MONITORING ECOSYSTEM RESPONSE TO RESTORATION AND CLIMATE CHANGE IN THE SNOHOMISH RIVER ESTUARY

Field operations and data summary

Report to Tulalip Tribes (resolution #2013-66)
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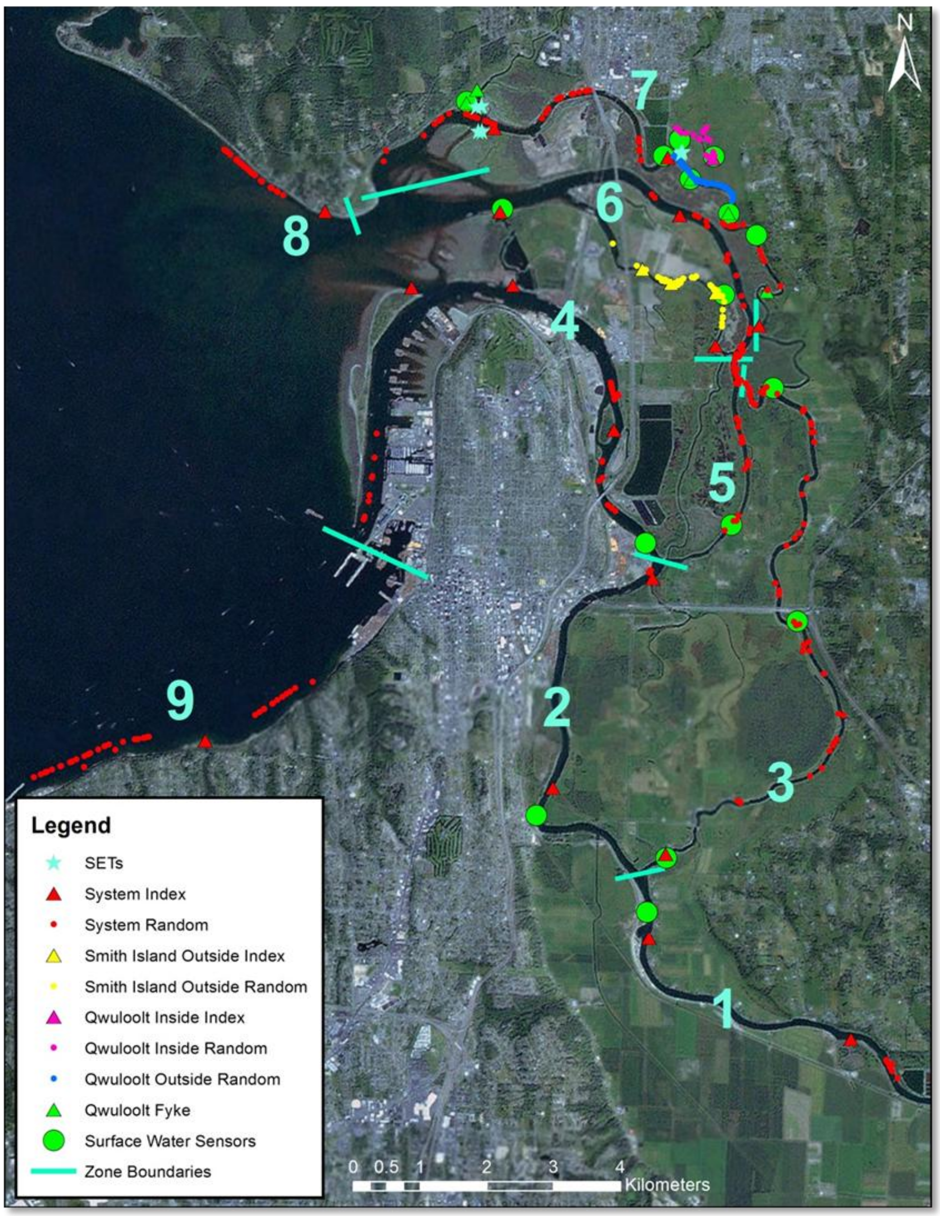

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1) INTRODUCTION

The Snohomish River estuary (Figure 1.1) is the second largest in the Puget Sound and provides habitat for Chinook and other salmonids (Snohomish Basin Salmon Recovery Forum 2005). These estuarine rearing and migration areas are necessary in the transition from freshwater to the critically important first year at sea. Similarly, estuaries provide vital habitat for a myriad of resident, migratory, and overwintering bird populations (City of Everett 2001, Wentworth-Davis 2011). The massive loss and degradation of juvenile salmonid habitat in the Snohomish estuary, as a result of modern human activities, was identified in the Snohomish Basin Recovery Plan as the primary factor limiting Chinook salmon survival in the basin (Snohomish River Basin Salmon Conservation Plan 2005). Additionally, degraded estuarine habitat conditions combined with a changing climate and sea level rise have **been identified as threats to Puget Sound avian assemblages (Audubon 2009)**. Fortunately, the Snohomish estuary has high potential for wild Chinook and avian recovery through restoration of estuarine wetlands, where over 486 hectares acres have been restored or identified as potential restoration projects. Coupled with extensive restoration actions is the need for ongoing monitoring throughout the estuary to track individual and cumulative effectiveness of restoration projects, and to determine the condition of Snohomish estuarine habitats in response to continuing anthropogenic stressors, including climate change. All ecosystem and salmon recovery planning efforts recognize the need for monitoring (e.g., Snohomish River Basin Salmon Conservation Plan 2005, Puget Sound Partnership Action Agenda 2012, Snohomish Basin 3-year Work Plan 2012) but such efforts are rare. In addition, bird surveys will achieve monitoring goals outlined in the Washington Wildlife Conservation Strategy (WDFW and the North American Marsh Bird Monitoring Program (Conway 2011). Many stakeholders and individual projects would benefit from comprehensive monitoring efforts, yet little coordination and collaboration occurs. The comprehensive monitoring plan for the Qwuloolt project (Rice et al. 2011) provides a template for project level restoration monitoring in the Snohomish that addresses a wide array of abiotic (e.g., land forms, hydrology) and biotic (vegetation, invertebrates, birds, fishes, and mammals) attributes, and is now informed and refined by three full years of implementation. In this project we facilitated effective project level monitoring, and continued and expanded system-wide monitoring efforts in support of the restoration and recovery of the Snohomish River estuary by: 1) ensuring the continuation of basic, ongoing fish monitoring; 2) **continuing avian monitoring at reference and project site**s; 3) installation of additional hydrologic and elevation/sedimentation monitoring equipment; and 4) expanded system-wide and project level monitoring through outreach and planning activities to increase participation by more stakeholders, and 5) acquire additional funding.

NOAA's Northwest Fisheries Science Center (NWFSC) has been monitoring fish in the Snohomish estuary for over a decade in collaboration with Tulalip Tribes. Application and development of a system-wide monitoring template has been closely related to intensive, pre-breach monitoring strategies conducted at the Qwuloolt restoration site (Rice et al. 2011) by NOAA/NWFSC and Tulalip Tribes since 2009. Our approach to monitoring in the Snohomish estuary and elsewhere is based on a five factor (landforms, hydrology, energy/nutrients, chemistry, biological interactions) and biological response (as the ultimate class of response variable) conceptual framework. This framework provides a comprehensive, coherent, and intuitive way to classify and prioritize metrics. This project addressed landforms and hydrology as abiotic ecosystem components, and fish and birds as biological metrics for both ultimate response and explanatory variables. Additionally, the overall monitoring approach is consistent with recommendations being developed to evaluate regional salmon recovery efforts (Puget Sound RITT 2012) and is based on the extensive work done in the Skagit River estuary (e.g., Beamer et al. 2005) that the NWFSC has been a contributor to since 2001. Through the implementation of a system-wide monitoring strategy in the Snohomish, this project aimed to expand long-term monitoring efforts and further develop a rigorous monitoring program of habitat (e.g., hydrology and sediment) and biota (e.g. fish and **bird**). A key component of this project was to expand and formalize collaborations with other lead entities in the area (e.g. Snohomish County), coordinating project level monitoring, and integrating it into estuary-wide efforts.

All expectations of the proposed work were met or exceeded with the exception of SET installations in the sediment component and CTD casts in the hydrology component. After consultation with expert collaborators SET installations were delayed to post breach inside Qwuloolt (2015-16), and to 2014 for the remainder of approximately 14 sites outside of Qwuloolt. The need for additional CTD casts was considered less important to overall project goals than more extensive compilation of historical data and modeling. The need for future CTD data is being evaluated in light of the considerable success of the hydrological data collection and analysis done to date.

Figure 1.1. Map of the Snohomish River estuary and the major channel network features. The location of the Snohomish River estuary relative to the Puget Sound is shown for reference.

2) OUTREACH, COLLABORATIONS, AND FUNDING

Comprehensive ecosystem monitoring in the Snohomish estuary provides invaluable information to a potentially large group of stakeholders, but requires significant personnel and equipment resources beyond what NOAA and Tulalip Tribes can sustainably provide. We contacted numerous potential partners in winter 2013 to discuss information needs for various entities and to look for opportunities to combine efforts and better support both restoration project level, and estuary wide, monitoring. A group meeting was held on January 23, 2013 at NOAA's Mukilteo Research Station and involved representatives from NOAA, Tulalip Tribes, Snohomish County, The City of Everett, and Jones and Stokes Consultants. At that meeting it was decided that NOAA would write letters to senior staff at Snohomish County and the City of Everett requesting significant, sustained participation by their agencies in system wide fish sampling. It was also decided that NOAA would distribute a field calendar to a wide range of potential volunteers soliciting help for field work. Both efforts were successful. The sampling schedule required two crews of 4-5 individuals for two days twice per month. Along with the NOAA staff contracted for the proposed work and several staff from the Tulalip Tribes, field participation included two biologists, one technician, and a boat from Snohomish County (Mar-Aug), one technician from the City of Everett (Mar-May), and several volunteers from the following groups:

Washington Conservation Corps
Puget Sound Beach Watchers
Sound Salmon Solutions
Washington Department of Fish and Wildlife
University of Washington
Gonzaga University
Washington Department of Ecology
Everett Community College

Efforts to secure additional funding for estuary wide fish monitoring or Qwuloolt restoration monitoring were mixed but NOAA did receive $70K in FY13 to partially support our estuary wide field work for a closely related, complimentary project on density dependent habitat use by juvenile Chinook. NOAA, the Skagit River System Cooperative, and Tulalip Tribes expect to receive significant additional support in FY14 to continue this project, which should include some support for estuary wide field work in the Snohomish.

3) SEDIMENTATION AND ELEVATION

Background

A key determinant of coastal wetland vulnerability to sea level rise (SLR) is whether the surface elevation in the intertidal zone can keep pace with sea level rise. It is crucial to quantify the vertical movement of coastal wetland surfaces, which will help identify sites under threat from SLR, thus informing conservation, mitigation and adaptation. The USGS is establishing a network of coastal marsh monitoring sites in the Pacific Northwest and California during 2012 and 2013 to assess the vulnerability of these coastal wetlands to changes in sea level rise (G. Guntenspergen, personal communication). Rod surface elevation table marker-horizon method (RSET and SET-MH) is the method used (see http://www.pwrc.usgs.gov/set/). The RSET and SET-MH developed by the USGS fills the critical need for precise and easily replicable local surface elevation change measurements. The RSET-MH was developed to quantify the surface and shallow subsurface processes contributing to wetland surface elevation change (Figure 3.1). An RSET involves very simple technology; it consists of a benchmark rod driven through the soil profile (Figure 3.2) to resistance (typically 10-25 m depth), and a portable horizontal arm that is attached at a fixed point anchored in concrete (Figure 3.3) to measure the distance to the substrate surface, using vertical pins (Figure 3.4). Installation, maintenance and data collection require minor training, and this is being provided as in-kind support by USGS.

Total surface height measurements have confidence intervals of ±1.3 mm, a figure well within the annual rate of eustatic SLR. RSETs are the only tool that can capture surface elevation change with this precision. RSET data are usually complemented with shallow accretionary monitoring using artificial soil marker horizons (MH) typically made of feldspar, which simultaneously quantify rates of vertical surface accretion (i.e., sediment deposition). The complete RSE/ MH setup provides net surface elevation change above the benchmark depth; moreover, as it has been repeatedly shown that vertical accretion is not a valid substitute for surface elevation change. The complete setup is necessary to identify the contribution of surface and shallow subsurface processes to surface elevation change at a specific site. Repeated measurements allow chronicling of net surface elevation change, which can be integrated with region-specific relative SLR (tide gauge data) to determine whether the surface elevation has kept pace with SLR over that time period.

RSET data can inform assessments of wetland vulnerability to SLR and bolster SLR wetland models to support science-based policy. RSET networks will contribute to increased confidence in identifying coastal wetland vulnerability, to more informed science based policy, and to improved accuracy and efficiency of coastal conservation, mitigation, and adaptation responses.

The USGS has established protocols for the installation of the RSET/MH technology and provided training sessions for this effort. USGS personnel were in the field during installation of our first six SETS to ensure quality control. USGS also has established protocols and templates for data collection and analysis and will provide these templates and training for this effort (Boumans 1993). USGS and WWU will provided this technical assistance as an in-kind effort for this project.

Because of funding limitations only one restoration site with SET installations has so far been established in Puget Sound - Nisqually National Wildlife Refuge in the southern portion of the Sound. In addition to the USGS effort, researchers at Western Washington University have SET sites in northern Puget Sound (Kairis and Rybczyk 2010). Establishment of the SET/MH sites at Qwuloot and across the Snohomish River Estuary will provide valuable additional information not only for the Snohomish, but for these larger efforts and increase the generality of the results. Previous studies have revealed high across-site variability in the processes that contribute to surface elevation change, making assumptions of uniformity in processes across wetlands inappropriate (G. Guntenspergen, personal communication). This highlights the need for site-specific data across a network of sites that accurately represent local and landscape contexts in order to evaluate the outcome of different sea level rise scenarios. Our approach will have within habitat and zone duplicates (for redundancy and replication), and have a landscape design for that has representation in all dominant tidally influenced vegetation zones across connectivity gradients.

