (rkm 110–141) from June 2007 through April 2010. This chapter begins with a synthesis of findings for the two fundamental questions the project was designed to address, followed by the management implications of these findings and directions for future research to support management.

7.1 Synthesis of Findings

In what types of habitats within the tidal freshwater area of the LCRE are juvenile salmonids found, when are they present, what are their densities, which stocks are present, and what are the fish community and environmental conditions they live in?

This question conveys a critical uncertainty about basic information regarding juvenile salmonids that we addressed through systematic monthly sampling in shallow, tidal freshwater habitats of the LCRE. Juvenile salmonids were spatially distributed throughout different types of habitats, including along the main river channel and off-channel, tributary confluence (delta), and wetland areas. Densities of juvenile salmon were variable across all habitat types and we found that no single habitat type consistently yielded a disproportionate number salmon. Seasonally, juvenile salmon density was highest in spring (mean ~0.07 fish/m^2), coinciding with peak emigration from upriver above Bonneville Dam (Ploskey et al. 2007). The season with the second highest density was winter (mean ~0.02 fish/m^2). Chinook and coho salmon were the only salmonid species encountered during every season. Chum salmon were captured during winter and spring months. Unmarked juvenile Chinook salmon were the most abundant salmonid captured (74% of the total salmonid catch), followed by chum salmon (10%), coho salmon (8%), and steelhead trout (<1%). Marked Chinook salmon composed 8% of the total salmonid catch. Unmarked Chinook salmon far outnumbered catches of marked Chinook salmon, indicating unmarked fish use shallow tidal freshwater to a greater extent than marked fish. Densities for unmarked and marked salmon combined were relatively low (mean <0.005 fish/m^2) at our sampling sites during summer and fall presumably because water temperatures were high (~25 ºC) and water-surface elevations were low (~3 m).

The mean size of unmarked Chinook salmon was generally lowest during periods that corresponded to the highest densities of this species. After April, the size of unmarked Chinook salmon increased throughout the summer and fall months with the largest mean fork lengths of fish occurring in November

and December. During winter months the length frequency distribution of unmarked Chinook salmon was bimodal with large numbers of small fish (e.g., <60 mm) and a smaller proportion of larger size classes (e.g., 90–120 mm). During spring months, small sized (e.g., <60 mm) fish continued to be predominant; however a greater number of fish occupied the 60- to 80-mm size range, and the larger sizes (e.g., 90–120 mm) of unmarked Chinook salmon were not captured. Summer months were dominated by fish ranging from 60 to 80 mm and fall months generally included juvenile Chinook salmon that ranged from 80 to 120 mm.

Genetic stock identification analyses for 1242 unmarked Chinook salmon sampled in the SRD showed a majority of the fish were from the Spring Creek Group Tule Fall (35%) and the Upper Columbia Summer/Fall (33%) stock groups. Smaller proportions were estimated for the West Cascade Tributary Fall (15%) and Willamette River Spring (8%) groups. Snake River Fall (3%), Deschutes River Fall (3%), and West Cascade Tributary Spring (2%) fish were also present. Most of the marked, hatchery fish were also from the Spring Creek Group Tule Fall (69%) and Upper Columbia Summer/Fall (20%) stock groups. Genetic estimates for the Upper Columbia Summer/Fall stock include potential contributions of fish introduced in the lower Columbia River (above and below Bonneville Dam) in addition to native fish from the upper Columbia River (Sather et al. 2009). Within sites sampled in the LRR, the genetic stock composition differed from that at the SRD sampling sites for similar sampling dates. Unmarked Chinook salmon in the LRR were generally dominated by a single stock group—the West Cascade Tributary Fall stock (62% to 89% by month). Other stocks sampled in the LRR included Spring Creek Group Tule Fall fish in February 2010 (15%) and May 2009 (16%), and Willamette River Spring Chinook salmon in February 2009 (20%). As opposed to fall Chinook salmon, we found few spring Chinook salmon from the interior Columbia River basin in our beach seine samples at the SRD or LRR study areas.

The fish community in the shallow, tidal freshwater SRD study area was determined from over 500 beach seine hauls capturing over 200,000 fish. The total SRD catch comprised 34 species, including 18 non-native species. Total catch abundance was approximately 75% native fishes and 25% non-native fishes. Summer months yielded the highest densities of fish, while the smallest densities of fish occurred during winter months. The overall mean lengths for common species captured at the SRD ranged from 39 to 54 mm. The most common fish was threespine stickleback (43% of total fish catch). This species exhibited bimodal seasonal distribution with peaks occurring during late summer and winter months. The next most abundant fishes were banded killifish (18%), peamouth (16%), and northern pikeminnow (6%). Juvenile salmonid individuals composed about 4% of the total catch.

We characterized and examined associations with fish for key environmental variables, such as hydrology, water temperature, vegetation, topography, and substrate in the SRD and LRR study areas where we sampled juvenile salmonids. The hydrology had the typical seasonal pattern for the contemporary Columbia River—lowest flows occurred late summer and early fall. Flows gradually began to increase through the winter months with the river reaching peak discharge in May and June. River discharge also demonstrated inter-annual fluctuations; during our study period June 2007 through April 2010, outflow at Bonneville Dam was lowest in September 2007 (~75 kcfs) and highest in June 2008 (>400 kcfs). Site-specific water-surface elevations generally followed annual, seasonal, weekly, and hourly patterns similar to those observed at Bonneville Dam; e.g., power peaking at Bonneville Dam caused corresponding rises in water level 40 km downstream at our SRD study area. Site-scale hydrodynamics were also influenced by topography and lateral connectivity with the main channel. Water temperature peaked during August through October (~25 ºC) and gradually declined

through the fall and winter months. While the overall seasonal patterns were similar, thermal conditions differed among sites. The emergent vegetation observed at the SRD and vicinity included a mixture of species indicative of various wetland communities with many sites dominated by creeping spikerush. Willow was the most common vegetation encountered during survey efforts. Topography ranged from gradually sloping, low-relief transitions from the uplands to steeply graded beach slopes. Substrate grain size ranged from sandy to silty. Consistent relationships between salmon density and macro-habitat features, environmental conditions, and structural attributes were not apparent. Assuming salmon density indicates relative importance, no single or suite of macro-habitat features, environmental conditions, or structural attributes emerged as most important for juvenile salmon in shallow tidal freshwater.

What is the ecological importance of shallow (0–5 m) tidal freshwater habitats to the recovery of listed salmonid stocks, including Upper Columbia River Spring Chinook salmon and steelhead and Snake River Fall Chinook salmon?

The large contribution of aquatic and terrestrial insects to the diets of juvenile salmon at the SRD sampling sites, and the generally high densities of insect prey in the benthos, drift, and fallout across seasons, indicate shallow tidal freshwater habitats appear to be well-suited to support juvenile salmon rearing. Moreover, relatively rare but high-energy prey items in the diets of juvenile Chinook salmon, such as large-bodied malacostracans and hemipterans, imply that tidal freshwater habitats could contribute to net energy gain in juvenile salmon. The underrepresentation of microcrustacean and fish prey items in the juvenile salmon diets may be related to factors including visual acuity, gape limitations, or low abundance of this prey in the water column. Overall, however, prey pools in the tidal freshwater areas we studied provide forage for juvenile Chinook salmon that contributes to their sustained growth.

From a bioenergetics perspective, understanding factors that may constrain or promote energy acquisition and gaining insight into how young fish partition consumed energy into metabolic pathways and growth under certain environmental conditions is critical to evaluating the ecological importance of certain habitats in supporting fish populations. Our bioenergetics modeling showed that mean predicted specific growth rates across sampling sites for simulation cohorts were positive and varied little, except during sustained high temperature extremes. This model output suggests the integrated effects of prey composition and quality, thermal experience, and species-specific physiology resulted in favorable growth for juvenile Chinook salmon at our sampling locations. Simulated feeding rates for juvenile salmon generally were moderate to high. This suggests that prey pools exploited by most cohorts were sufficient in terms of the number of organisms, appropriate sizes, etc. to allow salmon to feed close to their maximum daily ration. Juvenile salmon growth simulations revealed a temperature maximum at which growth drops precipitously. Although this occurred infrequently at sampling locations during our study period, given inter-annual uncertainty surrounding thermal regime, this response should be noted. The GCE, a measure of the ability of an organism to convert ingested food into new tissue given environmental conditions and prey quality/quantity, suggests that the prey base and thermal regime at sampling locations throughout the majority of our study allowed for the efficient allocation of energy to somatic growth, a critical factor for young, migratory animals.

Based on prey densities, modeled foraging behaviors, and diet compositions, it appears probable that intra-specific competition among juvenile Chinook salmon may have been relatively weak in the SRD study area. However, future research should seek to characterize factors that may promote or relax inter-specific competitive interactions among juvenile salmon and other species such as the native threespine stickleback. The consistently high GCEs for juvenile salmon at our sites also suggest competition among

juvenile salmon for prey resources may be weak, implying positive ecological importance for juvenile salmon residing in shallow tidal freshwater habitats.

Acoustically tagged juvenile salmon were monitored to evaluate the residence time of fish in off-channel habitats of the SRD. Results indicated seasonal differences among residency periods for tagged fish. Residence times for acoustic-tagged fish captured and released in the SRD study area averaged 34 days during winter to early spring 2010, indicating a direct association between over-wintering juvenile Chinook salmon and off-channel habitats, as opposed to short residence times (~hours) for tagged spring and summer migrants from upriver. While similar sizes (fork length = 95–145 mm) of fish were tagged for the residence time studies, we noted drastically different residence times between the winter and spring/summer groups. These results highlight the temporal and life-history differences between actively migrating fish detected in the spring and summer during 2007–2008 and those that residualized in shallow-water habitats during winter 2010. Similarly, it appears that during spring and summer, relatively large, actively migrating salmon did not appear to use shallow off-channel habitats to the same extent as smaller size classes based on densities and size distributions of salmon captured with beach seines (Chapter 2). During spring and summer 2007 and 2008, nearly all (89–97%) of acoustic-tagged, run-of-river yearling and subyearling Chinook salmon and steelhead migrating from upriver sources used the main channel in the SRD and vicinity as the primary migration pathway in the SRD and vicinity. The few juvenile salmon (3–11%) that were detected in off-channel areas of the SRD demonstrated little residualization in these habitats (a few hours). Although there does not appear to be a prolonged association between shallow-water habitats and large upriver outmigrants during spring and summer time periods, these fish may be receiving indirect benefits from these habitats via export of materials that support food webs used by fish use during their downstream migration.

Most fish (85%) captured, tagged, and released for the winter to early spring 2010 evaluation were estimated to be from stocks originating west of the Cascade Mountains. However, genetic stock identification indicated a small portion of the tagged Chinook salmon originated from upriver sources (e.g., Snake River stock groups). Furthermore, one-quarter of the tagged fish were estimated to be fall Chinook salmon belonging to a diverse composition of stock groups, including Snake River, Spring Creek, Upper Columbia, and West Cascade groups. It appears these fish did not exhibit the general life-history pattern of fall Chinook salmon, which typically migrate downstream as subyearlings during late spring and summer months. Instead, these fish seemed to have delayed migration and over-wintered in off-channel, tidal freshwater habitats where they presumably fed and grew.

The diet, prey, bioenergetics, and residence time data clearly indicate shallow tidal freshwater habitats are ecologically important to juvenile salmon in general. We encountered a diversity of stocks over all seasons in shallow tidal freshwater habitats from 2007 through 2010. The results of the genetic analysis indicate the proportion of Chinook salmon originating from areas east of the Cascades were lower than those from the west side. We encountered few spring (e.g., yearling) Chinook salmon from the interior Columbia River basin. It is possible the larger juvenile salmon from upriver stocks were present in the shallow tidal freshwater habitat but were not adequately represented in our samples due to factors such as gear avoidance. Access to a variety of quality habitats available during different times (spatial and temporal diversity) is essential to facilitate the expression of a diversity of life-history strategies for juvenile salmon (Bottom et al. 2005b). While our results did not indicate a predominance of upriver stock groups, shallow tidal freshwater habitats contribute to a variety of genetic stock groups, as well as multiple life-history strategies. This is supported by our observations of variability in life-history strategies between large (>95mm) Chinook salmon within our study area that was linked to migration

timing. A life-history trait characterized by extended residency during winter may improve chances of survival by increasing the fitness of fish that delay ocean migration during their first year. Despite little evidence for residualizaiton, large, active migrants from upriver sources detected in our study area during spring and summer may also be gaining direct and indirect benefits from export of prey and materials supporting aquatic food webs from shallow tidal freshwater habitats. This evidence of use supports restoration to aid recovery of wild fish populations regardless of watershed of origin.

7.2 Management Implications

The results from the 2007–2010 TFM study have implications for federal and state fisheries management in response to obligations under the ESA, the Natonal Environemntal Policy Act of 1969, as amended, and other laws and edicts. This section explains the management implications pertaining to the federal LCRE habitat restoration program, recovery of endangered Columbia River basin salmonid ESUs, survival benefit units for proposed restoration actions, the FCRPS BiOp's RPA, the NPCC's Fish and Wildlife Program, the proposed dam removal restoration at the SRD, landscape-scale monitoring of juvenile salmon density, permitting of development activities, the Columbia River Crossing project, and other research in the LCRE.

7.2.1 Federal LCRE Habitat Restoration Program

The Action Agencies are using an adaptive management framework to implement the federal LCRE habitat restoration program to help mitigate the adverse effects of the FCRPS on ESA-listed salmonid stocks in the Columbia River basin. In a typical adaptive management cycle, RME are used to inform periodic management evaluations of program progress and direction (Thom et al. 2000). The intent is for status and trends monitoring, action effectiveness research, and critical uncertainties research to maximize learning and minimize program risk and uncertainty (Diefenderfer et al. 2005). Restoration managers for the LCRE use RME results generally to help decide what habitats to restore, where to restore them, and which species benefit the most from restoration. These basic questions for the federal LCRE habitat restoration program, modified specifically to address tidal freshwater, can be addressed by the TFM study as follows.

- *Are tidal freshwater habitats used by juvenile salmon? If so, what habitat types are used the most and would be the highest priority for strategic restoration?*

  It is clear that juvenile salmon use shallow tidal freshwater habitats to feed and grow year-round, although such habitat use varies by season, stock of origin, life-history stage, and other factors. It is not clear, however, whether certain habitats are used more in comparison to others. Therefore, elucidating possible differences in juvenile salmon use between habitat types should be considered a high priority for ecosystem restoration and planning. In the meantime, the data support restoration of access and quality of a variety of shallow tidal freshwater habitats.

  Habitat use as evidenced by salmon density and diet was highly variable. Juvenile salmon were present in all types of habitat sampled, from off-channel wetlands to main-channel areas. The results of the bioenergetics modeling suggest maintenance of adequate temperatures in tidally influenced shallow-water habitats is key for adequately supporting production of juvenile salmon. Restoration actions focused on maintaining adequate flow and temperature regimes in these habitats will likely benefit juvenile salmon.

- *Are any tidal freshwater reaches (longitudinal segments) higher priority for restoration than others? Does lateral distance from the main-channel matter and, if so, how?*

  Juvenile salmon, depending on their origin and life-history stage, seem to use habitats in all three of the reaches (D, E, and G; Figure 1.2) we sampled (Chapter 2). Our data do not indicate a higher priority for one reach over another for restoration. Conversely, we suspect lateral distance between off-channel habitats and the main channel influences conditions such as structural hydrologic connectivity, temperature, and bioenergetics growth potential; however, more research is warranted.

- *Which species and stocks use tidal freshwater habitats the most and how do they benefit?*

  Unmarked Chinook salmon are the most common salmon species in LCRE tidal freshwater. The next most common species are chum and coho salmon. Genetic stock identification data for Chinook salmon varied depending on longitudinal position in the LCRE and time of year. Some fall Chinook salmon stock from east and west of the Cascade Mountains did not exhibit the typical life-history pattern to migrate downstream as subyearlings during late spring and summer months. Rather, they delayed migration and over-wintered in off-channel, tidal freshwater habitats, presumably to their benefit. Feeding ecology and bioenergetics data showed the positive contribution shallow tidal freshwater habitats in the SRD are making to juvenile salmon growth and development.

7.2.2 Recovery of Endangered Salmonid Evolutionarily Significant Units

There are 13 Pacific salmon and steelhead ESUs in the Columbia River basin currently listed as endangered or threatened under the ESA (Figure 7.1). Recovery plans have been drafted for the Interior Columbia domain and its Upper Columbia, Middle Columbia, and Snake subdomains (http://www.salmonrecovery.gov/RecoveryPlanning/). In addition, recovery modules have been developed for activities outside a given domain that have an effect on listed ESUs originating inside the domain; e.g., there is a draft recovery module for the LCRE. Critical habitat designations required under the ESA have been made. They include spawning, rearing, and migration pathway areas in upriver and lower river tributary watersheds, the main stem Columbia and Snake rivers where the large FCRPS and mid-Columbia public utility district hydropower dams are concentrated, and the LCRE. Recovery of the listed ESUs will require improvement in ecosystem conditions in the continuum of habitats these fish require.

Because juvenile salmon from all 13 ESUs migrate through the tidal freshwater portion of the Columbia River, habitat restoration in this area is an obvious strategy for recovery efforts. Such restoration should benefit listed salmon and steelhead and aid their recovery by

- facilitating expression of a diversity of life-history patterns in shallow-water habitats (e.g., access to suitable over-wintering areas)
- providing prey year-round to sustain growth and improve the probability of survival in the ocean
- exporting inorganic and organic materials from off-channel habitats to the main stem to support food webs for all migrants regardless of their residence time within the shallow-water habitats
- supporting wild fish populations regardless of their watershed of origin.

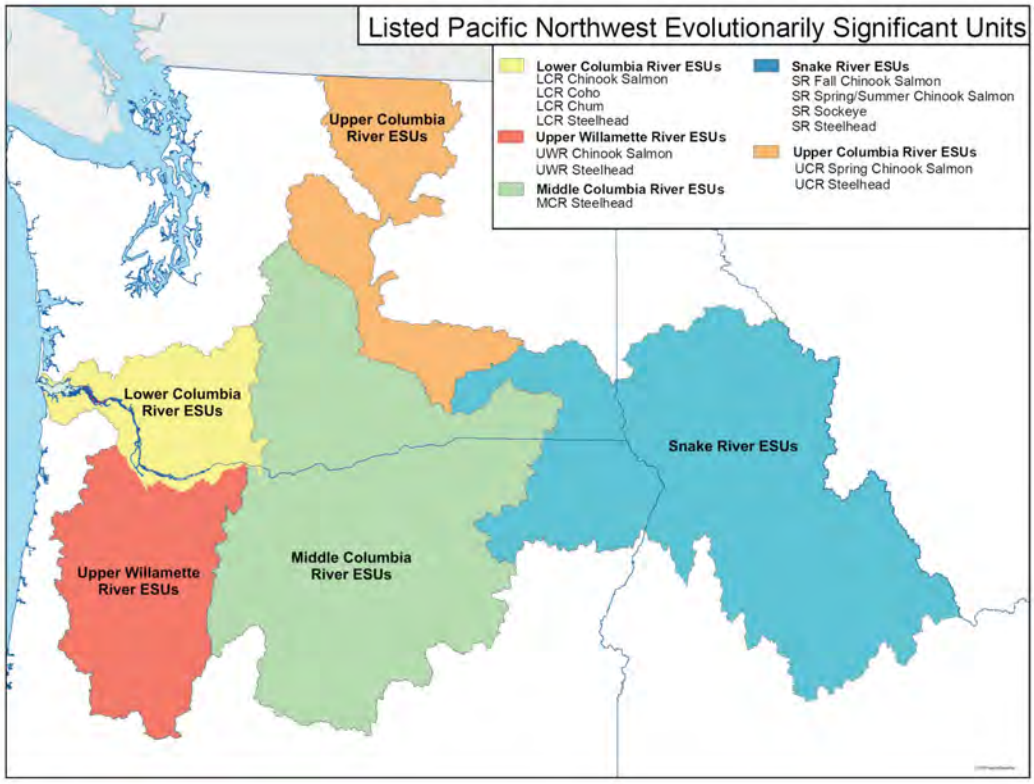

Figure 7.1. Evolutionarily Significant Units the Columbia River Basin Listed Under the Endangered Species Act (obtained on November 19, 2010 from http://www.nwr.noaa.gov/Salmon-Recovery-Planning/ESA-Recovery-Plans/Estuary-Module.cfm.)

7.2.3 Assigning Survival Benefit Units for Proposed Restoration Actions

In 2009, the Action Agencies created the Expert Regional Technical Group (ERTG) for LCRE Habitat Restoration in response to RPA Action 37 of the 2008 FCRPS BiOp (NOAA Fisheries 2008). The main purpose of the group is to assign *survival benefits units* for ocean- and stream-type juvenile salmon to LCRE habitat actions proposed or being implemented by the Action Agencies. Although it is not possible to predict the actual incremental survival benefit to salmon populations from a given restoration project, the ERTG can address the rearing potential of a restored site using available literature values for juvenile salmon densities in various LCRE habitats. Accordingly, the ERTG has developed a mathematical expression incorporating juvenile salmon density along with other data to assign project-specific survival benefit units. Thus, salmon density data from the TFM study averaged over temporal sampling episodes by study area and habitat type would be applicable to informing the ERTG's method to assign survival benefit units.

7.2.4 Fulfilling the FCRPS BiOp's Reasonable and Prudent Alternative

The TFM study helps the Action Agencies fulfill 8 of 16 RME subactions for the LCRE in the 2008 FCRPS BiOp's RPA (NOAA Fisheries 2008). This study provides a major contribution, summarized below, for the Action Agencies' legal mandate to implement the BiOp.

- Subaction 58.2 – *"Develop an index and monitor and evaluate life history diversity of salmonid populations at representative locations in the estuary."* TFM data on salmon density collected monthly at the SRD study area (see Chapter 2) are used to compute the life-history diversity index developed by Diefenderfer et al. (2010).
- Subaction 58.3 – *"Monitor and evaluate juvenile salmonid growth rates and prey resources at representative locations in the estuary and plume."* Prey resources and juvenile salmonid diet have been characterized (see Chapter 4) and growth rates have been modeled (see Chapter 5) for various tidal freshwater habitat types in the SRD (rkm 188–202) and LRR (rkm 110–141).
- Subaction 59.4 – *"Evaluate migration through and use of a subset of various shallow-water habitats from Bonneville Dam to the mouth toward understanding specific habitat use and relative importance to juvenile salmonids."* For the SRD and LRR study areas, migration characteristics and habitat use by juvenile salmonids have been well-documented (see Chapters 2 and 6).
- Subaction 59.5 – *"Monitor habitat conditions periodically, including water-surface elevation, vegetation cover, plan community structure, primary and secondary productivity, substrate characteristics, dissolved oxygen, temperature, and conductivity, at representative locations in the estuary as established through RM&E."* The TFM study has monitored water-surface elevation and water temperature continuously at most SRD sites since 2007 (Appendix A). One-time habitat characterizations have been performed at the nine SRD sites (Appendix B).
- Subaction 60.1 – *"Develop a limited number of reference sites for typical habitats…to use in action effectiveness evaluations."* TFM study Site B (Chatham Island) and Site H (McGuire Island) are part of the LCREP's reference site network of over 45 sites in the LCRE (Borde et al. 2009). The TFM study contributes fish monitoring (see Chapter 2) and habitat data (Appendix A; Appendix B) for these sites.
- Subaction 60.2 – *"Evaluate the effects of selected individual habitat restoration actions at project sites relative to reference sites and evaluate post-restoration trajectories based on project-specific goals and objectives."* The TFM study is providing site-specific, intensive action effectiveness research for the proposed dam removal and rechannelization restoration at the SRD. (See Section 7.2.6.)
- Subaction 61.1 – *"Continue work to define the ecological importance of the tidal freshwater, estuary, plume, and nearshore ocean environments to the viability and recovery of listed salmonid populations in the Columbia River Basin."* This subaction is the heart of the TFM study goal, as represented by the two fundamental TFM research questions (see Chapter 1). In essence, the entire TFM report addresses this subaction.
- Subaction 61.3 – *"Investigate the importance of early life history of salmon populations in tidal fresh water of the lower Columbia River."* Much like Subaction 61.1, the TFM study pertains directly to Subaction 61.3.

7.2.5 Implementing the NPCC's Fish and Wildlife Program

The NPCC, established under the authority of the Pacific Northwest Electric Power Planning and Conservation Act of 1980, is required to develop a fish and wildlife program to mitigate adverse effects of the FCRPS. The Council's Fish and Wildlife Program (FWP) is based on recommendations from federal, state, and local agencies, non-governmental organizations, regional Indian tribes, and the public.

Consideration of estuarine and ocean conditions in the FWP has been supported by the ISAB (Bisson et al. 2000) and others. Furthermore, the FWP involves a subbasin plan for the LCRE (LCREP and LCFRB 2004) containing an objective to "Develop an understanding of emigrating salmonid juvenile life history diversity...in the lower mainstem...." The most recent FWP and amendments were issued in November 2009 (NPCC 2009). The TFM study has implications for implementation of the 2009 FWP's "Estuary Strategies" (p.32), as follows:

- "*Long-term effectiveness monitoring for various types of habitat restoration projects in the estuary*." Since June 2007, the TFM study has conducted pre-restoration monitoring at the proposed dam removal and rechannelization site in the SRD. The monitoring is implementing a BACI experimental design. With at least 4 years of pre-restoration effectiveness monitoring, and plans for intensive post-restoration monitoring, the TFM study is performing the type of long-term effectiveness monitoring called for in the 2009 FWP.
- "*Continued evaluation of salmon and steelhead migration and survival rates in the lower Columbia River, the estuary, and the marine environment*." Estimating survival rates is outside the scope of the TFM project, but estimating migration rates is not. The TFM study conducted migration pathway and residence time research during 2007 and 2008. This research complements other investigations of migration rates—e.g., McComas et al. (2009)—and helps implement the strategy set forth in the FWP.
- "*Recognition and encouragement of continued partnerships in planning, monitoring, evaluating, and implementing activities in the estuary and lower Columbia River*." The TFM study is the result of meaningful, scientific collaboration of researchers from the NMFS, Oregon Department of Fish and Wildlife, PNNL, and University of Washington. The study is one example of the type of partnership the Council recognized as being key to successful implementation of the FWP in the LCRE.

The TFM study furthers the goals and objectives of the NPCC's FWP and its subbasin plans by providing basic scientific data about habitat usage by juvenile salmonids in the tidal freshwater reach that managers can use to prioritize habitat restoration projects to mitigate FCRPS effects on anadromous fishes.

7.2.6 Proposed Dam Removal Restoration at the Sandy River Delta

Site-specific understanding of the SRD gained from pre-restoration monitoring is applicable to a discussion of the efficacy of the proposed reconnection of the old Sandy River to the Columbia River. The primary outlet of the Sandy River was plugged with an earthen dam in the 1930s. The low degree of connectivity between the Sandy River and the historic confluence likely constrains the functional integrity of this floodplain-deltaic ecosystem. Removal of the dam will be aimed at reestablishing the connectivity of the Sandy River channel to its historic confluence. In pre-restoration sampling of fish and habitat characteristics within a formal BACI design, we noted the low degree of surface-water connectivity was correlated with low dissolved oxygen within the remnant channel, yet the absence of elevated water temperatures indicated the remnant channel maintains some degree of hyporheic connection with the Sandy River (Appendix A, Figure A.7). Vegetation surveys near the remnant channel indicate a large proportion of obligate wetland species (Appendix B, Figure B.11). Compared with other sites closer to the Columbia River, the remnant channel was also noted to have the greatest amount of submerged aquatic vegetation. We sampled juvenile Chinook and coho salmon in the remnant channel during our study (see Chapter 2, Figure 2.11). Removal of the earthen barrier likely would increase fish accessibility

to this channel, as well as to other habitats within the historic SRD. Changes in the flow regime, coupled with riparian plantings as part of other restoration efforts in the delta, will likely increase water quality, sediment export, and nutrient flux within the SRD. Confluences offer sources of heterogeneity in main stem rivers by influencing morphological features and aquatic habitats. Reconnecting the old Sandy River channel to the Columbia River will likely increase the opportunity and capacity of habitats for aquatic biota, including juvenile salmon.

7.2.7 Landscape-Scale Monitoring of Juvenile Salmon Density

Juvenile salmon abundance, represented by density (#/m^2) estimates in LCRE beach seine data, is an important indicator of salmon population status. As such, it is a key monitored variable for the Action Agencies' federal RME effort. It is also one of the NPCC's "High-Level Indicators" for its FWP. Estimating juvenile salmon density at the landscape-scale in the LCRE can provide managers with information about the status and trends in production of salmon stocks. Furthermore, these data may be associated with collective habitat restoration actions at the landscape scale and used to assess action effectiveness beyond the typical site-scale monitoring. Relative proportions of fish based on estimated densities of juvenile salmon and native and non-native fishes, and associated relationships with habitat conditions, are important higher-order indicators managers can use to assess the overall success of management actions at the landscape scale. The specific research objective would be to estimate landscape-scale fish densities and relationships to habitat conditions seasonally in the shallow waters of river reaches associated with extensive habitat restoration. A statistically robust sampling design to estimate juvenile salmon density at the landscape scale was developed by the 2007–2010 TFM study (Appendix H) and could be applied for the purpose of this high-level indicator.

7.2.8 Permitting of Development Activities

The presence of juvenile salmon in shallow, off-channel habitats during times other than the usual emigration seasons of spring and summer (see Chapter 2, Figure 2.14) has implications for permitting development activities. To minimize impacts on endangered fish species in the LCRE, permits from state and federal agencies usually require that in-water development activities occur during the wintertime "construction window"—November 1 through February 28. By design and necessity, this period is outside the peak spring and summer emigration seasons for juvenile salmonids. The TFM study, however, found that juvenile salmon can be present in shallow, tidal freshwater areas at all times of the year. The implication is that regulators and developers will need to be aware of the possibility of the presence of juvenile salmonids at shallow-water development sites during the wintertime construction window. It might be necessary to take measures to deter fish from entering the area, monitor fish presence, and estimate take.

7.2.9 Columbia River Crossing Project

The Columbia River Crossing is a large development effort to replace the Interstate-5 bridge over the Columbia River between Portland, Oregon, and Vancouver, Washington. The crossing is located at rkm 171 in the lower Columbia River about 21 km downstream from the SRD study area. The draft Environmental Impact Statement for the project released in May 2008 contained by reference an Ecosystems Technical Report describing potential impacts on aquatic habitats, plants, fish, mammals, and other animals. The final Environmental Impact Statement, scheduled for 2011, will describe analyses of

potential environmental effects. A locally preferred alternative has been selected and preparation of a Biological Assessment is underway for submittal to NMFS and the U.S. Fish and Wildlife Service. The ESA approval of the project would occur through a BiOp for the affected species and habitats. The final Environmental Impact Statement, Biological Assessment, and BiOps should be informed by data derived from the 2007–2010 TFM report on migration characteristics of listed salmonids in the lower Columbia River.