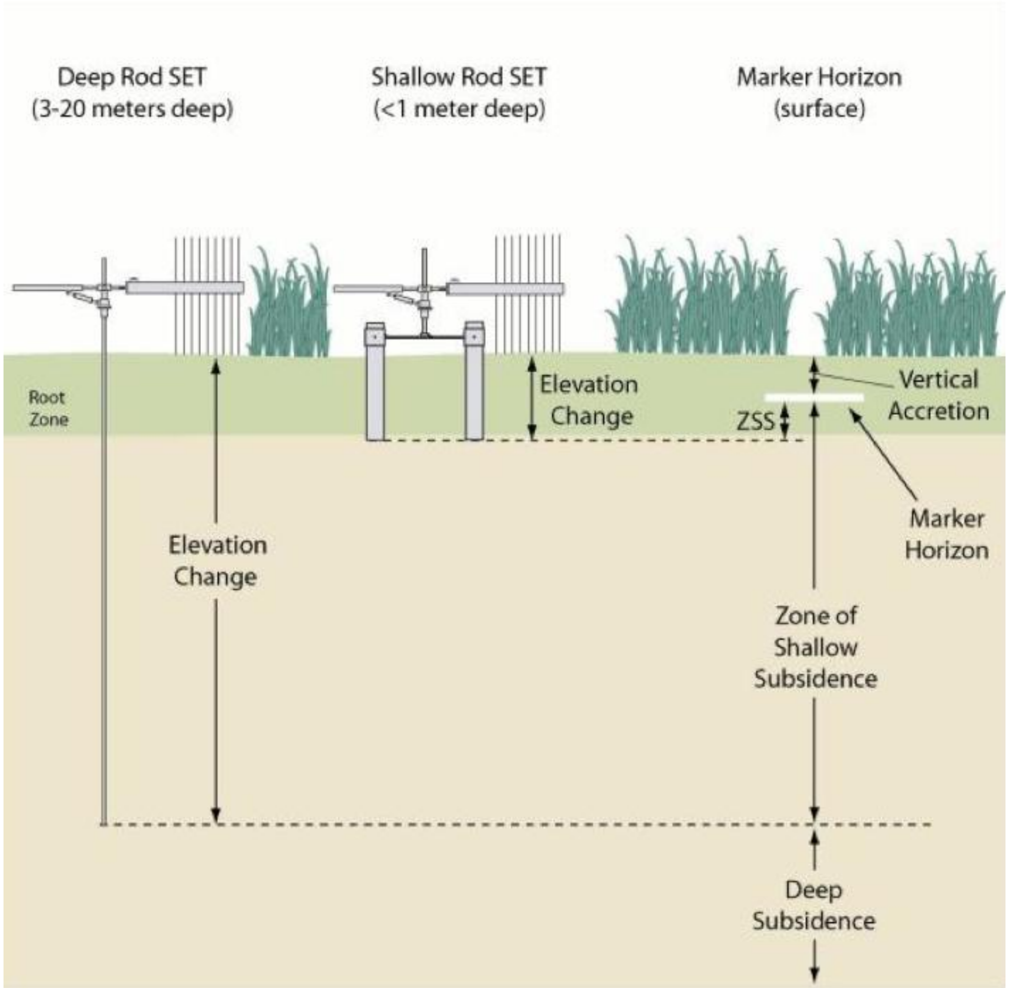

Figure 3.1. Rod surface elevation table - marker horizon (RSET-MH) in both shallow and deep configurations. All installations associated with the current work will be deep.

Figure 3.2. Driving stainless steel benchmark rods through the soil profile. Typical refusal depth in Snohomish installation in 2013 was approximately 18 meters.

Figure 3.3. Capped SET mounting receiver and copper survey marker.

Figure 3.4. Measuring surface elevation with rods at one of four positions for each location. Feldspare marker horizons being installed at the four corner locations of the SET plot indicated by four short PVC pipes.

Methods

Sites are being selected to install SETs in the major vegetation zones (emergent, scrub-shrub, forested), across connectivity gradients (upstream-downstream and laterally across sloughs), accessible by boat from adjacent sloughs. Locations were selected that looked representative of the overall wetland for a given area (e.g., emergent sedge) and were not in or immediately adjacent to tidal channels. SETS and marker horizons were installed following the methods described by Cahoun and Lynch at http://www.pwrc.usgs.gov/set/. Distance from the sloughs for the initial installations ranged from 12 to 85 meters, and typical refusal depth of rods was 18 meters.

Results

Six RSET/MH installations were completed in 2013, four were surveyed and read (Table 3.1, Figure 3.4.), and additional matching support from NOAA, Tulalip Tribes, and USGS enabled the purchase of double the supplies and equipment, allowing for over 20 sites eventually, rather than just 10. After consultation with USGS and WWU collaborators it was decided that further installations should be postponed until winter/spring of 2014 at tidally influenced Qwuloolt reference sites, and others across the estuary, and to after the levee breach at the Qwuloolt site, likely to occur in late 2015. This will allow more careful planning of site locations, and avoid disturbance and misplacement within the Qwuloolt site.

Table 3.1. Positions and elevations of SET locations installed in 2013.

SET	Northing WSP 4601 survey ft	Easting WSP 4601 survey ft	Reciever Top Elevation NAVD88 survey ft	Marsh Surface Elevation NAVD88 survey ft
13.01	384155.463	1304517.594	7.617	7.210
13.02	384210.775	1304801.967	7.367	7.042
13.03	382952.331	1304624.131	7.836	7.488
13.04	382950.002	1304809.18	8.221	7.788
13.05	NA	NA	NA	6.742
13.06	NA	NA	NA	6.529

Figure 3.4. Locations of RSETs installed in 2013.

4) HYDROLOGY

Background

Tidal flooding is the primary driver of physical attributes (e.g., hydrology, elevation, channel morphology, and soil chemistry) that determine the biological character of estuarine wetlands (e.g., vegetation and animal community assemblages), but many of the specific cause and effect relationships are not well established. Uncertainties concerning wetland processes, restoration responses/effectiveness, and climate change impacts in estuarine wetlands are often related to unquantified hydrological parameters. Monitoring and analyzing surface water dynamics could provide invaluable information for restoration effectiveness monitoring as well as inform future restoration project design. In addition, developing an understanding of the linkages between riverine and tidal hydrodynamics can be useful for examining climate change scenarios where changes in watershed precipitation and temperature dynamics may impact restoration effectiveness in the long term as a result in changes to estuarine hydrology and tidal influence. To evaluate hydrodynamics within the Snohomish River estuary, we rely on monitoring data collected from discrete surface water sampling, discrete water column profiling, and continuous water sensor monitoring as well as hydrodynamic modeling efforts. This project monitoring status report is primarily focused on description of salt intrusion and habitat conditions with respect to marine influence within the estuary. More detailed analyses of the data presented in this report are planned, and will be included in a peer reviewed manuscript (Hall et al. in prep).

Methods

Continuous water sensors

Continuous water sensors that measure water level, temperature, and salinity at 10-minute intervals have been deployed throughout the estuary (Figure 4.1, Table 4.1). The continuous water sensors have been deployed strategically to target the Qwuloolt restoration project area, ongoing fyke trap locations, and key hydrological features and transition zones (e.g., major bifurcations and estimated salinity intrusion limits) (Figure 4.1). The geographic extent of the deployments is also designed to fall within the zone of tidal influence, with respect to water elevation. Gage readings at USGS Station 12155500 indicate that tidal influence on water elevation extends above the town of Snohomish, WA. Prior to 2013, deployments were restricted to fyke trap sites (QCF, EBF, FWF, and SP1), lower Ebey Slough (EB1 and EB2), and inside Qwuloolt (QTG and JC1) (Figure 4.1, Table 4.1). In January 2013, the continuous water sensor monitoring plan was expanded to include key locations within the mainstem (MS1, MS2, and MS3), Steamboat Slough (SB1 and SB2), and upper Ebey Slough (EB3, EB4, and EB5) as well as the active fyke trap sites (QCF, EBF, and FWF) and lower Ebey Slough sites (EB1 and EB2) (Figure 4.1, Table 4.1). Future deployments are planned within the Qwuloolt restoration area to provide pre-breach and post-breach conditions within the newly constructed channel system. In addition, continuous water sensor monitoring sites were recently installed within and near the Spencer Island restoration project area by Snohomish County. If data sharing arrangements are secured, both projects will benefit from system wide hydrological context and increased spatial coverage to include Union Slough.

Solinst brand sensors (LTC Junior) were initially used exclusively for continuous water sensor monitoring within the Snohomish River estuary. These sensors have proven unreliable, with multiple sensor failures and data loss events occurring throughout the monitoring period (Table 4.1) as well as difficulties associated with regular sensor calibrations. We are currently replacing Solinst sensors with Schlumberger brand (CTD Diver) sensors as budgets allow. The first batch of CTD Divers is currently in their first deployment and a CTD Diver has been deployed in tandem with a Solinst sensor for quality control (Table 4.1).

All continuous water sensors are being uploaded, cleaned, and calibrated (if needed) every 90-days on day-time low tide events. The uploaded data are being processed using atmospheric pressure data collected at nearby facilities (NOAA research station at Mukilteo and the Arlington Airport) to derive water depth. Measured cable lengths and high resolution RTK GPS data are used to convert these water level data to water elevation. The derived water elevation, temperature, and salinity time series are then processed to add river flow metrics derived from USGS Station 12150800 located near Monroe, WA and tidal conditions at the Marysville, Quilceda Creek tide prediction station. Flow conditions during each 10-minute sampling interval were classified into Environmental Flow Components (EFC) using Indicators of Hydrologic Alteration (IHA) software (Version 7.1) using the entire period of record for daily flow at USGS Station 12150800 (Water Years 1963-2013). IHA calculates five EFCs; extreme low flows, low flows, high flow pulses, small floods, and large floods that represent the full spectrum of flow conditions present within the period of record. Salinity characteristics were based on the following classification system of mixohaline (brackish) habitat types as detailed in Cowardin et al. (1979); polyhaline (18 – 30 ppt), mesohaline (5 – 18 ppt), oligohaline (0.5 – 5 ppt), and freshwater (0 – 0.5 ppt).

Continuous water sensor data were used to calculate the proportion of time habitat conditions were in each of the mixohaline habitat types as described above. In addition, these data series were used to determine the upstream extent of the oligohaline (0.5 – 5.0 ppt) zone. Sensor data were also summarized to determine the minimum, maximum, and average salinities over the period of record for each site among EFC flow conditions. Additional analyses of these data have not been completed at this time, but are planned as part of a peer-reviewed manuscript on salt intrusion and hydrodynamics in the Snohomish River estuary (Hall et al. in prep).

Discrete surface water sampling

Discrete samples of surface water temperature and salinity were obtained from fish survey efforts in the Snohomish River estuary between 2001 and 2013 (Figure 4.2). Measurements were taken at the surface near the river bank and were collected using YSI® brand conductivity and temperature sensors. While fish sampling study designs have changed over time, sampling generally occurred bi-weekly or monthly between February and September on ebbing tides. The fish sampling design was primarily index site based in earlier years (2001-2009), but has transitioned to a combination of index and random stratified sampling.

Data from these surface water measurements were used to determine upstream extent of the oligohaline (0.5 – 5.0 ppt) zone based on the maximum salinity measurements during the entire period of record. In addition, these data are the only surface water data series with good spatial coverage in the Snohomish River estuary in calendar year 2006, which coincides with the run year for the Finite Volume Coastal Ocean Model (FVCOM) hydrodynamic model (detailed below). Data from calendar year 2006 were also used to compare FVCOM model output results with *in situ* measurements. Additional analyses of these data have not been completed at this time, but are planned as part of a peer-reviewed manuscript on salt intrusion and hydrodynamics in the Snohomish River estuary (Hall et al. in prep).

Discrete water column sampling

Vertical water profiles were collected on spring tides during low and high flow conditions in the mainstem Snohomish River and during high flow conditions in Ebey Slough (Figure 4.3). Stations were positioned approximately 1 – 2 km and extended from the mouth upriver approximately 24.5 km to the town of Snohomish, Washington. As indicated by gage data at USGS Station 12155500, the entire length of river channel covered in this survey is tidally influenced. Vertical profiles were collected using a SeaBird ® SEACAT SBE19Plus V2 Profiler set to record conductivity, temperature, and density. Casts were conducted from the side of a skiff at the thalweg of the channel using a davit with a descent and ascent rate of approximately 0.25 m/s. The CTD was soaked at the surface for one minute before each cast. To maintain station at each site, the skiff motor was engaged to match river velocity. Lead weights were added as needed to reduce angular drift of the CTD during each cast. Upcast data were processed in 0.5 m bins to produce vertical water profiles of salinity, temperature, and density at each station.

Stations were sampled from downstream to upstream during the low and high tide. The low flow mainstem Snohomish River survey was completed August 19, 2009, with an average river discharge of 43 m3/s (USGS Station 12150800) during the survey. Average tide heights were -0.1 and 2.9 m during low and high tide mainstem Snohomish River surveys, respectively (NOAA Marysville, Quilceda Creek, tide predictions). The high flow mainstem Snohomish River survey was completed May 28, 2010, with an average river discharge of 538 m3/s during the survey (USGS Station 12150800). Average tide heights were -0.1 and 3.0 m during low and high tide surveys mainstem Snohomish River, respectively (NOAA Marysville, Quilceda Creek, tide prediction). The high flow Ebey Slough survey was completed May 29, 2010, with an average river discharge of 317 m3/s during the survey (USGS Station 12150800). Average tide heights were 0.5 and 3.2 m during low and high tide Ebey Slough surveys, respectively (NOAA Marysville, Quilceda Creek, tide predictions).

Maximum salinity values from water column profiles were used to determine the upstream extent of the oligohaline (0.5 – 5.0 ppt) zone across both sampling events. The water column profiles within each sampling event were also analyzed to evaluate stratification during these sampling events. Additional analyses of these data have not been completed at this time, but are planned as part of a peer-reviewed manuscript on salt intrusion and hydrodynamics in the Snohomish River estuary (Hall et al. in prep).

Water column profiles were not completed during the 2013 monitoring effort as was originally planned. The need for additional CTD casts was considered less important to overall project goals than more extensive compilation of historical data and modeling. Future water column profiles will be planned based on the results of the data synthesis efforts, which should help focus efforts on areas and/or events of interests.

Hydrodynamic modeling

Previous modeling efforts lead by the Tulalip Tribes and researchers at the Pacific Northwest National Laboratories produced a finite volume unstructured coastal ocean model (FVCOM) for the Snohomish River estuary (Zhaoqing and Khangaonkar 2008). This model was calibrated from a relatively short time series of data collected during the fall of 2006, and the output was restricted to this timeframe. The model has since been run using the existing calibrations and boundary conditions to generate 1-hour solutions for the entire 2006 calendar year. The output from this 2006 calendar year run is currently being analyzed to evaluate model accuracy relative to discrete surface water sampling data collected in 2006. In addition, the model outputs are being used to generate summary rasters to describe the hydrodynamic conditions within the estuary at a fine spatial scale. The results presented in this report are restricted to analyses related to salinity and salinity intrusion. Future analyses will consider temperature and water flow dynamics as well. Data from continuous water sensors, discrete surface water sampling, and discrete water column profiles will also be used to extend the calibration and validation data for extending the temporal output of the FVCOM model for future years (e.g., 2007 – Present). These future analyses will be included as part of a peer-reviewed manuscript on salt intrusion and hydrodynamics in the Snohomish River estuary (Hall et al. in prep).

Results

Continuous water sensors

Ebey Slough:

Mixohaline conditions within Ebey Slough show clear lateral gradients from downstream to upstream (Figure 4.4) during the time continuous water sensors have been deployed (Table 4.1). Habitat conditions transition from dynamic mixohaline conditions that include polyhaline, mesohaline, oligohaline, and freshwater conditions at the downstream most location (QCF) to exclusively freshwater conditions at the upstream most location (EB5) (Figure 4.4).

Polyhaline conditions (15 – 30 ppt) were primarily restricted to the downstream most site at QCF (Figure 4.4), with polyhaline conditions being observed 11% of the time. However, polyhaline conditions have been observed as far upstream as EB2 (Figure 4.4). Between EB1 and EB2 (including sites EB1, EBF, FWF, and EB2), polyhaline conditions have been observed for less than 1% of the time. These intrusion events are primarily restricted to periods of low flow (1,550 – 5,090 CFS flows in July to August) and large high tides (up to 3.6 meter high tides). The salt intrusion events are strongly associated with the incoming highest high water tide, with habitat conditions changing rapidly to freshwater as the tide recedes to lowest low water (e.g., see Figure 6 for an example time series of one event).

Mesohaline conditions (5 -18 ppt) extend upstream from QCF, where a majority (53%) of the time habitat conditions are mesohaline, to EB4, where habitat conditions are mesohaline only 5% of the time (Figure 4.4). Oligohaline conditions (0.5 – 5 ppt) extend upstream to EB4, where habitat conditions are primarily freshwater (96%) but oligohaline conditions occur 4% of the time.

Mainstem:

Currently, there are only three continuous monitoring locations within the mainstem, which start at river kilometer 10.0 and extend to river kilometer 17.6 (Figure 4.1, Table 4.1). All mainstem sites are freshwater dominated, with oligohaline and mesohaline conditions only being observed at the downstream most location at MS3 (Figure 4.5). At the downstream most mainstem site (MS3), habitat conditions are freshwater 64% of the time, while oligohaline conditions occur 22% of the time and mesohaline conditions occur 14% of the time (Figure 4.5).

Steamboat and Union Slough:

Habitat conditions are dynamic within Steamboat Slough as determined by continuous water sensors (Figure 4.1, Table 4.1). At the downstream most station in Steamboat Slough (SB1), habitat conditions that fall within all functional mixohaline groups (Figure 4.5). At SB1, freshwater conditions are present the least often (10%) while mesohaline conditions occur the most often (42%) (Figure 4.5). Interestingly, freshwater conditions have not been recorded at the upstream most station in Steamboat Slough (SB2) and habitat conditions are relatively balanced among polyhaline (27%), mesohaline (29%), and oligohaline (44%) at SB2 (Figure 4.3). The lack of freshwater conditions and maintenance of brackish to marine conditions indicates that tidal trapping may prevent flushing of marine water from upper Steamboat Slough.

With only one station and limited temporal coverage in Union Slough (Figure 4.1, Table 4.1), we have relatively little information on hydrodynamics and habitat conditions in Union Slough. The limited time series we do have indicates that conditions up to SP1 are primarily freshwater (77%), with 15% oligohaline and 8% mesohaline (Figure 4.5). Recently deployed sensors at the Spencer Island restoration site managed by Snohomish County may provide additional information regarding habitat conditions and dynamics in Union Slough.

Discrete surface water and water column sampling

Water column profiles during high and low flow events indicate that maximum upstream extent of oligohaline (0.5 – 5.0 ppt) habitat conditions as determined by the discrete water column profile surveys extends approximately 2.0 km upstream of the first primary bifurcation along the mainstem that forms upper Ebey Slough. Outside of the mainstem channel, the upstream extent of oligohaline habitat conditions were limited to the bifurcations of Union Slough, upper and lower Ebey Slough, and Steamboat Slough near Otter Island (Figure 4.10). Water column profiles indicate that salt wedges and freshwater lenses within in the river network are restricted to the lower portions of the network during high river flows on an incoming high tide. Water column profiles of the mainstem during the low and high flow surveys are presented as an example (Figure 4.7). These profiles show that stratification breaks down after 5.8 km upstream during an incoming tide with high river flows (Figure 4.7). During ebbing tides with high river flow, and during both ebbing and flooding tides with low river flows, water columns are well mixed and salt intrusion takes the form of a homogenous water body (Figure 4.7).

Based on data from 1,494 discrete surface water samples between 2001 and 2013, the maximum upstream extent of oligohaline (0.5 – 5.0 ppt) habitat conditions was observed just upstream of the Steamboat Slough bifurcation from the mainstem channel and upstream of the Otter Island and Steamboat Slough junctions on upper Ebey Slough (Figure 4.10). Within upper Steamboat Slough, discrete surface water samples have been taken from 2005 – 2013. Of the 59 measurements in this section, salinity values ranged from 0 – 7.5 ppt, which indicates that freshwater flushing does occur within this section. However, salinity falls within the oligohaline zone based on averages of measurements taken in upper Steamboat Slough between 2005 and 2013 (average 0.7 ppt).

Hydrodynamic modeling

Maximum, minimum, and average salinity values from hourly FVCOM output for the calendar year of 2006 were used to determine the extent of mixohaline habitat zones within the estuary (Figure 4.8). Looking at the maximum modeled salinities within the estuary, polyhaline habitat conditions extend approximately 1.5 km upstream of the Steamboat Slough bifurcation, and extends downstream into Steamboat Slough approximately 1.1 km. Polyhaline conditions extend up Union Slough to approximately 0.7 km downstream of the Steamboat Slough bifurcation. From Possession Sound, polyhaline conditions extend upstream to approximately 0.2 km downstream of the lower Ebey Slough bifurcation at Otter Island. Mesohaline habitat conditions extend upstream along the mainstem to approximately 2.0 km downstream of the first primary bifurcation along the mainstem that forms upper Ebey Slough. Outside of the mainstem, mesohaline habitat conditions occur within the entire stretch of lower Ebey Slough, Union Slough, and Steamboat Slough. The upstream limit of mesohaline habitat conditions within upper Ebey Slough extends to approximately 4.3 km downstream of beginning of upper Ebey Slough. Oligohaline habitat conditions extend upstream through all channels to approximately 2.0 km upstream of the first primary bifurcation along the mainstem that forms upper Ebey

Slough, with habitat conditions upstream of this locations being restricted to freshwater conditions (Figure 4.10).

Modeled salinity data appear to agree well with *in situ* discrete surface water samples (Figure 4.9). Validation analyses are currently underway, although the complete results of this effort are not presented here (see Hall et al. in prep). These validation analyses in combination with calibration runs using combinations of continuous water sensor data, discrete surface water samples, and discrete water column profiles are planned in the future pending funding. Completion of these efforts will help develop more comprehensive multi-year simulations which could be used to run more comprehensive habitat classification analyses and future scenario testing (e.g., climate change simulations).

Summary

Salt intrusion is a dynamic process and the extent and persistence depend on tidal and river forces. Previous descriptions indicate that salt intrusion is relatively limited within the estuary (SEWIPS 2001), with salt intrusion being limited to areas downstream of the Steamboat Slough bifurcation and bifurcation and confluence complex at Otter Island (Figure 4.10). Analysis of *in situ* monitoring data from continuous water sensors, discrete water column profiles, and discrete surface water samples in combination with recent hydrodynamic modeling efforts indicate that salt intrusion is much more extensive in the Snohomish Estuary. Integrating the information from these data sources suggests that oligohaline habitat conditions can extend through the entire slough complex to approximately 2.0 km upstream of the first primary bifurcation along the mainstem that forms upper Ebey Slough (Figure 4.10). As is evident from the continuous water sensor data series, the duration of oligohaline conditions is relatively short in the upper reaches of the estuary (Figure 4.4 and 4.5), characterization of these conditions is useful for restoration effectiveness monitoring as well as informing future restoration project design. The preliminary analyses of persistence of oligohaline, mesohaline, and polyhaline conditions in the lower reaches of the mainstem and slough complexes from the continuous water sensor data can also inform restoration effectiveness monitoring as well as informing future restoration project design. These analyses will be further developed as FVCOM model output data are analyzed in the same way, which will produce detailed high resolution maps of mixohaline conditions and persistence throughout the estuary. More detailed analyses of the data summarized here will be included in a peer-reviewed manuscript (Hall et al. in prep).

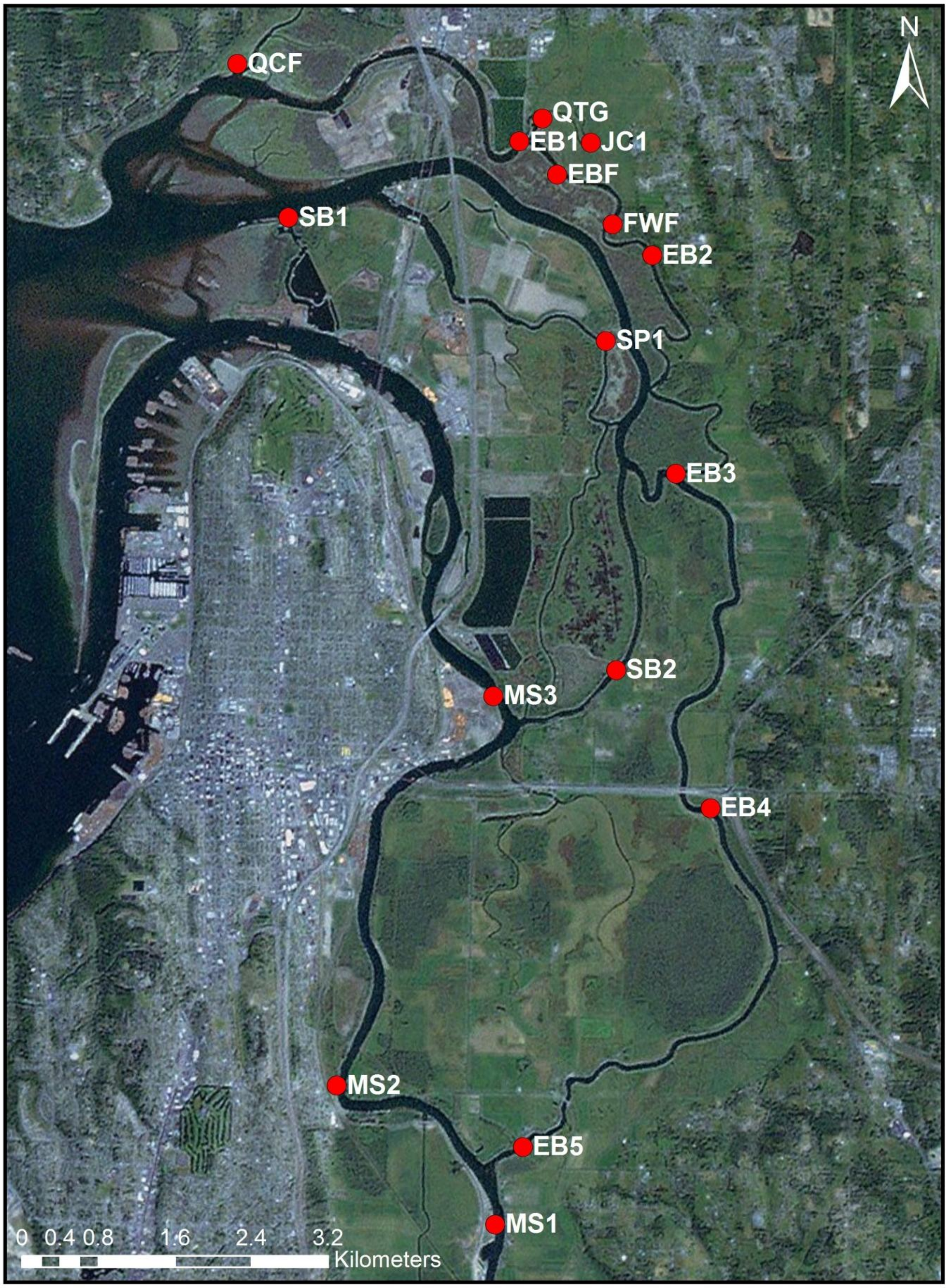

Figure 4.1: Locations of continuous (10-minute interval) water elevation, temperature, and salinity monitoring points within the Snohomish River estuary.

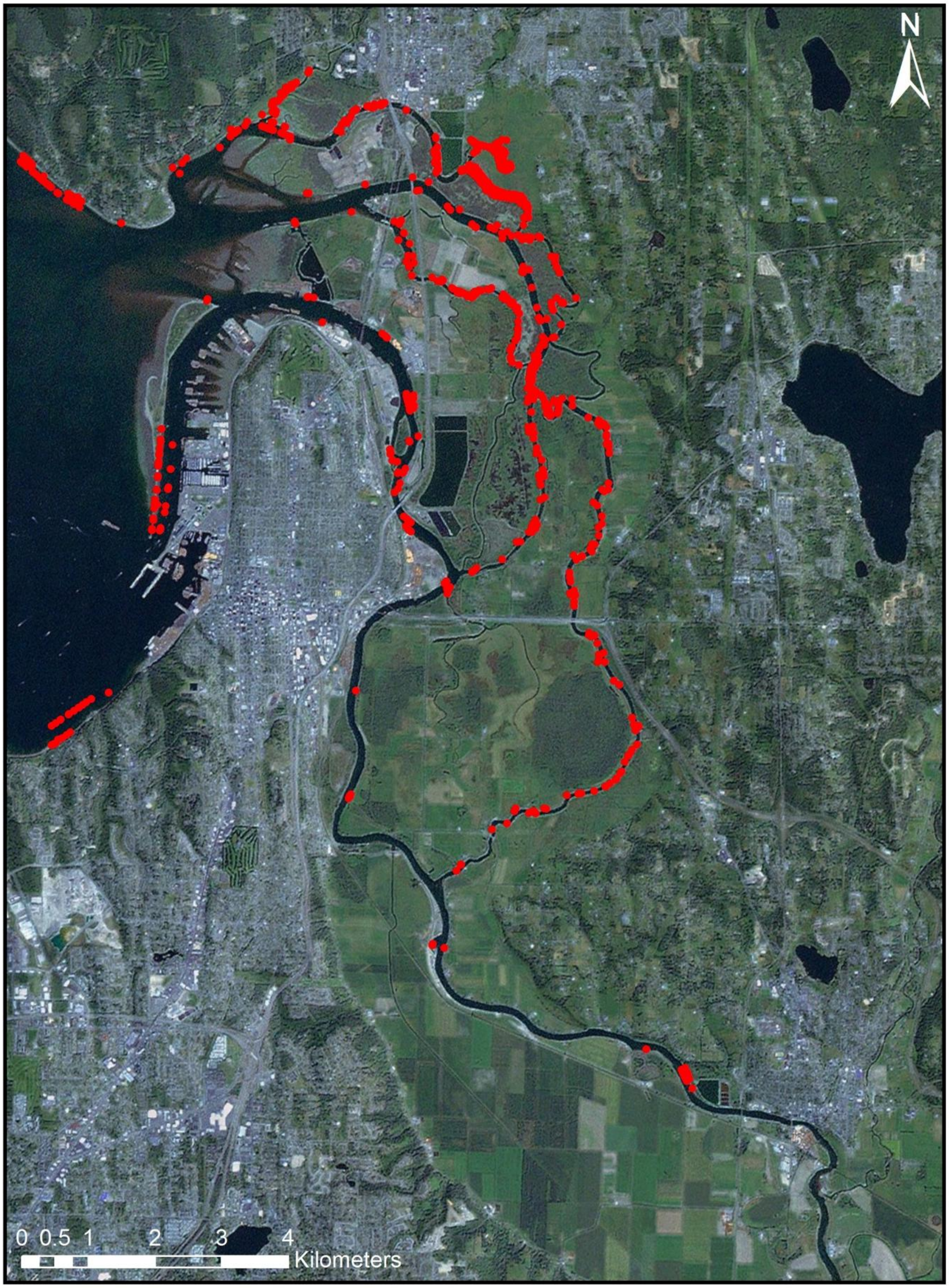

Figure 4.2. Discrete surface water measurement locations within the Snohomish River estuary that were taken with fish sampling efforts between 2001 and 2013.