7.2.10 Research by Others in the LCRE

The TFM study has implications for research by others in the LCRE because the study contributes to the collective knowledge base researchers share in the process of scientific investigation. The LCRE research, funded mostly by BPA under the Council's FWP and USACE under the Anadromous Fish Evaluation Program (AFEP), is conducted by state and federal agencies, non-governmental organizations, and others. Johnson et al. (2008) provided a research plan, much of which was incorporated into the 2008 FCRPS BiOp (NOAA Fisheries 2008).

Many ongoing research projects will continue to be informed by the TFM study. The data collected from this study has been used to inform the calculation of a life-history index (Diefenderfer et al. 2010), which is part of the Salmon Benefits study (AFEP EST-P-09-01). Additional projects include the reference site study (conducted under FWP 2003-011-00) and the post-FCRPS survival study (AFEP EST-P-04-01). The ecosystem monitoring study (FWP 2003-007-00) is incorporating habitat characterizations from TFM sampling sites (C and H, Figure 2.1). The integrated status and trends monitoring study (FWP 2010-082-00) has developed a master sample-tracking tool for lower Columbia River tributary watersheds and is proposing to apply it to the main stem LCRE; the TFM study's monitoring design to estimate juvenile salmon density at a landscape-scale (Appendix H) may have implications for this effort. The tidal fluvial study (AFEP EST-P-10-01) is currently developing a stock-specific, genetic basis for strategic restoration in tidal fluvial habitats; we intend to collaborate with these researchers as appropriate. The cumulative effects study (AFEP EST-P-02-04) is using water-surface elevation data from the TFM study to investigate mechanics and causation of water-level variations and shallow-water inundation time longitudinally and laterally within the LCRE. Finally, the TFM study will be a significant resource for the planned LCRE-wide RME synthesis report recommended by the Action Agencies (2010).

In its recent report on Columbia River food webs, the ISAB (2011) provides an overview of the mechanisms relating aquatic food webs within the context of current ecological conditions as well as the potential for interaction with restoration efforts within the basin. The spatial extent of the basin and the complexity of environmental conditions inherently present challenges with regard to elucidating key knowledge gaps concerning food web conditions in the Columbia River basin. Several of the recommendations presented in the ISAB report were implemented during the 2007–2010 TFM data collection effort, albeit on limited spatial and temporal scales. These efforts include examining prey availability, consumption of prey by salmon, and bioenergetics modeling. Work completed as part of the TFM study relates directly to ISAB's recommendation stating "…work should: Determine the ability of the system to provide sufficient food to support viable populations of fishes…for the long term." In addition, beginning in June 2010, the TFM study transitioned to a more focused approach aimed at action effectiveness research. While our research efforts will retain similar approaches aimed at assessing food web interactions for juvenile Chinook salmon in shallow tidal freshwater habitat, we have expanded our

objectives to address important research elements discussed in the 2011 ISAB food web report, including assessment of potential competition between non-native fishes and juvenile salmon, assessments of primary productivity, and characterization of nutrients. The suite of elements being undertaken as part of future research will continue to address recommendations proposed by the ISAB, and, as a result, will allow the study to maintain a direct connection with the NPCC's Columbia River Fish and Wildlife Program.

7.3 Future Directions

In 2010, the TFM study was transferred from BPA to the USACE as part of the *Memorandum of Agreement on Columbia River Estuary Habitat Actions* between the State of Washington, BPA, USACE, and the U.S. Bureau of Reclamation (available at http://www.salmonrecovery.gov/ColumbiaBasinFishAccords/ EstuaryHabWa.aspx). The focus for our research is shifting from mostly fundamental ecology to more applied research related to the effectiveness of restoration. Scientific understanding of the effects of tidal freshwater habitat restoration on juvenile salmon communities will help quantify benefits to salmon from LCRE habitat restoration actions. The overall objectives for the new USACE study are as follows:

1. Determine site-scale responses of restoration actions by assessing before-and-after a restoration activity, including
   - controlling factors (e.g., hydrology and water quality) and structural attributes (e.g., vegetation and substrate)
   - variability of fish community structure, including presence/absence of juvenile salmon, residence times, and bioenergetics
   - diet overlap to infer changes in potential for inter-specific competition between juvenile salmon and native and non-native resident fish species.
2. Estimate landscape-scale fish densities and relationships to habitat conditions seasonally in shallow water of river reaches associated with extensive habitat restoration.

Based on findings to date, we recommend future research on remaining critical uncertainties and action effectiveness. Critical uncertainties include

- juvenile salmon residence time and growth rates year-round in tidal freshwater habitats
- presence, timing, and residence time of PIT-tagged juvenile salmon originating above Bonneville Dam
- trends in early life-history diversity of naturally produced juvenile salmon in the LCRE
- ecological interactions between juvenile salmon and stickleback, between juvenile salmon and non-native plant and animal species, and between hatchery and unmarked salmon in tidal freshwater.

Action effectiveness research is needed on the following:

- juvenile salmon passage through culverts and tide gates under roads, tracks, levees, dikes, and other obstructions between restored sites and the LCRE
- wintertime use of off-channel reference and restored areas in tidal freshwater

- juvenile salmon density differences pre- versus post-restoration and restored versus reference or control site
- landscape density estimates
- indices of survival benefits of restoration.

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Appendix A

Environmental Conditions

Appendix A
Environmental Conditions

Prepared by Amanda Bryson

This appendix contains data on the smolt monitoring index at Bonneville Dam and the water-surface elevation and water temperature from the sampling sites in the Sandy River delta (SRD) and vicinity.

A.1 Smolt Monitoring Index at Bonneville Dam

Run timing patterns indicated by the daily, species-specific smolt monitoring index at Bonneville Dam were consistent among years, 2007–2010 (Figure A.1). The two or three peaks of "Chinook (+0)" during spring reflect releases of fish from lower river hatcheries. The downstream migration of yearling and subyearling salmon species typically peaks in May and early July, respectively.

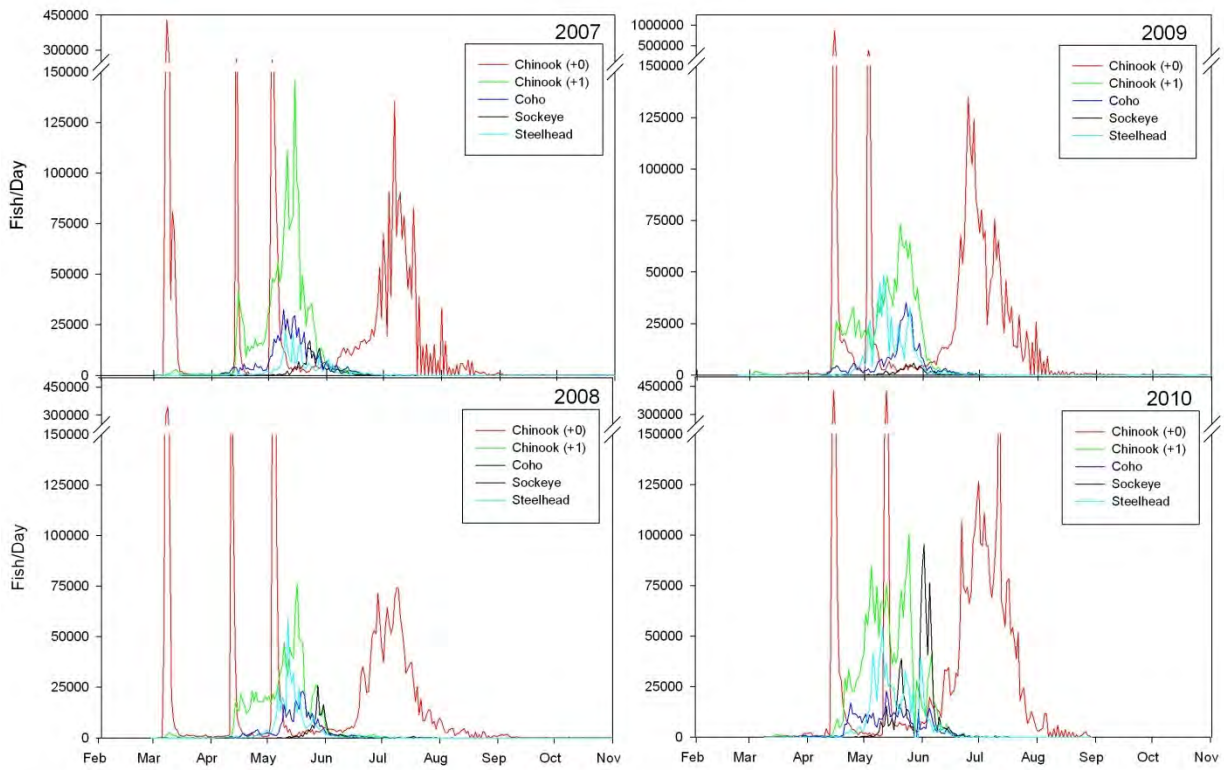


Figure A.1. Bonneville Dam Smolt Monitoring Index. Summary counts combine all rearing types (i.e., hatchery, wild, and unknown) within a given species. Data were obtained from DART (Data Access in Realtime; http://www.cbr.washington.edu/dart/).

A.2 Water-Surface Elevation

Temporal patterns in water-surface elevation were consistent among sampling sites (Figures A.2, A.3, and A.4). The annual freshet was evident in late spring 2008, 2009, and 2010. A peak in water-surface elevation also occurred in early 2009. Water-surface elevations are lowest in late summer and fall.

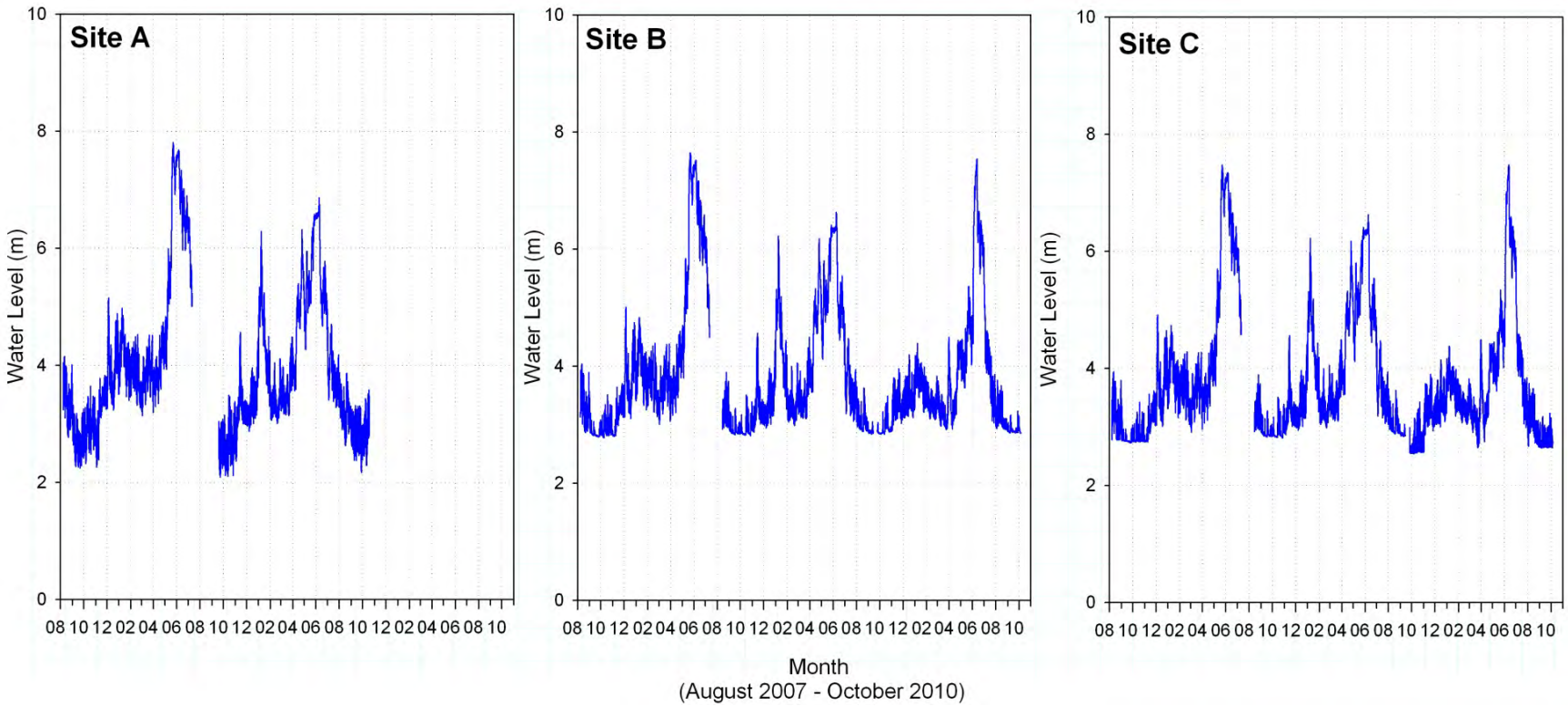


Figure A.2. Water-Surface Elevation (m) from Hobo Data Loggers at Sites A, B, and C. The water elevations associated with Site C between August 2009 and October 2010 are uncertain because the sensor elevation was discovered to have changed from the time of its original deployment. Data associated with this sensor should be considered within the context of general patterns of water fluctuations and not used for comparison between sites.

Water-surface elevation at Site N was least like the other sites in that the amplitude of change resembled a step pattern, which is explained by periods of intermittent hydraulic connectivity (Figure A.3). The upstream end of Site N is blocked with earthen fill and does not maintain connectivity with the Sandy River. However, during periods of high flow, excess water from the Sandy River flows over the floodplain and enters into Site N via a former channel within the historic delta. Connectivity between Site N and the Columbia River is maintained at the channel outlet. Thus, the water elevation at Site N is likely influenced by the hydrology from the main stem of both the Columbia and Sandy rivers.

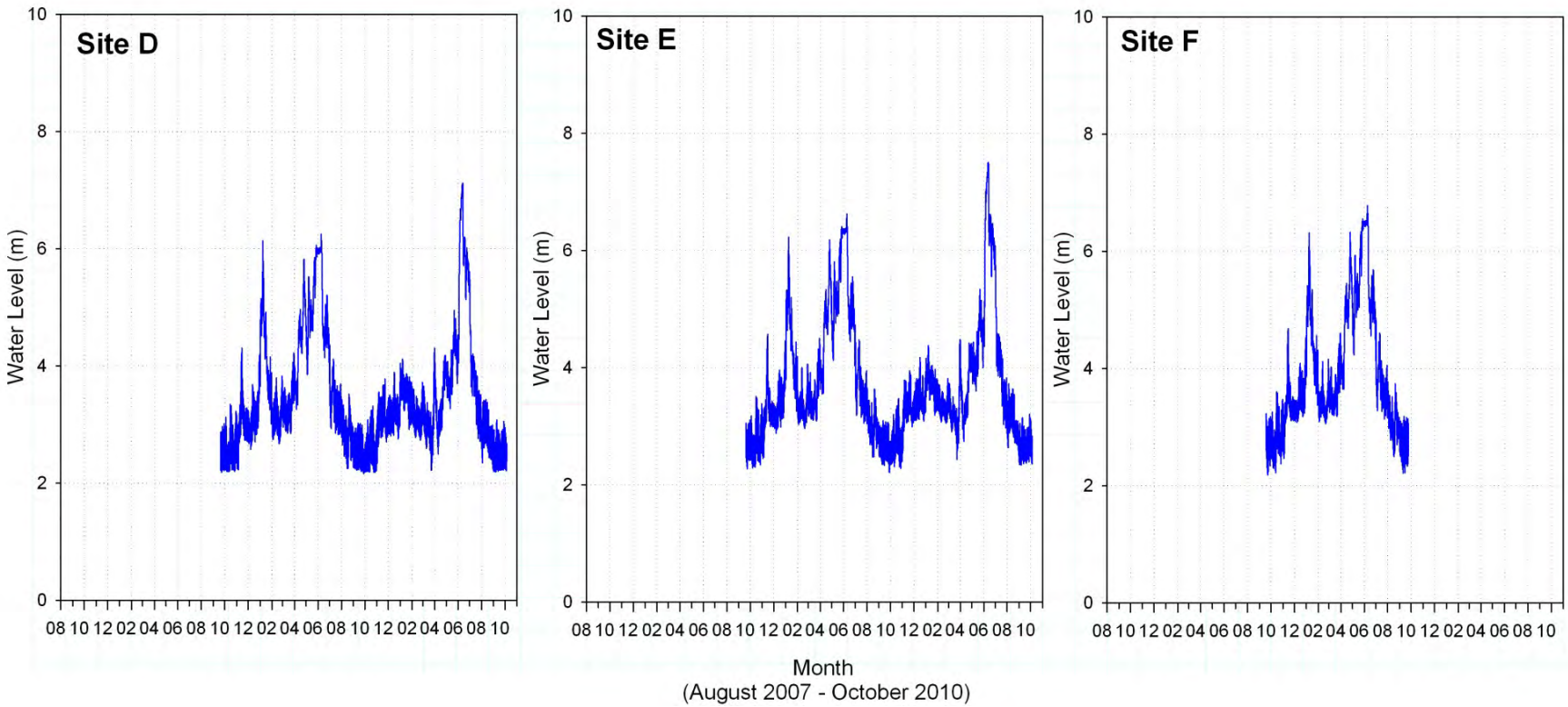


Figure A.3. Water-Surface Elevation (m) from Hobo Data Loggers at Sites D, E, and F. Data collection occurred from September 2008 through October 2010, except for Site F which went through September 2009.

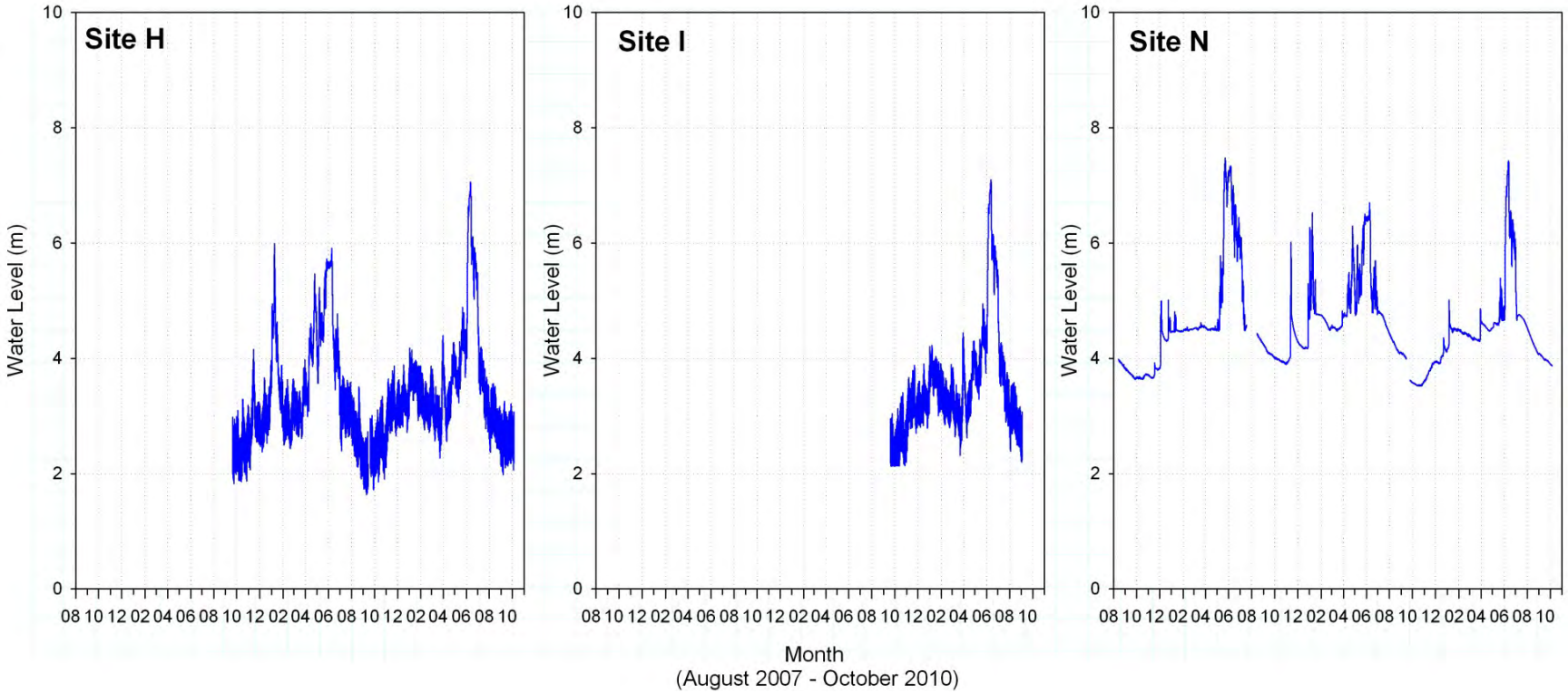


Figure A.4. Water-Surface Elevation (m) from Hobo Data Loggers at Sites H, I, and N. The water-surface elevations associated with Site H between August 2009 and October 2010 are uncertain because the sensor elevation at Site H changed from the time of its original deployment. Data associated with this sensor should be considered within the context of general patterns of water fluctuations and not used for comparison between sites.

A.3 Water Temperature

Water temperatures varied through time similarly among the sampling sites (Figures A.5, A.6, and A.7). Annually, water temperatures were lowest in January (~3–5 ºC) and highest in September (~22–26 ºC). Water temperature at Site N, the shallow wetland channel in the SRD, was 2–3 degrees cooler than at Site C nearby at the mouth of the old Sandy River. While there is not a continuous overland flow between the Sandy River and Site N, relatively cool stable temperatures are likely maintained via groundwater seepage or hyporheic flow. Site D usually had the highest peak water temperatures.

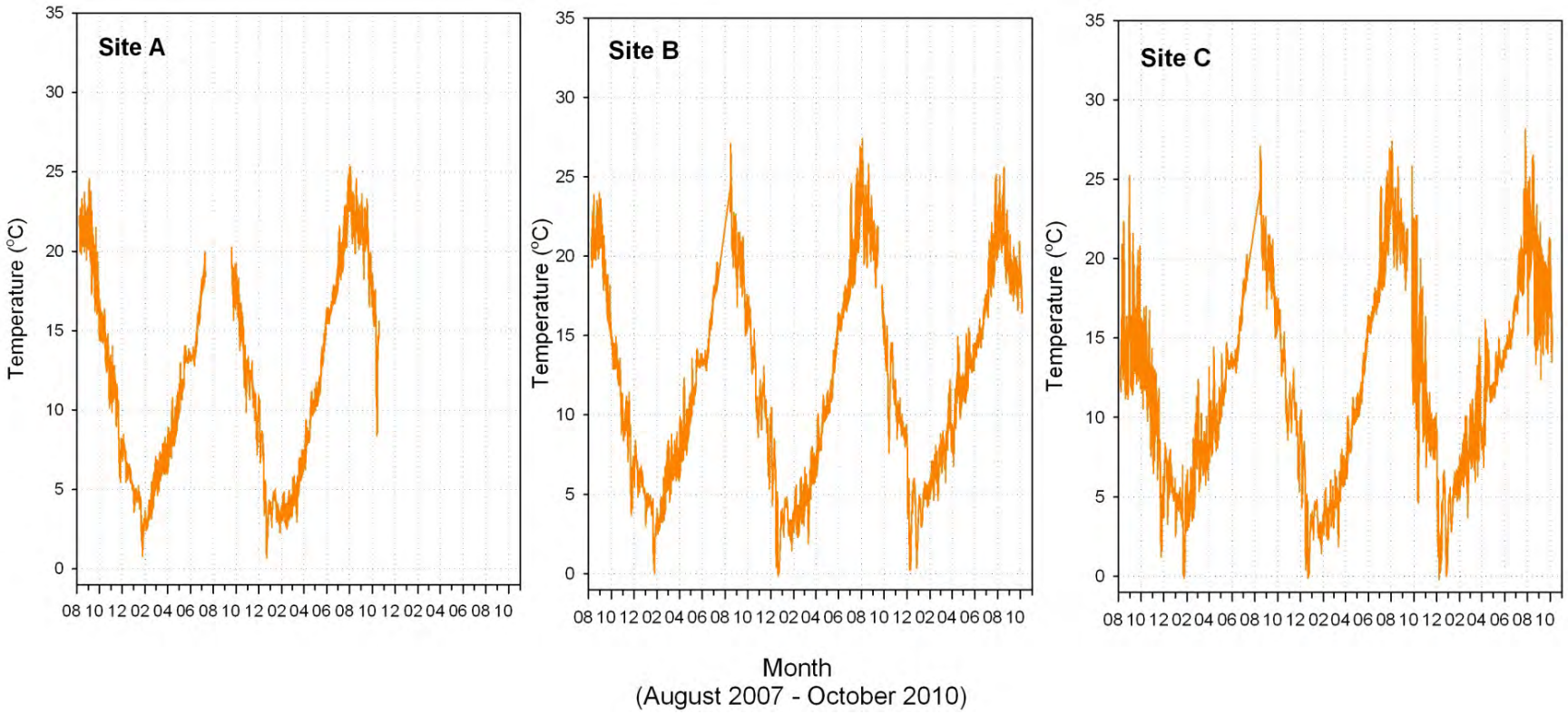


Figure A.5. Water Temperature from Hobo Data Loggers at Sites A, B, and C. Data collection occurred from August 2007 through October 2010.

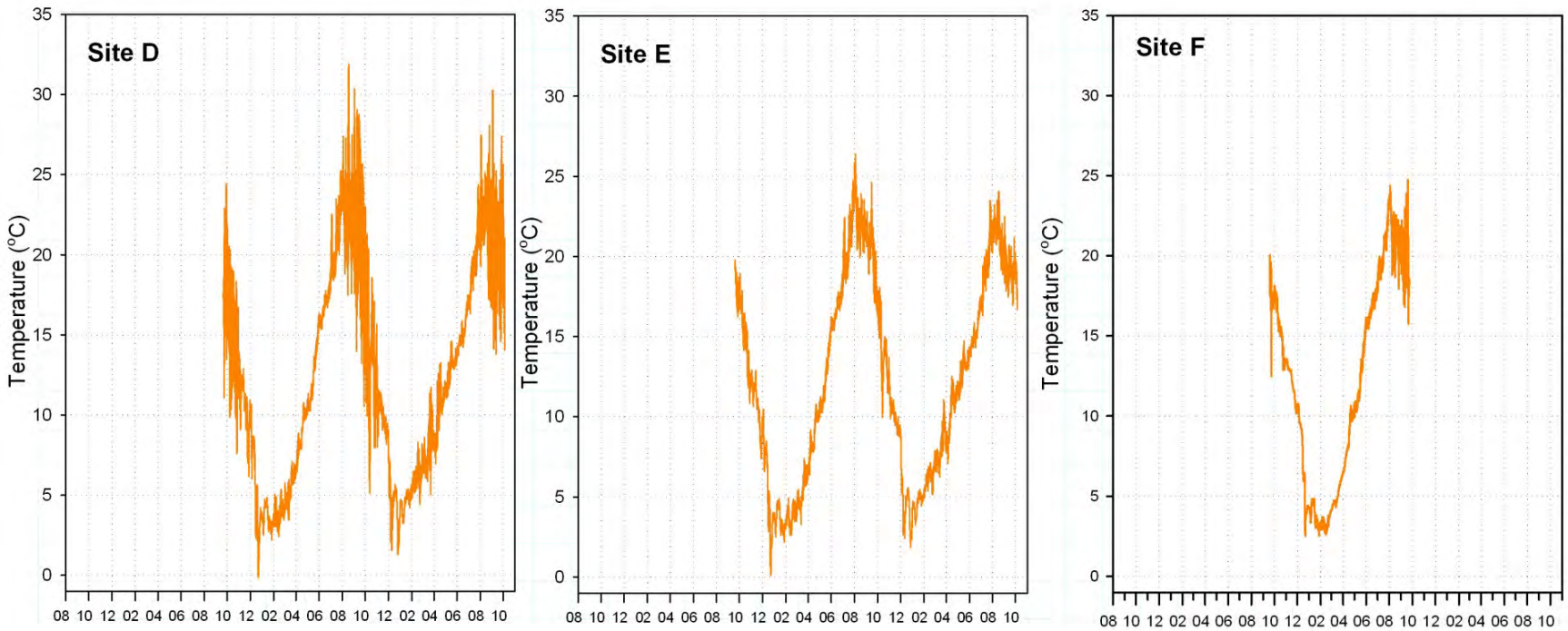


Figure A.6. Water Temperature from Hobo Data Loggers at Sites E, F, and H. Data collection occurred from August 2008 through October 2010.

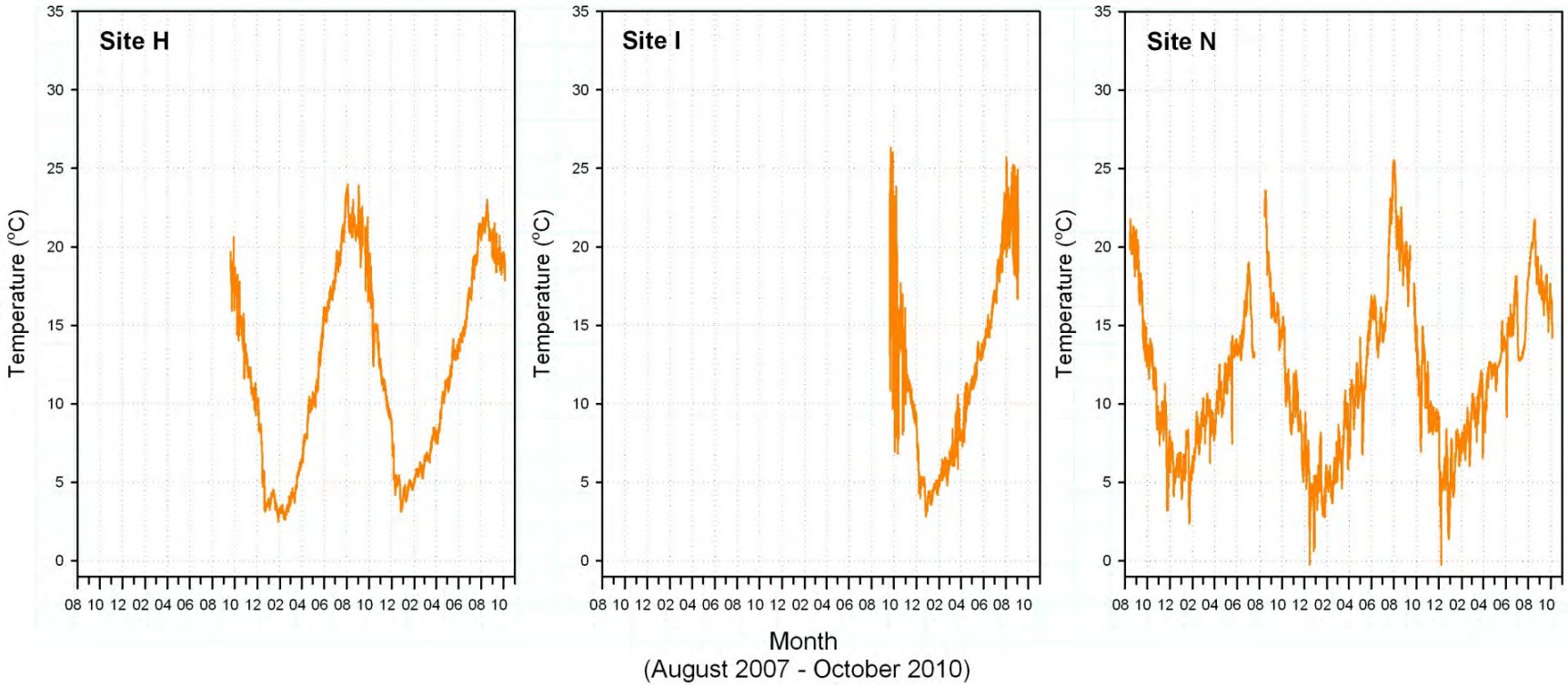


Figure A.7. Water Temperature from Hobo Data Loggers at Sites H, I, and N. Data collection occurred from August 2007 through October 2010.