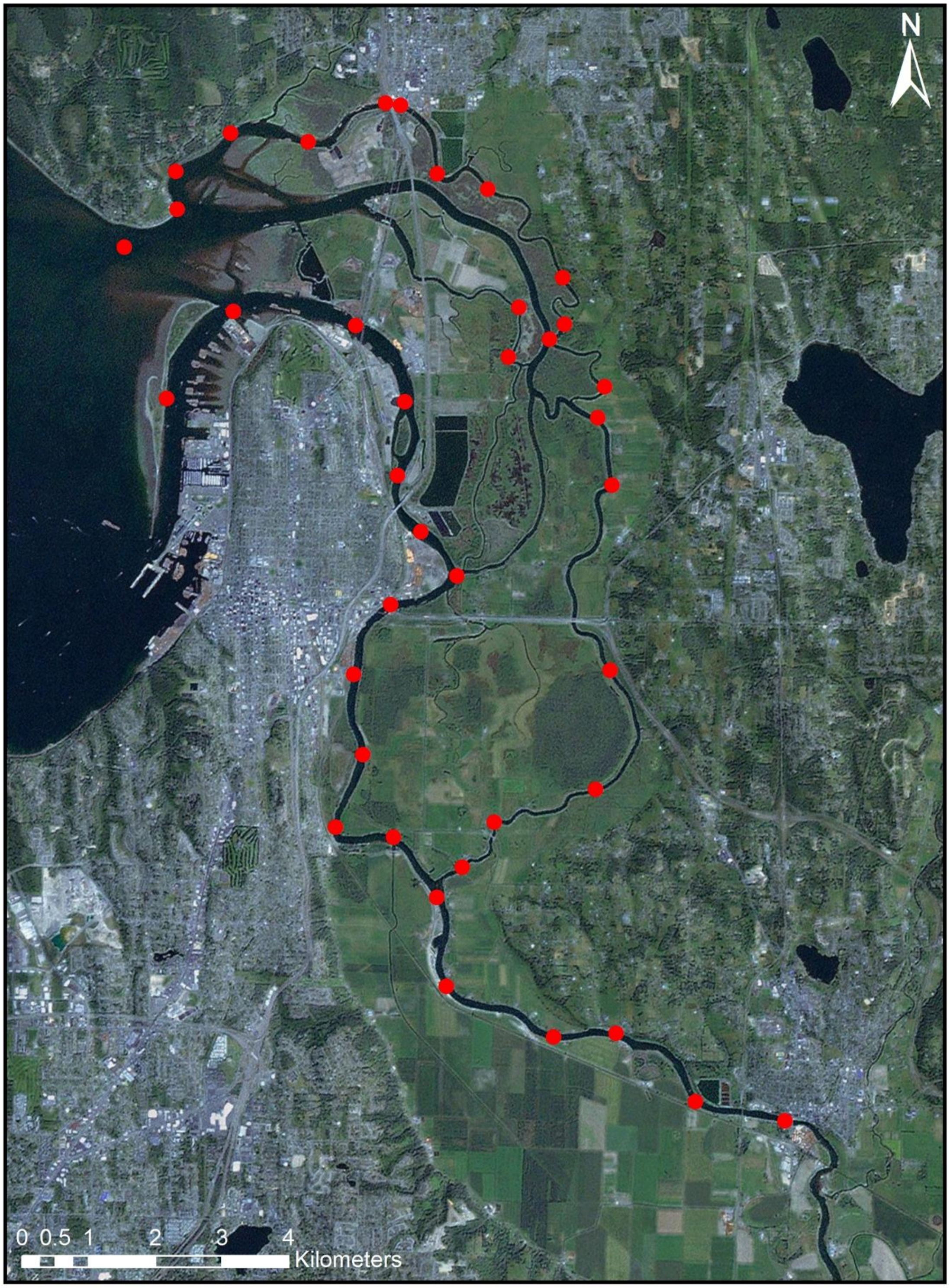

Figure 4.3. Discrete water column profile monitoring sites within the Snohomish River estuary that were sampled on August 19, 2009 and May 28-29, 2010.

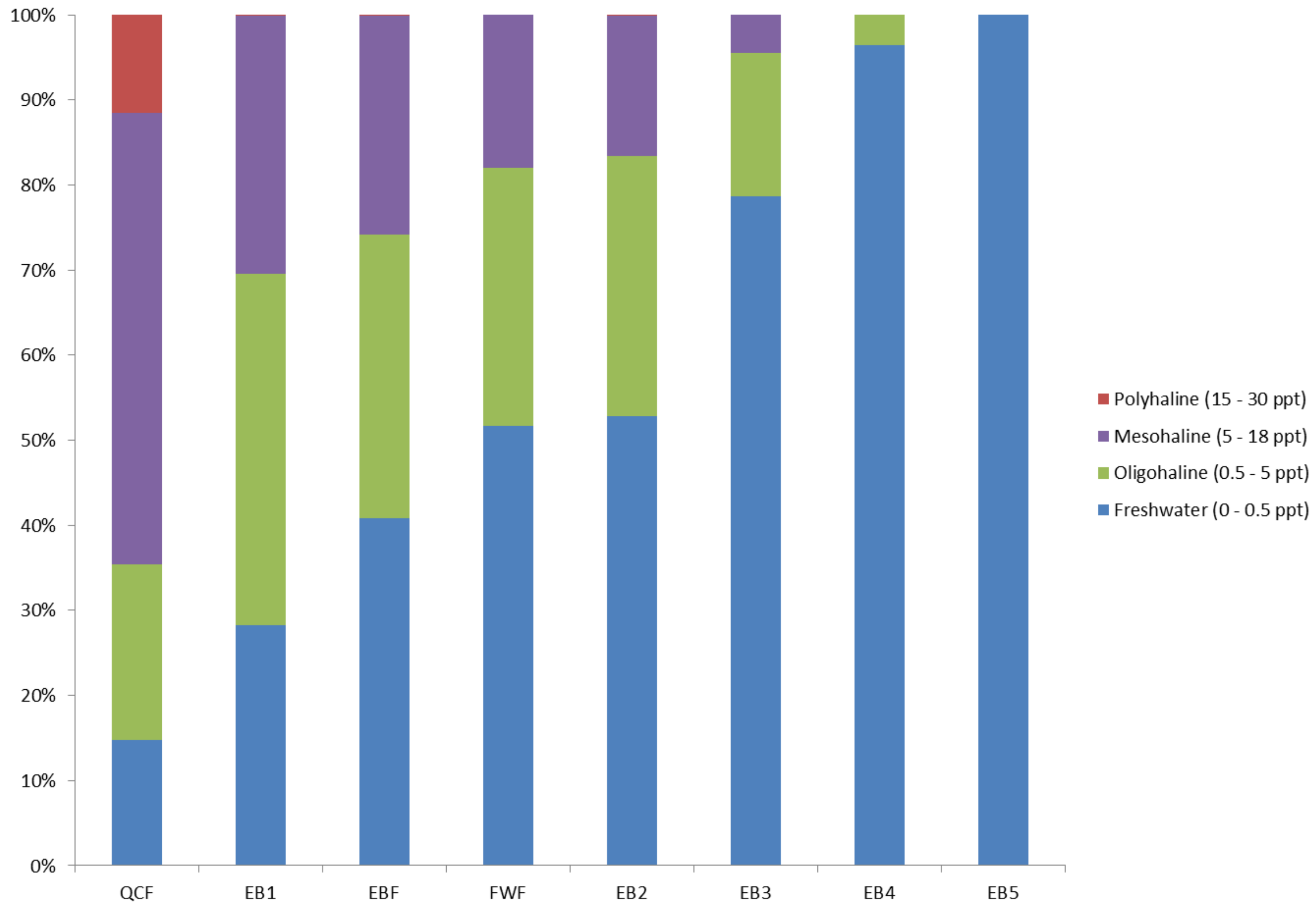

Figure 4.4. Proportion of time habitat conditions fall within mixohaline (brackish) habitat types; polyhaline (18 – 30 ppt), mesohaline (5 – 18 ppt), oligohaline (0.5 – 5 ppt), and freshwater (0 – 0.5 ppt), as measured by continuous water elevation, temperature, and salinity monitoring points in Ebey Slough (Figure 4.1, Table 4.1). Monitoring sites are organized from left to right to represent downstream to upstream in Ebey Slough (Figure 4.1).

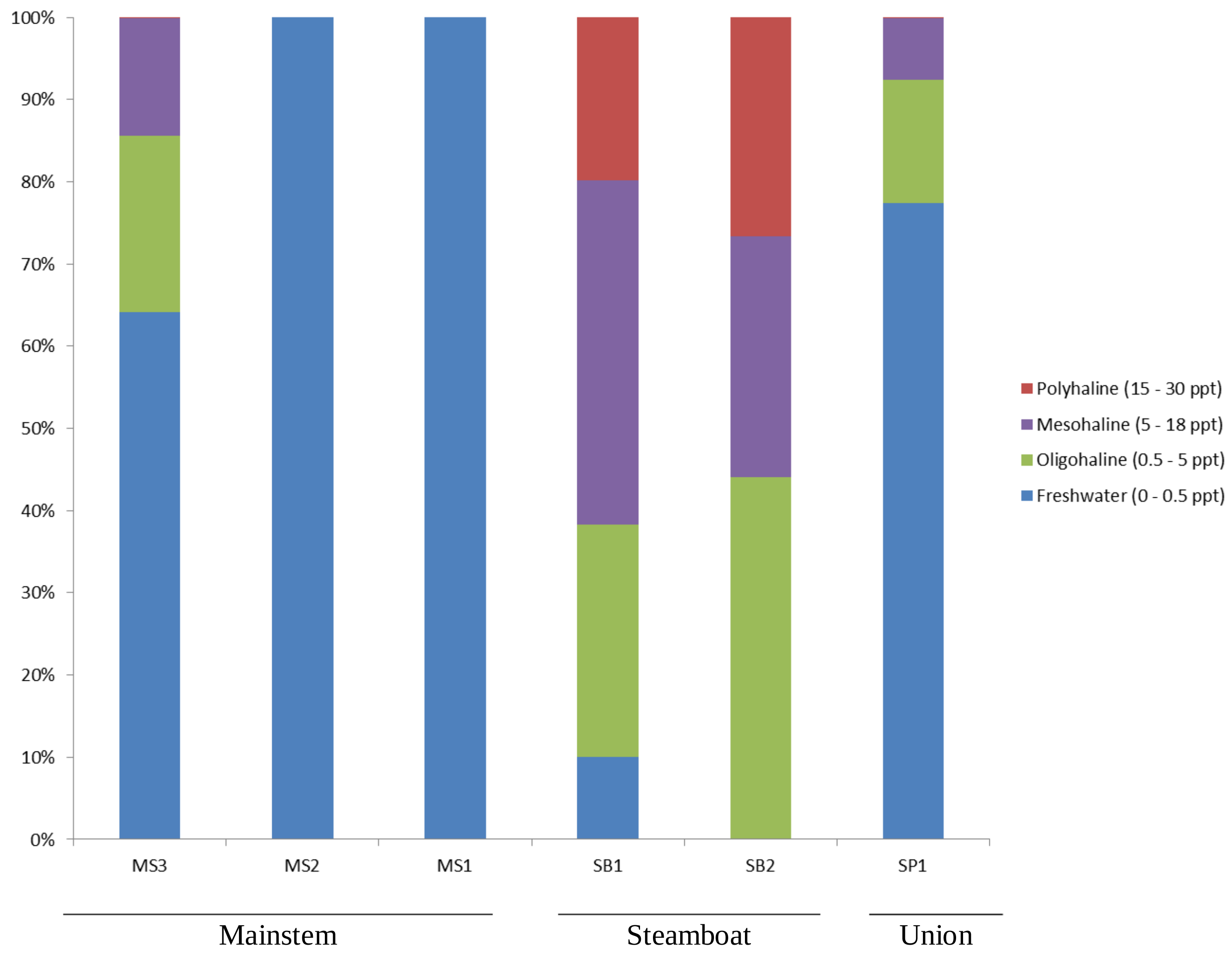

Figure 4.5. Proportion of time habitat conditions fall within mixohaline (brackish) habitat types; polyhaline (18 – 30 ppt), mesohaline (5 – 18 ppt), oligohaline (0.5 – 5 ppt), and freshwater (0 – 0.5 ppt), as measured by continuous water elevation, temperature, and salinity monitoring points in Ebey Slough (Figure 4.1, Table 4.1). Monitoring sites are organized from left to right to represent downstream to upstream in the mainstem, Steamboat Slough, and Union Slough (Figure 4.1).

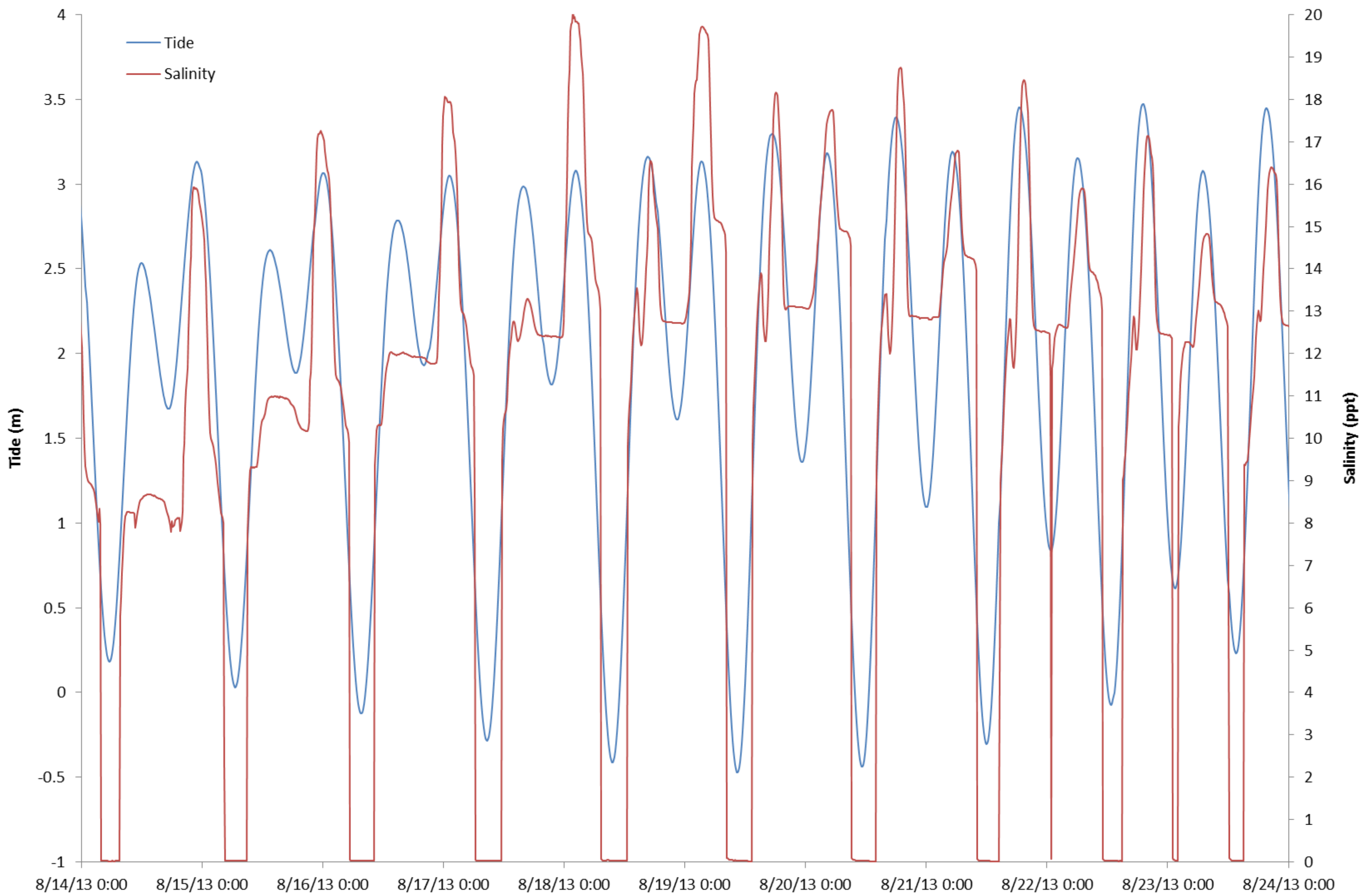

Figure 4.6.Time series snapshot of continuous water sensor salinity data at EBF during a salt intrusion event where habitat conditions transition to polyhaline (18 – 30 ppt) during high tide stages. This event was associated with daily flows of 2,460 CFS, which is considered a low flow stage based on EFC classifications (From Hall et al. in prep).

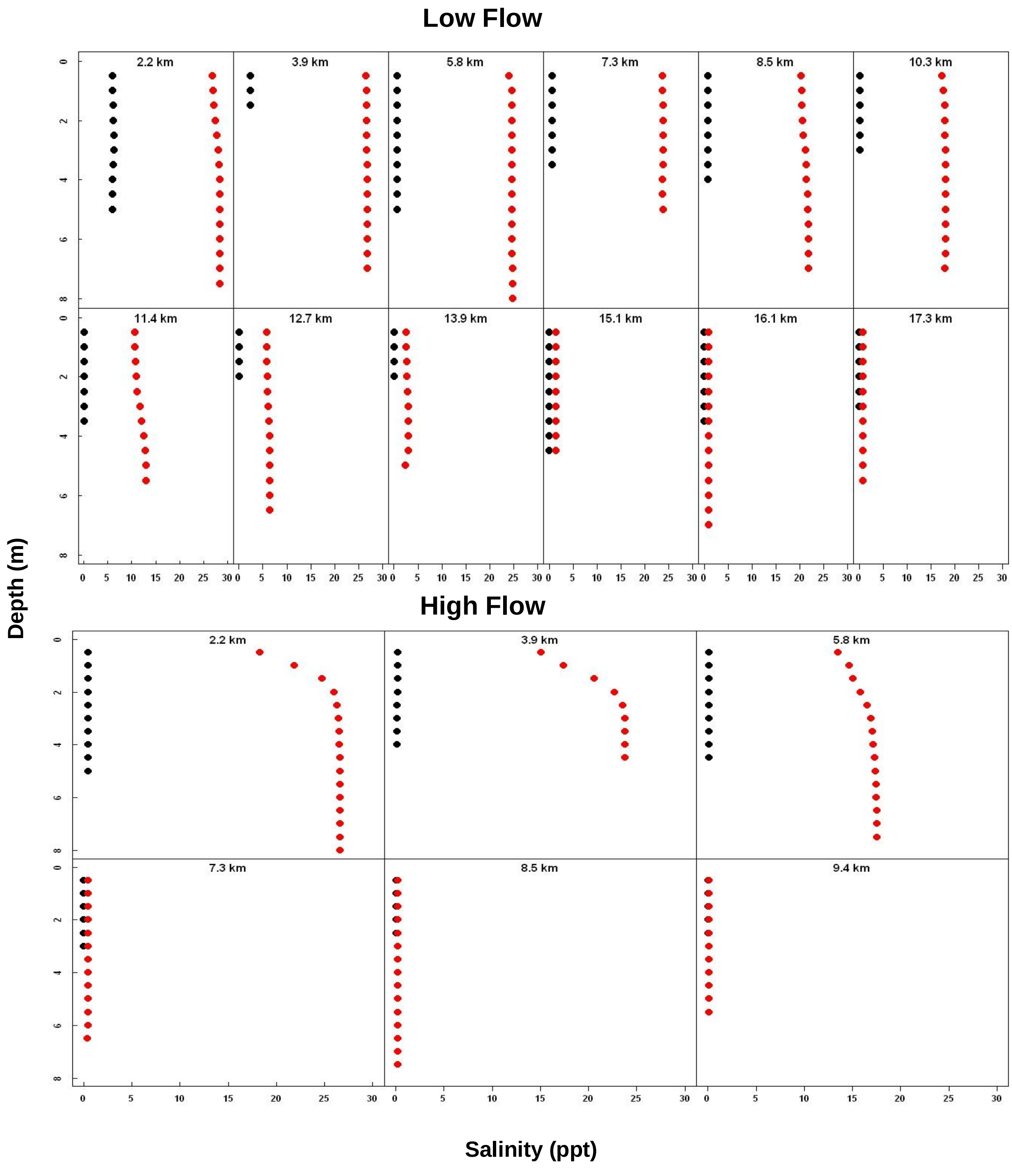

Figure 4.7. Water column profiles from discrete water column profile surveys during low (top) and high (bottom) river flows. Red profiles represent measurements taken during flooding tides and black profiles represent ebbing tides (From Hall et al. in prep).

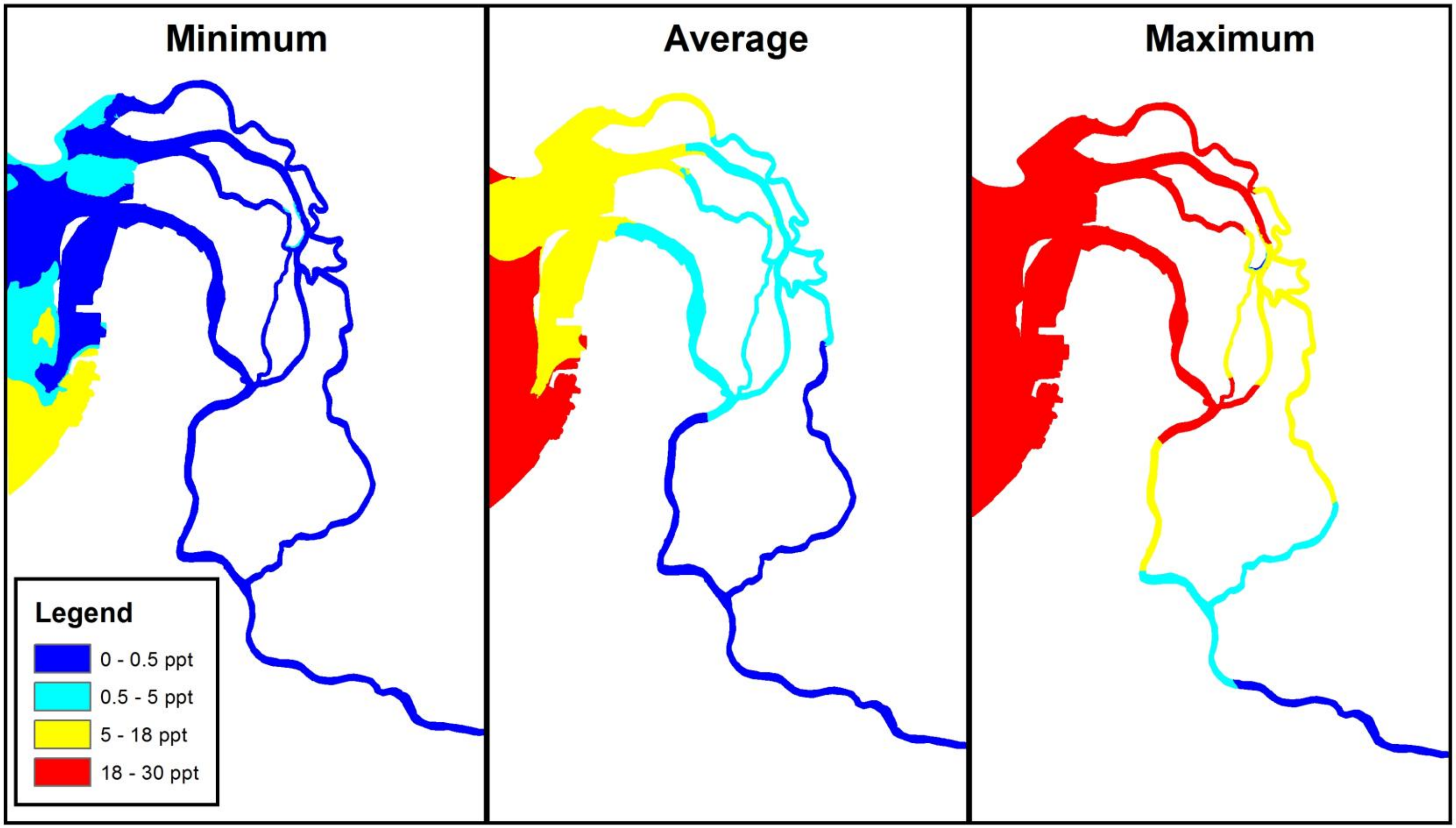

Figure 4.8. Minimum (left), average (middle), and maximum (right) salinity by mixohaline habitat conditions as derived FVCOM 1-hour solutions for 2006 calendar year (From Hall et al. in prep).

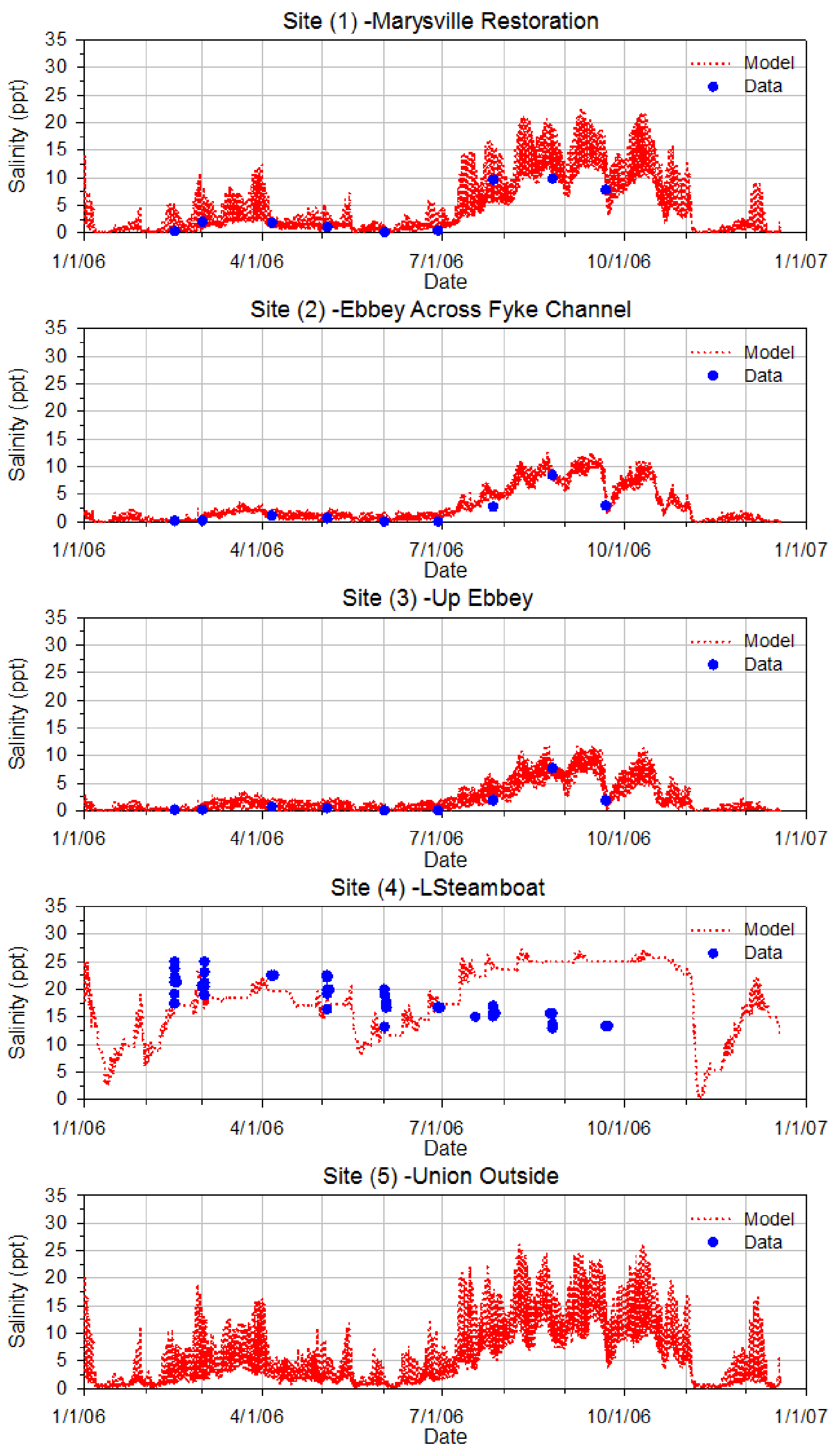

Figure 4.9. Example of FVCOM model output validation using discrete surface water sampling data from 2006 (From Hall et al. in prep).

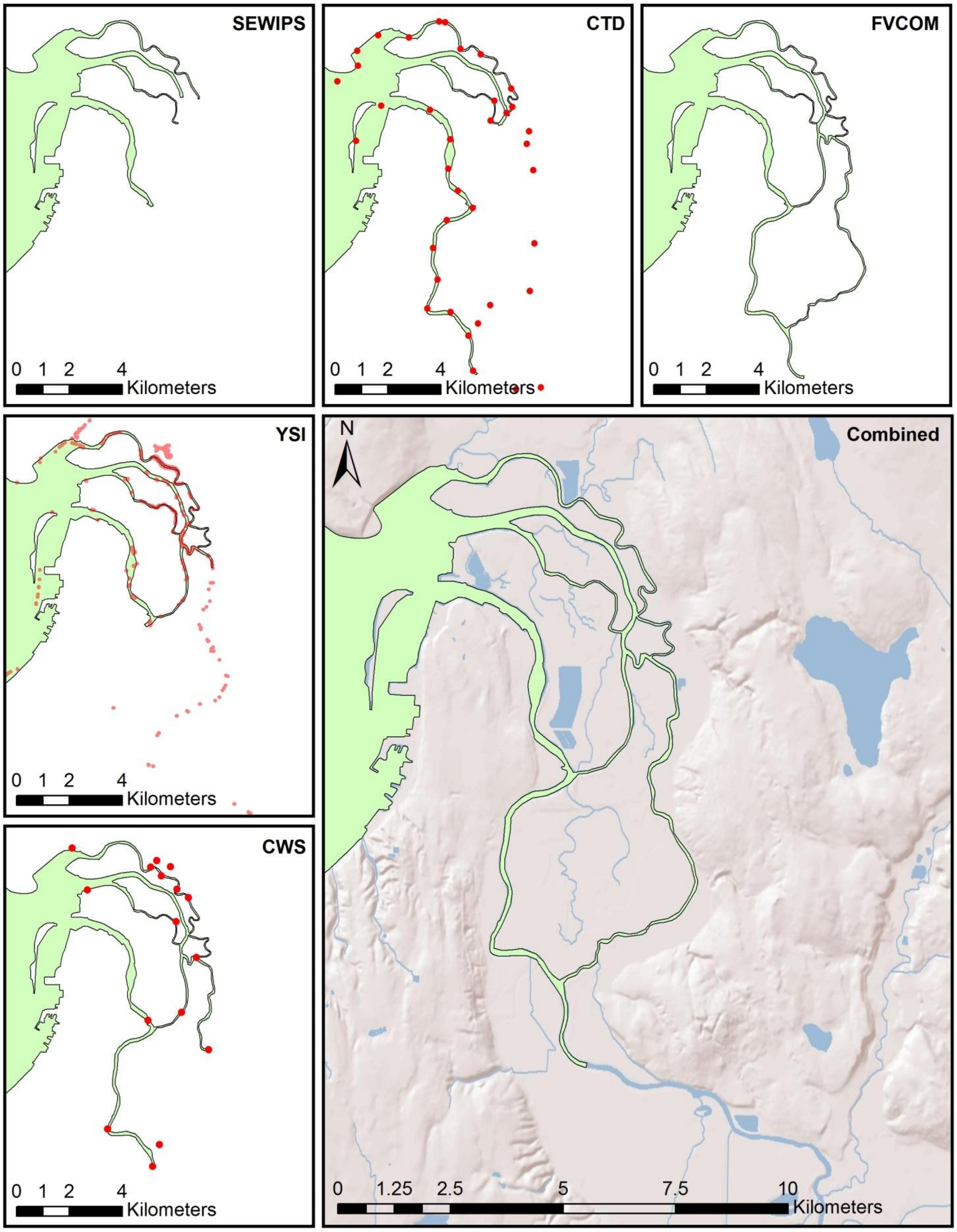

Figure 4.10. Extent of salt intrusion based on the extent of oligohaline habitat conditions (0.5 – 5.0 ppt) as determined by continuous water sensors (CWS), discrete surface water samples (YSI), discrete water column profiles (CTD), hydrodynamic modeling (FVCOM), and SEWIPS reports. Sample stations shown for reference and are represented by red dots where applicable. These components were used to develop a composite map of the oligohaline habitat extent conditions (From Hall et al. in prep).