Appendix B

Habitat Characterizations

Appendix B

Habitat Characterizations

Prepared by Amy Borde and Shon Zimmerman

Habitat characterizations performed at each site, except Site I, included data on substrate, slope, and plant communities.

B.1 Substrate

The shallow-water habitats sampled for the tidal freshwater monitoring (TFM) study primarily comprise substrates ranging from sandy to silty (Figure B.1). Sites dominated by the mid-range fractions (e.g., >70% fine to medium sands) included B, F, and H. Only three sites (C, D, and H) included coarse sediment fractions that exceeded 15% of the overall grain size composition. Compared to other sites, the overall composition of sediment at Sites C and D was distributed across multiple grain sizes (Figure 4.1). The grain size composition at these sites is likely linked to their proximity to deltaic river confluence (either historic or current) habitats. Grain size composition at Sites A and E was greater than 70% for the very fine to clay fractions. These off-channel sites both maintain a gradually sloping beach face characterized by wetland vegetation that grows to the water's edge and is often submerged during high flows. Site N is also similar to Sites A and E with regard to the majority of substrate composition consisting of fine sediments. The pond-like nature of Site N likely inhibits sediment mixing.

B.2 Slope

The topography of the TFM sites ranges from gradually sloping, low-relief transitions from the uplands to steeply graded beach slopes. Sites C, D, and F include expansive flats that extend from steep upland areas to the river channel. These sites are the most difficult to access during periods of low flow. The micro-topographies at Sites C and D are unique from other sites in that small hummocks are scattered throughout the expansive flats. These hummocks may be residual formations resulting from sediment deposition within the Sandy River delta. During periods of low flow, these hummocks trap water, which creates features similar to wetland pannes; however, the persistence of these panne features is transient because the water elevation in the vicinity of the TFM sites regularly fluctuates as a result of dam operations, and to a lesser, extent tidal amplitude.

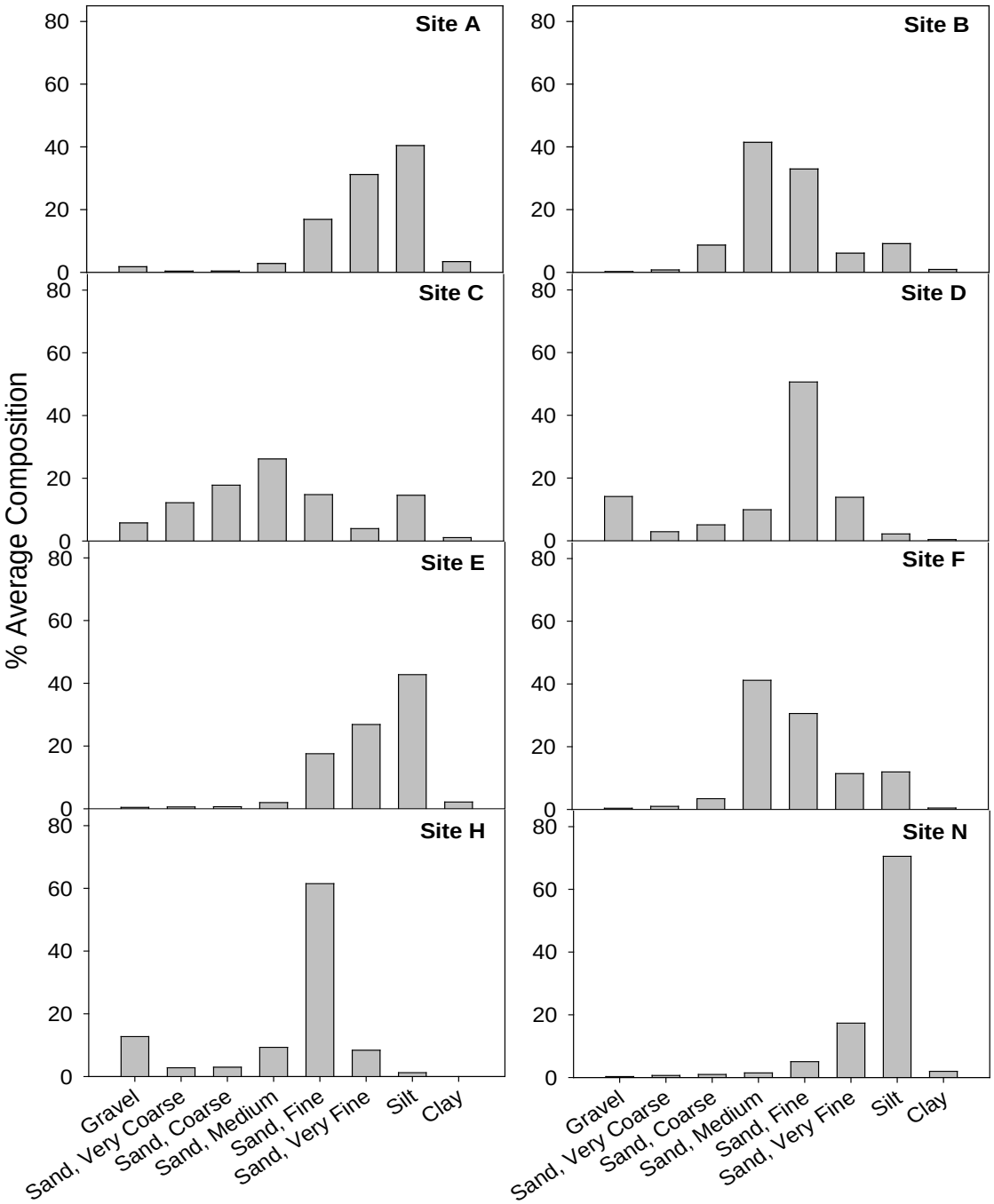


Figure B.1. Average Percent Composition of Grain Size from the TFM Beach Seine Sites

B.3 Plant Communities

Plant community types can be grouped into several broad classes ranging from submerged aquatic vegetation at the lower elevations to stable riparian communities at the higher elevations in the study area. We encountered 62 species of plants throughout the eight sites investigated in 2007 and 2008. The most commonly encountered vegetation included willow (*Salix* spp.*)*, which was noted at all eight sites surveyed. The frequency of occurrence of creeping spikerush (*Eleocharis palustris)*, horsetail (*Equisetum*

spp.*)*, rice cutgrass (*Leersia oryzoides)*, marsh seedbox (*Ludwigia palustris*), water milfoil (*Myriophyllum* spp.*)*, and reed canary grass (*Phalaris arundinacea*) occurred secondary to *Salix* spp., because these plants were found at six of the eight sites (Table B.1). While reed canary grass, an invasive wetland species, was present at most sites, the relative cover was less than 5% at all sites except Sites A and N, where the relative cover accounted for 10% to 15% (Figure B.2).

With the exception of Site N, submerged aquatic vegetation (SAV) was not quantified as part of the vegetation assessments. However, observations regarding the presence and species composition of SAV were noted. At Site N, SAV species present in the vegetation survey included Canadian waterweed (*Elodea Canadensis*), curly-leaved pondweed (*Potamogeton crispus*), and coontail (*Ceratophyllum demersum*). These species were observed at other sites, as was milfoil.

The emergent vegetation noted at the TFM beach seine sites included a mixture of species indicative of various wetland communities. Most of the sites with a moderate or high percentage of cover of emergent vegetation (A, B, C, and E) were dominated by creeping spikerush (Figure B.2). This community is common throughout the overflow plain and is also characterized by the presence of reed canary grass and slough sedge (*Carex obnupta*). Knotgrass (*Paspalum distichum)*, a co-dominant species at Site B, is indicative of areas with seasonal inundation and summer drying. At Site N, the emergent vegetation was dominated by swamp smartweed (*Polygonum hydropiperoides*) in the lower emergent zone and reed canary grass in the mid to high emergent zone. The percentage of obligate wetland species exceeded 43% of the total taxa evaluated at Sites A, B, C, E, and N (Figure B.2).

Saplings were primarily cottonwood (*Populus balsamifera*) and willow; however, invasive desert false indigo (*Amorpha fruticosa*) saplings were also present at Site A. The sapling communities were distinctive in that there was very little overlap between them, with willow saplings occurring at a slightly lower elevation (3.0 to 4.5 m) than cottonwood saplings (4.5 to 6.0 m) (Sites D and F). Of note is that desert false indigo often occurred at the same elevation as mature willow and willow and cottonwood saplings, indicating the potential for this invasive species to out-compete the native vegetation in this elevation range (4.0 to 6.0 m).

A well-established riparian community existed in the uplands adjacent to the beach face at each of the sites evaluated. The riparian community generally occurred at an elevation above 6.0 m. Cottonwood was present at all sites (except A) and was mixed with other understory species including willow species, red-osier dogwood (*Cornus stolonifera*), and Oregon ash (*Fraxinus latifolia*). At Site A, the riparian area was dominated by willow species and Oregon ash. At many sites, the invasive species desert false indigo and Himalayan blackberry (*Rubus discolor*) were present on the edge of the riparian zone and at times were a dense component of the understory.

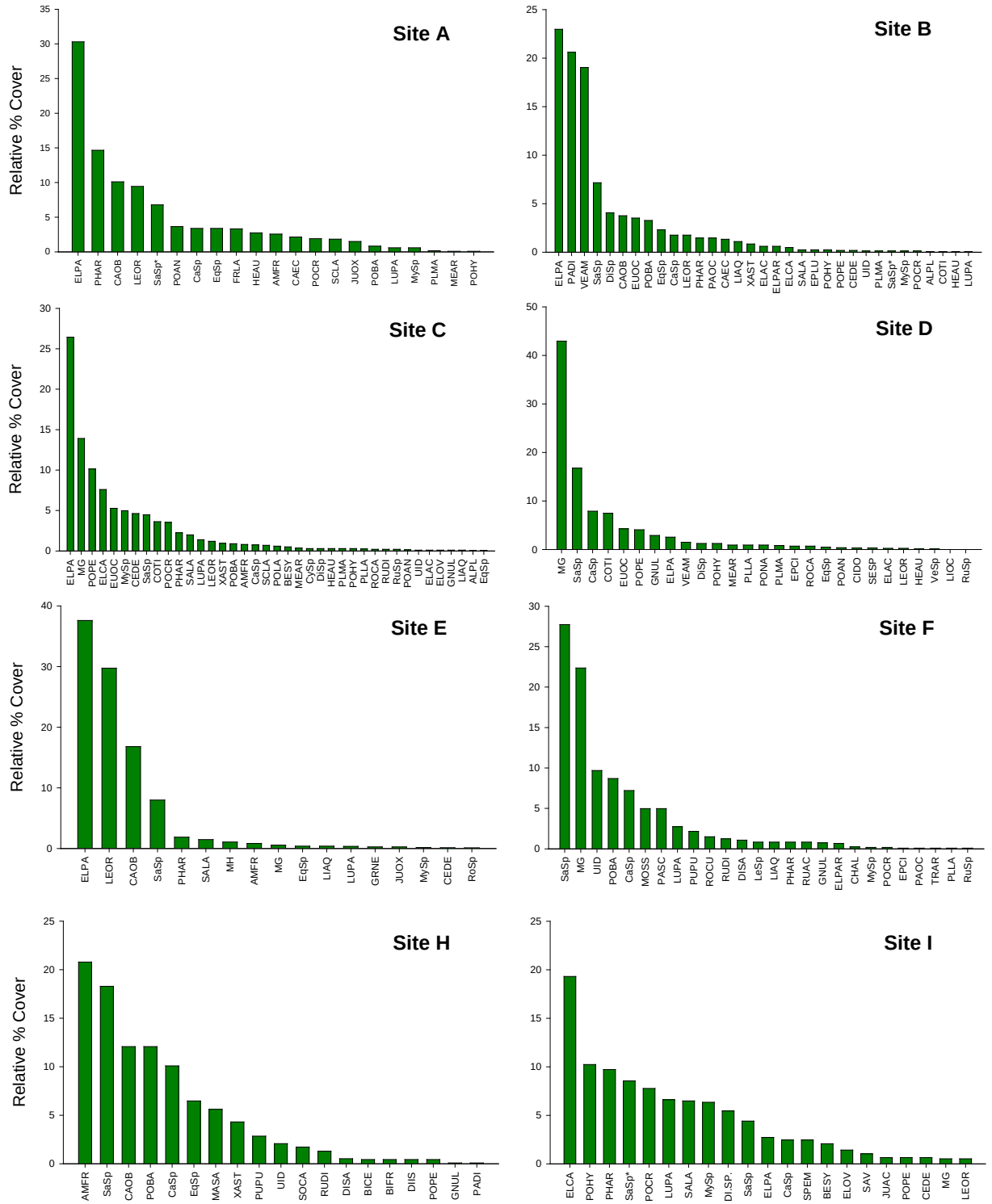


Figure B.2. Relative Percent Cover of Vegetation from Transect Surveys at Each of the TFM Beach Seine Sites. Plant names are represented by four-letter codes that reflect the first two letters of the genus and species names (see Table 4.1 in the report by Sather et al. [2009]: *Ecology of Juvenile Salmon in Shallow Tidal Freshwater Habitats in the Vicinity of the Sandy River Delta, Lower Columbia River, 2008*. PNNL-18450, Pacific Northwest National Laboratory, Richland, Washington).

Plant community cover maps based on the delineation of dominant vegetation communities in the field were analyzed for percent cover of emergent community types. Emergent areas were defined as the elevations between 3.0 and 4.5 m, where emergent vegetation would be expected to develop in this hydrogeomorphic reach. The delineation of open water areas and riparian areas was outside this range of elevation and was highly variable with arbitrary boundaries because of the extensive nature of these cover classes, i.e., extending far beyond the study area boundaries. Therefore, these classes were not included in the assessment of "emergent" community type percent cover. Percent cover of the emergent community types is presented in Table B.1. The vegetation communities, indicated by field transects and mapping based on a global positioning system, were variable among sampling sites (Figures B.3–B.11).

Table B.1. Percent Cover of Community Types Within the Emergent Zone

Site	% Emergent Bare	% Emergent Vegetation	% Emergent Shrubs	% Emergent Saplings
A	9	77	0	14
B	8	42	0	50
C	5	24	0	71
D	11	0	1	88
E	13	67	0	20
F	52	7	0	41
H	69	2	0	29
N	0	45	0	55