Table 4.1. Temporal coverage for continuous (10-minute interval) water elevation, temperature, and salinity data by site and river locations. All Ebey Slough measurements were made from the confluence of Ebey Slough with Steamboat Slough. Jones Creek sites were also measured from the Ebey Slough confluence with Steamboat Slough, but these stations are currently behind a flap style tide gate. The mainstem sites were measured from the southern extent of Jetty Island. Steamboat and Union Slough sites were measured from the southern tip of Priest Point. See Figure 4.1 for a map of the sites. Bold values indicate incidents of sensor failure and data loss or recovery outcome.

Channel	Site	River km	Start Date	End Date	Days	Sensor Type	Notes
Ebey	QCF	2.0	2/18/2010	12/22/2010	307	Solinst	
			12/22/2010	3/22/2011	**90**	Solinst	**Sensor Failed, No Data Recovery**
			1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	Solinst	Deployment Ongoing, End Date is Planned Retrieval Date
	EB1	6.1	5/3/2010	12/22/2010	233	Solinst	
			6/3/2011	9/14/2011	103	Solinst	
			1/31/2013	4/5/2013	**64**	Solinst	**Sensor Failed, Partial Data Recovery**
			4/5/2013	1/7/2014	277	Solinst/CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date, Solinst and CTD Diver Deployed Together for QA/QC
	EBF	6.7	2/18/2010	12/22/2010	307	Solinst	
			2/8/2011	4/7/2011	58	Solinst	
			6/3/2011	10/13/2011	132	Solinst	
			10/13/2011	12/8/2011	**147**	Solinst	**Sensor Failed, Partial Data Recovery**
			1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	Solinst	Deployment Ongoing, End Date is Planned Retrieval Date
	FWF	7.7	2/18/2010	4/7/2011	413	Solinst	
			1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	Solinst	Deployment Ongoing, End Date is Planned Retrieval Date
	EB2	8.4	4/29/2010	4/7/2011	343	Solinst	
			6/3/2011	9/14/2011	103	Solinst	
			10/13/2011	3/28/2012	**167**	Solinst	**Sensor Failed, Partial Data Recovery**
			1/31/2013	7/1/2013	151	Solinst	
			7/1/2013	9/17/2013	**78**	Solinst	**Sensor Failed, No Data Recovery**
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	EB3	12.3	1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	EB4	16.7	1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	EB5	22.2	1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	QTG	6.5	4/29/2010	12/22/2010	237	Solinst	
			12/22/2010	9/14/2011	**266**	Solinst	**Sensor Failed, No Data Recovery**
	JC1	7.3	5/13/2010	9/1/2010	111	Solinst	
			10/8/2010	1/27/2011	111	Solinst	

Table 4.1 (continued). Temporal coverage for continuous (10-minute interval) water elevation, temperature, and salinity data by site and river locations. All Ebey Slough measurements were made from the confluence of Ebey Slough with Steamboat Slough. Jones Creek sites were also measured from the Ebey Slough confluence with Steamboat Slough, but these stations are currently behind a flap style tide gate. The mainstem sites were measured from the southern extent of Jetty Island. Steamboat and Union Slough sites were measured from the southern tip of Priest Point. See Figure 4.1 for a map of the sites. Bold values indicate incidents of sensor failure and data loss or recovery outcome.

Channel	Site	River km	Start Date	End Date	Days	Sensor Type	Notes
Mainstem	MS3	10.0	1/31/2013	9/17/2013	229	Solinst	
			4/11/2013	7/1/2013	81	Solinst	
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	MS2	15.0	1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	MS1	17.6	1/31/2013	9/17/2013	229	Solinst	
			9/17/2013	1/7/2014	112	Solinst	Deployment Ongoing, End Date is Planned Retrieval Date
Steamboat	SB1	2.4	1/31/2013	7/1/2013	151	Solinst	
			7/1/2013	9/17/2013	**78**	Solinst	**Sensor Failed, No Data Recovery**
			9/17/2013	1/7/2014	112	CTD Diver	Deployment Ongoing, End Date is Planned Retrieval Date
	SB2	10.6	4/11/2013	9/17/2013	159	Solinst	
			9/17/2013	1/7/2014	112	Solinst	Deployment Ongoing, End Date is Planned Retrieval Date
Union	SP1	6.7	2/18/2010	4/1/2010	42	Solinst	
			12/17/2010	4/7/2011	111	Solinst	

Table 4.2. Minimum, Average, and Maximum salinity conditions at continuous water senor locations for the entire period of record (Figure 4.1, Table 4.1) and by flow condition. See Table 4.3 for flow condition summaries.

Channel	Site	Flow Condition	Min of Salinity (ppt)	Average of Salinity (ppt)	Max of Salinity (ppt)
Ebey	QCF	extreme low flow	0.02	13.86	24.25
		high flow pulse	0.00	4.51	23.93
		low flow	0.00	10.09	25.38
		small flood	2.15	5.43	9.61
		Total	**0.00**	**8.79**	**25.38**
	EB1	extreme low flow	0.01	10.32	19.88
		high flow pulse	0.00	0.70	12.30
		low flow	0.01	4.61	21.93
		small flood	3.22	6.67	8.07
		Total	**0.00**	**3.75**	**21.93**
	EBF	extreme low flow	0.01	8.57	16.80
		high flow pulse	0.00	0.35	15.50
		low flow	0.00	3.81	24.67
		small flood	0.00	0.72	9.89
		Total	**0.00**	**3.13**	**24.67**
	FWF	extreme low flow	0.00	7.37	19.47
		high flow pulse	0.00	0.26	9.82
		low flow	0.00	2.82	20.96
		small flood	0.00	0.27	8.68
		Total	**0.00**	**2.22**	**20.96**
	EB2	extreme low flow	0.01	8.51	15.18
		high flow pulse	0.00	0.20	11.61
		low flow	0.00	2.60	19.12
		small flood	0.00	0.22	15.60
		Total	**0.00**	**2.11**	**19.12**
	EB3	extreme low flow	0.06	3.13	11.11
		high flow pulse	0.00	0.01	0.03
		low flow	0.01	1.05	14.17
		small flood	NA	NA	NA
		Total	**0.00**	**0.72**	**14.17**
	EB4	extreme low flow	0.03	0.22	2.36
		high flow pulse	0.00	0.01	0.01
		low flow	0.01	0.10	2.97
		small flood	NA	NA	NA
		Total	**0.00**	**0.07**	**2.97**
	EB5	extreme low flow	0.02	0.03	0.06
		high flow pulse	0.00	0.01	0.01
		low flow	0.01	0.02	0.35
		small flood	NA	NA	NA
		Total	**0.00**	**0.01**	**0.35**
	QTG	extreme low flow	0.21	4.55	10.10
		high flow pulse	0.01	0.66	9.26
		low flow	0.03	2.61	10.81
		small flood	0.01	0.40	2.72
		Total	**0.01**	**2.29**	**10.81**
	JC1	extreme low flow	0.10	0.22	0.42
		high flow pulse	0.03	0.32	0.96
		low flow	0.01	0.50	1.45
		small flood	0.44	0.62	0.79
		Total	**0.01**	**0.45**	**1.45**

Table 4.2 (continued). Minimum, Average, and Maximum salinity conditions at continuous water senor locations for the entire period of record (Figure 4.1, Table 4.1) and by flow condition. See Table 4.3 for flow condition summaries.

Channel	Site	Flow Condition	Min of Salinity (ppt)	Average of Salinity (ppt)	Max of Salinity (ppt)
Mainstem	MS3	extreme low flow	3.87	6.10	10.49
		high flow pulse	0.00	0.03	6.46
		low flow	0.00	2.41	19.40
		small flood	NA	NA	NA
		Total	**0.00**	**1.63**	**19.40**
	MS2	extreme low flow	0.11	0.16	0.27
		high flow pulse	0.00	0.00	0.02
		low flow	0.00	0.06	0.52
		small flood	NA	NA	NA
		Total	**0.00**	**0.04**	**0.52**
	MS1	extreme low flow	0.03	0.03	0.16
		high flow pulse	0.00	0.01	0.02
		low flow	0.00	0.02	0.56
		small flood	NA	NA	NA
		Total	**0.00**	**0.01**	**0.56**
Steamboat	SB1	extreme low flow	NA	NA	NA
		high flow pulse	0.02	7.95	26.51
		low flow	0.13	11.85	26.22
		small flood	NA	NA	NA
		Total	**0.02**	**9.69**	**26.51**
	SB2	extreme low flow	17.36	19.35	22.31
		high flow pulse	2.42	3.55	6.98
		low flow	2.29	13.30	22.99
		small flood	NA	NA	NA
		Total	**2.29**	**10.00**	**22.99**
Union	SP1	extreme low flow	NA	NA	NA
		high flow pulse	0.00	0.05	6.68
		low flow	0.00	1.50	18.46
		small flood	0.00	0.01	0.01
		Total	**0.00**	**0.98**	**18.46**

Table 4.3. Flow conditions for derived Environmental Flow Components (EFC) for the Snohomish River, which were used to classify daily flow conditions for continuous water sensor data series.

EFC Flow Stage	Min Flow (CFS)	Max Flow (CFS)	Average Flow (CFS)	Count Flow (Days)
extreme low flow	777	2280	1740	1870
low flow	2290	12100	6772	11925
high flow pulse	12200	55600	18391	4008
small flood	12200	91500	30591	506
large flood	12500	132000	34923	100
Total	**777**	**132000**	**9598**	**18409**

5) FISH

Background

Surveillance monitoring of wild salmon populations during juvenile life stages provides critical information for salmon recovery efforts, but the complex life history and large and dynamic nature of estuaries makes effective monitoring challenging. In addition, beneficial effects of estuarine restoration on juvenile salmon at the population level have never been conclusively demonstrated. Collecting information that might reflect such positive changes in realized function of restored habitats (Simenstad and Cordell 2000) requires extensive and intensive sampling in space and time, and, ideally, the collection of data on diet, residence time, growth, life history diversity, and disease. Fish/habitat relationships cannot be characterized effectively without intensive sampling in space and time because of strong seasonal heterogeneity of fish use of estuarine habitat, protracted—even multimodal—distributions of wild juvenile Chinook in estuarine habitats (Beamer et al. 2005, Rice 2007), and influences in one habitat may not be evident until downstream, later in the life cycle. Consequently, we recommend sampling every two weeks at least from late winter into early fall (and preferably year-round), every year, across the full range of estuarine habitats to develop as full a picture of fish use as possible.

The two major classes of monitoring metric are overall assemblage composition, and population and individual attributes of selected species, especially salmon. The simplest and most common metrics are presence/absence and abundance at single or few time points, integrated over the year. For estimates of relevant densities we use cumulative means, or "fish days" per unit of area and/or effort. Putting site level data into the larger context of the system is critical in interpreting monitoring data. For example, if density dependent processes are limiting juvenile salmon rearing in the estuary (Beamer et al. 2005, Beamer and Greene in prep), declining local densities may be a positive response to a given restoration action.

Methods

Sampling design and protocols

The overall approach to the sampling scheme was to cover the entire landscape over most of the year, using a subset of historically sampled NOAA index sites (Rowse and Fresh 2003) to maintain the time series, but also to add stratified random sites across the entire estuary to ensure full spatial coverage and reduce bias. System-wide fish sampling in the Snohomish River estuary occurred twice per month between February and August and once during September. We chose a stratified random sampling design to select sites from the mainstem Snohomish River, all three distributary sloughs as well as the nearshore areas to the north and south of the river mouth. We divided the estuary and nearshore shorelines into 9 zones based on the major bifurcations in the system and the north and south nearshore shorelines, and allocated random sites within each zone as described below. Random sites for each data collection event (DCE) were selected within each zone using GIS as described (QAPP 2013). In addition, we included 16 index sites, sampled during every DCE, throughout the landscape with at least one site in each of the 9 zones. Index sites were chosen from a set of sites that NOAA had been monitored to varying degrees since 2001.

In addition to the random sites selected for each system-wide sampling event, an additional 6 random sites were sampled in lower Ebey Slough adjacent to the Qwuloolt restoration project site as part of our intensive fish sampling program. Sites were sampled twice per month from Feb-Aug and once per month the rest of the year to maintain year round coverage. Intensive fish monitoring of the Qwuloolt restoration site also included sampling in blind tidal channels in four locations. Fyke traps were deployed during every sampling event from Feb-Aug.

To select the random sites, high resolution orthophotos (23 cm) of the Snohomish River estuary were used to derive a center flow path polyline for all major channels and sloughs using ArcMap (Version 10.0). The center flow path polyline was divided into segments between each bifurcation in the estuary system. Bifurcation and stream order were derived for each channel segment based on estimated channel widths at each bifurcation from high resolution orthophotos as described in Beamer et al. (2005). These channel segments were further split based on classification of fishable shorelines based on the high resolution orthophotos. Shorelines with pilings, large wood accumulations, armoring, and boat moorage were classified as not fishable. Restricting site selection to areas that were deemed “fishable” resulted in an uneven distribution of sites within each zone (see Zone 2). Random sample stations were generated within each channel segment and sampling zone using ArcMap (Version 10.0) based on the allocations listed in Table 5.1. These allocations were based on a combination of the number of fishing days available per DCE, the number of sites that could be sampled per fishing day, a minimum target of three random sites per zone, and the length of the channel within each zone relative the entire channel network. A map showing the sampling zones and an example of the planned sample effort for index and random sites for a DCE is provided in Figure 5.1.

We used two distinct methods for sampling fish: beach seines and fyke traps. For main channel slough habitats, fish were sampled using a modified Puget Sound beach seine measuring 36m in length and 1.8m (wings) to 3.0m (bag) in height made of 3mm (wings) to 1.5mm (bag) knot-less nylon mesh to sample fish assemblage at each site. All beach seines were conducted during a falling tide in a neap series whenever possible. At each site the seine set was in a semi-circle from upstream to downstream with one end held on shore and the other set from the boat. Once the net was set, both sides were pulled in together with three or four individuals until the entire catch was consolidated in the bag (i.e. center of the net). Fish were immediately removed from the bag and placed into 5-gallon buckets with fresh water from the site and held for processing.

Off channel, or blind tidal channel, habitats were sampled using a fyke trap. Sampling of off-channel habitat was primarily associated with the Qwuloolt intensive sampling program, therefore sites were limited to areas adjacent to the project site (lower Ebey Slough and Quilceda Creek). Traps were set at high slack water and spanned the entire channel. Fish residing in the channel were funneled into the trap as the water level receded during the ebbing tide. All fish were removed from the traps at or near low water and were processed immediately before being released. Water temperature and salinity were recorded at the start of each sampling event.

For both sampling methods, fish processing was largely the same. Up to 25 individuals of each species were measured to fork length where applicable and to total length when no fork is present. Any additional individuals of each species were counted. For our system-wide sampling efforts, up to five marked and five unmarked (10 total) juvenile Chinook salmon from each zone as described above, were sacrificed with a lethal dose of MS-222. For our intensive monitoring of the Qwuloolt site we selected up to five additional, marked and unmarked, Chinook from the six beach seines and each of the four fyke trap locations. Sacrificed individuals were taken to the lab to have otoliths, stomachs, and coded wire tags removed and archived for future analysis and all individual carcasses were subsequently frozen. Any individuals that appeared unduly stressed or dead upon retrieval of the net were selected before healthy individuals were sacrificed.

Table 5.1**:** Sample allocations for index and random sites within each zone and channel.

Channel	Zone	Index	Random	Total
Mainstem	1	2	1	3
Mainstem	2	2*	0	2
Upper Ebey Slough	3	1	4	5
Mainstem	4	3	4	7
Upper Steamboat Slough	5	0	2	2
Lower Steamboat Slough	6	2	3	5
Lower Union Slough (Includes Smith Island Intensive)	6	1	4	5
Lower Ebey Slough (system)	7	2	6	8
Lower Ebey Slough (QW intensive)	7	1	6	7
Jones Creek	7	1	4	5
Quilceda Creek	7	0	3**	3
Priest Point Shoreline	8	1	2	3
Mukilteo Shoreline	9	1	3	4

*Originally derived as random sites but site conditions restricted sampling to the same location, thus these sites were reclassified as index sites.

**Random sites were allocated to Quilceda Creek but were not sampled in 2013.

Connectivity was derived for each random and index point sampled as a function of both the distance and complexity of the pathway through the estuary. Connectivity was derived as described in Beamer et al. (2005) at a 152 meter (500 ft) resolution along the center flow path. Each random and index sample point was attributed with the connectivity estimate for the closest connectivity grid within the channel segment of the point.

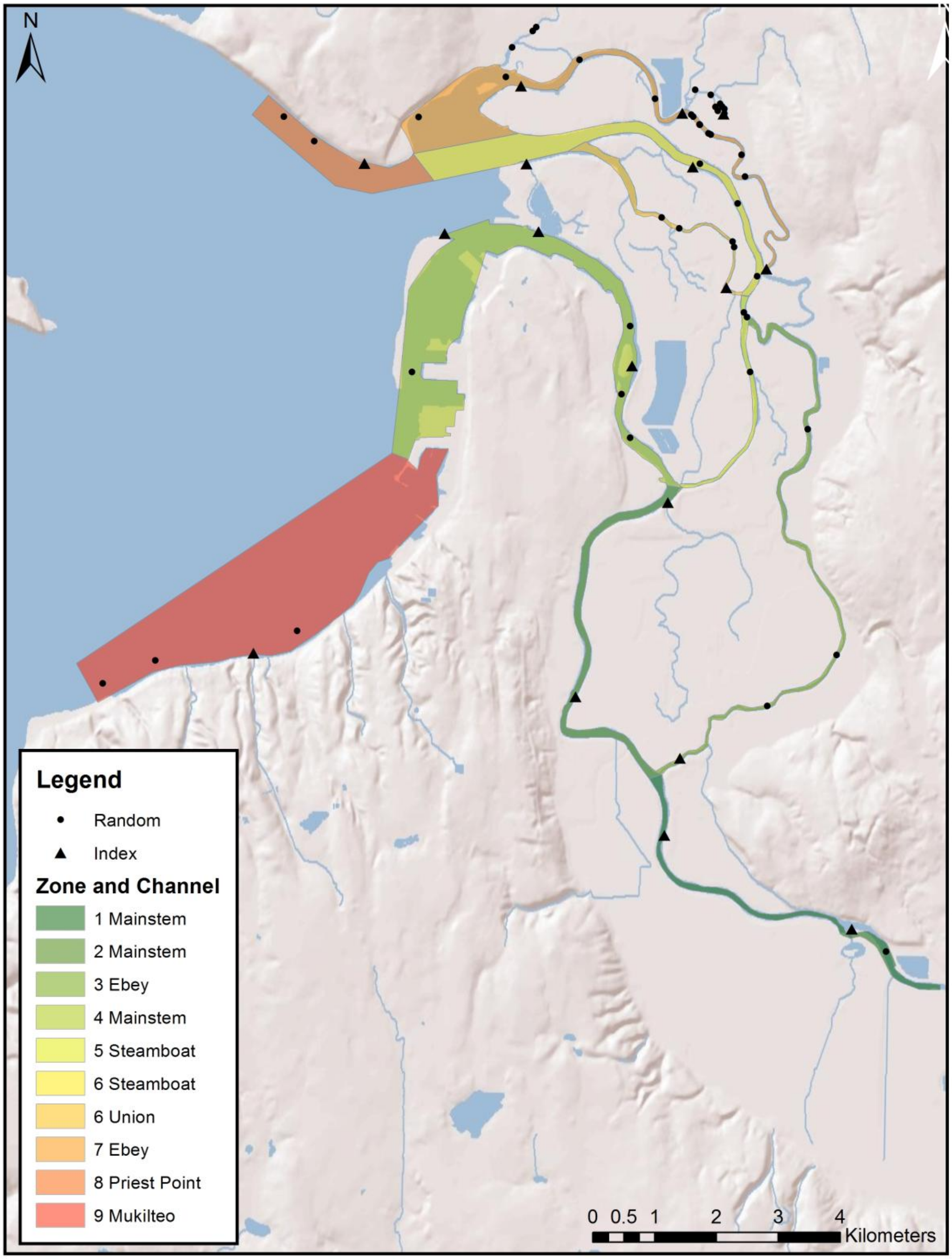

Figure 5.1. Example allocation of random fish sampling sites for each zone and channel in the Snohomish River estuary and nearshore areas for each sampling cycle in 2013. Numbers of sites allocated per sampling cycle (DCE) are provided in Table 5.1.

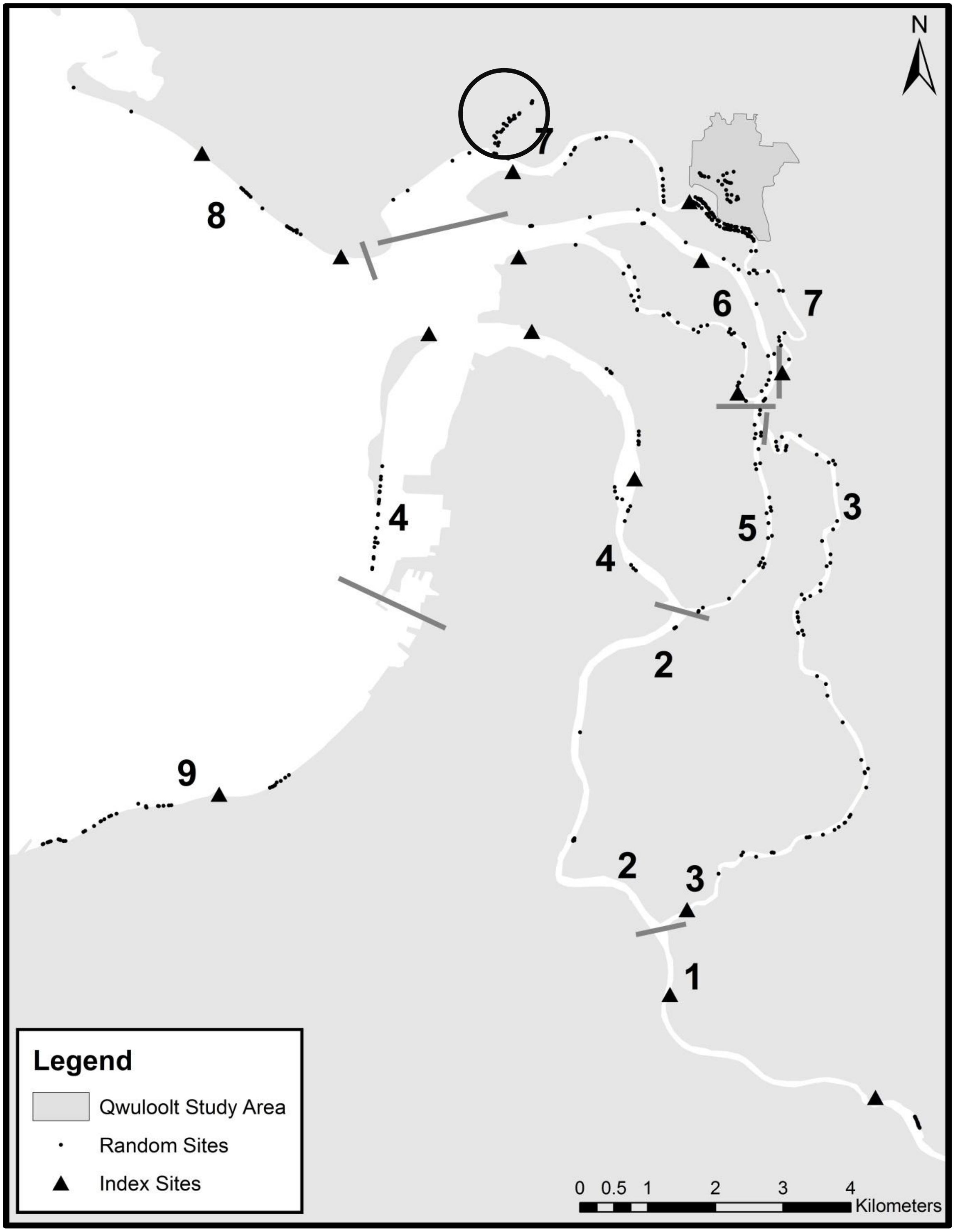

Figure 5.2. Resulting sites selected by the sampling design allocation (Table 5.1, Figure 5.1) in 2013 by sample zone. Divisions for sample zones are indicated by grey bars with zones indicated by numbers between the channel bifurcations. Not all sites allocated were used, for example, the Quilceda Creek sites (black circle) dropped due to low catch.

Analysis

For preliminary analysis of fish data we used descriptive statistics, simple graphical analysis, and multivariate techniques. Our goals in this limited context are to provide a summary of field effort and basic patterns of fish use of the estuary in space and time.

Results

Effort

A total of 672 beach seines were completed throughout the estuary during 2013 (Fig 5.3, Table 5.2). We sampled 435 random sites throughout the mainstem Snohomish River and all three distributary sloughs as well as the nearshore areas to the north and south of the river delta. The remaining 237 beach seine sets occurred at the 16 index sites dispersed throughout the landscape. Effort was not uniformly distributed for two main reasons; 1) not all zones were equal length therefore site allocation was unequal among zones, and 2) due to conditions “on the ground” (e.g. shoreline armoring, pilings, logs/stumps) not all areas within each zone were suitable for beach seining. The majority of the effort occurred in Ebey slough and the mainstem Snohomish River. Ebey Slough is the longest of the three distributary sloughs and therefore had the largest allocation of random sample sites (n = 111sites/sets) within the system. In addition, the intensive sampling of lower Ebey slough associated with the Qwuloolt restoration project accounted for 114 of the 170 total sets in zone 7. The mainstem Snohomish River had the largest allocation of index sites (7 sites with 90 sets) and thus had the greatest number of continuously sampled sites across the landscape. However, Zone 2 (middle mainstem Snohomish River) was sampled less frequently due to shoreline armoring/bank modification which precluded the use of beach seines in much of the area. The lowest effort occurred in Union slough (n = 65 sets), the smallest of the distributary sloughs in the estuary, but did get 4 random sites adjacent to the Smith Island restoration project during each sampling event from Mar-Aug. Upper Union Slough is largely unfishable using our chosen methods due to the prevalence of large woody debris and the width of the channel.

Sampling by month was relatively consistent during 2013 (Table 5.2). Sets were made in each of the 9 zones every month though the total number of sets varied slightly from month to month during the early part of the season. The average total number of sets each month (Feb –Aug) was 86 with a high of 90 in April and August and low of 78 sets in February. The number of random sites sampled each month (Feb-Aug) ranged between 50 and 60 while index sets ranged between 27 and 31. The number of sites sampled in September was cut in half due to circumstances that precluded us from sampling in the latter half of the month. Variation in effort among months was primarily the result of one or more of the following factors: river flow, catch levels, and daylight/tide window. High river flows made some sites unfishable due to current velocities and/or the lack of a suitable area for hauling the net ashore. Increasing catch levels result in increased processing times which may affect the number of sites that can be sampled within the given tide window. Finally, early season (Feb-Mar) sampling is particularly susceptible to shortened field days due to an interaction between day length and tide cycle.

Table 5.2. Distribution of fishing effort by channel, zone, and site type during 2013.

			# sets		
Channel	Zone	# index sites	index	random	total
Mainstem					
	1	*2*	20	14	34
	2	*2*	25	4	29
	4	*3*	45	35	80
Ebey					
	3	*1*	15	54	69
	7	*3*	48	170*	218*
Steamboat					
	5	*0*		28	28
	6	*2*	30	22	52
Union					
	6	*1*	26	39	65
Nearshore					
	8	*1*	14	27	41
	9	*1*	14	42	56
Totals			**237**	**435***	**672***

*Includes the intensive sampling of lower Ebey Slough associated with the Qwuloolt restoration project

Table 5.3. Fishing effort distribution by month and site type in 2013. Effort in January, October, November and December reflects sampling associated only with the Qwuloolt restoration project.

Month	Index	Random	Total
Jan	1	6	7
Feb	28	50	78
Mar	27	53	80
Apr	30	60	90
May	31	57	88
Jun	31	57	88
Jul	31	57	88
Aug	30	60	90
Sep	15	27	42
Oct	1	6	7
Nov	1	6	7
Dec	1	6	7
	237	*435*	***672***

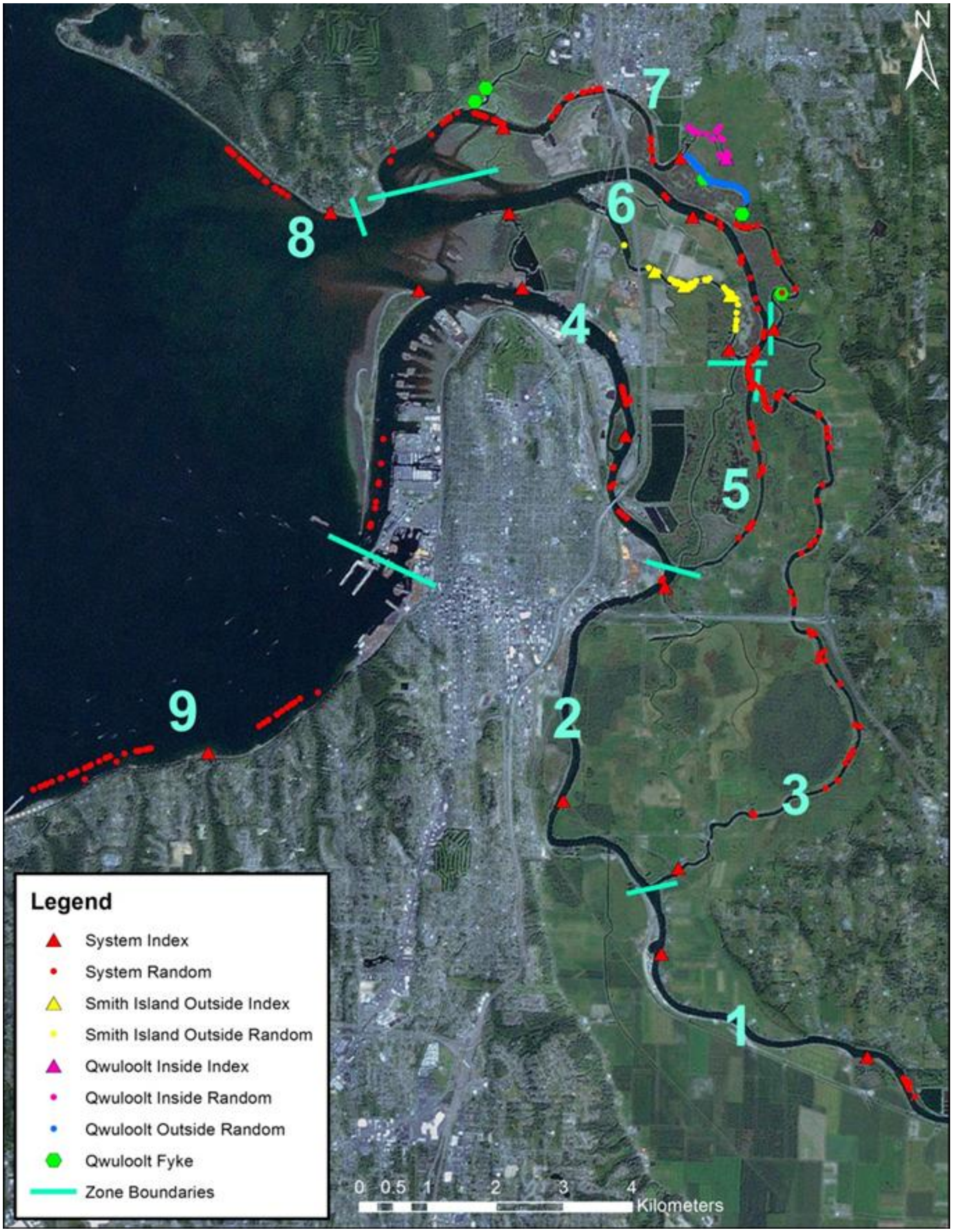

Figure 5.3. Distribution of fish sites actually sampled in the Snohomish River estuary and nearshore areas during 2013. Note Qwuloolt (blue points) and Smith Island (yellow triangles and dots) intensive sites.