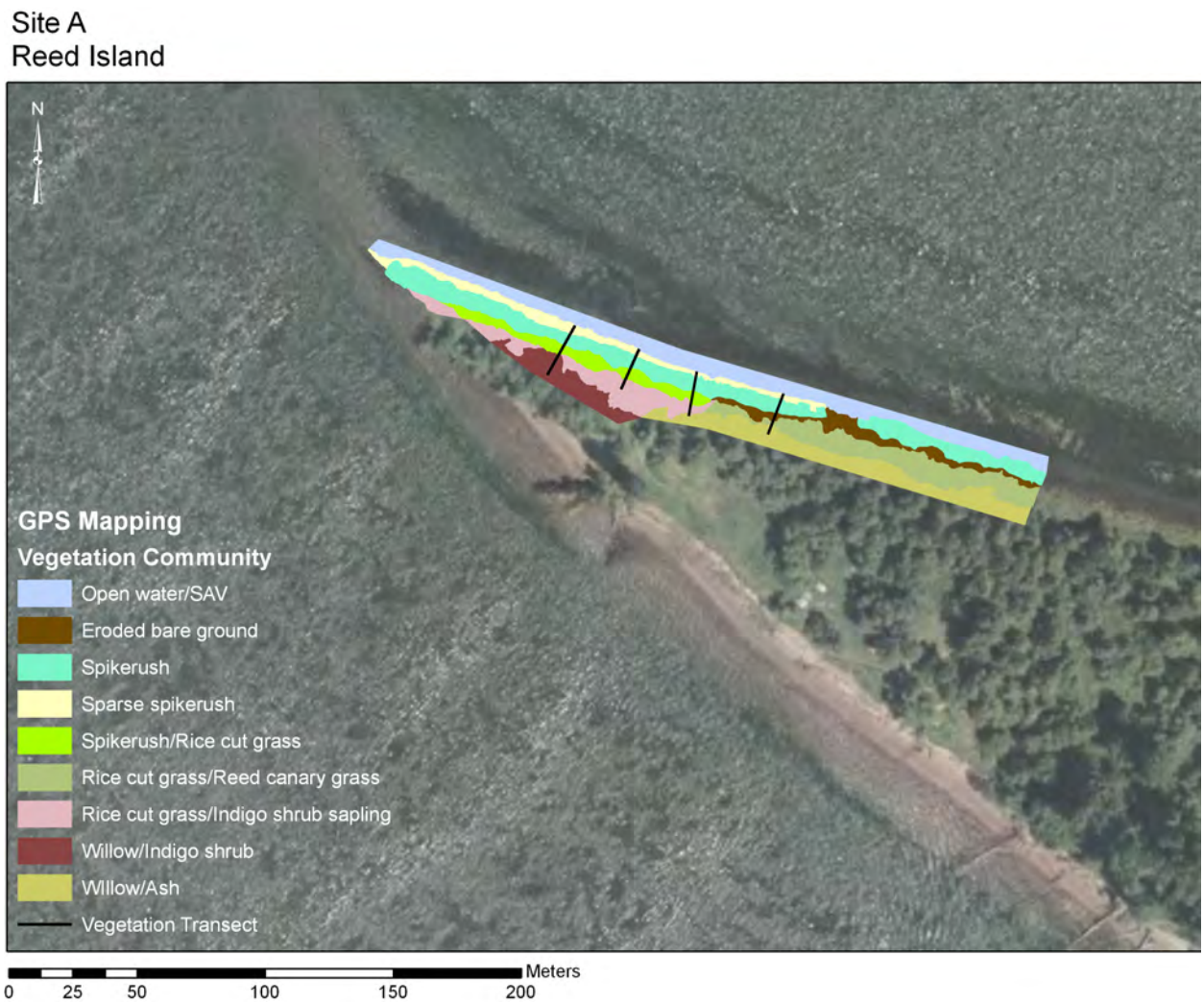


Figure B.3. Vegetation Map for Site A

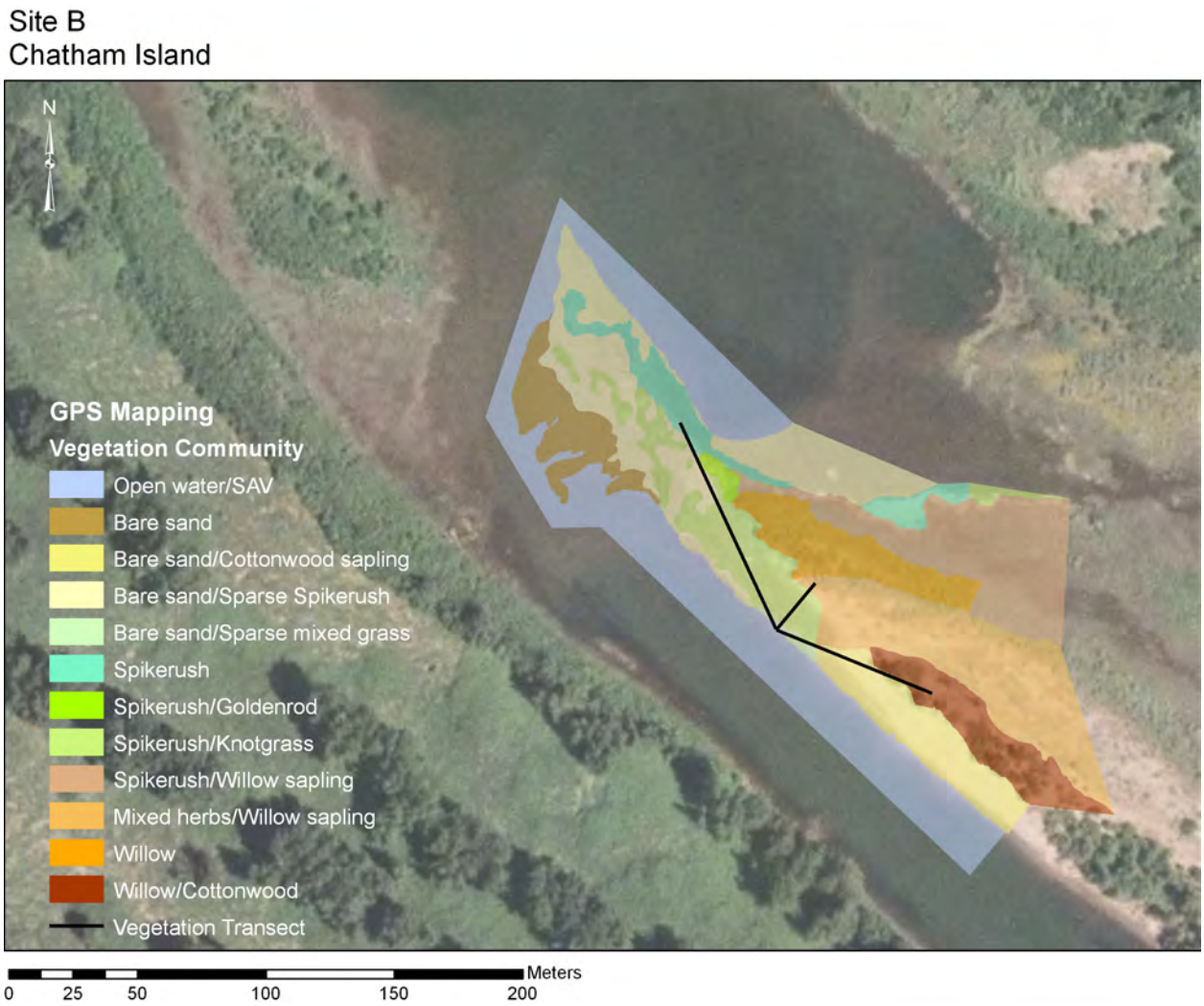


Figure B.4. Vegetation Map for Site B

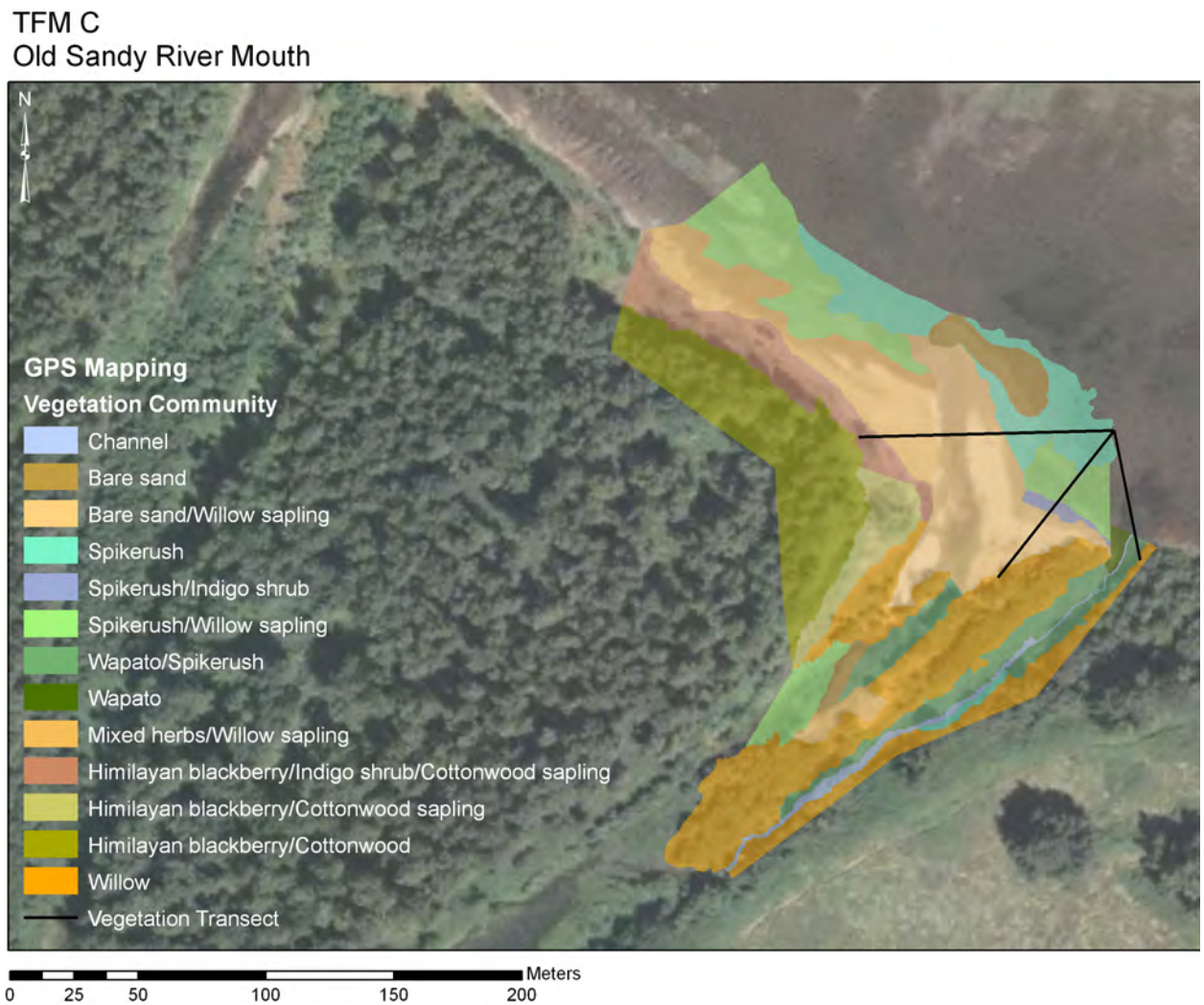


Figure B.5. Vegetation Map for Site C

TFM D
Sandy River Mouth

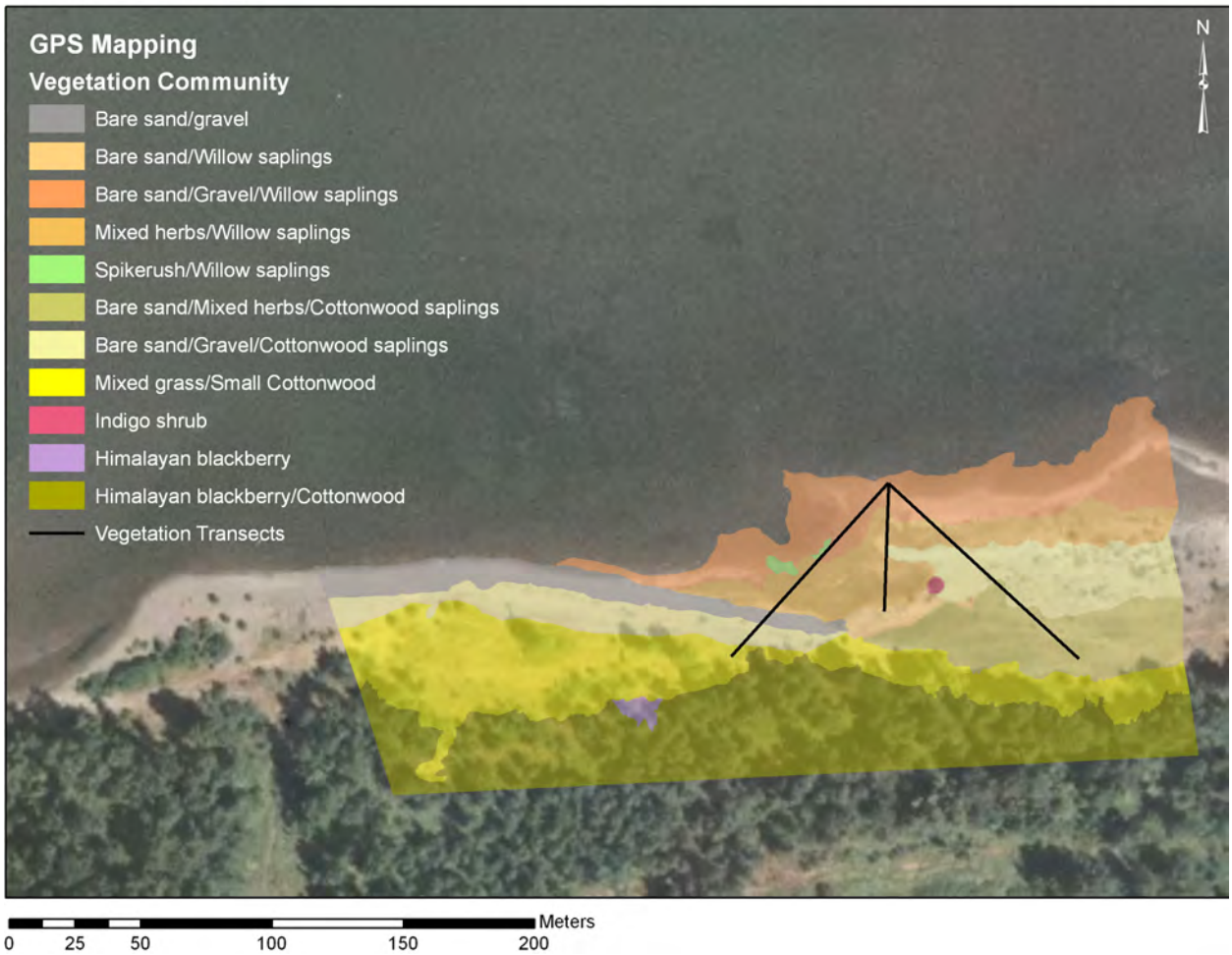


Figure B.6. Vegetation Map for Site D

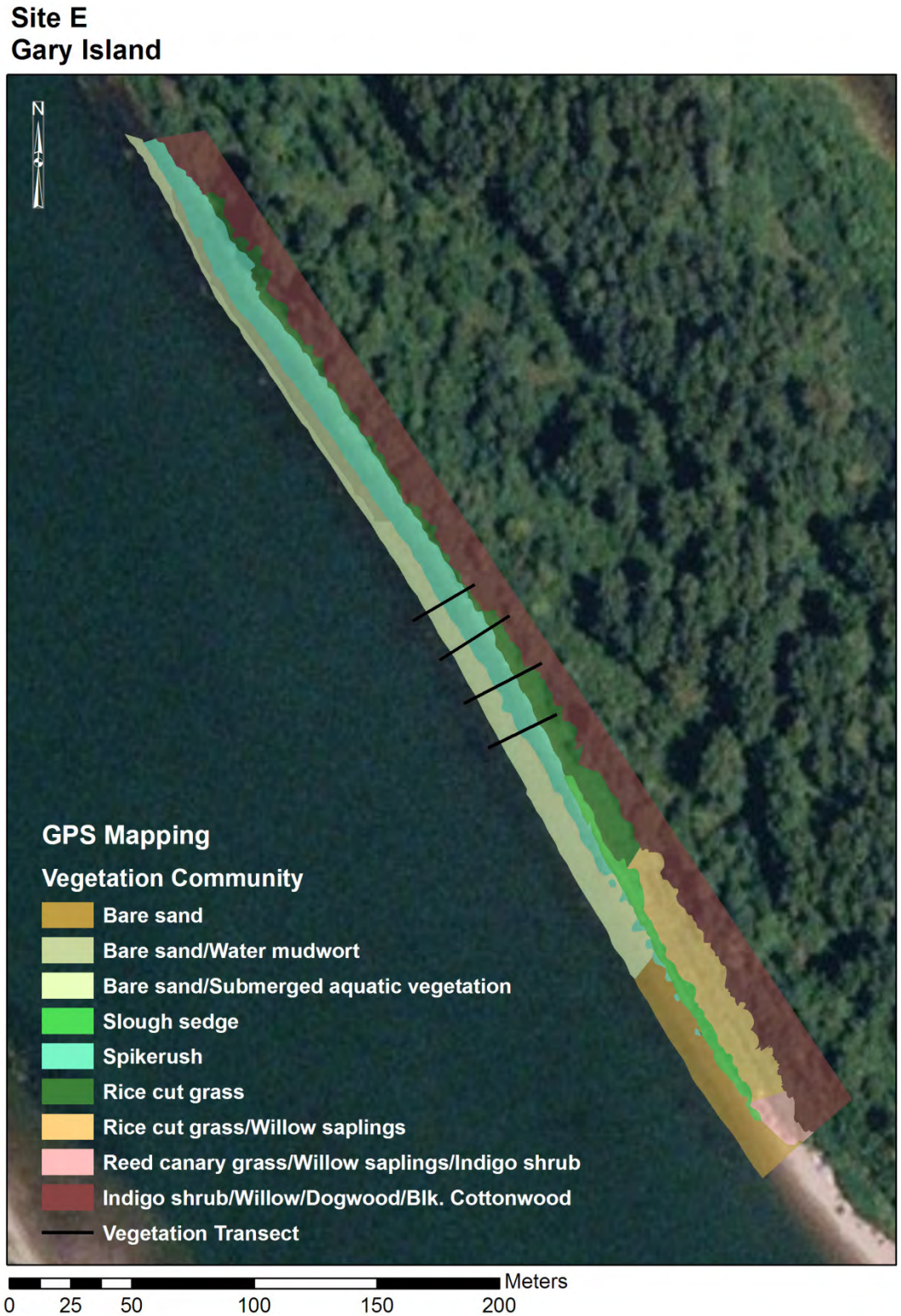


Figure B.7. Vegetation Map for Site E

Site F

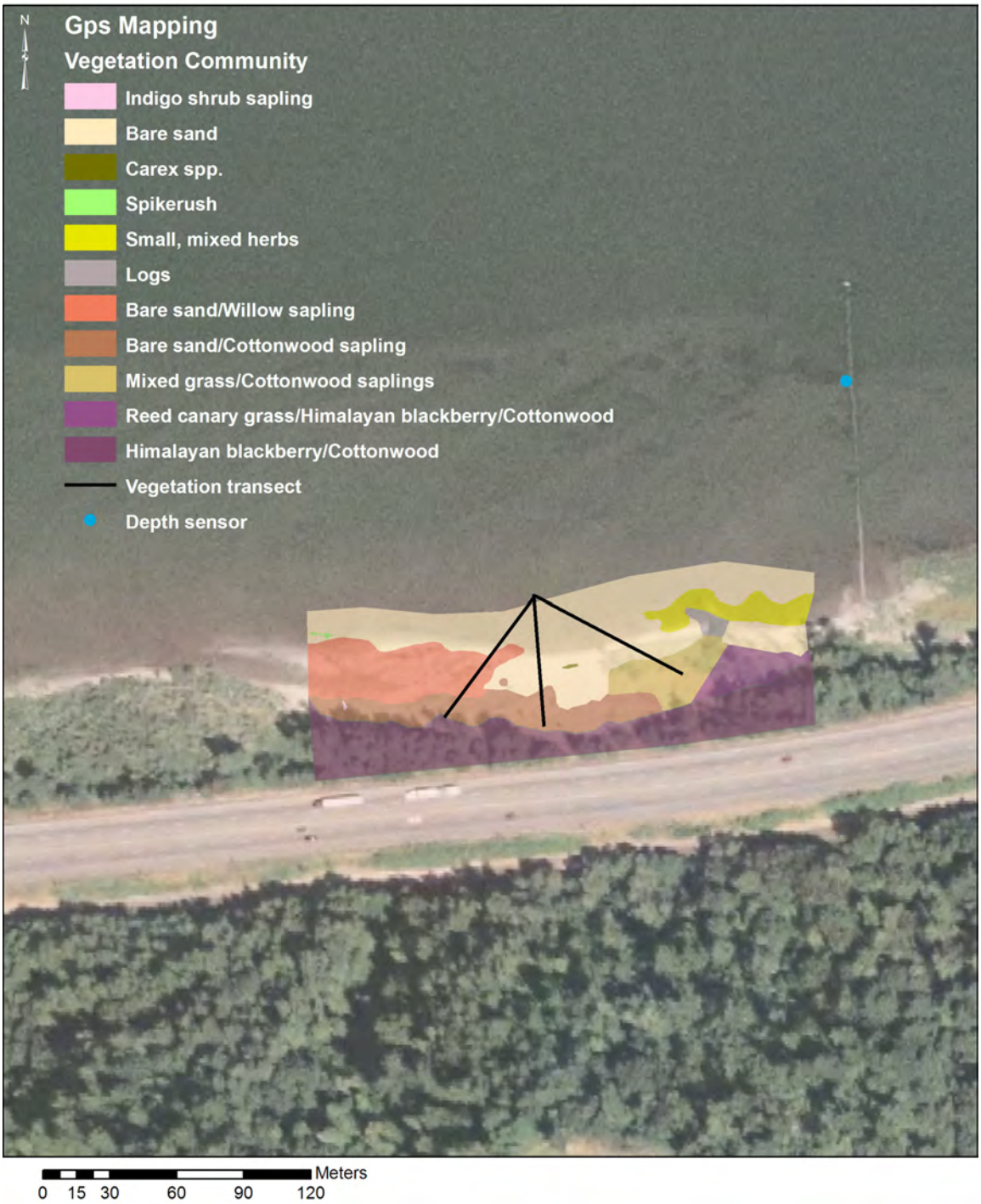


Figure B.8. Vegetation Map for Site F

Site H
McGuire Island

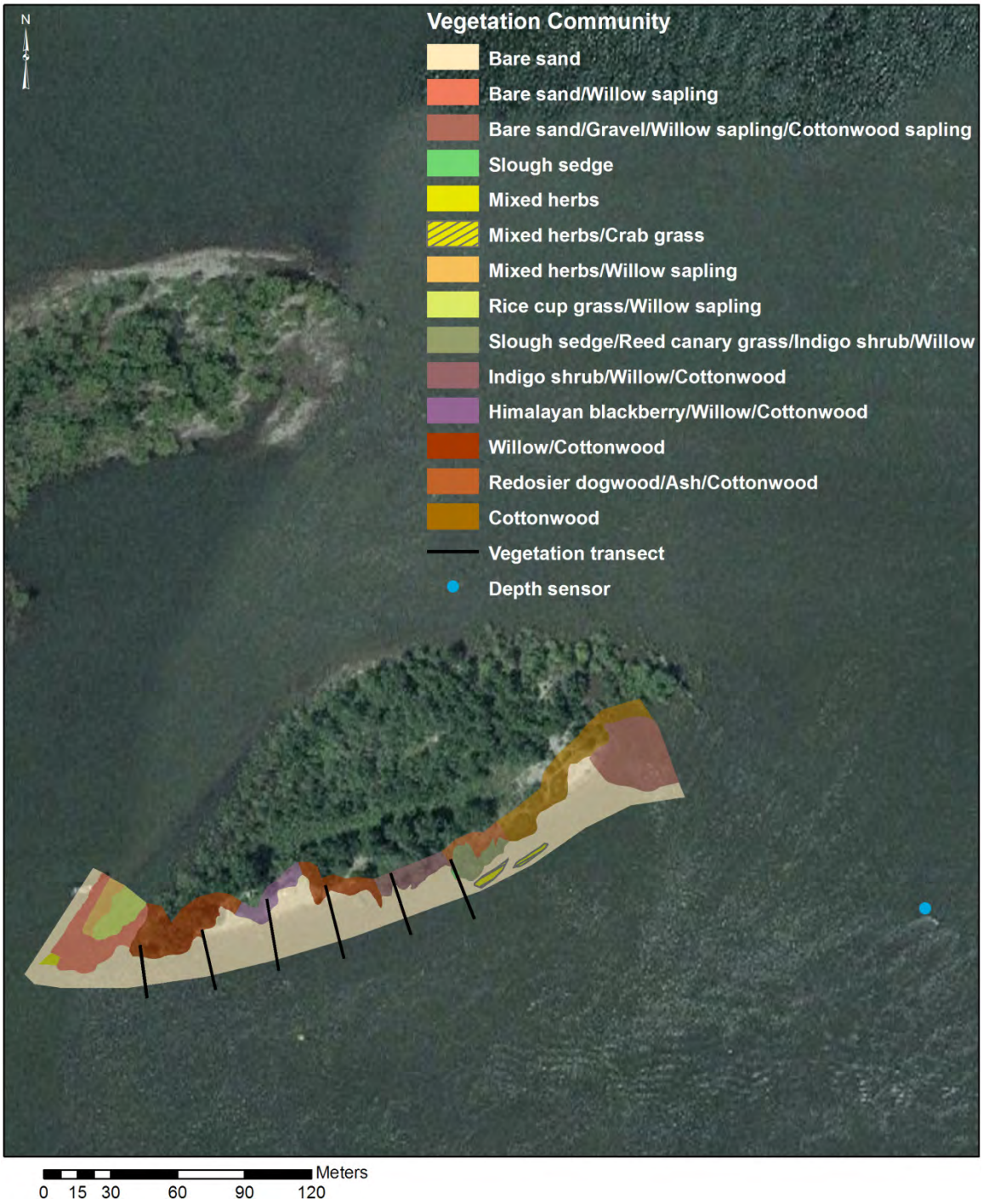


Figure B.9. Vegetation Map for Site H

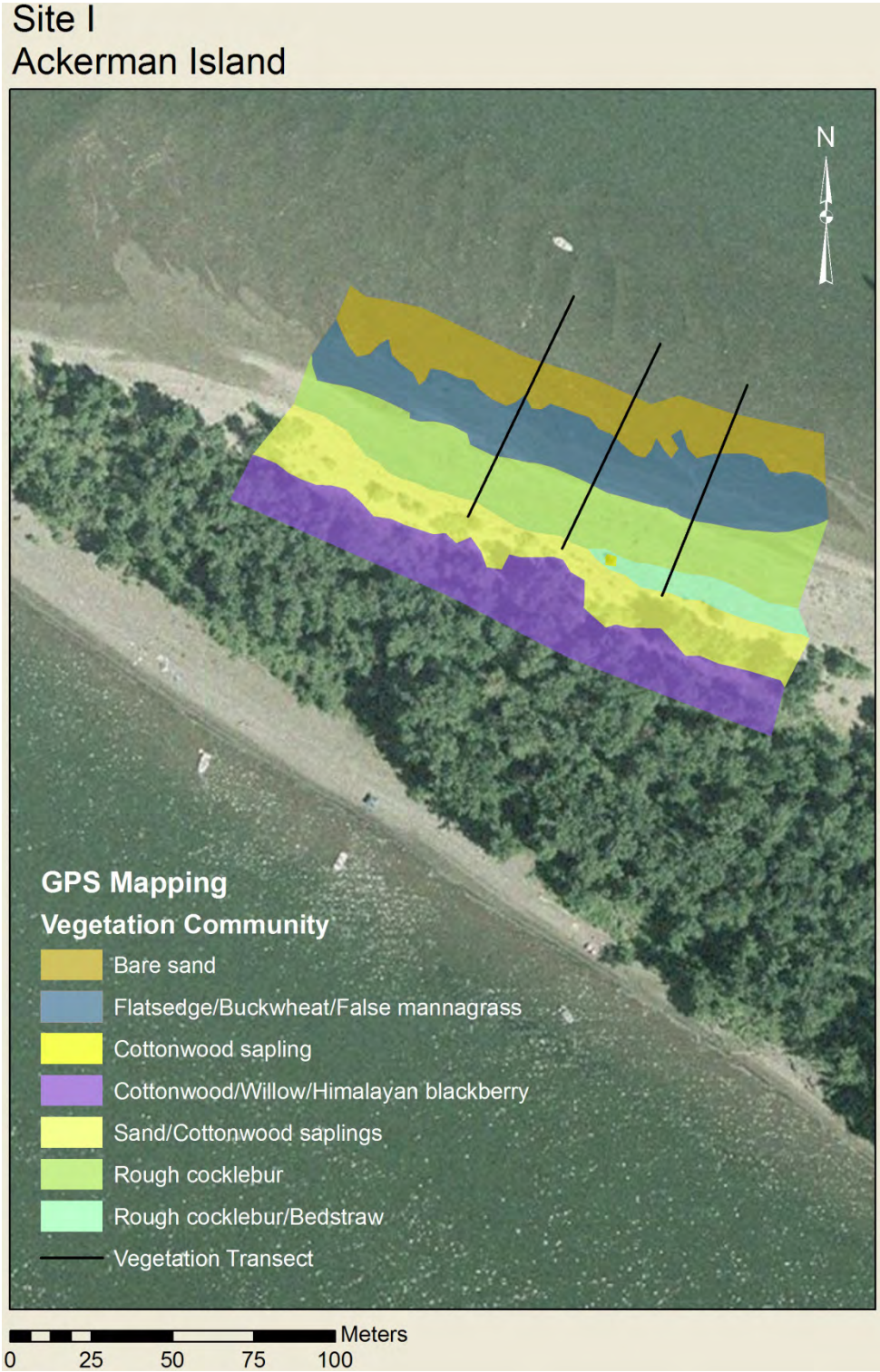


Figure B.10. Vegetation Map for Site I

Site N
Old Sandy Channel

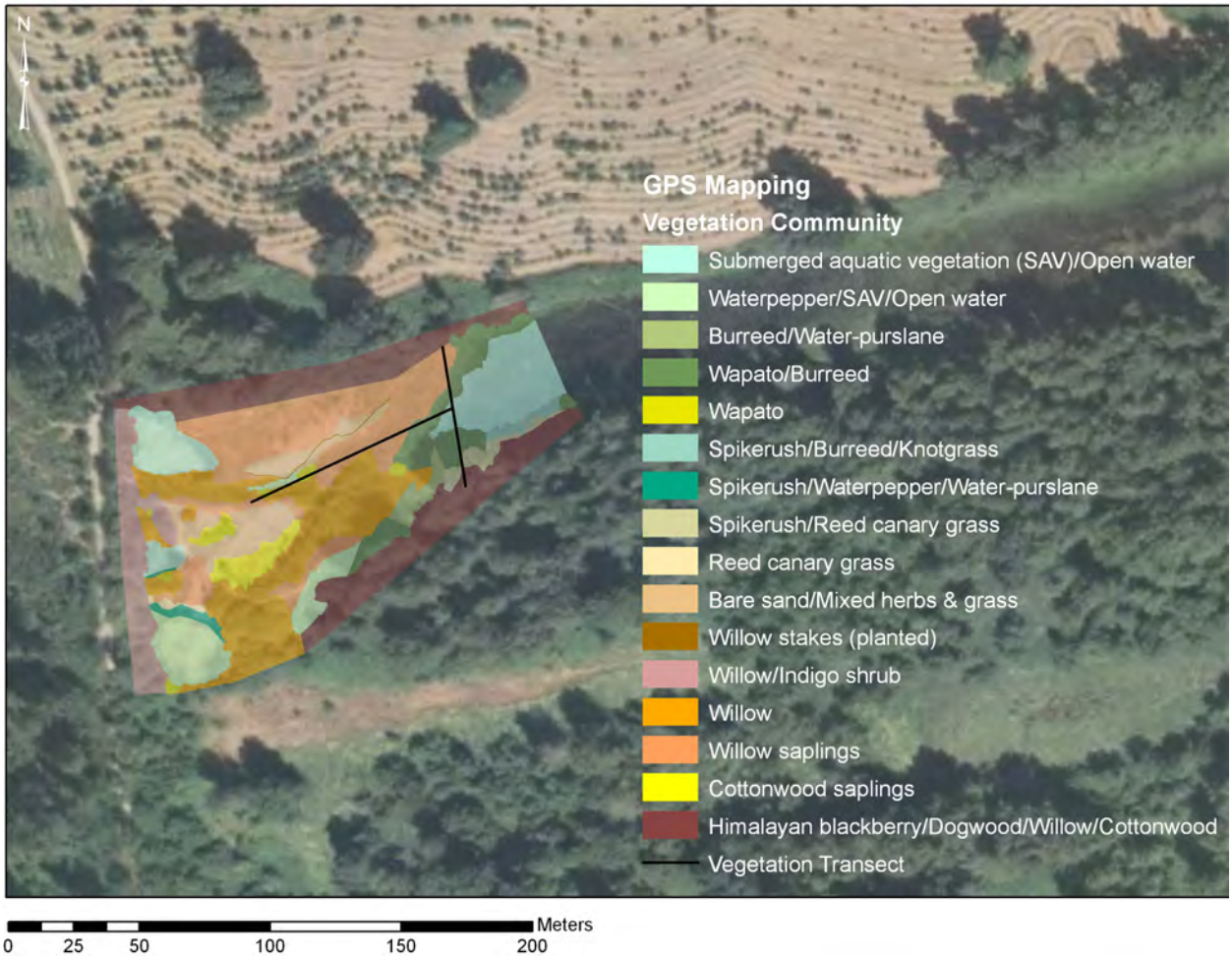


Figure B.11. Vegetation Map for Site N

Appendix C

Photo Points

Appendix C

Photo Points

Prepared by Amanda Bryson

To visually document changing habitat conditions, photographs were taken from the benchmark in the same direction for each sampling trip at each sampling site in the SRD. The photographs are presented by site and year.

C.1 Site A – 2008

July

August

September

October

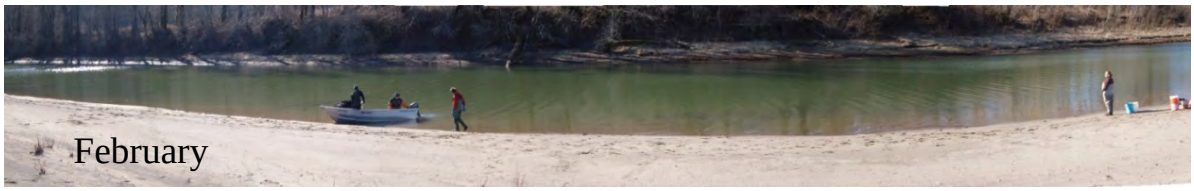
December

C.2 Site A – 2009

C.3 Site A – 2010

C.4 Site B – 2008

C.5 Site B – 2009



June

July

August

September

October

November

C.6 Site B – 2010

C.7 Site C – 2008

May

June

August

September

October

C.8 Site C – 2009

June

July

September

October

November

C.9 Site C – 2010

C.10 Site D – 2008

April

August

September

October

November

December

C.11 Site D – 2009

C.12 Site D – 2010

C.13 Site E – 2008

C.14 Site E – 2009

C.15 Site E – 2010

C.16 Site F – 2009

C.17 Site F – 2010

C.18 Site H – 2009

C.19 Site H – 2010

C.20 Site I – 2009

C.21 Site I – 2010

C.22 Site N – 2009

C.23 Site N – 2010

Appendix D

Juvenile Chinook Salmon Genetic Stock Identification

Appendix D

Juvenile Chinook Salmon Genetic Stock Identification

Prepared by David Teel

Genetic stock groups comprise West Cascade Tributary falls (WC F), West Cascade Tributary springs (WC Sp), Willamette River springs (WR Sp), Spring Creek Group falls (SCG F), Upper Columbia River summer/falls (UCR Su/F), Deschutes River falls (Desch F), Mid and Upper Columbia River springs (MCR Sp), Snake River falls (Snake F), Snake River springs (Snake Sp), and Rogue River falls (Rogue F) Chinook salmon. Confidence intervals were obtained from 100 bootstrap resamplings of baseline and mixture genotypes. The estimated proportional stock compositions are presented separately for unmarked Chinook salmon in the Sandy River delta and vicinity (Table D.1), unmarked Chinook salmon in the lower river reaches (Cowlitz to Lewis rivers) (Table D.2), and for marked Chinook salmon in both areas (Table D.3). These data support the genetics results presented in Chapter 2.

Table D.1. Estimated Proportional Stock Composition (Shaded Rows) for Unmarked Chinook Salmon Sampled from June 2007 Through April 2010 at Sites in the Sandy River Delta and Vicinity. The 95% confidence intervals are presented in the rows below.

Survey	n	WC Fall	WC Spring	WR Spring	SCG Fall	UCR Su/F	Desch Fall	MCR Spring	Snake Fall	Snake Spring	Rogue Fall
Jan 2010	25	0.087	0.097	0.379	0.437	0.000	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.160	0.168	0.000	0.000	0.000	0.000	0.000	0.000
		0.199	0.264	0.559	0.640	0.106	0.005	0.080	0.000	0.000	0.030
Feb 2009	25	0.122	0.133	0.401	0.187	0.071	0.033	0.000	0.053	0.000	0.000
		0.000	0.000	0.175	0.041	0.000	0.000	0.000	0.000	0.000	0.000
		0.329	0.267	0.596	0.342	0.199	0.124	0.083	0.202	0.083	0.083
Feb 2010	96	0.043	0.020	0.025	0.894	0.000	0.000	0.007	0.000	0.011	0.000
		0.000	0.000	0.000	0.755	0.000	0.000	0.000	0.000	0.000	0.000
		0.136	0.112	0.057	0.936	0.011	0.021	0.018	0.028	0.042	0.018
Mar 2009	85	0.020	0.012	0.024	0.921	0.024	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.808	0.000	0.000	0.000	0.000	0.000	0.000
		0.124	0.063	0.070	0.942	0.050	0.012	0.024	0.047	0.000	0.000
Mar 2010	136	0.077	0.028	0.010	0.833	0.038	0.000	0.000	0.015	0.000	0.000
		0.032	0.000	0.000	0.698	0.000	0.000	0.000	0.000	0.000	0.000
		0.196	0.077	0.035	0.867	0.082	0.012	0.000	0.041	0.000	0.000
Apr 2008	39	0.111	0.000	0.026	0.505	0.309	0.026	0.000	0.024	0.000	0.000
		0.046	0.000	0.000	0.311	0.132	0.000	0.000	0.000	0.000	0.000
		0.245	0.026	0.089	0.623	0.435	0.122	0.000	0.118	0.000	0.000
2010	160	0.327	0.000	0.053	0.408	0.189	0.016	0.000	0.008	0.000	0.000
		0.232	0.000	0.013	0.303	0.110	0.000	0.000	0.000	0.000	0.000
		0.392	0.050	0.080	0.473	0.273	0.061	0.000	0.041	0.000	0.001

Table D.1. (contd)

Survey	n	WC Fall	WC Spring	WR Spring	SCG Fall	UCR Su/F	Desch Fall	MCR Spring	Snake Fall	Snake Spring	Rogue Fall
May 2008	61	0.200	0.018	0.060	0.171	0.412	0.038	0.000	0.101	0.000	0.000
		0.083	0.000	0.000	0.062	0.256	0.000	0.000	0.000	0.000	0.000
		0.333	0.118	0.115	0.243	0.530	0.160	0.000	0.214	0.000	0.020
May 2009	105	0.083	0.010	0.019	0.239	0.594	0.046	0.000	0.000	0.010	0.000
		0.041	0.000	0.000	0.119	0.408	0.008	0.000	0.000	0.000	0.000
		0.193	0.056	0.038	0.283	0.661	0.141	0.009	0.076	0.029	0.000
Jun 2007	73	0.246	0.000	0.000	0.012	0.516	0.161	0.000	0.065	0.000	0.000
		0.079	0.000	0.000	0.000	0.384	0.029	0.000	0.000	0.000	0.000
		0.325	0.028	0.001	0.047	0.661	0.244	0.000	0.211	0.024	0.021
Jun 2008	67	0.220	0.051	0.000	0.030	0.574	0.044	0.000	0.082	0.000	0.000
		0.085	0.000	0.000	0.000	0.378	0.000	0.000	0.000	0.000	0.000
		0.336	0.132	0.068	0.074	0.714	0.123	0.000	0.195	0.000	0.000
Jun 2009	132	0.128	0.003	0.008	0.018	0.714	0.079	0.000	0.045	0.000	0.005
		0.067	0.000	0.000	0.000	0.574	0.007	0.000	0.000	0.000	0.000
		0.205	0.029	0.023	0.041	0.786	0.157	0.008	0.129	0.000	0.026
Jul 2009	32	0.083	0.000	0.056	0.000	0.728	0.089	0.000	0.045	0.000	0.000
		0.000	0.000	0.000	0.000	0.456	0.000	0.000	0.000	0.000	0.000
		0.211	0.105	0.122	0.065	0.844	0.229	0.062	0.234	0.057	0.065
Aug 2007, 2008, 2009	31	0.205	0.079	0.297	0.000	0.389	0.000	0.000	0.031	0.000	0.000
		0.039	0.000	0.065	0.000	0.210	0.000	0.000	0.000	0.000	0.000
		0.328	0.289	0.423	0.069	0.583	0.108	0.000	0.195	0.000	0.032
Nov 2007, 2009	28	0.108	0.090	0.661	0.068	0.000	0.034	0.000	0.039	0.000	0.000
		0.000	0.000	0.453	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		0.251	0.290	0.821	0.143	0.075	0.108	0.000	0.143	0.068	0.000
Dec 2007, 2009	31	0.185	0.156	0.549	0.000	0.110	0.000	0.000	0.000	0.000	0.000
		0.033	0.000	0.311	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		0.314	0.332	0.717	0.064	0.283	0.064	0.000	0.063	0.032	0.085

Table D.2. Estimated Proportional Stock Composition (Shaded Rows) for Unmarked Chinook Salmon Sampled at Sites in the Cowlitz to Lewis Region in 2009 and 2010. The 95% confidence intervals are presented in the rows below.

Survey	n	WC Fall	WC Spring	WR Spring	SCG Fall	UCR Su/F	Desch Fall	MCR Spring	Snake Fall	Snake Spring	Rogue Fall
Feb 2009	29	0.620	0.090	0.202	0.054	0.000	0.034	0.000	0.000	0.000	0.000
		0.321	0.000	0.037	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		0.804	0.321	0.330	0.169	0.163	0.112	0.000	0.000	0.034	0.000

Table D.2. (contd)

Survey	n	WC Fall	WC Spring	WR Spring	SCG Fall	UCR Su/F	Desch Fall	MCR Spring	Snake Fall	Snake Spring	Rogue Fall
Feb 2010	148	0.745	0.080	0.014	0.151	0.004	0.000	0.000	0.007	0.000	0.000
		0.615	0.051	0.000	0.047	0.000	0.000	0.000	0.000	0.000	0.000
		0.804	0.194	0.041	0.189	0.037	0.020	0.000	0.028	0.000	0.020
May 2009	118	0.784	0.010	0.000	0.157	0.029	0.000	0.000	0.019	0.000	0.000
		0.651	0.000	0.000	0.074	0.000	0.000	0.000	0.000	0.000	0.000
		0.824	0.102	0.007	0.250	0.093	0.025	0.000	0.057	0.000	0.020
Nov 2009	37	0.888	0.033	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		0.654	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
		0.931	0.218	0.149	0.131	0.103	0.027	0.021	0.000	0.000	0.000

Table D.3. Estimated Proportional Stock Composition (shaded rows), 95% Confidence Intervals (rows below) and Sample Size for Marked (adipose fin clipped) Chinook Salmon Sampled at Sites in the Sandy Delta Region in 2008 and in the Cowlitz to Lewis Region in 2009

Survey	n	WC Fall	WC Spring	WR Spring	SCG Fall	UCR Su/F	Desch Fall	MCR Spring	Snake Fall	Snake Spring	Rogue Fall
Mar 2008	25	0.000	0.038	0.000	0.962	0.000	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.811	0.000	0.000	0.000	0.000	0.000	0.000
		0.167	0.081	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
Apr 2008	65	0.023	0.000	0.000	0.977	0.000	0.000	0.000	0.000	0.000	0.000
		0.000	0.000	0.000	0.784	0.000	0.000	0.000	0.000	0.000	0.000
		0.171	0.059	0.000	1.000	0.029	0.000	0.000	0.000	0.000	0.000
May 2008	25	0.000	0.029	0.080	0.731	0.120	0.000	0.040	0.000	0.000	0.000
		0.000	0.000	0.000	0.457	0.000	0.000	0.000	0.000	0.000	0.000
		0.175	0.215	0.201	0.861	0.200	0.100	0.120	0.080	0.000	0.000
May 2009	34	0.120	0.000	0.000	0.880	0.000	0.000	0.000	0.000	0.000	0.000
		0.030	0.000	0.000	0.705	0.000	0.000	0.000	0.000	0.000	0.000
		0.270	0.026	0.000	0.970	0.000	0.000	0.000	0.000	0.000	0.000

Appendix E

Relativized Electivity Index Values for Prey of Juvenile Chinook Salmon

Appendix E

Relativized Electivity Index Values for Prey of Juvenile Chinook Salmon

Prepared by Adam Storch

This appendix contains Relativized Electivity Index values (E_i^*) for taxa encountered by juvenile Chinook salmon at the sampling sites (Tables E.1 through E.20). Values are calculated for the scenario where 100% of ambiguous prey (i.e., taxa that could be encountered in either the benthos or the drift; see Chapter 4) were attributed to the benthos. Electivity values are standardized so that predator preference is represented on a scale ranging from -1.0 to 1.0, where, $E_i^* = -1.0$ indicates complete selection against a particular prey item, $E_i^* = 0.0$ indicates that prey item is consumed in proportion to its abundance in the environment, and $E_i^* = 1.0$ indicates complete selection for the prey type. To represent the general diet of juvenile salmon, diet proportions (i.e., p_i, see Section 4.1) from individual fish were averaged and then a single electivity index value was calculated.

In the following tables, the meanings of the codes are as follows:

- * = Prey item was not encountered in the diet or in the environment.
- -- = No Chinook salmon appropriate for gastric lavage were encountered.
- † = No prey item from habitat strata was encountered in the diet.
- ‡ = No prey items were in the prey availability sample.
- • = Gut contents and/or prey were not sampled.

Table E.1. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites A and B During June, September, and December 2009 and March 2010

Taxon	A				B			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	0.630	--	0.349	--	-0.698	--	--	0.469
Annelida	*	--	*	--	*	--	--	*
Arachnida	-1.000	--	-1.000	--	-0.384	--	--	-1.000
Coleoptera	*	--	*	--	-0.384	--	--	-1.000
Copepoda	-1.000	--	*	--	-1.000	--	--	-1.000
Diptera	-0.540	--	-1.000	--	-0.502	--	--	-0.953
Ephemeroptera	*	--	*	--	*	--	--	*
Hemiptera	-1.000	--	*	--	-0.058	--	--	0.509
Isopopda	0.060	--	*	--	*	--	--	*
Megaloptera	*	--	*	--	*	--	--	*
Mollusca	-1.000	--	-1.000	--	-1.000	--	--	-1.000
Mysidae	0.389	--	0.663	--	0.754	--	--	0.509
Nemata/Nematomorpha	0.308	--	-1.000	--	-0.255	--	--	-1.000
Odonata	*	--	*	--	*	--	--	0.509
Ostracoda	-1.000	--	-1.000	--	-1.000	--	--	-1.000
Plecoptera	*	--	*	--	*	--	--	*
Tardigrada	*	--	*	--	*	--	--	-1.000
Trichoptera	*	--	*	--	*	--	--	*

Table E.2. Relativized Electivity Index Values (Ei^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites C and D During June, September, and December 2009 and March 2010

Taxon	C				D			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	0.149	•	--	0.719	0.113	--	--	*
Annelida	-1.000	•	--	*	*	--	--	*
Arachnida	*	•	--	-1.000	*	--	--	-1.000
Coleoptera	*	•	--	-1.000	*	--	--	-1.000
Copepoda	-1.000	•	--	-1.000	-1.000	--	--	*
Diptera	-0.743	•	--	0.746	0.096	--	--	0.714
Ephemeroptera	*	•	--	-1.000	*	--	--	*
Hemiptera	*	•	--	*	-0.238	--	--	*
Isopopda	*	•	--	*	*	--	--	*
Megaloptera	*	•	--	*	*	--	--	*
Mollusca	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Mysidae	0.703	•	--	*	0.113	--	--	*
Nemata/Nematomorpha	-0.407	•	--	-1.000	0.454	--	--	*
Odonata	*	•	--	-1.000	*	--	--	*
Ostracoda	-1.000	•	--	-1.000	*	--	--	-1.000
Plecoptera	0.149	•	--	-1.000	*	--	--	*
Tardigrada	*	•	--	-1.000	*	--	--	-1.000
Trichoptera	*	•	--	-1.000	*	--	--	*

Table E.3. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites E and F During June, September, and December 2009 and March 2010

Taxon	E				F			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	-0.711	--	--	0.717	0.073	†	*	0.415
Annelida	0.738	--	--	*	*	†	*	*
Arachnida	-0.078	--	--	*	0.132	†	*	*
Coleoptera	*	--	--	-1.000	*	†	*	*
Copepoda	-1.000	--	--	-1.000	-1.000	†	-1.000	*
Diptera	-0.744	--	--	-0.035	-0.719	†	0.108	-0.165
Ephemeroptera	-0.124	--	--	*	*	†	0.216	*
Hemiptera	0.218	--	--	*	*	†	*	*
Isopopda	*	--	--	*	*	†	*	*
Megaloptera	*	--	--	*	*	†	*	*
Mollusca	-1.000	--	--	-1.000	*	†	-1.000	*
Mysidae	-0.124	--	--	*	0.530	†	0.216	*
Nemata/Nematomorpha	-0.926	--	--	-1.000	-0.788	†	-1.000	-1.000
Odonata	*	--	--	*	*	†	0.216	*
Ostracoda	-0.907	--	--	-1.000	*	†	*	*
Plecoptera	*	--	--	*	*	†	0.216	*
Tardigrada	*	--	--	*	*	†	*	*
Trichoptera	*	--	--	*	*	†	0.216	-0.073

Table E.4. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites H and I During June, September, and December 2009 and March 2010

Taxon	H				I			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	-0.070	--	†	0.289	-0.570	--	--	0.358
Annelida	*	--	†	*	*	--	--	*
Arachnida	-1.000	--	†	-1.000	*	--	--	*
Coleoptera	*	--	†	*	*	--	--	*
Copepoda	-1.000	--	†	*	-1.000	--	--	*
Diptera	-0.370	--	†	-0.336	0.422	--	--	0.230
Ephemeroptera	0.677	--	†	*	*	--	--	0.244
Hemiptera	*	--	†	*	*	--	--	*
Isopopda	*	--	†	*	*	--	--	*
Megaloptera	*	--	†	*	*	--	--	*
Mollusca	-1.000	--	†	-1.000	-1.000	--	--	-1.000
Mysidae	*	--	†	*	0.473	--	--	*
Nemata/Nematomorpha	-0.414	--	†	-1.000	-0.872	--	--	-1.000
Odonata	0.349	--	†	*	*	--	--	*
Ostracoda	-1.000	--	†	-1.000	*	--	--	-1.000
Plecoptera	*	--	†	0.649	*	--	--	0.244
Tardigrada	*	--	†	*	*	--	--	*
Trichoptera	*	--	†	*	0.166	--	--	*

Table E.5. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites A and B During June, September, and December 2009 and March 2010

Taxon	A				B			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	0.630	--	0.349	--	-0.698	--	--	0.469
Annelida	*	--	*	--	*	--	--	*
Arachnida	-1.000	--	-1.000	--	-0.384	--	--	-1.000
Coleoptera	*	--	*	--	-0.384	--	--	-1.000
Copepoda	-1.000	--	*	--	-1.000	--	--	-1.000
Diptera	-0.536	--	-1.000	--	-0.502	--	--	-0.953
Ephemeroptera	*	--	*	--	*	--	--	*
Hemiptera	-1.000	--	*	--	-0.058	--	--	0.509
Isopopda	0.063	--	*	--	*	--	--	*
Megaloptera	*	--	*	--	*	--	--	*
Mollusca	-1.000	--	-1.000	--	-1.000	--	--	-1.000
Mysidae	0.389	--	0.663	--	0.754	--	--	0.509
Nemata/Nematomorpha	0.308	--	-1.000	--	-0.255	--	--	-1.000
Odonata	*	--	*	--	*	--	--	0.509
Ostracoda	-1.000	--	-1.000	--	-1.000	--	--	-1.000
Plecoptera	*	--	*	--	*	--	--	*
Tardigrada	*	--	*	--	*	--	--	-1.000
Trichoptera	*	--	*	--	*	--	--	*

Table E.6. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites C and D During June, September, and December 2009 and March 2010

Taxon	C				D			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	0.080	•	--	0.719	0.113	--	--	*
Annelida	-1.000	•	--	*	*	--	--	*
Arachnida	*	•	--	-1.000	*	--	--	-1.000
Coleoptera	*	•	--	-1.000	*	--	--	-1.000
Copepoda	-1.000	•	--	-1.000	-1.000	--	--	*
Diptera	-0.773	•	--	0.746	0.096	--	--	0.714
Ephemeroptera	*	•	--	-1.000	*	--	--	*
Hemiptera	*	•	--	*	-0.238	--	--	*
Isopopda	*	•	--	*	*	--	--	*
Megaloptera	*	•	--	*	*	--	--	*
Mollusca	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Mysidae	0.666	•	--	*	0.113	--	--	*
Nemata/Nematomorpha	-0.463	•	--	-1.000	0.454	--	--	*
Odonata	*	•	--	-1.000	*	--	--	*
Ostracoda	-1.000	•	--	-1.000	*	--	--	-1.000
Plecoptera	0.402	•	--	-1.000	*	--	--	*
Tardigrada	*	•	--	-1.000	*	--	--	-1.000
Trichoptera	*	•	--	-1.000	*	--	--	*

Table E.7. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites E and F During June, September, and December 2009 and March 2010

	E				F			
Taxon	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	-0.711	--	--	0.717	0.073	†	*	0.415
Annelida	0.738	--	--	*	*	†	*	*
Arachnida	-0.078	--	--	*	0.132	†	*	*
Coleoptera	*	--	--	-1.000	*	†	*	*
Copepoda	-1.000	--	--	-1.000	-1.000	†	-1.000	*
Diptera	-0.744	--	--	-0.035	-0.719	†	0.029	-0.165
Ephemeroptera	-0.124	--	--	*	*	†	0.139	*
Hemiptera	0.218	--	--	*	*	†	*	*
Isopopda	*	--	--	*	*	†	*	*
Megaloptera	*	--	--	*	*	†	*	*
Mollusca	-1.000	--	--	-1.000	*	†	-1.000	*
Mysidae	-0.124	--	--	*	0.530	†	0.139	*
Nemata/Nematomorpha	-0.926	--	--	-1.000	-0.788	†	-1.000	-1.000
Odonata	*	--	--	*	*	†	0.139	*
Ostracoda	-0.907	--	--	-1.000	*	†	*	*
Plecoptera	*	--	--	*	*	†	0.452	*
Tardigrada	*	--	--	*	*	†	*	*
Trichoptera	*	--	--	*	*	†	0.139	-0.073

Table E.8. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites H and I During June, September, and December 2009 and March 2010

Taxon	H				I			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Amphipoda	-0.289	--	†	0.041	-0.570	--	--	0.263
Annelida	*	--	†	*	*	--	--	*
Arachnida	-1.000	--	†	-1.000	*	--	--	*
Coleoptera	*	--	†	*	*	--	--	*
Copepoda	-1.000	--	†	*	-1.000	--	--	*
Diptera	-0.548	--	†	-0.542	0.422	--	--	0.128
Ephemeroptera	0.736	--	†	*	*	--	--	0.142
Hemiptera	*	--	†	*	*	--	--	*
Isopopda	*	--	†	*	*	--	--	*
Megaloptera	*	--	†	*	*	--	--	*
Mollusca	-1.000	--	†	-1.000	-1.000	--	--	-1.000
Mysidae	*	--	†	*	0.473	--	--	*
Nemata/Nematomorpha	-0.583	--	†	-1.000	-0.872	--	--	-1.000
Odonata	0.136	--	†	*	*	--	--	*
Ostracoda	-1.000	--	†	-1.000	*	--	--	-1.000
Plecoptera	*	--	†	0.698	*	--	--	0.454
Tardigrada	*	--	†	*	*	--	--	*
Trichoptera	*	--	†	*	0.166	--	--	*

Table E.9. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites A and B During June, September, and December 2009 and March 2010

Taxon	A				B			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	*	--	*	--	*	--	--	*
Amphipoda	0.570	--	0.211	--	-0.183	--	--	0.747
Annelida	*	--	*	--	*	--	--	*
Arachnida	-0.030	--	*	--	-0.989	--	--	-1.000
Argulidae	*	--	-1.000	--	*	--	--	*
Cladocera	-0.999	--	-1.000	--	-0.994	--	--	-0.821
Coleoptera	*	--	*	--	*	--	--	*
Copepoda	-1.000	--	-1.000	--	-0.999	--	--	-0.839
Diptera	-0.974	--	-1.000	--	-0.979	--	--	-0.443
Ephemeroptera	*	--	*	--	*	--	--	*
Hemiptera	*	--	*	--	0.160	--	--	-0.293
Isopopda	-0.030	--	*	--	*	--	--	*
Megaloptera	-1.000	--	*	--	*	--	--	*
Mollusca	*	--	*	--	*	--	--	*
Mysidae	0.306	--	0.691	--	0.694	--	--	-0.863
Nemata/Nematomorpha	0.222	--	*	--	0.160	--	--	-1.000
Odonata	*	--	*	--	*	--	--	0.314
Ostracoda	*	--	*	--	-1.000	--	--	-1.000
Rotifera	*	--	*	--	*	--	--	*
Tardigrada	*	--	-1.000	--	*	--	--	*
Trichoptera	*	--	*	--	*	--	--	*

Table E.10. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites C and D During June, September, and December 2009 and March 2010

Taxon	C				D			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	0.406	•	--	*	-1.000	--	--	*
Amphipoda	0.084	•	--	0.733	0.559	--	--	*
Annelida	-1.000	•	--	*	*	--	--	*
Arachnida	0.084	•	--	-1.000	-1.000	--	--	-1.000
Argulidae	*	•	--	*	*	--	--	*
Cladocera	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Coleoptera	*	•	--	*	*	--	--	*
Copepoda	-1.000	•	--	-1.000	-0.999	--	--	-1.000
Diptera	-0.910	•	--	0.432	-0.872	--	--	0.750
Ephemeroptera	*	•	--	-1.000	*	--	--	*
Hemiptera	*	•	--	*	-0.943	--	--	*
Isopopda	*	•	--	*	*	--	--	*
Megaloptera	-1.000	•	--	*	-1.000	--	--	*
Mollusca	*	•	--	*	*	--	--	*
Mysidae	0.668	•	--	*	0.404	--	--	*
Nemata/Nematomorpha	0.084	•	--	-1.000	0.667	--	--	-1.000
Odonata	*	•	--	*	*	--	--	*
Ostracoda	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Rotifera	*	•	--	*	*	--	--	*
Tardigrada	*	•	--	-1.000	*	--	--	-1.000
Trichoptera	*	•	--	*	*	--	--	*

Table E.11. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites E and F During June, September, and December 2009 and March 2010

	E				F			
Taxon	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	*	--	--	*	*	-1.000	*	*
Amphipoda	-0.240	--	--	0.161	-0.383	-1.000	*	-0.566
Annelida	0.583	--	--	*	*	-1.000	*	*
Arachnida	0.571	--	--	-1.000	0.401	-0.960	0.499	*
Argulidae	*	--	--	*	*	*	*	*
Cladocera	-0.959	--	--	-1.000	-0.965	-1.000	-1.000	-1.000
Coleoptera	*	--	--	*	*	0.833	0.198	-1.000
Copepoda	-0.997	--	--	-1.000	-0.997	-1.000	-1.000	-1.000
Diptera	-0.989	--	--	0.737	-0.986	-1.000	-0.935	-0.431
Ephemeroptera	-0.383	--	--	*	-1.000	-1.000	*	*
Hemiptera	-0.057	--	--	-1.000	*	-1.000	*	*
Isopopda	*	--	--	*	*	*	*	*
Megaloptera	*	--	--	*	-1.000	*	*	*
Mollusca	*	--	--	*	*	-1.000	*	*
Mysidae	-0.383	--	--	*	0.708	*	0.198	*
Nemata/Nematomorpha	0.054	--	--	-1.000	0.401	*	*	*
Odonata	*	--	--	*	*	*	0.198	*
Ostracoda	-0.996	--	--	-1.000	-1.000	*	-1.000	-1.000
Rotifera	*	--	--	*	*	*	*	*
Tardigrada	*	--	--	*	-1.000	*	*	-1.000
Trichoptera	*	--	--	*	*	*	0.198	0.760

Table E.12. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites H and I During June, September, and December 2009 and March 2010

Taxon	H				I			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	-0.133	--	†	*	*	--	--	*
Amphipoda	0.667	--	†	0.768	-0.942	--	--	0.452
Annelida	*	--	†	*	*	--	--	*
Arachnida	-0.133	--	†	*	*	--	--	0.511
Argulidae	*	--	†	*	*	--	--	*
Cladocera	-0.992	--	†	-1.000	-0.973	--	--	-1.000
Coleoptera	*	--	†	*	*	--	--	*
Copepoda	-1.000	--	†	-1.000	-0.996	--	--	-1.000
Diptera	-0.993	--	†	-0.443	-0.609	--	--	-0.718
Ephemeroptera	0.314	--	†	*	*	--	--	0.511
Hemiptera	-1.000	--	†	*	*	--	--	*
Isopopda	*	--	†	*	*	--	--	*
Megaloptera	*	--	†	*	-1.000	--	--	*
Mollusca	*	--	†	*	-1.000	--	--	*
Mysidae	*	--	†	-1.000	0.719	--	--	*
Nemata/Nematomorpha	-0.133	--	†	-1.000	0.210	--	--	-1.000
Odonata	-0.133	--	†	*	*	--	--	*
Ostracoda	*	--	†	-1.000	-1.000	--	--	-1.000
Rotifera	*	--	†	*	0.210	--	--	*
Tardigrada	*	--	†	-1.000	*	--	--	-1.000
Trichoptera	*	--	†	*	0.210	--	--	*

Table E.13. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites A and B During June, September, and December 2009 and March 2010

Taxon	A				B			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	*	--	*	--	*	--	--	*
Amphipoda	0.535	--	-0.074	--	-0.183	--	--	0.743
Annelida	*	--	*	--	*	--	--	*
Arachnida	0.261	--	*	--	-0.989	--	--	-1.000
Argulidae	*	--	-1.000	--	*	--	--	*
Cladocera	-0.998	--	-1.000	--	-0.987	--	--	-0.677
Coleoptera	*	--	*	--	*	--	--	*
Copepoda	-1.000	--	-1.000	--	-0.998	--	--	-0.707
Diptera	-0.977	--	-1.000	--	-0.979	--	--	-0.451
Ephemeroptera	*	--	*	--	*	--	--	*
Hemiptera	*	--	*	--	0.160	--	--	-0.301
Isopopda	-0.080	--	*	--	*	--	--	*
Megaloptera	-1.000	--	*	--	*	--	--	*
Mollusca	*	--	*	--	*	--	--	*
Mysidae	0.261	--	0.720	--	0.693	--	--	-0.865
Nemata/Nematomorpha	0.174	--	*	--	0.160	--	--	-1.000
Odonata	*	--	*	--	*	--	--	0.306
Ostracoda	*	--	*	--	-1.000	--	--	-1.000
Rotifera	*	--	-1.000	--	*	--	--	*
Tardigrada	*	--	*	--	*	--	--	*
Trichoptera	*	--	*	--	*	--	--	*

Table E.14. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites C and D During June, September, and December 2009 and March 2010

Taxon	C				D			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	0.563	•	--	*	-1.000	--	--	*
Amphipoda	-0.055	•	--	0.733	0.559	--	--	*
Annelida	-1.000	•	--	*	*	--	--	*
Arachnida	0.283	•	--	-1.000	-1.000	--	--	-1.000
Argulidae	*	•	--	*	*	--	--	*
Cladocera	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Coleoptera	*	•	--	*	*	--	--	*
Copepoda	-1.000	•	--	-1.000	-0.997	--	--	-1.000
Diptera	-0.931	•	--	0.432	-0.872	--	--	0.750
Ephemeroptera	*	•	--	-1.000	*	--	--	*
Hemiptera	*	•	--	*	-0.943	--	--	*
Isopopda	*	•	--	*	*	--	--	*
Megaloptera	-1.000	•	--	*	-1.000	--	--	*
Mollusca	*	•	--	*	*	--	--	*
Mysidae	0.584	•	--	*	0.404	--	--	*
Nemata/Nematomorpha	-0.055	•	--	-1.000	0.667	--	--	-1.000
Odonata	*	•	--	*	*	--	--	*
Ostracoda	-1.000	•	--	-1.000	-1.000	--	--	-1.000
Rotifera	*	•	--	-1.000	*	--	--	-1
Tardigrada	*	•	--	*	*	--	--	*
Trichoptera	*	•	--	*	*	--	--	*

Table E.15. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites E and F During June, September, and December 2009 and March 2010

Taxon	E				F			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Arachnida	*	--	--	*	0.200	-0.767	‡	*
Coleoptera	0.171	--	--	-1.000	-1.000	-0.839	‡	*
Collembola	0.359	--	--	*	*	*	‡	*
Diptera	-0.837	--	--	-0.500	-0.845	-0.701	‡	0.333
Ephemeroptera	*	--	--	*	*	*	‡	*
Hemiptera	0.227	--	--	0.454	0.368	-0.018	‡	0.000
Hymenoptera	0.404	--	--	*	0.273	0.569	‡	0.000
Lepidoptera	*	--	--	*	*	*	‡	*
Megaloptera	*	--	--	*	*	*	‡	*
Odonata	*	--	--	*	*	*	‡	*
Plecoptera	-1.000	--	--	*	*	*	‡	*
Psocoptera	*	--	--	*	*	*	‡	0.000
Thysanoptera	-0.425	--	--	*	0.200	*	‡	-1.000
Trichoptera	-0.930	--	--	*	-1.000	*	‡	*

Table E.16. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites H and I During June, September, and December 2009 and March 2010

Taxon	H				I			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Actinopterygii	0.065	--	†	*	*	--	--	*
Amphipoda	0.577	--	†	0.768	-0.949	--	--	0.327
Annelida	*	--	†	*	*	--	--	*
Arachnida	0.065	--	†	*	*	--	--	0.643
Argulidae	*	--	†	*	*	--	--	*
Cladocera	-0.988	--	†	-1.000	-0.952	--	--	-1.000
Coleoptera	*	--	†	*	*	--	--	*
Copepoda	-1.000	--	†	-1.000	-0.993	--	--	-1.000
Diptera	-0.995	--	†	-0.443	-0.648	--	--	-0.782
Ephemeroptera	0.480	--	†	*	*	--	--	0.394
Hemiptera	-1.000	--	†	*	*	--	--	*
Isopopda	*	--	†	*	*	--	--	*
Megaloptera	*	--	†	*	-1.000	--	--	*
Mollusca	*	--	†	*	-1.000	--	--	*
Mysidae	*	--	†	-1.000	0.686	--	--	*
Nemata/Nematomorpha	-0.274	--	†	-1.000	0.146	--	--	-1.000
Odonata	-0.274	--	†	*	*	--	--	*
Ostracoda	*	--	†	-1.000	-1.000	--	--	-1.000
Rotifera	*	--	†	-1.000	*	--	--	-1
Tardigrada	*	--	†	*	0.457	--	--	*
Trichoptera	*	--	†	*	0.146	--	--	*

Table E.17. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites A and B During June, September, and December 2009 and March 2010

Taxon	A				B			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Arachnida	0.079	--	†	--	0.026	--	--	-1.000
Coleoptera	*	--	†	--	-0.434	--	--	-1.000
Collembola	*	--	†	--	0.477	--	--	0.368
Diptera	-0.515	--	†	--	-0.812	--	--	-0.198
Ephemeroptera	*	--	†	--	-0.117	--	--	*
Hemiptera	-0.033	--	†	--	-0.017	--	--	*
Hymenoptera	0.104	--	†	--	0.003	--	--	*
Lepidoptera	*	--	†	--	*	--	--	*
Megaloptera	*	--	†	--	-0.117	--	--	*
Odonata	*	--	†	--	*	--	--	*
Plecoptera	*	--	†	--	*	--	--	*
Psocoptera	*	--	†	--	0.328	--	--	0.368
Thysanoptera	*	--	†	--	*	--	--	*
Trichoptera	0.145	--	†	--	-0.820	--	--	*

Table E.18. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites C and D During June, September, and December 2009 and March 2010

Taxon	C				D			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Arachnida	-0.039	•	--	*	*	--	--	*
Coleoptera	-0.039	•	--	*	*	--	--	*
Collembola	*	•	--	*	*	--	--	*
Diptera	-0.987	•	--	-0.278	-0.858	--	--	0.000
Ephemeroptera	*	•	--	*	-1.000	--	--	*
Hemiptera	0.379	•	--	0.179	0.495	--	--	*
Hymenoptera	-0.039	•	--	*	0.495	--	--	*
Lepidoptera	*	•	--	*	-1.000	--	--	*
Megaloptera	*	•	--	*	*	--	--	*
Odonata	*	•	--	*	*	--	--	*
Plecoptera	*	•	--	*	*	--	--	*
Psocoptera	*	•	--	*	*	--	--	*
Thysanoptera	*	•	--	*	*	--	--	*
Trichoptera	*	•	--	*	-1.000	--	--	*

Table E.19. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites E and F During June, September, and December 2009 and March 2010

Taxon	E				F			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Arachnida	*	--	--	*	0.200	-0.767	‡	*
Coleoptera	0.171	--	--	-1.000	-1.000	-0.839	‡	*
Collembola	0.359	--	--	*	*	*	‡	*
Diptera	-0.837	--	--	-0.500	-0.845	-0.701	‡	0.333
Ephemeroptera	*	--	--	*	*	*	‡	*
Hemiptera	0.227	--	--	0.454	0.368	-0.018	‡	0.000
Hymenoptera	0.404	--	--	*	0.273	0.569	‡	0.000
Lepidoptera	*	--	--	*	*	*	‡	*
Megaloptera	*	--	--	*	*	*	‡	*
Odonata	*	--	--	*	*	*	‡	*
Plecoptera	-1.000	--	--	*	*	*	‡	*
Psocoptera	*	--	--	*	*	*	‡	0.000
Thysanoptera	-0.425	--	--	*	0.200	*	‡	-1.000
Trichoptera	-0.930	--	--	*	-1.000	*	‡	*

Table E.20. Relativized Electivity Index Values (E_i^*) for Taxa Encountered by Juvenile Chinook Salmon in the Benthos at Sites H and I During June, September, and December 2009 and March 2010

Taxon	H				I			
	June 2009	Sept 2009	Dec. 2009	Mar 2010	June 2009	Sept 2009	Dec. 2009	Mar 2010
Arachnida	0.327	--	‡	--	-1.000	--	--	0.485
Coleoptera	*	--	‡	--	*	--	--	*
Collembola	*	--	‡	--	*	--	--	*
Diptera	-0.854	--	‡	--	-0.521	--	--	-0.793
Ephemeroptera	*	--	‡	--	*	--	--	*
Hemiptera	0.327	--	‡	--	0.261	--	--	*
Hymenoptera	0.327	--	‡	--	0.389	--	--	*
Lepidoptera	*	--	‡	--	*	--	--	*
Megaloptera	*	--	‡	--	*	--	--	*
Odonata	*	--	‡	--	*	--	--	*
Plecoptera	*	--	‡	--	*	--	--	*
Psocoptera	*	--	‡	--	*	--	--	*
Thysanoptera	-1.000	--	‡	--	0.261	--	--	*
Trichoptera	-1.000	--	‡	--	-1.000	--	--	-1.000

Appendix F

Index of Relative Importance for Prey Taxa Identified in the Gut Contents of Juvenile Chinook Salmon Collected at Study Sites Near the Sandy River Delta, Oregon

Appendix F

Index of Relative Importance for Prey Taxa Identified in the Gut Contents of Juvenile Chinook Salmon Collected at Study Sites Near the Sandy River Delta, Oregon

Prepared by Adam Storch

This appendix details the juvenile salmon diet data from analysis of salmon gut content samples (Chapter 4). To represent the general diet of juvenile salmon, diet proportions by percentage of total number of items and percentage of total weight for individual fish were averaged (Chapter 4). In the tables that follow (Tables F.1 through F.22), dashes indicate the months in which no Chinook salmon were encountered or sampling could not be conducted. In a given month, the sum of values may not equal 100% due to rounding. Juvenile salmon diet data collection commenced in March 2008 and ended in April 2010. The data are presented separately for each site and separately for 2008, 2009, and 2010. The tables list percent Index of Relative Importance (%IRI) values for prey consumed by juvenile Chinook salmon.

Table F.1. Site A During 2008

Taxon	A									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	0	0	0	0	3.01	--	0	0	0	0
Amphipoda	0	0	0	39.95	7.27	--	32.99	0	0	2.44
Annelida	0	0	0	0	0	--	0	0	0	0
Arachnida	0	0	1.76	0.57	1.07	--	0	4.26	1.08	10.11
Arthropoda	0	0	0	0	0	--	0	0	1.08	0
Cladocera	0	0	0	25.19	1.32	--	0	0	0	0
Coleoptera	0	0	0	2.25	0	--	0	0	20.47	0
Collembola	0	0	0	0	0	--	0	0	0	0
Copepoda	0	0	0	5.4	1.05	--	0	0	0	0
Diptera	100	100	14.72	23.94	32.55	--	16.22	20.48	11.25	57.18
Ephemeroptera	0	0	0	0	0	--	0	0	0	0
Hemiptera	0	0	0	2.21	2.08	--	0	12.49	30.12	8.11
Hymenoptera	0	0	0	0	0.92	--	30.58	4.26	2.41	0
Insecta	0	0	0	0	45.5	--	20.21	26.49	5.41	0
Isopopda	0	0	0	0	0	--	0	0	0	0
Lepidoptera	0	0	0	0	0.59	--	0	0	0	0
Megaloptera	0	0	0	0	0	--	0	0	0	0
Mollusca	0	0	0	0	0	--	0	13.18	0	0
Mysidae	0	0	83.52	0	4.23	--	0	0	10.68	0
Nemata	0	0	0	0	0.39	--	0	0	0	0
Nematomorpha	0	0	0	0	0	--	0	18.86	0	0
Neuroptera	0	0	0	0	0	--	0	0	0	0
Odonata	0	0	0	0	0	--	0	0	2.14	12.98
Orthoptera	0	0	0	0	0	--	0	0	0	0
Ostracoda	0	0	0	0	0	--	0	0	0	0
Plant	0	0	0	0	0	--	0	0	0	0
Platyhelminthes	0	0	0	0	0	--	0	0	0	0
Plecoptera	0	0	0	0	0	--	0	0	0	2.63
Psocoptera	0	0	0	0	0	--	0	0	15.36	6.54
Rotifera	0	0	0	0	0	--	0	0	0	0
Tardigrada	0	0	0	0	0	--	0	0	0	0
Thysanoptera	0	0	0	0	0	--	0	0	0	0
Trichoptera	0	0	0	0.48	0	--	0	0	0	0

Table F.2. Site B During 2008

Taxon	B									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	0	0	0	0	0	0	--	--	--
Amphipoda	--	0	8.51	9.72	6.79	4.95	0.56	--	--	--
Annelida	--	0	0	0	0	0	0	--	--	--
Arachnida	--	0	0	1.97	0.7	0	30.79	--	--	--
Arthropoda	--	0	0	0	0	0	0	--	--	--
Cladocera	--	0	0	0	0.52	0	0.22	--	--	--
Coleoptera	--	0	0	0	0	8.41	0	--	--	--
Collembola	--	0	0	0	0.68	0	0.25	--	--	--
Copepoda	--	0	0	1.18	0.49	0	0	--	--	--
Diptera	--	81.99	68.26	81.53	55.69	42.2	53.72	--	--	--
Ephemeroptera	--	0	0	0	0	5.83	0	--	--	--
Hemiptera	--	0	0	0	4.41	18.58	3.91	--	--	--
Hymenoptera	--	8.1	0	0	20.01	2.8	4.99	--	--	--
Insecta	--	3.61	0	0	0	0	3.48	--	--	--
Isopopda	--	0	0	0	0	0	0	--	--	--
Lepidoptera	--	0	0	0	0	0	0	--	--	--
Megaloptera	--	0	0	0	0	0	0	--	--	--
Mollusca	--	0	0	0	0	0	0	--	--	--
Mysidae	--	0	23.23	0	8.84	9.87	0.68	--	--	--
Nemata	--	0	0	0	0	0	0	--	--	--
Nematomorpha	--	0	0	5.61	0.23	0	0.75	--	--	--
Neuroptera	--	0	0	0	0	0	0	--	--	--
Odonata	--	0	0	0	0.99	7.35	0.63	--	--	--
Orthoptera	--	0	0	0	0	0	0	--	--	--
Ostracoda	--	0	0	0	0	0	0	--	--	--
Plant	--	0	0	0	0	0	0	--	--	--
Platyhelminthes	--	0	0	0	0	0	0	--	--	--
Plecoptera	--	0	0	0	0	0	0	--	--	--
Psocoptera	--	0	0	0	0	0	0	--	--	--
Rotifera	--	0	0	0	0	0	0	--	--	--
Tardigrada	--	0	0	0	0	0	0	--	--	--
Thysanoptera	--	0	0	0	0	0	0	--	--	--
Trichoptera	--	6.3	0	0	0.66	0	0	--	--	--

Table F.3. Site C During 2008

Taxon	C									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	0	0	0	0.87	0.77	--	--	--	5.25	--
Amphipoda	0	0	6.11	0.78	25.28	--	--	--	0	--
Annelida	0	0	0	0	0	--	--	--	0	--
Arachnida	0	0	0	0	0.46	--	--	--	0	--
Arthropoda	0	0	0	0	0	--	--	--	0	--
Cladocera	0	0	0	2.06	1.21	--	--	--	3.47	--
Coleoptera	0	0	4.29	0	0	--	--	--	0	--
Collembola	0	0	0	0	0	--	--	--	0	--
Copepoda	0	0	0	0	0.4	--	--	--	0	--
Diptera	97.65	100	62.6	91.56	43.07	--	--	--	4.82	--
Ephemeroptera	2.35	0	0	0	0.88	--	--	--	0	--
Hemiptera	0	0	0	0	6.53	--	--	--	11.77	--
Hymenoptera	0	0	9.81	0	0	--	--	--	0	--
Insecta	0	0	7.02	0	0.44	--	--	--	74.69	--
Isopopda	0	0	0	0	0	--	--	--	0	--
Lepidoptera	0	0	0	0	0.46	--	--	--	0	--
Megaloptera	0	0	0	0	0	--	--	--	0	--
Mollusca	0	0	0	0	0	--	--	--	0	--
Mysidae	0	0	0	0.58	1.47	--	--	--	0	--
Nemata	0	0	0	0	0	--	--	--	0	--
Nematomorpha	0	0	10.17	0.36	0	--	--	--	0	--
Neuroptera	0	0	0	0	0	--	--	--	0	--
Odonata	0	0	0	3.79	3.77	--	--	--	0	--
Orthoptera	0	0	0	0	0	--	--	--	0	--
Ostracoda	0	0	0	0	0	--	--	--	0	--
Plant	0	0	0	0	0	--	--	--	0	--
Platyhelminthes	0	0	0	0	0	--	--	--	0	--
Plecoptera	0	0	0	0	0	--	--	--	0	--
Psocoptera	0	0	0	0	0.42	--	--	--	0	--
Rotifera	0	0	0	0	0	--	--	--	0	--
Tardigrada	0	0	0	0	0	--	--	--	0	--
Thysanoptera	0	0	0	0	0	--	--	--	0	--
Trichoptera	0	0	0	0	14.84	--	--	--	0	--

Table F.4. Site D During 2008

Taxon	D									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	0	14.15	0	0	0	--	--	--	--	--
Amphipoda	0	0	0	3.19	19.33	--	--	--	--	--
Annelida	0	0	0	0	0	--	--	--	--	--
Arachnida	0	0	2.86	0	7.31	--	--	--	--	--
Arthropoda	0	0	0	0	0	--	--	--	--	--
Cladocera	0	0	39.81	19.38	4.43	--	--	--	--	--
Coleoptera	0	0	0	0	1.04	--	--	--	--	--
Collembola	16.54	0	0	0	0	--	--	--	--	--
Copepoda	0	0	0	4.09	0	--	--	--	--	--
Diptera	70.34	78.04	17.07	67.67	52.64	--	--	--	--	--
Ephemeroptera	0	1.88	0	0	0	--	--	--	--	--
Hemiptera	0	0	0	2.91	1.47	--	--	--	--	--
Hymenoptera	0	0	0	0	0	--	--	--	--	--
Insecta	0	4.45	0	0	1.16	--	--	--	--	--
Isopopda	0	0	0	0	0	--	--	--	--	--
Lepidoptera	0	0	0	0	0	--	--	--	--	--
Megaloptera	0	0	0	0	0	--	--	--	--	--
Mollusca	0	0	0	0	0	--	--	--	--	--
Mysidae	0	0	40.26	2.76	7.39	--	--	--	--	--
Nemata	0	0	0	0	0	--	--	--	--	--
Nematomorpha	0	0	0	0	0.23	--	--	--	--	--
Neuroptera	0	0	0	0	0	--	--	--	--	--
Odonata	13.12	0	0	0	0	--	--	--	--	--
Orthoptera	0	0	0	0	0	--	--	--	--	--
Ostracoda	0	0	0	0	0	--	--	--	--	--
Plant	0	0	0	0	0	--	--	--	--	--
Platyhelminthes	0	0	0	0	0	--	--	--	--	--
Plecoptera	0	0	0	0	0.22	--	--	--	--	--
Psocoptera	0	0	0	0	0	--	--	--	--	--
Rotifera	0	0	0	0	0	--	--	--	--	--
Tardigrada	0	1.48	0	0	0	--	--	--	--	--
Thysanoptera	0	0	0	0	0	--	--	--	--	--
Trichoptera	0	0	0	0	4.78	--	--	--	--	--

Table F.5. Site E During 2008

Taxon	E									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	0	0	--	0	--	0	--	0	0
Amphipoda	--	9.28	0.67	--	20.81	--	0	--	0	16.11
Annelida	--	4.18	0	--	0	--	0	--	0	0
Arachnida	--	0	1.48	--	8.86	--	0	--	5.1	2.03
Arthropoda	--	0	0	--	0	--	0	--	0	0
Cladocera	--	3.89	13.31	--	6.96	--	0	--	0	0
Coleoptera	--	0.33	1.35	--	0.21	--	0	--	10.43	1.09
Collembola	--	0.33	0	--	0	--	0	--	0	0
Copepoda	--	0.81	0	--	0.17	--	0	--	0	0
Diptera	--	81.19	55.06	--	42.14	--	38.21	--	31.39	43.48
Ephemeroptera	--	0	0	--	0	--	0	--	0	0
Hemiptera	--	0	6.99	--	0.76	--	31.97	--	8.74	5.58
Hymenoptera	--	0	0	--	15.96	--	29.82	--	8.88	0.5
Insecta	--	0	0	--	0	--	0	--	28.25	10.5
Isopopda	--	0	0	--	0	--	0	--	0	0
Lepidoptera	--	0	0.67	--	0	--	0	--	0	0
Megaloptera	--	0	0	--	0	--	0	--	0	0
Mollusca	--	0	0	--	0	--	0	--	0	0
Mysidae	--	0	19.79	--	0.61	--	0	--	0	0
Nemata	--	0	0	--	0	--	0	--	0	0
Nematomorpha	--	0	0	--	0	--	0	--	0	0
Neuroptera	--	0	0	--	0	--	0	--	0	0
Odonata	--	0	0	--	3.51	--	0	--	7.21	16.31
Orthoptera	--	0	0	--	0	--	0	--	0	0
Ostracoda	--	0	0	--	0	--	0	--	0	0
Plant	--	0	0	--	0	--	0	--	0	0
Platyhelminthes	--	0	0	--	0	--	0	--	0	0
Plecoptera	--	0	0	--	0	--	0	--	0	0.93
Psocoptera	--	0	0	--	0	--	0	--	0	3.47
Rotifera	--	0	0	--	0	--	0	--	0	0
Tardigrada	--	0	0	--	0	--	0	--	0	0
Thysanoptera	--	0	0	--	0	--	0	--	0	0
Trichoptera	--	0	0.67	--	0	--	0	--	0	0

Table F.6. Site F During 2008

Taxon	F									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	--	--	--	--	--	0	--
Amphipoda	--	--	--	--	--	--	--	--	0	--
Annelida	--	--	--	--	--	--	--	--	0	--
Arachnida	--	--	--	--	--	--	--	--	8.78	--
Arthropoda	--	--	--	--	--	--	--	--	0	--
Cladocera	--	--	--	--	--	--	--	--	0	--
Coleoptera	--	--	--	--	--	--	--	--	5.29	--
Collembola	--	--	--	--	--	--	--	--	0	--
Copepoda	--	--	--	--	--	--	--	--	0	--
Diptera	--	--	--	--	--	--	--	--	5.55	--
Ephemeroptera	--	--	--	--	--	--	--	--	0	--
Hemiptera	--	--	--	--	--	--	--	--	30.59	--
Hymenoptera	--	--	--	--	--	--	--	--	11.11	--
Insecta	--	--	--	--	--	--	--	--	0	--
Isopopda	--	--	--	--	--	--	--	--	0	--
Lepidoptera	--	--	--	--	--	--	--	--	0	--
Megaloptera	--	--	--	--	--	--	--	--	0	--
Mollusca	--	--	--	--	--	--	--	--	0	--
Mysidae	--	--	--	--	--	--	--	--	0	--
Nemata	--	--	--	--	--	--	--	--	0	--
Nematomorpha	--	--	--	--	--	--	--	--	0	--
Neuroptera	--	--	--	--	--	--	--	--	0	--
Odonata	--	--	--	--	--	--	--	--	0	--
Orthoptera	--	--	--	--	--	--	--	--	0	--
Ostracoda	--	--	--	--	--	--	--	--	0	--
Plant	--	--	--	--	--	--	--	--	0	--
Platyhelminthes	--	--	--	--	--	--	--	--	0	--
Plecoptera	--	--	--	--	--	--	--	--	0	--
Psocoptera	--	--	--	--	--	--	--	--	38.68	--
Rotifera	--	--	--	--	--	--	--	--	0	--
Tardigrada	--	--	--	--	--	--	--	--	0	--
Thysanoptera	--	--	--	--	--	--	--	--	0	--
Trichoptera	--	--	--	--	--	--	--	--	0	--

Table F.7. Site H During 2008

Taxon	H									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	--	--	--	0	0	0	--
Amphipoda	--	--	--	--	--	--	0	0	3.51	--
Annelida	--	--	--	--	--	--	0	0	0	--
Arachnida	--	--	--	--	--	--	1.8	2.45	12.02	--
Arthropoda	--	--	--	--	--	--	0	0	12.61	--
Cladocera	--	--	--	--	--	--	0	0	0	--
Coleoptera	--	--	--	--	--	--	0	0	3.29	--
Collembola	--	--	--	--	--	--	0	0	0	--
Copepoda	--	--	--	--	--	--	0	0	1	--
Diptera	--	--	--	--	--	--	42.18	11.71	37.14	--
Ephemeroptera	--	--	--	--	--	--	15.05	0	1.12	--
Hemiptera	--	--	--	--	--	--	11.61	29.32	11.82	--
Hymenoptera	--	--	--	--	--	--	4.21	0.87	1.05	--
Insecta	--	--	--	--	--	--	21.69	15.83	9.27	--
Isopopda	--	--	--	--	--	--	0	0	0	--
Lepidoptera	--	--	--	--	--	--	0	0	0	--
Megaloptera	--	--	--	--	--	--	0	0	0	--
Mollusca	--	--	--	--	--	--	2.66	0	0	--
Mysidae	--	--	--	--	--	--	0	29.76	2.77	--
Nemata	--	--	--	--	--	--	0	0	0	--
Nematomorpha	--	--	--	--	--	--	0	0	0	--
Neuroptera	--	--	--	--	--	--	0	0	0	--
Odonata	--	--	--	--	--	--	0	5.33	0	--
Orthoptera	--	--	--	--	--	--	0	0	0	--
Ostracoda	--	--	--	--	--	--	0	0	0	--
Plant	--	--	--	--	--	--	0	0	0	--
Platyhelminthes	--	--	--	--	--	--	0	0	0	--
Plecoptera	--	--	--	--	--	--	0	0	3.38	--
Psocoptera	--	--	--	--	--	--	0.8	2.48	1.02	--
Rotifera	--	--	--	--	--	--	0	0	0	--
Tardigrada	--	--	--	--	--	--	0	0	0	--
Thysanoptera	--	--	--	--	--	--	0	0	0	--
Trichoptera	--	--	--	--	--	--	0	2.25	0	--

Table F.8. Site I During 2008

Taxon	I									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	--	--	--	--	--	0	--
Amphipoda	--	--	--	--	--	--	--	--	0	--
Annelida	--	--	--	--	--	--	--	--	0	--
Arachnida	--	--	--	--	--	--	--	--	2.65	--
Arthropoda	--	--	--	--	--	--	--	--	0	--
Cladocera	--	--	--	--	--	--	--	--	0	--
Coleoptera	--	--	--	--	--	--	--	--	0	--
Collembola	--	--	--	--	--	--	--	--	0	--
Copepoda	--	--	--	--	--	--	--	--	0	--
Diptera	--	--	--	--	--	--	--	--	75.47	--
Ephemeroptera	--	--	--	--	--	--	--	--	0	--
Hemiptera	--	--	--	--	--	--	--	--	6.69	--
Hymenoptera	--	--	--	--	--	--	--	--	0	--
Insecta	--	--	--	--	--	--	--	--	0	--
Isopopda	--	--	--	--	--	--	--	--	0	--
Lepidoptera	--	--	--	--	--	--	--	--	0	--
Megaloptera	--	--	--	--	--	--	--	--	0	--
Mollusca	--	--	--	--	--	--	--	--	0	--
Mysidae	--	--	--	--	--	--	--	--	6.2	--
Nemata	--	--	--	--	--	--	--	--	0	--
Nematomorpha	--	--	--	--	--	--	--	--	0	--
Neuroptera	--	--	--	--	--	--	--	--	0	--
Odonata	--	--	--	--	--	--	--	--	0	--
Orthoptera	--	--	--	--	--	--	--	--	0	--
Ostracoda	--	--	--	--	--	--	--	--	0	--
Plant	--	--	--	--	--	--	--	--	0	--
Platyhelminthes	--	--	--	--	--	--	--	--	0	--
Plecoptera	--	--	--	--	--	--	--	--	2.6	--
Psocoptera	--	--	--	--	--	--	--	--	6.39	--
Rotifera	--	--	--	--	--	--	--	--	0	--
Tardigrada	--	--	--	--	--	--	--	--	0	--
Thysanoptera	--	--	--	--	--	--	--	--	0	--
Trichoptera	--	--	--	--	--	--	--	--	0	--

Table F.9. Site N During 2008

Taxon	N									
	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	--	0	--	--	--	--	--
Amphipoda	--	--	--	--	0	--	--	--	--	--
Annelida	--	--	--	--	0	--	--	--	--	--
Arachnida	--	--	--	--	0	--	--	--	--	--
Arthropoda	--	--	--	--	0	--	--	--	--	--
Cladocera	--	--	--	--	28.2	--	--	--	--	--
Coleoptera	--	--	--	--	0	--	--	--	--	--
Collembola	--	--	--	--	0	--	--	--	--	--
Copepoda	--	--	--	--	20.76	--	--	--	--	--
Diptera	--	--	--	--	20.71	--	--	--	--	--
Ephemeroptera	--	--	--	--	0	--	--	--	--	--
Hemiptera	--	--	--	--	0	--	--	--	--	--
Hymenoptera	--	--	--	--	0	--	--	--	--	--
Insecta	--	--	--	--	17.88	--	--	--	--	--
Isopopda	--	--	--	--	0	--	--	--	--	--
Lepidoptera	--	--	--	--	0	--	--	--	--	--
Megaloptera	--	--	--	--	0	--	--	--	--	--
Mollusca	--	--	--	--	0	--	--	--	--	--
Mysidae	--	--	--	--	0	--	--	--	--	--
Nemata	--	--	--	--	0	--	--	--	--	--
Nematomorpha	--	--	--	--	0	--	--	--	--	--
Neuroptera	--	--	--	--	0	--	--	--	--	--
Odonata	--	--	--	--	0	--	--	--	--	--
Orthoptera	--	--	--	--	0	--	--	--	--	--
Ostracoda	--	--	--	--	0	--	--	--	--	--
Plant	--	--	--	--	0	--	--	--	--	--
Platyhelminthes	--	--	--	--	0	--	--	--	--	--
Plecoptera	--	--	--	--	0	--	--	--	--	--
Psocoptera	--	--	--	--	0	--	--	--	--	--
Rotifera	--	--	--	--	0	--	--	--	--	--
Tardigrada	--	--	--	--	0	--	--	--	--	--
Thysanoptera	--	--	--	--	12.46	--	--	--	--	--
Trichoptera	--	--	--	--	0	--	--	--	--	--

Table F.10. Site A During 2009

Taxon	A											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	0	0	0	--	0	0	0	--	--	36.79	--	0
Amphipoda	35.27	6.64	0	--	3.42	25.9	0	--	--	0	--	5.75
Annelida	0	0	0	--	20.63	0	0	--	--	0	--	0
Arachnida	0	0	0	--	0	0.85	0	--	--	0	--	0
Arthropoda	0	0	0	--	0	0	0	--	--	0	--	0
Cladocera	0	0	0	--	0	2.17	0	--	--	0	--	0
Coleoptera	0	0	0	--	3.89	0	0	--	--	4.1	--	0
Collembola	0	0	0	--	0	0	0	--	--	3.71	--	0
Copepoda	0	0	0	--	0	0	0	--	--	0	--	0
Diptera	12.91	14.78	68.33	--	50.33	27.51	100	--	--	40.93	--	0
Ephemeroptera	0	0	0	--	0	0	0	--	--	0	--	0
Hemiptera	10.49	0	0	--	0	0.98	0	--	--	7.84	--	0
Hymenoptera	0	0	0	--	0	1.78	0	--	--	0	--	0
Insecta	0	0	31.67	--	0	3.23	0	--	--	0	--	0
Isopopda	0	0	0	--	0	1.78	0	--	--	0	--	0
Lepidoptera	0	0	0	--	2.24	0	0	--	--	0	--	0
Megaloptera	0	0	0	--	0	0	0	--	--	0	--	0
Mollusca	0	0	0	--	0	0	0	--	--	0	--	0
Mysidae	25.49	55	0	--	14.43	26.71	0	--	--	0	--	94.25
Nemata	0	0.94	0	--	0	3.86	0	--	--	0	--	0
Nematomorpha	0	0	0	--	0	0	0	--	--	0	--	0
Neuroptera	0	0	0	--	0	0	0	--	--	0	--	0
Odonata	0	0	0	--	0	0	0	--	--	0	--	0
Orthoptera	0	0	0	--	0	0	0	--	--	0	--	0
Ostracoda	15.82	0	0	--	0	0	0	--	--	0	--	0
Plant	0	3.47	0	--	0	0	0	--	--	0	--	0
Platyhelminthes	0	0.94	0	--	0	0	0	--	--	0	--	0
Plecoptera	0	18.24	0	--	0	0	0	--	--	0	--	0
Psocoptera	0	0	0	--	0	0	0	--	--	0	--	0
Rotifera	0	0	0	--	0	0	0	--	--	0	--	0
Tardigrada	0	0	0	--	0	0	0	--	--	0	--	0
Thysanoptera	0	0	0	--	0	0	0	--	--	0	--	0
Trichoptera	0	0	0	--	5.06	5.22	0	--	--	6.64	--	0

Table F.11. Site B During 2009

Taxon	B											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	0	0	0	0	0	--	0	--	--
Amphipoda	--	--	--	0	25.49	0.77	50.36	0	--	0	--	--
Annelida	--	--	--	0	0	0	0	0	--	0	--	--
Arachnida	--	--	--	0	3.24	16.76	0	0	--	0	--	--
Arthropoda	--	--	--	0	0	0	0	0	--	0	--	--
Cladocera	--	--	--	0	7.27	7.62	0	4.53	--	0	--	--
Coleoptera	--	--	--	0	2.97	4.21	0	23.11	--	13.47	--	--
Collembola	--	--	--	0	1.9	11.26	0	0	--	0	--	--
Copepoda	--	--	--	0	1	0.31	0	0	--	0	--	--
Diptera	--	--	--	100	42.59	29.23	49.64	46.9	--	28.74	--	--
Ephemeroptera	--	--	--	0	1.9	0.53	0	0	--	0	--	--
Hemiptera	--	--	--	0	7.22	3.34	0	25.47	--	23.42	--	--
Hymenoptera	--	--	--	0	3.44	4.26	0	0	--	0	--	--
Insecta	--	--	--	0	0	0.75	0	0	--	0	--	--
Isopopda	--	--	--	0	0	0	0	0	--	0	--	--
Lepidoptera	--	--	--	0	0	0	0	0	--	0	--	--
Megaloptera	--	--	--	0	0	0.56	0	0	--	0	--	--
Mollusca	--	--	--	0	0	0	0	0	--	0	--	--
Mysidae	--	--	--	0	1.9	14.23	0	0	--	0	--	--
Nemata	--	--	--	0	1.07	0.58	0	0	--	0	--	--
Nematomorpha	--	--	--	0	0	0	0	0	--	0	--	--
Neuroptera	--	--	--	0	0	0	0	0	--	0	--	--
Odonata	--	--	--	0	0	0	0	0	--	34.38	--	--
Orthoptera	--	--	--	0	0	0	0	0	--	0	--	--
Ostracoda	--	--	--	0	0	0	0	0	--	0	--	--
Plant	--	--	--	0	0	0	0	0	--	0	--	--
Platyhelminthes	--	--	--	0	0	0	0	0	--	0	--	--
Plecoptera	--	--	--	0	0	0	0	0	--	0	--	--
Psocoptera	--	--	--	0	0	1.42	0	0	--	0	--	--
Rotifera	--	--	--	0	0	0	0	0	--	0	--	--
Tardigrada	--	--	--	0	0	0	0	0	--	0	--	--
Thysanoptera	--	--	--	0	0	0	0	0	--	0	--	--
Trichoptera	--	--	--	0	0	4.17	0	0	--	0	--	--

Table F.12. Site C During 2009

Taxon	C											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	0	--	0	0.98	15.91	--	--	--	--	--
Amphipoda	--	--	0	--	0	1.29	16.82	--	--	--	--	--
Annelida	--	--	0	--	0	0	0	--	--	--	--	--
Arachnida	--	--	0	--	0	0.49	1.18	--	--	--	--	--
Arthropoda	--	--	0	--	0	0	0	--	--	--	--	--
Cladocera	--	--	0	--	0	0	0	--	--	--	--	--
Coleoptera	--	--	0	--	0	4.85	4.3	--	--	--	--	--
Collembola	--	--	0	--	0	0	0	--	--	--	--	--
Copepoda	--	--	2.47	--	2.06	0	0	--	--	--	--	--
Diptera	--	--	15.34	--	82.98	59.94	33.54	--	--	--	--	--
Ephemeroptera	--	--	0	--	0	0	0	--	--	--	--	--
Hemiptera	--	--	0	--	2.5	5.94	11.57	--	--	--	--	--
Hymenoptera	--	--	0	--	0	0.59	6.33	--	--	--	--	--
Insecta	--	--	21.35	--	0	5.84	4.29	--	--	--	--	--
Isopopda	--	--	0	--	0	0	0	--	--	--	--	--
Lepidoptera	--	--	0	--	8.02	0	0	--	--	--	--	--
Megaloptera	--	--	0	--	0	0	0	--	--	--	--	--
Mollusca	--	--	0	--	0	0	0	--	--	--	--	--
Mysidae	--	--	60.84	--	0	18.17	0	--	--	--	--	--
Nemata	--	--	0	--	4.44	1.35	0	--	--	--	--	--
Nematomorpha	--	--	0	--	0	0	0	--	--	--	--	--
Neuroptera	--	--	0	--	0	0	0	--	--	--	--	--
Odonata	--	--	0	--	0	0	5.11	--	--	--	--	--
Orthoptera	--	--	0	--	0	0	0	--	--	--	--	--
Ostracoda	--	--	0	--	0	0	0	--	--	--	--	--
Plant	--	--	0	--	0	0	0	--	--	--	--	--
Platyhelminthes	--	--	0	--	0	0	0	--	--	--	--	--
Plecoptera	--	--	0	--	0	0.55	0	--	--	--	--	--
Psocoptera	--	--	0	--	0	0	0	--	--	--	--	--
Rotifera	--	--	0	--	0	0	0	--	--	--	--	--
Tardigrada	--	--	0	--	0	0	0	--	--	--	--	--
Thysanoptera	--	--	0	--	0	0	0	--	--	--	--	--
Trichoptera	--	--	0	--	0	0	0.96	--	--	--	--	--

Table F.13. Site D During 2009

Taxon	D											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	0	--	0	0	60.87	--	--	--	0	--
Amphipoda	--	--	0	--	1.53	0.75	2.34	--	--	--	0	--
Annelida	--	--	5.69	--	0	0	0.92	--	--	--	0	--
Arachnida	--	--	0	--	1.65	0	0	--	--	--	11.44	--
Arthropoda	--	--	0	--	0	0.32	0	--	--	--	0	--
Cladocera	--	--	0	--	0	0.07	0	--	--	--	0	--
Coleoptera	--	--	0	--	1.4	0	0	--	--	--	0	--
Collembola	--	--	0	--	0	0	0	--	--	--	0	--
Copepoda	--	--	0	--	1.46	0.39	0	--	--	--	0	--
Diptera	--	--	87.65	--	73.71	92.27	17.93	--	--	--	13.09	--
Ephemeroptera	--	--	0	--	0	0	0	--	--	--	0	--
Hemiptera	--	--	0	--	1.1	1.55	0	--	--	--	67.14	--
Hymenoptera	--	--	0	--	0.68	0.76	1.31	--	--	--	8.34	--
Insecta	--	--	0	--	12.23	1.01	6.65	--	--	--	0	--
Isopopda	--	--	0	--	0	0	0	--	--	--	0	--
Lepidoptera	--	--	0	--	0	0	0	--	--	--	0	--
Megaloptera	--	--	0	--	0	0	0	--	--	--	0	--
Mollusca	--	--	0	--	0	0	0	--	--	--	0	--
Mysidae	--	--	0	--	5.24	1.28	0	--	--	--	0	--
Nemata	--	--	0	--	1	1.61	0	--	--	--	0	--
Nematomorpha	--	--	0	--	0	0	0	--	--	--	0	--
Neuroptera	--	--	0	--	0	0	0	--	--	--	0	--
Odonata	--	--	0	--	0	0	0	--	--	--	0	--
Orthoptera	--	--	0	--	0	0	0	--	--	--	0	--
Ostracoda	--	--	0	--	0	0	0	--	--	--	0	--
Plant	--	--	0	--	0	0	0	--	--	--	0	--
Platyhelminthes	--	--	6.66	--	0	0	0	--	--	--	0	--
Plecoptera	--	--	0	--	0	0	0	--	--	--	0	--
Psocoptera	--	--	0	--	0	0	0	--	--	--	0	--
Rotifera	--	--	0	--	0	0	0	--	--	--	0	--
Tardigrada	--	--	0	--	0	0	0	--	--	--	0	--
Thysanoptera	--	--	0	--	0	0	0	--	--	--	0	--
Trichoptera	--	--	0	--	0	0	9.97	--	--	--	0	--

Table F.14. Site E During 2009

Taxon	E											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	--	0	0	0	--	--	0	0	--
Amphipoda	--	--	--	--	23.74	1.14	9.77	--	--	0	0	--
Annelida	--	--	--	--	0	0.94	0	--	--	0	0	--
Arachnida	--	--	--	--	1.47	30.87	0	--	--	13.53	21.65	--
Arthropoda	--	--	--	--	0	0	0	--	--	0	0	--
Cladocera	--	--	--	--	4.5	50.84	0	--	--	0	0	--
Coleoptera	--	--	--	--	2.04	0.13	0	--	--	0	3.99	--
Collembola	--	--	--	--	0	0.38	0	--	--	0	3.07	--
Copepoda	--	--	--	--	0.56	0.6	0	--	--	0	0	--
Diptera	--	--	--	--	12.79	10.52	20.16	--	--	36.48	27.77	--
Ephemeroptera	--	--	--	--	1.61	0.13	0	--	--	0	0	--
Hemiptera	--	--	--	--	2.27	0.92	0	--	--	0	32.71	--
Hymenoptera	--	--	--	--	0.54	1.4	64.05	--	--	0	5.28	--
Insecta	--	--	--	--	0	0.43	6.02	--	--	49.99	2.46	--
Isopopda	--	--	--	--	0	0	0	--	--	0	0	--
Lepidoptera	--	--	--	--	0	0	0	--	--	0	0	--
Megaloptera	--	--	--	--	0	0	0	--	--	0	0	--
Mollusca	--	--	--	--	0	0	0	--	--	0	0	--
Mysidae	--	--	--	--	23.04	0.45	0	--	--	0	0	--
Nemata	--	--	--	--	0.66	0.3	0	--	--	0	0.23	--
Nematomorpha	--	--	--	--	0	0	0	--	--	0	0	--
Neuroptera	--	--	--	--	0.54	0	0	--	--	0	0	--
Odonata	--	--	--	--	0	0	0	--	--	0	0	--
Orthoptera	--	--	--	--	0	0	0	--	--	0	0	--
Ostracoda	--	--	--	--	26.24	0.06	0	--	--	0	0	--
Plant	--	--	--	--	0	0	0	--	--	0	0	--
Platyhelminthes	--	--	--	--	0	0	0	--	--	0	0	--
Plecoptera	--	--	--	--	0	0	0	--	--	0	0	--
Psocoptera	--	--	--	--	0	0	0	--	--	0	2.84	--
Rotifera	--	--	--	--	0	0	0	--	--	0	0	--
Tardigrada	--	--	--	--	0	0	0	--	--	0	0	--
Thysanoptera	--	--	--	--	0	0.22	0	--	--	0	0	--
Trichoptera	--	--	--	--	0	0.68	0	--	--	0	0	--

Table F.15. Site A During 2009

Taxon	F											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	17.66	0	0	0	36.88	--	0	--	--	0
Amphipoda	--	--	0	100	16.9	2.97	17.66	--	0	--	--	0
Annelida	--	--	0	0	0	0	0	--	0	--	--	0
Arachnida	--	--	0	0	1.41	1.19	0	--	8.05	--	--	7.46
Arthropoda	--	--	0	0	0	0	0	--	0	--	--	0
Cladocera	--	--	0	0	1.03	11.47	0	--	0	--	--	0
Coleoptera	--	--	0.88	0	0	0	0	--	2.87	--	--	17.23
Collembola	--	--	0	0	1.33	0	0	--	0	--	--	3.73
Copepoda	--	--	0	0	3.41	0.38	0	--	0	--	--	0
Diptera	--	--	78	0	17.57	55.02	0	--	6.43	--	--	33.65
Ephemeroptera	--	--	0	0	0	0	0	--	0	--	--	9.42
Hemiptera	--	--	1.4	0	3.13	8.12	0	--	13.45	--	--	3.35
Hymenoptera	--	--	0.82	0	1.49	2.51	0	--	69.2	--	--	0
Insecta	--	--	1.24	0	16.31	15.06	0	--	0	--	--	0
Isopopda	--	--	0	0	0	0	0	--	0	--	--	0
Lepidoptera	--	--	0	0	0	0	0	--	0	--	--	0
Megaloptera	--	--	0	0	0	0	0	--	0	--	--	0
Mollusca	--	--	0	0	0	0	0	--	0	--	--	0
Mysidae	--	--	0	0	37.42	2.48	45.46	--	0	--	--	10.28
Nemata	--	--	0	0	0	0.39	0	--	0	--	--	0
Nematomorpha	--	--	0	0	0	0	0	--	0	--	--	0
Neuroptera	--	--	0	0	0	0	0	--	0	--	--	0
Odonata	--	--	0	0	0	0	0	--	0	--	--	6.19
Orthoptera	--	--	0	0	0	0	0	--	0	--	--	0
Ostracoda	--	--	0	0	0	0	0	--	0	--	--	0
Plant	--	--	0	0	0	0	0	--	0	--	--	0
Platyhelminthes	--	--	0	0	0	0	0	--	0	--	--	0
Plecoptera	--	--	0	0	0	0	0	--	0	--	--	4.55
Psocoptera	--	--	0	0	0	0	0	--	0	--	--	0
Rotifera	--	--	0	0	0	0	0	--	0	--	--	0
Tardigrada	--	--	0	0	0	0	0	--	0	--	--	0
Thysanoptera	--	--	0	0	0	0.4	0	--	0	--	--	0
Trichoptera	--	--	0	0	0	0	0	--	0	--	--	4.14

Table F.16. Site H During 2009

Taxon	H											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	--	0	0	9.97	0	0	--	0	0	0
Amphipoda	--	--	--	0	51.23	48.77	1.74	6.38	--	0	7.15	0
Annelida	--	--	--	0	0	0	0	0	--	0	2.31	0
Arachnida	--	--	--	0	0	0.71	0	0	--	18.37	16.09	0
Arthropoda	--	--	--	0	0	0	0	0	--	0	0	0
Cladocera	--	--	--	0	1.24	7.97	1.07	0	--	0	0	0
Coleoptera	--	--	--	0	1.97	0	6.23	0	--	2.81	11.06	0
Collembola	--	--	--	0	0	0	0	0	--	0	0	0
Copepoda	--	--	--	0	0	0	0	0	--	0	0	0
Diptera	--	--	--	17.06	24.41	21.59	11.76	19.32	--	16.61	13.02	35.17
Ephemeroptera	--	--	--	0	5.22	3.64	0	0	--	0	0	0
Hemiptera	--	--	--	0	1.54	0.71	7.45	1.69	--	41.26	21.81	0
Hymenoptera	--	--	--	0	0.87	1.16	56.05	72.61	--	5.55	7.65	0
Insecta	--	--	--	0	0	0	3.29	0	--	5.87	16.16	64.83
Isopopda	--	--	--	0	0	0	0	0	--	0	0	0
Lepidoptera	--	--	--	0	0	0	0	0	--	0	0	0
Megaloptera	--	--	--	0	0	0	0	0	--	0	2	0
Mollusca	--	--	--	0	1.63	0	0	0	--	4.67	0	0
Mysidae	--	--	--	60.07	9.03	0	0	0	--	0	0	0
Nemata	--	--	--	0	1.05	0.68	0	0	--	0	0	0
Nematomorpha	--	--	--	0	0	0	0	0	--	0	0	0
Neuroptera	--	--	--	0	0	0	0	0	--	2.88	0	0
Odonata	--	--	--	0	0	4.79	0	0	--	0	0	0
Orthoptera	--	--	--	0	0	0	0	0	--	0	0	0
Ostracoda	--	--	--	0	0	0	0	0	--	0	0	0
Plant	--	--	--	0	0	0	0	0	--	0	0	0
Platyhelminthes	--	--	--	0	0	0	0	0	--	0	0	0
Plecoptera	--	--	--	22.87	0	0	0	0	--	0	0	0
Psocoptera	--	--	--	0	0	0	0	0	--	1.97	1.18	0
Rotifera	--	--	--	0	0	0	0	0	--	0	0	0
Tardigrada	--	--	--	0	0	0	0	0	--	0	0	0
Thysanoptera	--	--	--	0	0	0	0	0	--	0	0	0
Trichoptera	--	--	--	0	1.82	0	12.42	0	--	0	1.57	0

Table F.17. Site I During 2009

Taxon	I											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	5.59	0	--	--	0	0	0	--	--	0	--	--
Amphipoda	7.69	16.53	--	--	44.85	11.38	0	--	--	0	--	--
Annelida	59.93	0	--	--	0	0	0	--	--	0	--	--
Arachnida	0	0	--	--	2.9	0	0	--	--	0	--	--
Arthropoda	0	0	--	--	0	0	0	--	--	0	--	--
Cladocera	0	0	--	--	0	4.55	0	--	--	0	--	--
Coleoptera	0	0	--	--	0	0	0	--	--	0	--	--
Collembola	0	0	--	--	0	0	0	--	--	0	--	--
Copepoda	0	0	--	--	0	0.09	0	--	--	0	--	--
Diptera	15.38	51.21	--	--	8.13	79.39	31.93	--	--	57.12	--	--
Ephemeroptera	7.85	0	--	--	3.46	0	0	--	--	0	--	--
Hemiptera	0	0	--	--	0	0.26	29.64	--	--	42.88	--	--
Hymenoptera	0	0	--	--	0	0.67	15.6	--	--	0	--	--
Insecta	0	0	--	--	12.2	0.09	0	--	--	0	--	--
Isopopda	0	0	--	--	0	0	0	--	--	0	--	--
Lepidoptera	0	0	--	--	0	0	0	--	--	0	--	--
Megaloptera	0	0	--	--	0	0	0	--	--	0	--	--
Mollusca	0	0	--	--	0	0	12.1	--	--	0	--	--
Mysidae	0	0	--	--	28.46	3.02	0	--	--	0	--	--
Nemata	3.56	0	--	--	0	0.23	0	--	--	0	--	--
Nematomorpha	0	0	--	--	0	0	0	--	--	0	--	--
Neuroptera	0	0	--	--	0	0	0	--	--	0	--	--
Odonata	0	0	--	--	0	0	0	--	--	0	--	--
Orthoptera	0	32.26	--	--	0	0	0	--	--	0	--	--
Ostracoda	0	0	--	--	0	0	0	--	--	0	--	--
Plant	0	0	--	--	0	0	0	--	--	0	--	--
Platyhelminthes	0	0	--	--	0	0	0	--	--	0	--	--
Plecoptera	0	0	--	--	0	0	0	--	--	0	--	--
Psocoptera	0	0	--	--	0	0	0	--	--	0	--	--
Rotifera	0	0	--	--	0	0.06	0	--	--	0	--	--
Tardigrada	0	0	--	--	0	0	0	--	--	0	--	--
Thysanoptera	0	0	--	--	0	0.1	10.73	--	--	0	--	--
Trichoptera	0	0	--	--	0	0.15	0	--	--	0	--	--

Table F.18. Site N During 2009

Taxon	N											
	Jan.	Feb	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Actinopterygii	--	--	0	--	--	--	--	--	--	--	--	--
Amphipoda	--	--	1.13	--	--	--	--	--	--	--	--	--
Annelida	--	--	0	--	--	--	--	--	--	--	--	--
Arachnida	--	--	0	--	--	--	--	--	--	--	--	--
Arthropoda	--	--	0	--	--	--	--	--	--	--	--	--
Cladocera	--	--	0	--	--	--	--	--	--	--	--	--
Coleoptera	--	--	0	--	--	--	--	--	--	--	--	--
Collembola	--	--	0	--	--	--	--	--	--	--	--	--
Copepoda	--	--	56.41	--	--	--	--	--	--	--	--	--
Diptera	--	--	24.82	--	--	--	--	--	--	--	--	--
Ephemeroptera	--	--	0	--	--	--	--	--	--	--	--	--
Hemiptera	--	--	0	--	--	--	--	--	--	--	--	--
Hymenoptera	--	--	0	--	--	--	--	--	--	--	--	--
Insecta	--	--	0	--	--	--	--	--	--	--	--	--
Isopopda	--	--	16.5	--	--	--	--	--	--	--	--	--
Lepidoptera	--	--	0	--	--	--	--	--	--	--	--	--
Megaloptera	--	--	0	--	--	--	--	--	--	--	--	--
Mollusca	--	--	0	--	--	--	--	--	--	--	--	--
Mysidae	--	--	0	--	--	--	--	--	--	--	--	--
Nemata	--	--	0	--	--	--	--	--	--	--	--	--
Nematomorpha	--	--	0	--	--	--	--	--	--	--	--	--
Neuroptera	--	--	0	--	--	--	--	--	--	--	--	--
Odonata	--	--	1.13	--	--	--	--	--	--	--	--	--
Orthoptera	--	--	0	--	--	--	--	--	--	--	--	--
Ostracoda	--	--	0	--	--	--	--	--	--	--	--	--
Plant	--	--	0	--	--	--	--	--	--	--	--	--
Platyhelminthes	--	--	0	--	--	--	--	--	--	--	--	--
Plecoptera	--	--	0	--	--	--	--	--	--	--	--	--
Psocoptera	--	--	0	--	--	--	--	--	--	--	--	--
Rotifera	--	--	0	--	--	--	--	--	--	--	--	--
Tardigrada	--	--	0	--	--	--	--	--	--	--	--	--
Thysanoptera	--	--	0	--	--	--	--	--	--	--	--	--
Trichoptera	--	--	0	--	--	--	--	--	--	--	--	--

Table F.19. Sites A and B from January Through April 2010

Taxon	A				B			
	Jan.	Feb	Mar.	Apr.	Jan.	Feb	Mar.	Apr.
Actinopterygii	--	0	--	0	--	--	0	0
Amphipoda	--	0	--	0	--	--	13.5	33.66
Annelida	--	0	--	0	--	--	0	0
Arachnida	--	1.85	--	0	--	--	0	0
Arthropoda	--	0	--	0	--	--	0	0
Cladocera	--	0	--	0	--	--	1.48	2.9
Coleoptera	--	0	--	0	--	--	0	0
Collembola	--	0	--	0	--	--	1.03	0
Copepoda	--	0	--	0	--	--	1.98	4.04
Diptera	--	72.26	--	93.14	--	--	70.01	43.32
Ephemeroptera	--	0	--	6.86	--	--	0	0
Hemiptera	--	0	--	0	--	--	1.76	7.8
Hymenoptera	--	5.05	--	0	--	--	0	0
Insecta	--	1.85	--	0	--	--	0	0
Isopopda	--	0	--	0	--	--	0	0
Lepidoptera	--	0	--	0	--	--	0	0
Megaloptera	--	0	--	0	--	--	0	0
Mollusca	--	0	--	0	--	--	0	0
Mysidae	--	9.89	--	0	--	--	7.85	0
Nemata	--	0	--	0	--	--	0	0
Nematomorpha	--	0	--	0	--	--	0	0
Neuroptera	--	0	--	0	--	--	0	0
Odonata	--	0	--	0	--	--	1.29	8.28
Orthoptera	--	0	--	0	--	--	0	0
Ostracoda	--	0	--	0	--	--	0	0
Plant	--	0	--	0	--	--	0	0
Platyhelminthes	--	0	--	0	--	--	0	0
Plecoptera	--	0	--	0	--	--	0	0
Psocoptera	--	9.09	--	0	--	--	1.11	0
Rotifera	--	0	--	0	--	--	0	0
Tardigrada	--	0	--	0	--	--	0	0
Thysanoptera	--	0	--	0	--	--	0	0
Trichoptera	--	0	--	0	--	--	0	0

Table F.20. Sites C and D from January Through April 2010

Taxon	C				D			
	Jan.	Feb	Mar.	Apr.	Jan.	Feb	Mar.	Apr.
Actinopterygii	55.26	--	0	0	--	--	0	37.14
Amphipoda	15.32	--	11.04	0	--	--	0	0
Annelida	0	--	0	0	--	--	0	0
Arachnida	0	--	0	0	--	--	0	0
Arthropoda	0	--	0	0	--	--	0	0
Cladocera	0	--	0	0	--	--	0	59.23
Coleoptera	0	--	0	0	--	--	0	0
Collembola	0	--	0	8.84	--	--	0	0
Copepoda	0	--	0	0	--	--	0	0.45
Diptera	21.88	--	86.29	91.16	--	--	100	3.18
Ephemeroptera	0	--	0	0	--	--	0	0
Hemiptera	0	--	2.67	0	--	--	0	0
Hymenoptera	3.8	--	0	0	--	--	0	0
Insecta	0	--	0	0	--	--	0	0
Isopopda	0	--	0	0	--	--	0	0
Lepidoptera	0	--	0	0	--	--	0	0
Megaloptera	0	--	0	0	--	--	0	0
Mollusca	0	--	0	0	--	--	0	0
Mysidae	0	--	0	0	--	--	0	0
Nemata	3.74	--	0	0	--	--	0	0
Nematomorpha	0	--	0	0	--	--	0	0
Neuroptera	0	--	0	0	--	--	0	0
Odonata	0	--	0	0	--	--	0	0
Orthoptera	0	--	0	0	--	--	0	0
Ostracoda	0	--	0	0	--	--	0	0
Plant	0	--	0	0	--	--	0	0
Platyhelminthes	0	--	0	0	--	--	0	0
Plecoptera	0	--	0	0	--	--	0	0
Psocoptera	0	--	0	0	--	--	0	0
Rotifera	0	--	0	0	--	--	0	0
Tardigrada	0	--	0	0	--	--	0	0
Thysanoptera	0	--	0	0	--	--	0	0
Trichoptera	0	--	0	0	--	--	0	0

Table F.21. Sites E and F from January Through April 2010

Taxon	E				F			
	Jan.	Feb	Mar.	Apr.	Jan.	Feb	Mar.	Apr.
Actinopterygii	--	0	0	2.52	--	0	0	0
Amphipoda	--	0	6.74	12.47	--	10.88	17.81	53.94
Annelida	--	0	0	0	--	0	0	0
Arachnida	--	0	0	1.18	--	0	0	0
Arthropoda	--	0	0	0	--	0	0	0
Cladocera	--	0	0	0	--	0	0	0
Coleoptera	--	0	0	1.26	--	0	0	0
Collembola	--	0	0	0	--	3.89	0	0
Copepoda	--	0	0	0	--	0	0	0
Diptera	--	18.81	90.31	57.54	--	75.13	70.28	46.06
Ephemeroptera	--	0	0	0	--	0	0	0
Hemiptera	--	0	2.95	0	--	0	1.84	0
Hymenoptera	--	0	0	2.29	--	0	1.18	0
Insecta	--	0	0	0	--	10.1	3.18	0
Isopopda	--	0	0	0	--	0	0	0
Lepidoptera	--	0	0	0	--	0	0	0
Megaloptera	--	0	0	0	--	0	0	0
Mollusca	--	0	0	0	--	0	0	0
Mysidae	--	0	0	1.75	--	0	0	0
Nemata	--	0	0	0	--	0	0	0
Nematomorpha	--	0	0	0	--	0	0	0
Neuroptera	--	0	0	0	--	0	0	0
Odonata	--	81.19	0	19.74	--	0	0	0
Orthoptera	--	0	0	0	--	0	0	0
Ostracoda	--	0	0	0	--	0	0	0
Plant	--	0	0	0	--	0	0	0
Platyhelminthes	--	0	0	0	--	0	0	0
Plecoptera	--	0	0	0	--	0	0	0
Psocoptera	--	0	0	1.26	--	0	4.2	0
Rotifera	--	0	0	0	--	0	0	0
Tardigrada	--	0	0	0	--	0	0	0
Thysanoptera	--	0	0	0	--	0	0	0
Trichoptera	--	0	0	0	--	0	1.51	0

Table F.22. Sites H and I from January Through April 2010

Taxon	H				I			
	Jan.	Feb	Mar.	Apr.	Jan.	Feb	Mar.	Apr.
Actinopterygii	0	--	0	0	0	--	0	0
Amphipoda	4.71	--	55.19	93.27	62.74	--	4.6	26.27
Annelida	0	--	0	0	0	--	0	0
Arachnida	4.46	--	0	0	0	--	0.51	0
Arthropoda	0	--	0	0	0	--	0	0
Cladocera	0	--	0	0	0	--	0	13.56
Coleoptera	1.99	--	0	0	0	--	0	5.2
Collembola	15.34	--	0	0	0	--	0	0
Copepoda	0.47	--	0	0	0	--	0	0
Diptera	38.53	--	9.82	5.33	11.3	--	91.02	45.93
Ephemeroptera	2.22	--	0	0	0	--	2.45	0
Hemiptera	2.85	--	0	0	0	--	0	0
Hymenoptera	1.17	--	3.93	0.41	5.05	--	0	9.04
Insecta	4.09	--	0	0	0	--	0	0
Isopopda	0	--	0	0	0	--	0	0
Lepidoptera	0.57	--	0	0	0	--	0	0
Megaloptera	0	--	0	0	0	--	0	0
Mollusca	0	--	0	0	0	--	0	0
Mysidae	8.02	--	0	0	0	--	0	0
Nemata	0	--	0	0	0	--	0	0
Nematomorpha	0	--	0	0	0	--	0	0
Neuroptera	0	--	0	0	0	--	0	0
Odonata	0.66	--	0	0	0	--	0	0
Orthoptera	0	--	0	0	0	--	0	0
Ostracoda	0	--	0	0	0	--	0	0
Plant	0	--	0	0	0	--	0	0
Platyhelminthes	0	--	0	0	0	--	0	0
Plecoptera	10.61	--	31.06	0	20.91	--	1.42	0
Psocoptera	0	--	0	0	0	--	0	0
Rotifera	0	--	0	0	0	--	0	0
Tardigrada	0.23	--	0	0	0	--	0	0
Thysanoptera	0	--	0	0	0	--	0	0
Trichoptera	4.06	--	0	1	0	--	0	0

Appendix G

Diet for Bioenergetics Modeling

Appendix G

Diet Data for Bioenergetics Modeling

Prepared by Adam Storch

This appendix details mean diet composition proportions (mg wet biomass) for Chinook salmon captured at study sites near the Sandy River delta for input to the bioenergetics model. The diet sampled was described by Sather et al. in Chapter 2 of this report. Bioenergetics methods were explained in Chapter 5. The data on mean diet composition proportions (mg wet biomass) of juvenile Chinook salmon for input to the bioenergetics model are presented by sampling site in Tables G.1 through G.9.

Table G.1. Site A Input to the Bioenergetics Model

Taxon	Simulation Day																			
	78	109	136	168	198	259	294	324	344	388	414	442	506	535	561	660	715	778	833	872[c]
Amphipoda	0.00	0.00	0.00	0.16	0.11	0.25	0.00	0.00	0.01	0.28	0.11	0.00	0.00	0.18	0.00	0.00	0.02	0.00	0.00	0.00
Annelida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Aquatic Diptera (adult)	0.00	0.00	0.01	0.00	0.11	0.03	0.05	0.08	0.29	0.00	0.14	0.00	0.11	0.21	0.00	0.02	0.00	0.00	0.38	0.06
Aquatic Diptera (larvae)	0.00	1.00	0.00	0.12	0.03	0.00	0.00	0.00	0.04	0.12	0.18	0.75	0.00	0.04	0.00	0.00	0.00	0.01	0.25	0.00
Aquatic Diptera (pupae)	0.90	0.00	0.20	0.14	0.10	0.04	0.11	0.01	0.36	0.00	0.04	0.00	0.42	0.20	0.35	0.50	0.00	0.74	0.30	0.31
Aquatic Diptera (unidentidied life stage)	0.00	0.00	0.17	0.07	0.16	0.07	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
Aquatic Insecta[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Arachnida	0.00	0.00	0.01	0.01	0.04	0.00	0.02	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.38	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Coleoptera	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.01	0.00	0.00	0.00	0.06
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diptera (unidentified source and life stage)	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.00	0.00	0.15	0.00	0.00
Ephemeroptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00
Fish (embryo, larvae and juvenile)	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00
Hemiptera	0.00	0.00	0.00	0.04	0.04	0.00	0.16	0.39	0.14	0.14	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Hymenoptera	0.00	0.00	0.00	0.00	0.06	0.38	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00
Insecta (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.12	0.23	0.25	0.12	0.00	0.00	0.00	0.25	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mysidae	0.00	0.00	0.62	0.00	0.06	0.00	0.00	0.07	0.00	0.44	0.25	0.00	0.12	0.25	0.00	0.00	0.98	0.04	0.00	0.37
Nemata/Nematomorpha	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.03	0.09	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Insecta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
Trichoptera	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.04	0.00	0.04	0.00	0.00	0.00	0.03

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May 2008 and 2009

Table G.2. Site B Input to the Bioenergetics Model

Taxon	Simulation Day														
	108	136	168	197	226	260	469	505	536	561	597	660	816	835	876[c]
Amphipoda	0.00	0.02	0.06	0.07	0.05	0.01	0.00	0.16	0.01	0.44	0.00	0.00	0.15	0.25	0.09
Annelida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.11	0.00	0.00	0.04	0.00	0.12	0.00	0.17	0.13	0.00	0.00	0.02	0.31	0.29	0.09
Aquatic Diptera (larvae)	0.02	0.12	0.60	0.03	0.06	0.00	0.00	0.14	0.04	0.29	0.00	0.06	0.37	0.24	0.13
Aquatic Diptera (pupae)	0.73	0.65	0.08	0.14	0.00	0.02	1.00	0.21	0.23	0.00	0.00	0.12	0.06	0.06	0.43
Aquatic Diptera (unidentidied life stage)	0.00	0.00	0.04	0.32	0.43	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Insecta[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arachnida	0.00	0.00	0.01	0.01	0.00	0.12	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.01
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Coleoptera	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.03	0.06	0.00	0.16	0.06	0.00	0.00	0.01
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.16	0.00	0.00	0.00	0.00	0.00	0.02
Copepoda	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.01	0.03
Diptera (unidentified source and life stage)	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.27	0.39	0.00	0.00	0.00	0.00
Ephemeroptera	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fish (embryo, larvae and juvenile)	0.00	0.00	0.00	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	0.00	0.00	0.00	0.03	0.14	0.06	0.00	0.07	0.04	0.00	0.45	0.39	0.01	0.08	0.03
Hymenoptera	0.06	0.00	0.00	0.25	0.01	0.10	0.00	0.05	0.04	0.00	0.00	0.00	0.00	0.00	0.02
Insecta (unidentified source and life stage)	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Mysidae	0.00	0.20	0.00	0.10	0.07	0.02	0.00	0.01	0.15	0.00	0.00	0.00	0.05	0.00	0.11
Nemata/Nematomorpha	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.01	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.34	0.03	0.06	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Insecta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Trichoptera	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May 2008 and 2009

Table G.3. Site C Input to the Bioenergetics Model

Taxon	Simulation Day													
	78	108	135	168	198	323	443	506	536	562	760	815	834	876[c]
Amphipoda	0.00	0.00	0.03	0.05	0.25	0.00	0.00	0.00	0.05	0.06	0.14	0.06	0.00	0.01
Annelida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.01	0.00	0.07	0.02	0.14	0.00	0.00	0.09	0.05	0.01	0.00	0.18	0.78	0.08
Aquatic Diptera (larvae)	0.44	0.67	0.06	0.57	0.02	0.01	0.00	0.61	0.21	0.01	0.12	0.11	0.06	0.34
Aquatic Diptera (pupae)	0.37	0.33	0.51	0.13	0.21	0.00	0.06	0.10	0.27	0.09	0.00	0.51	0.14	0.30
Aquatic Diptera (unidentidied life stage)	0.18	0.00	0.14	0.07	0.16	0.01	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.07
Aquatic Insecta[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.01	0.00	0.00	0.00	0.00	0.05
Arachnida	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coleoptera	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.07	0.02	0.00	0.00	0.00	0.01
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.03	0.16	0.00	0.13	0.00	0.00
Ephemeroptera	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish (embryo, larvae and juvenile)	0.00	0.00	0.00	0.03	0.00	0.02	0.00	0.00	0.01	0.11	0.73	0.00	0.00	0.00
Hemiptera	0.00	0.00	0.00	0.00	0.04	0.07	0.00	0.05	0.03	0.14	0.00	0.02	0.00	0.03
Hymenoptera	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.03
Insecta (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.00	0.91	0.02	0.00	0.05	0.06	0.00	0.00	0.00	0.00
Mysidae	0.00	0.00	0.00	0.01	0.01	0.00	0.57	0.00	0.21	0.00	0.00	0.00	0.00	0.00
Nemata/Nematomorpha	0.00	0.00	0.05	0.01	0.00	0.00	0.00	0.05	0.01	0.00	0.01	0.00	0.00	0.05
Odonata	0.00	0.00	0.00	0.05	0.03	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Terrestrial Insecta	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Trichoptera	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May 2008 and 2009

Table G.4. Site D Input to the Bioenergetics Model

Taxon	Simulation Day												
	79	109	136	169	198	442	505	535	561	693	816	835	855[c]
Amphipoda	0.00	0.00	0.00	0.02	0.15	0.00	0.01	0.01	0.04	0.00	0.00	0.00	0.01
Annelida	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.24	0.13	0.00	0.04	0.09	0.19	0.00	0.04	0.06	0.02	0.42	0.08	0.00
Aquatic Diptera (larvae)	0.20	0.20	0.05	0.35	0.15	0.49	0.54	0.63	0.04	0.00	0.00	0.13	0.30
Aquatic Diptera (pupae)	0.38	0.50	0.36	0.11	0.18	0.18	0.12	0.17	0.11	0.00	0.58	0.13	0.24
Aquatic Diptera (unidentidied life stage)	0.00	0.06	0.08	0.11	0.19	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.04
Aquatic Insecta[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arachnida	0.00	0.00	0.02	0.00	0.06	0.00	0.06	0.00	0.00	0.02	0.00	0.00	0.04
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.14	0.24	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.07
Coleoptera	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
Collembola	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.02	0.00	0.00	0.00
Ephemeroptera	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fish (embryo, larvae and juvenile)	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.40	0.00
Hemiptera	0.00	0.00	0.00	0.04	0.02	0.00	0.01	0.03	0.00	0.80	0.00	0.00	0.01
Hymenoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.08	0.00	0.00	0.00
Insecta (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.02	0.19	0.00	0.00	0.00	0.05
Mysidae	0.00	0.00	0.35	0.03	0.09	0.00	0.12	0.04	0.00	0.00	0.00	0.00	0.23
Nemata/Nematomorpha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Odonata	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Insecta	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May 2008 and 2009

Table G.5. Site E Input to the Bioenergetics Model

Taxon	Simulation Day														
	109	135	197	260	324	344	506	533	562	659	686	778	815	834	872[c]
Amphipoda	0.10	0.01	0.19	0.00	0.00	0.15	0.29	0.04	0.02	0.00	0.00	0.00	0.05	0.10	0.15
Annelida	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.01	0.02	0.04	0.00	0.01	0.20	0.07	0.15	0.00	0.07	0.17	0.00	0.28	0.35	0.05
Aquatic Diptera (larvae)	0.03	0.06	0.14	0.00	0.00	0.01	0.18	0.08	0.03	0.00	0.00	0.00	0.12	0.11	0.12
Aquatic Diptera (pupae)	0.66	0.42	0.31	0.00	0.00	0.26	0.08	0.21	0.33	0.20	0.06	0.07	0.33	0.23	0.25
Aquatic Diptera (unidentidied life stage)	0.16	0.00	0.03	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Aquatic Insecta[a]	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
Arachnida	0.00	0.00	0.06	0.00	0.07	0.01	0.03	0.24	0.00	0.11	0.09	0.00	0.00	0.00	0.02
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.02	0.00	0.02	0.00	0.00	0.00	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Coleoptera	0.00	0.00	0.00	0.00	0.07	0.00	0.03	0.00	0.00	0.00	0.03	0.00	0.00	0.04	0.02
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.06	0.03	0.15	0.00	0.00
Ephemeroptera	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Fish (embryo, larvae and juvenile)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Hemiptera	0.00	0.19	0.00	0.41	0.11	0.04	0.02	0.03	0.00	0.00	0.49	0.00	0.02	0.00	0.11
Hymenoptera	0.00	0.00	0.17	0.44	0.03	0.02	0.01	0.07	0.26	0.00	0.04	0.00	0.00	0.01	0.01
Insecta (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.52	0.08	0.00	0.01	0.33	0.62	0.02	0.00	0.00	0.00	0.00
Mysidae	0.00	0.17	0.01	0.00	0.00	0.00	0.13	0.03	0.00	0.00	0.00	0.00	0.00	0.03	0.15
Nemata/Nematomorpha	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Odonata	0.00	0.00	0.02	0.00	0.17	0.20	0.00	0.00	0.00	0.00	0.00	0.91	0.00	0.11	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00
Terrestrial Insecta	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Trichoptera	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May 2008 and 2009

Table G.6. Site F Input to the Bioenergetics Model

Taxon	Simulation Day											
	323	443	470	505	534	562	632	717	778	815	833	876[c]
Amphipoda	0.00	0.00	1.00	0.14	0.10	0.05	0.00	0.00	0.07	0.08	0.58	0.12
Annelida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.04	0.00	0.00	0.05	0.22	0.00	0.06	0.04	0.00	0.33	0.05	0.14
Aquatic Diptera (larvae)	0.00	0.67	0.00	0.17	0.18	0.00	0.00	0.39	0.04	0.30	0.20	0.18
Aquatic Diptera (pupae)	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.02	0.00	0.10	0.17	0.12
Aquatic Diptera (unidentidied life stage)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Insecta[a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Arachnida	0.08	0.00	0.00	0.00	0.01	0.00	0.13	0.03	0.00	0.00	0.00	0.00
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coleoptera	0.08	0.01	0.00	0.00	0.00	0.00	0.03	0.15	0.00	0.00	0.00	0.00
Collembola	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.02
Copepoda	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.01	0.00	0.03	0.00	0.83	0.06	0.00	0.01
Ephemeroptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
Fish (embryo, larvae and juvenile)	0.00	0.27	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	0.46	0.01	0.00	0.04	0.09	0.00	0.11	0.01	0.00	0.00	0.00	0.07
Hymenoptera	0.15	0.01	0.00	0.09	0.05	0.00	0.64	0.00	0.00	0.01	0.00	0.07
Insecta (unidentified source and life stage)	0.00	0.03	0.00	0.15	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.10
Mysidae	0.00	0.00	0.00	0.28	0.03	0.47	0.00	0.15	0.00	0.00	0.00	0.16
Nemata/Nematomorpha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
Terrestrial Insecta	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.05	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May and June 2009

Table G.7. Site H Input to the Bioenergetics Model

Taxon	Simulation Day														
	261	294	324	469	507	535	563	596	660	693	717	758	813	833	853[c]
Amphipoda	0.00	0.00	0.03	0.00	0.50	0.47	0.01	0.38	0.00	0.06	0.00	0.07	0.64	0.66	0.49
Annelida	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.09	0.02	0.03	0.00	0.09	0.06	0.05	0.09	0.11	0.06	0.34	0.19	0.00	0.24	0.07
Aquatic Diptera (larvae)	0.01	0.00	0.03	0.00	0.16	0.15	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.03	0.15
Aquatic Diptera (pupae)	0.24	0.03	0.13	0.00	0.05	0.11	0.13	0.03	0.02	0.01	0.00	0.12	0.01	0.05	0.08
Aquatic Diptera (unidentidied life stage)	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Aquatic Insecta[a]	0.00	0.00	0.05	0.12	0.00	0.00	0.00	0.00	0.02	0.09	0.00	0.11	0.31	0.00	0.00
Arachnida	0.01	0.01	0.09	0.00	0.00	0.00	0.00	0.00	0.24	0.13	0.00	0.03	0.00	0.00	0.00
Arthropoda	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coleoptera	0.00	0.00	0.06	0.00	0.02	0.00	0.03	0.00	0.02	0.06	0.00	0.02	0.00	0.00	0.01
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.01	0.02	0.02	0.05	0.00	0.02	0.00	0.00	0.13	0.02	0.00	0.02
Ephemeroptera	0.18	0.00	0.01	0.00	0.04	0.05	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.05
Fish (embryo, larvae and juvenile)	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
Hemiptera	0.13	0.50	0.36	0.00	0.01	0.00	0.02	0.07	0.46	0.36	0.00	0.03	0.00	0.00	0.01
Hymenoptera	0.05	0.00	0.01	0.00	0.01	0.01	0.58	0.41	0.04	0.07	0.00	0.01	0.00	0.01	0.01
Insecta (unidentified source and life stage)	0.19	0.01	0.12	0.00	0.00	0.00	0.02	0.00	0.02	0.08	0.66	0.03	0.00	0.00	0.00
Mysidae	0.00	0.25	0.05	0.87	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.04
Nemata/Nematomorpha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.06	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.02
Other[b]	0.04	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Terrestrial Insecta	0.03	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00
Trichoptera	0.00	0.02	0.00	0.00	0.02	0.00	0.10	0.00	0.00	0.00	0.00	0.05	0.00	0.01	0.01

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May and June 2009

Table G.8. Site I Input to the Bioenergetics Model

Taxon	Simulation Day										
	325	386	415	506	535	562	661	759	813	825	876[c]
Amphipoda	0.00	0.04	0.05	0.56	0.27	0.00	0.00	0.69	0.03	0.10	0.41
Annelida	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Diptera (adult)	0.55	0.00	0.69	0.00	0.07	0.03	0.87	0.00	0.09	0.33	0.03
Aquatic Diptera (larvae)	0.00	0.29	0.00	0.09	0.43	0.41	0.00	0.00	0.56	0.17	0.26
Aquatic Diptera (pupae)	0.06	0.00	0.00	0.00	0.14	0.23	0.00	0.00	0.17	0.24	0.07
Aquatic Diptera (unidentidied life stage)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Aquatic Insecta[a]	0.01	0.00	0.26	0.00	0.00	0.00	0.00	0.23	0.03	0.00	0.00
Arachnida	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Arthropoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Coleoptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
Collembola	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copepoda	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diptera (unidentified source and life stage)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.03	0.01
Ephemeroptera	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.12	0.00	0.01
Fish (embryo, larvae and juvenile)	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hemiptera	0.10	0.00	0.00	0.00	0.01	0.19	0.13	0.00	0.00	0.00	0.00
Hymenoptera	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.04	0.00	0.06	0.01
Insecta (unidentified source and life stage)	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Mysidae	0.21	0.00	0.00	0.19	0.03	0.00	0.00	0.00	0.00	0.00	0.11
Nemata/Nematomorpha	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Odonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other[b]	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Terrestrial Diptera	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terrestrial Insecta	0.06	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Trichoptera	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada
[c]Mean diet composition from May and June 2009

Table G.9. Site I Input to the Bioenergetics Model (contd)

Taxon	Simulation Day	
	198	444
Amphipoda	0.00	0.00
Annelida	0.00	0.00
Aquatic Diptera (adult)	0.11	0.02
Aquatic Diptera (larvae)	0.14	0.27
Aquatic Diptera (pupae)	0.00	0.37
Aquatic Diptera (unidentidied life stage)	0.00	0.00
Aquatic Insecta[a]	0.00	0.00
Arachnida	0.00	0.00
Arthropoda	0.00	0.00
Cladocera	0.37	0.00
Coleoptera	0.00	0.00
Collembola	0.00	0.00
Copepoda	0.12	0.27
Diptera (unidentified source and life stage)	0.00	0.00
Ephemeroptera	0.00	0.00
Fish (embryo, larvae and juvenile)	0.00	0.00
Hemiptera	0.00	0.00
Hymenoptera	0.00	0.00
Insecta (unidentified source and life stage)	0.17	0.00
Mysidae	0.00	0.00
Nemata/Nematomorpha	0.00	0.00
Odonata	0.00	0.00
Other[b]	0.00	0.06
Terrestrial Diptera	0.00	0.00
Terrestrial Insecta	0.09	0.00
Trichoptera	0.00	0.00

[a]Lepidoptera, Orthoptera, Plecoptera, Megaloptera, and Neuroptera
[b]Isopoda, Ostracoda, plant material, Mollusca, Platyhelminthes, Rotifera, and Tardigrada

Appendix H

Sampling Design for Monitoring Juvenile Density

Appendix H

Sampling Design for Monitoring Juvenile Density

Prepared by John Skalski

It is anticipated that estimates of mean fish density during the four intra-annual months sampled will not themselves be compared. The fish populations represented by these four months of the year (i.e., February, May, July, and November) are inherently different in stock composition and behavior (i.e., migrant vs. residualized). Instead, trends over time will be compared primarily between specific months across years. In so doing, the fish stocks represented by the different months of the sampling will be evaluated over time and with regard to their responses to restoration activities that might be stock specific.

H.1 Density and Variance Estimators

H.1.1 Estimates of Mean Density in the Current Year

Mean fish density can be estimated for the entire tidal freshwater zone (D, E, F, and G) or a separate reach, a separate habitat type across reaches, or by strata. Define:

d_{kl}^{ij} = fish density (i.e., fish/m2) in the jth seine $(j=1,2)$ at the ith site $(i=1,\ldots,4)$ in the lth habitat $(l=1,\ldots,3)$ at the kth river reach $(k=1,\ldots,4)$;

N_{kl} = total number of sites in the lth habitat $(l=1,\ldots,3)$ at the kth river reach $(k=1,\ldots,4)$;

n_{kl} = number of sites actually canvassed in the lth habitat $(l=1,\ldots,3)$ at the kth river reach $(k=1,\ldots,4)$ (nominally $n_{kl}=4$ for $\forall k$ and l);

m = number of beach seines collected per location.

For convenience, subscripts for month or year of sampling will be ignored in this section.

H.1.2 Density Within Stratum

The average fish density in the klth stratum will be estimated as

$$\hat{\bar{D}}_{kl} = \bar{d}_{kl} = \frac{\sum_{i=1}^{n_{kl}} \left[\frac{\sum_{j=1}^{m} d_{kl}^{ij}}{m} \right]}{n_{kl}} = \frac{\sum_{i=1}^{n_{kl}} \sum_{j=1}^{m} d_{kl}^{ij}}{n_{kl} m} \qquad \text{H.1}$$

with associated variance

$$\mathrm{Var}\left(\bar{d}_{kl}\right) = \left(1 - \frac{n_{kl}}{N_{kl}}\right)\frac{S_1^2}{n_{kl}} + \frac{S_2^2}{n_{kl}m}, \qquad \text{H.2}$$

where

$$S_1^2 = \frac{\sum_{i=1}^{N_{kl}}\left(\bar{D}_{kl}^{i} - \bar{\bar{D}}_{kl}\right)^2}{\left(N_{kl} - 1\right)} \qquad \text{H.3}$$

and

$$S_2^2 = \frac{\sum_{i=1}^{N_{kl}}\sum_{j=1}^{M}\left(D_{kl}^{ij} - \bar{D}_{kl}^{i}\right)^2}{N_{kl}\left(M - 1\right)}, \qquad \text{H.4}$$

and where

$$\bar{D}_{kl}^{i} = \frac{\sum_{i=1}^{M} d_{kl}^{ij}}{M},$$

$$\bar{\bar{D}}_{kl} = \frac{\sum_{i=1}^{N_{kl}}\sum_{j=1}^{M} d_{kl}^{ij}}{N_{kl}M}, \qquad \text{H.5}$$

for M (i.e., potential beach seines that could be collected at a site) is very large. The variance expression H.2 can be estimated by the sample data where

$$\widehat{\mathrm{Var}}\left(\bar{d}_{kl}\right) = \frac{\left(1 - \frac{n_{kl}}{N_{kl}}\right)s_1^2}{n_{kl}} + \frac{\frac{n_{kl}}{N_{kl}}s_2^2}{n_{kl}m}, \qquad \text{H.6}$$

where

$$s_1^2 = \frac{\sum_{i=1}^{n_{kl}}\left(\bar{d}_{kl}^{i} - \bar{d}_{kl}\right)^2}{\left(n_{kl} - 1\right)} = \text{between-site-within-stratum variance}, \qquad \text{H.7}$$

and

$$s_2^2 = \frac{\sum_{i=1}^{n_{kl}} \sum_{j=1}^{m} \left(d_{kl}^{ij} - \bar{d}_{kl}^{i} \right)^2}{n_{kl}\,(m-1)} = \text{between-beach-seines-within-a-site variance,} \qquad \text{H.8}$$

and where

$$\bar{d}_{kl}^{i} = \frac{\sum_{j=1}^{m} d_{kl}^{ij}}{m} = \text{mean density at site } i\,. \qquad \text{H.9}$$

Estimator H.1 and variance estimator H.6 are used to estimate mean fish density and its variance within one of the 12 reach–habitat strata.

H.1.3 **Estuary-Wide Density**

Average fish density across the 12 reach–habitat strata (i.e., "estuary-wide") will be estimated by the weighted average

$$\hat{\bar{\bar{D}}} = \frac{\sum_{k=1}^{4} \sum_{l=1}^{3} N_{kl} \bar{d}_{kl}}{\sum_{k=1}^{4} \sum_{l=1}^{3} N_{kl}}, \qquad \text{H.10}$$

with variance

$$\mathrm{Var}\left(\hat{\bar{\bar{D}}} \right) = \sum_{k=1}^{4} \sum_{l=1}^{3} W_{kl}^2 \cdot \mathrm{Var}\left(\bar{d}_{kl} \right), \qquad \text{H.11}$$

where

$$W_{kl} = \frac{N_{kl}}{\sum_{k=1}^{4} \sum_{l=1}^{3} N_{kl}}, \qquad \text{H.12}$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\bar{\bar{D}}} \right) = \sum_{k=1}^{4} \sum_{l=1}^{3} W_{kl}^2 \, \widehat{\mathrm{Var}}\left(\bar{d}_{kl} \right). \qquad \text{H.13}$$

The weights W_{kl} are appropriate for making inferences back to the sampling frame of sties accessible to beach seining. If, in addition the weights are representative of the proportions of areas in each stratum, then inferences may be extended to the shorelines in the estuary (i.e., D, E, F, and G).

H.1.4 **Reach Density**

The average fish density within a river reach will be estimated by the weighted average of fish densities across habitats where

$$\hat{\bar{D}}_k = \sum_{l=1}^{3} W_{l|k} \cdot \bar{d}_{kl} \,, \qquad \text{H.14}$$

with variance

$$\mathrm{Var}\left(\hat{\bar{D}}_k\right) = \sum_{l=1}^{3} W_{l|k}^2 \cdot \mathrm{Var}\left(\bar{d}_{kl}\right), \qquad \text{H.15}$$

where

$$W_{l|k} = \frac{N_{kl}}{\sum_{l=1}^{3} N_{kl}}, \qquad \text{H.16}$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_k\right) = \sum_{l=1}^{3} W_{l|k}^2 \; \widehat{\mathrm{Var}}\left(\bar{d}_{kl}\right). \qquad \text{H.17}$$

H.1.5 **Habitat Density**

The average fish density within a habitat will be estimated by the weighted average of fish densities across reaches, where

$$\hat{\bar{D}}_l = \sum_{k=1}^{4} W_{k|l} \cdot \bar{d}_{kl} \,, \qquad \text{H.18}$$

with variance

$$\mathrm{Var}\left(\hat{\bar{D}}_l\right) = \sum_{k=1}^{4} W_{k|l}^2 \; \mathrm{Var}\left(\bar{d}_{kl}\right), \qquad \text{H.19}$$

where

$$W_{k|l} = \frac{N_{kl}}{\sum_{k=1}^{4} N_{kl}}, \qquad \text{H.20}$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_l\right) = \sum_{k=1}^{4} W_{k|l}^2 \, \widehat{\mathrm{Var}}\left(\bar{d}_{kl}\right). \qquad \text{H.21}$$

H.2 Retrospective Adjustment of $\hat{\bar{D}}_{kl}$ in Year t Using Year $t+1$ Data

The monitoring design has an annual rotational fraction of $f = 0.25$. One-quarter of the sites within a stratum are replaced each year with new locations selected at random from the sampling frame. Because of the positive correlation in fish density between consecutive years (e.g., February 2000 to February 2001), the estimate of density in the past year can be updated with an anticipated improvement in precision. The degree of precision improvement will depend on the degree of inter-annual correlation.

In any initial year t, the estimate of mean density is composed of an estimate of $\hat{\bar{D}}_{kl}$ based on matched sites (sites sampled in both years t and $t+1$) and non-matched sites (sampled in year t but not year $t+1$). An updated estimate of $\hat{\bar{D}}_{kl}$ in year t, taking into account the positive correlation in density over time, can be computed as

$$\tilde{\bar{D}}_{kl} = W \cdot \hat{\bar{D}}'_U + (1 - W) \cdot \hat{\bar{D}}'_M, \qquad \text{H.22}$$

where

$$\hat{\bar{D}}'_{U1} = \frac{\sum_{i=1}^{u} \sum_{j=1}^{2} d_{kl}^{ij}}{2u}, \qquad \text{H.23}$$

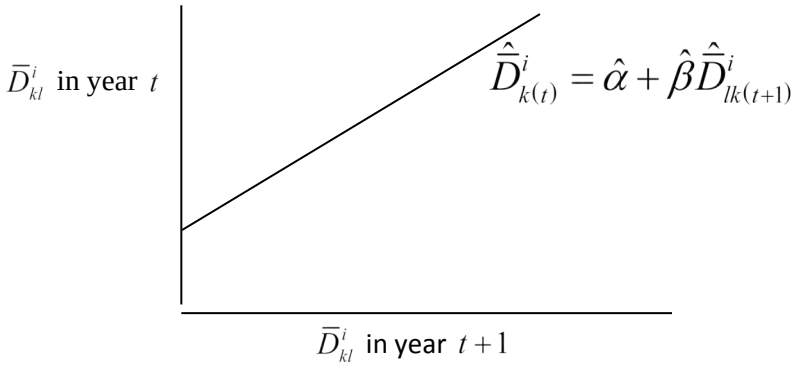
= estimated mean based on unmatched (u) sites surveyed in strata kl (nominally $u = 1$),

$\hat{\bar{D}}'_{M1}$ = revised estimate of mean density in year t based on regression of matched density values in years t and $t+1$, where

$$\hat{\bar{D}}'_{M1} = \alpha + \beta\left(\hat{\bar{D}}_{M2}\right), \qquad \text{H.24}$$

$\hat{\bar{D}}'_{M2}$ = estimated mean density in year $t+1$ for the matched sites,

and where the regression relationship is



using the m matched sites collected in both years t and $t+1$ (nominally m = 3).

The weights in Eq. (H.22) are of the form

$$W = \frac{\dfrac{1}{\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{U1}\right)}}{\dfrac{1}{\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{U1}\right)} + \dfrac{1}{\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)}} = \frac{\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_{M1}\right)}{\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_{U1}\right) + \widehat{\mathrm{Var}}\left(\hat{\bar{D}}_{M1}\right)}. \qquad \text{H.25}$$

In turn,

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}_{U1}\right) = \frac{\left(1 - \dfrac{u}{N_{kl}}\right)s_1^2}{u} + \frac{\dfrac{u}{N_{kl}}s_2^2}{um}, \qquad \text{H.26}$$

based on Eq. (H.6). In the case of a 25% rotation with n = 4 sites, the $\mathrm{Var}\left(\hat{\bar{D}}_{U1}\right)$ will reduce to only the second term in Eq. (H.26).

The variance of $\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right)$ is based on double sampling (Cochran 1977:339), in which case,

$$\widehat{\mathrm{Var}}\left(\hat{\bar{D}}'_{M1}\right) = \frac{\mathrm{MSE}}{r} + \frac{s_{D_M}^2 - \mathrm{MSE}}{n} - \frac{s_{D_M}^2}{N_{kl}}, \qquad \text{H.27}$$

where

$$r = \text{number of matched sites (i.e., } n-u=r\text{)}, \qquad \text{H.28}$$

$$s_{D_M}^2 = \frac{\sum_{i=1}^{r}\left(\hat{D}_{kl}^i - \hat{\bar{D}}_{M1}\right)^2}{(r-1)}, \qquad \text{H.29}$$

$$\hat{\bar{D}}_{M1} = \frac{\sum_{i=1}^{m}\bar{d}_{kl}^i}{m} \text{ for site-specific estimates in year } t, \qquad \text{H.30}$$

MSE = the MSE from the analysis of variance for the regression of $\bar{d}_{kl}^i$ in year t versus $\bar{d}_{kl}^i$ in year $t+1$.

Cochran (1977:346-347) shows the variance estimator H.22 has the expected value of

$$\text{Var}\left(\tilde{\bar{D}}_{kl}\right) = \frac{\left(1-\frac{n}{N}\right)S_1^2\left(n-u\rho^2\right)}{\left(n^2-u^2\rho^2\right)}. \qquad \text{H.31}$$

Optimal fraction $\left(P_{\text{OPT}}\right)$ of n that should be matched one year to the next is

$$P_{\text{OPT}} = \frac{\sqrt{1-\rho^2}}{1+\sqrt{1-\rho^2}}, \qquad \text{H.32}$$

where ρ is the coefficient correlation from year t to year $t+1$.

In practice, if fish densities are not different between habitats, it may be possible to pool observations across habitats within a river reach when performing the regression analysis and the retrospective estimation of abundance.

H.3 Estimating Differences in Fish Density Between Years t And $t+1$

Let the $\tilde{d}_{kl}^i$ be the average density estimate at site i in stratum kl based on matched samples (i.e., sites sampled in both years t and $t+1$) in year t. Let $\tilde{d}_{kl}^{i\prime}$ be the average density estimate at site i in stratum kl based on matched samples in year $t+1$. Then the difference in fish density between years t and $t+1$ at site i in stratum kl is

$$\hat{\Delta}_{kl}^i = \tilde{d}_{kl}^i - \tilde{d}_{kl}^{i\prime}. \qquad \text{H.33}$$

The estimate of the average change in fish density in stratum kl between years t and $t+1$ is

$$\hat{\Delta}_{kl} = \frac{\sum_{i=1}^{n_{kl}} \hat{\Delta}_{kl}^{i}}{n_{kl}}. \qquad \text{H.34}$$

An estimate of "estuary-wide" change in fish density between years t and $t+1$ can then be calculated as a weighted average, where

$$\hat{\bar{\bar{\Delta}}} = \frac{\sum_{k=1}^{4}\sum_{l=1}^{3} N_{kl}\hat{\Delta}_{kl}}{\sum_{k=1}^{4}\sum_{l=1}^{3} N_{kl}}, \qquad \text{H.35}$$

with variance

$$\mathrm{Var}\left(\hat{\bar{\bar{\Delta}}}\right) = \sum_{k=1}^{4}\sum_{l=1}^{3} W_{kl}^{2}\ \mathrm{Var}\left(\hat{\Delta}_{kl}\right), \qquad \text{H.36}$$

where

$$W_{kl} = \frac{N_{kl}}{\sum_{k=1}^{4}\sum_{l=1}^{3} N_{kl}}, \qquad \text{H.37}$$

and estimated variance

$$\widehat{\mathrm{Var}}\left(\hat{\bar{\bar{\Delta}}}\right) = \sum_{k=1}^{4}\sum_{l=1}^{3} W_{kl}^{2}\ \widehat{\mathrm{Var}}\left(\hat{\Delta}_{kl}\right). \qquad \text{H.38}$$

In turn, the variance of $\hat{\Delta}_{kl}$ can be expressed as

$$\mathrm{Var}\left(\hat{\Delta}_{kl}\right) = \left(1 - \frac{n_{kl}}{N_{kl}}\right)\frac{S_{\Delta_{kl}}^{2}}{n_{kl}} + \frac{\left(S_{2}^{2} + S_{2}^{2\prime}\right)}{mn_{kl}}, \qquad \text{H.39}$$

where

$$S_{\Delta_{kl}}^{2} = \frac{\sum_{i=1}^{N_{kl}}\left(\Delta_{kl}^{i} - \Delta_{kl}\right)^{2}}{\left(N_{kl} - 1\right)}, \qquad \text{H.40}$$

S_2^2 = Eq. (H.4) for year t,

$S_2^{2\prime}$ = Eq. (H.4) for year $t+1$.

This variance can be estimated by

$$\widehat{\mathrm{Var}}\left(\hat{\Delta}_{kl}\right) = \frac{\left(1-\frac{n_{kl}}{N_{kl}}\right)s_{\Delta_{kl}}^2}{n_{kl}} + \frac{\frac{n_{kl}}{N_{kl}}\left(s_2^2 + s_2^{2\prime}\right)}{n_{kl}m}, \qquad \text{H.41}$$

where

$$s_{\Delta_{kl}}^2 = \frac{\sum_{i=1}^{n_{kl}}\left(\hat{\Delta}_{kl}^i - \hat{\Delta}_{kl}\right)^2}{\left(n_{kl}-1\right)}, \qquad \text{H.42}$$

and where

s_2^2 = Eq. (H.8) for year t,

$s_2^{2\prime}$ = Eq. (H.8) for year $t+1$.

The estimator H.34 for the annual change in density is not the most efficient estimator of $\bar{\bar{\Delta}}$ because it does not use the unmatched sites within a year. However, with only one unmatched site per stratum, variance calculations cannot be performed to combine results for the matched and unmatched sites properly. For this reason, they are ignored in this analysis plan.

H.4 Projected Precision

Precision of the tidal freshwater monitoring (TFM) project will be defined in terms of relative error, where

$$P\left(\left|\frac{\hat{\bar{\bar{D}}} - \bar{\bar{D}}}{\bar{\bar{D}}}\right| < \varepsilon\right) = 1-\alpha\,. \qquad \text{H.43}$$

In other words, the desired precision is to have a relative error $\left(\text{i.e., } \left|\frac{\hat{\bar{\bar{D}}} - \bar{\bar{D}}}{\bar{\bar{D}}}\right|\right)$ less than ε, $(1-\alpha)100\%$ of the time. The value of ε is approximately equal to

$$\varepsilon = Z_{1-\frac{\alpha}{2}} \, \mathrm{CV}\left(\hat{\bar{\bar{D}}}\right). \qquad \text{H.45}$$

Using the preliminary survey data from the fixed and blitz sites in 2009, variance components were estimated. Under conditions of homogeneity in variances and strata size, the value of ε can be further approximated as

$$\varepsilon = Z_{1-\frac{\alpha}{2}} \frac{1}{\sqrt{lk}} \cdot \sqrt{\frac{\mathrm{CV}_1^2}{n} + \frac{\mathrm{CV}_2^2}{nm}}, \qquad \text{H.46}$$

where

$$\mathrm{CV}_1 = \frac{S_1}{\bar{\bar{D}}}, \qquad \text{H.47}$$

and

$$\mathrm{CV}_2 = \frac{S_2}{\bar{\bar{D}}}. \qquad \text{H.48}$$

The expected values of ε, 95% of the time, were calculated under alternative levels of effort (Table H.1). Either n = 3 or 4 sites per reach–habitat stratum and m = 1 or 2 beach seines per site were considered when estimating total salmon density, total Chinook salmon density, or total non-native fish density (Table H.2). Estimated efforts in terms of field-crew days were computed for each of those four alternative monitoring scenarios (Table H.3).

Table H.1. Average Coefficients of Variation (CVs) for Between Sites/Strata (CV_1), and Between Seines/Site (CV_2) for Alternative Response Variables in Tidal Freshwater Monitoring

Response Variable	Between Sites (CV_1)	Between Seines (CV_2)
Salmonid density	0.3438	1.2718
Chinook salmon density	0.2796	1.3453
Non-native fish density	1.9502	1.9863

Table H.2. Estimated ε, 95% of the Time, as a Function of Sampling Effort and Response Variable for Estimating "Estuary-Wide" Fish Density in a Monthly Sample

Response Variable	# Seines/Site	# Sites/Stratum	ε
Salmonid	1	3	0.4304
	2	3	0.3145
	1	4	0.3727
	2	4	0.2734
	2	5	0.2436
	3	5	0.2051

Table H.2. (contd)

Response Variable	# Seines/Site	# Sites/Stratum	ε
Chinook salmon	1	3	0.4489
	2	3	0.3239
	1	4	0.3887
	2	4	0.2805
Non-native fish	1	3	0.9093
	2	3	0.7851
	1	4	0.7875
	2	4	0.6799

Table H.3. Estimated Field-Crew Days Needed for Alternative Levels of Monitoring Effort

# Seines/Site	# Sites/Stratum	Total # of Sites	Total # of Seines	Field-Crew Days
1	3	36	36	2.4
2	3	36	72	3.0
1	4	48	48	3.2
2	4	48	96	4.0

H.5 Test for a Regional Trend

Using a straight-line regression of annual response versus year (i.e., t = 0, 1, 2, 3, 4), the null hypothesis of no increase in salmon density can be written as

$$\mathrm{H_o}: \quad \beta \le 0 \qquad \text{H.49}$$

vs.

$$\mathrm{H_a}: \quad \beta > 0 \,, \qquad \text{H.50}$$

where β is the slope of the regression model $\hat{\bar{D}}_i = \alpha + \beta t$. The null hypothesis can be tested using the *t*-statistic

$$t_{m-2} = \frac{\left|\hat{\beta} - 0\right|}{\sqrt{\dfrac{\mathrm{MSE}}{\sum_{i=1}^{m}\left(t_i - \bar{t}\right)^2}}} \,. \qquad \text{H.51}$$

H.5.1 **Power Calculations**

In the special case of a 5-year test of trends:

$$\sum_{i=1}^{m}\left(t_i - \bar{t}\right) = 10 \quad \text{for } t_i = (0,1,2,3,4) \qquad \text{H.52}$$

$$E(\text{MSE}) = \sigma_N^2 + \overline{\text{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)} \qquad \text{H.53}$$

where

σ_D^2 = natural variation in response,

$\text{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)$ = variance in the annual estimate (for a specific month) of mean fish density.

$$\beta = D_0(1+\Delta) \text{ for a linear change in response } \bar{\bar{D}}_i = \bar{\bar{D}}_0(1 - i\Delta) \qquad \text{H.54}$$

and where

Δ = annual fractional increase in mean fish density,

$\bar{\bar{D}}_0$ = average fish density in the first year.

Taking into account factors a through c, the noncentrality parameter associated with the noncentral *F*-distribution under H_a can be written as

$$\Phi_{1,3} = \frac{1}{\sqrt{2}} \cdot \frac{\left|\bar{\bar{D}}_0 \Delta\right|}{\sqrt{\dfrac{\sigma_D^2 + \overline{\text{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}}{10}}}. \qquad \text{H.55}$$

Currently, we have no estimate of the natural variation in mean fish density (i.e., σ_D^2). Until further information is collected, it will be assumed the natural variation is near zero (i.e., $\sigma_D^2 = 0$), then the noncentrality parameter can be rewritten as

$$\Phi_{1,3} = \sqrt{5} \cdot \frac{|\Delta|}{\text{CV}}, \qquad \text{H.56}$$

where

$$\mathrm{CV} = \frac{\sqrt{\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}}{\bar{\bar{D}}} \quad . \qquad \text{H.57}$$

H.5.2 Example: Power Calculations for Detecting a Five-Year Increase of 25%

Assuming n = 4 replicate sites per reach–habitat stratum and m = 2 seines/site, the projected coefficient of variation (CV) for an estuary-wide estimate of mean fish density is 0.1395 (= 0.2734/1.96) (Table 4.2). Consider a 0.25 increase in mean density over 5 years (i.e., 0.25 = (0.0625) × 4 changes in 5 years of monitoring), then

$$\Phi_{1,3} = \sqrt{5} \cdot \frac{|0.0625|}{0.1395} = 1.0018 \quad , \qquad \text{H.58}$$

which corresponds to a statistical power of $1-\beta$ = 0.48, at α = 0.10, one-tailed.

H.5.3 Example: Detecting a 10-Year Increase of 50%

The noncentrality parameter for a 10-year test of a linear trend is

$$\Phi_{1,8} = \frac{1}{\sqrt{2}} \cdot \frac{\left|\bar{\bar{D}}_0 \Delta\right|}{\sqrt{\dfrac{\mathrm{Var}\left(\hat{\bar{\bar{D}}} \middle| \bar{\bar{D}}\right)}{82.5}}} \qquad \text{H.59}$$

or

$$\Phi_{1,8} = \sqrt{41.25} \cdot \frac{|\Delta|}{\mathrm{CV}} \quad . \qquad \text{H.60}$$

The power to detect a 50% increase in estuary-wide, mean salmonid density within 10 years can be calculated where Δ = 0.05556 [i.e., 0.05556 (9) = 0.50], where

$$\Phi_{1,8} = \sqrt{41.25} \cdot \frac{|0.05556|}{0.1395} = 2.5580. \qquad \text{H.61}$$

Reading the noncentral *F*-table, $1-\beta$ = 0.98 at α = 0.10, one-tailed. This power calculation is based on the assumption that the average CV for the future estimates of estuary-wide, mean salmonid density will be 0.1395 and σ_D^2 = 0.

H.6 Recommendations

Precision calculations based on preliminary survey data on salmonid density suggest "estuary-wide" (i.e., reaches D, E, F, and G) estimates of mean density might be calculated with a precision of ± 27.34, 95% of the time (i.e., CV = 0.1395), with $n = 4$ sites/stratum and $m = 2$ seines/site. A lesser effort will produce values of $\varepsilon = 0.30$–0.43. Power calculations suggest with that level of annual precision, the monitoring project would have a statistical power of $1-\beta = 0.98$ at $\alpha = 0.10$, one-tailed, of detecting a 50% increase in mean salmonid density over a 10-year period (i.e., assuming $\sigma_D^2 = 0$).

Additional work will be done to estimate the interannual variation in density $\left(\sigma_D^2\right)$ so that the power calculations can be refined.

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