Assemblage composition

Strong seasonal structure was observed in both beach seine and fyke trap catches, but spatial structuring was much stronger in seine catches than traps due to much greater sampling area and number of seine sites (Figures 5.4 and 5.6). Upstream-downstream and seasonal gradients are apparent in the multivariate analyses of system-wide beach seines (Figure 5.4, Table 5.4). Assemblage composition was very similar at Qwuloolt and Smith Island restoration sites (Figure 5.7).

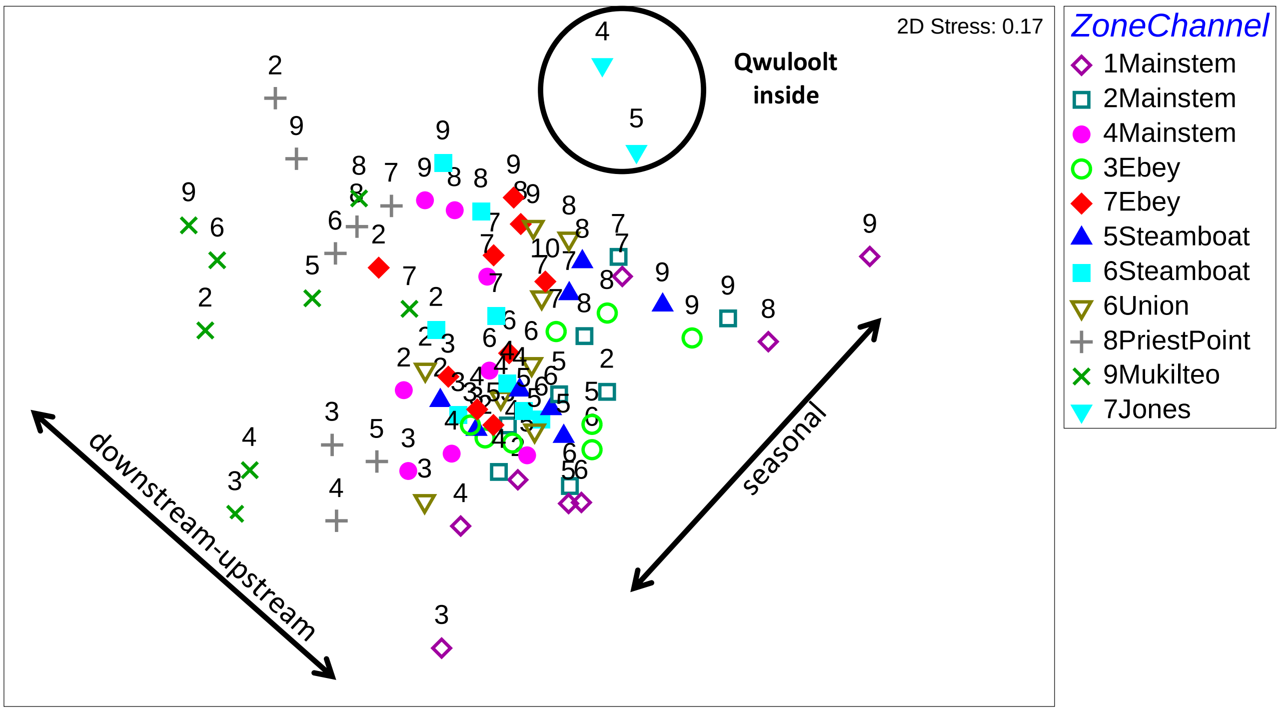

Figure 5.4. MDS plot of 2013 seine fish catch for all months (indicated by numbers) and areas sampled in the estuary. Each point represents one month/zone/channel combination (See Figure 5.5 below). Tests for overall differences by month: R=0.46, p=0.001; zone/channel: R=0.66, p=0.001.

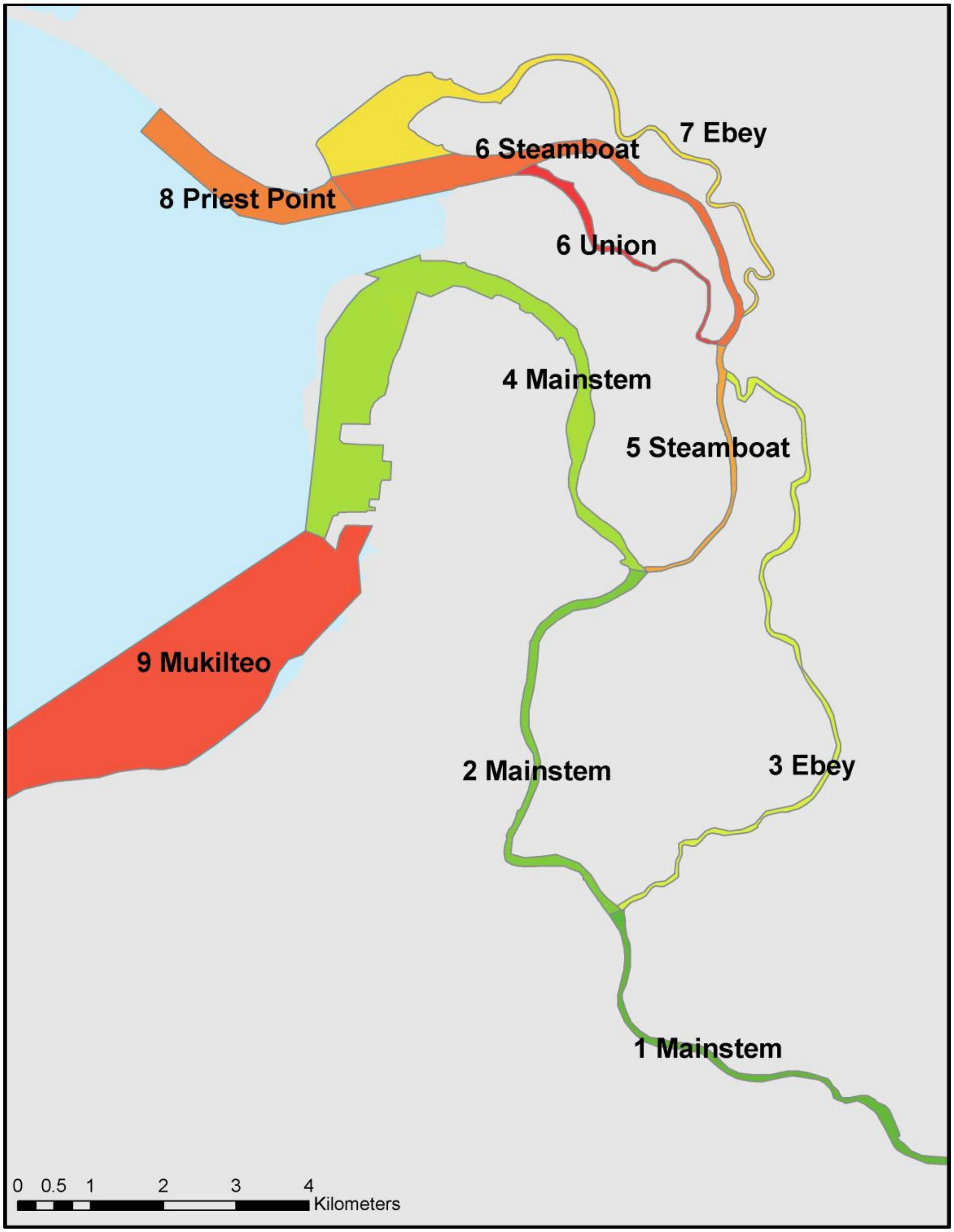

Figure 5.5. Combined zone and channel designations used in multivariate fish analyses.

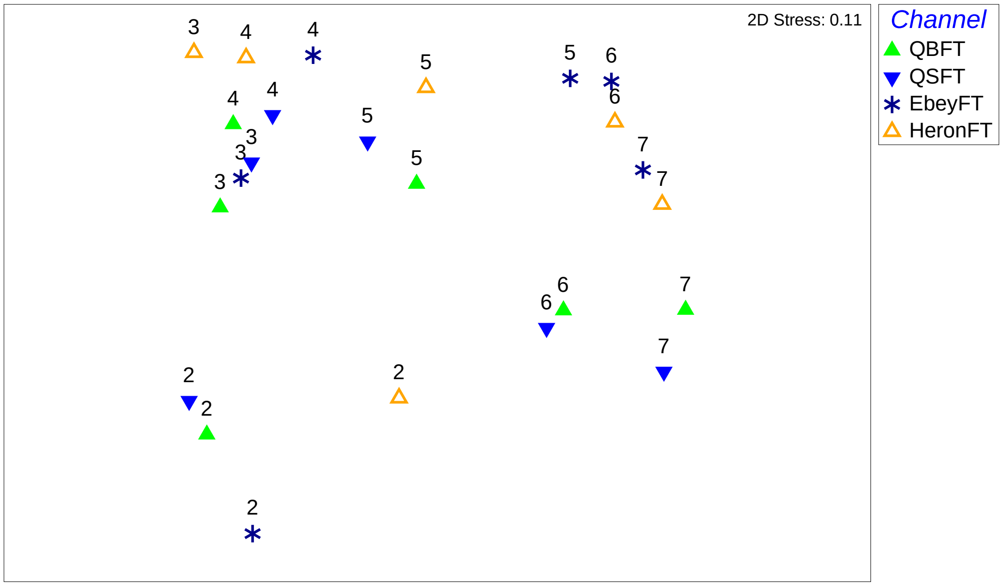

Figure 5.6. MDS plot of 2013 fyke trap fish catch for all months (indicated by numbers) and trap sites sampled in the estuary. Each point represents one month/site combination (QB=Quilceda big, QS=Quilceda small, Ebey=Ebey Island across from Qwuloolt, Heron=Heron Point adjacent to Qwuloolt. Tests for overall differences by month: R=0.76, p=0.001; site: R=0.30, p=0.001.

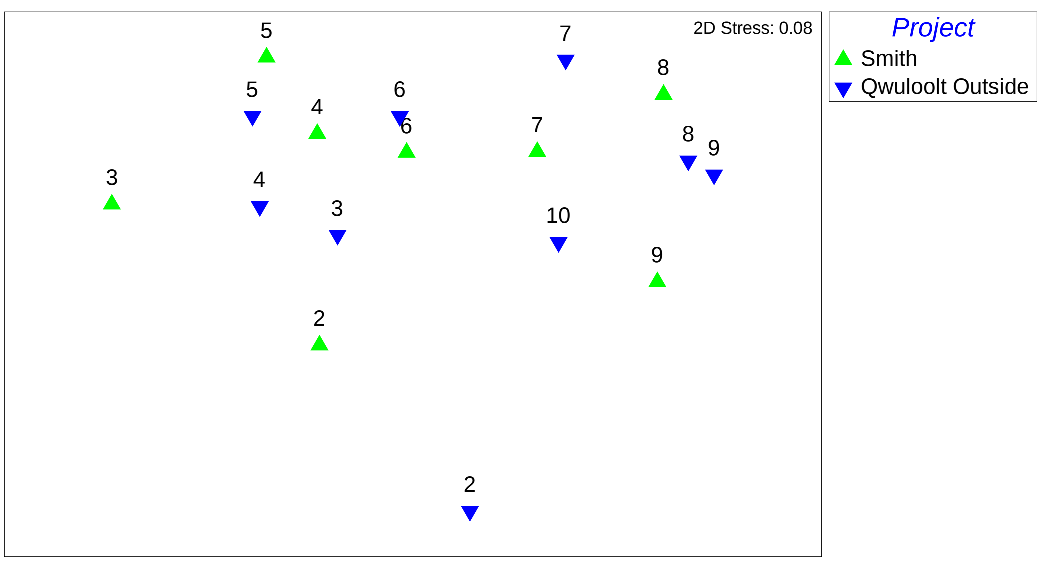

Figure 5.7. MDS plot of 2013 seine fish catch for all months (indicated by numbers) and sites sampled in tidally influenced sloughs adjacent to the Qwuloolt and Smith Island restoration sites. Each point represents one month/site combination. Tests for overall differences by month: R=0.67, p=0.001; site: R=-0.06, p=0.758.

Table 5.4. Contributions of species to statistical similarity of fish assemblages within each zone/channel segments across all months (SIMPER test, top 90% cut-off; average zone/channel group similarity in parentheses).

Species	Average abundance	% Statistical contribution to group similarity
1Mainstem (30.36)		
Chinook UM	3.98	24.69
coho	2.35	23.43
starry	1.53	11.87
chum	2.46	11.16
peamouth	2.31	8.13
mtn whitefish	0.91	4.83
stickle	1.60	4.68
prickly	1.37	4.55
2Mainstem (44.44)		
stickle	3.55	24.12
coho	2.98	21.37
Chinook UM	3.57	16.47
starry	2.71	13.72
prickly	1.94	11.09
chum	1.77	4.98
4Mainstem (49.65)		
stickle	4.18	21.36
starry	2.97	20.99
Chinook UM	3.19	16.80
staghorn	2.69	15.16
chum	2.89	8.75
surf smelt	1.20	4.42
coho	1.67	4.36
3Ebey (54.08)		
coho	3.98	24.96
Chinook UM	4.14	19.84
starry	2.82	16.83
stickle	3.01	16.00
prickly	1.56	7.85
peamouth	2.71	7.48
7Ebey (52.81)		
stickle	4.66	26.15
starry	3.53	21.34
Chinook UM	2.01	7.95
prickly	1.36	7.83
staghorn	1.65	7.81
coho	2.12	7.79
shiner	2.19	5.41
peamouth	1.37	5.19
chum	2.18	4.49

Table 5.4 continued.

Species	Average abundance	% Statistical contribution to group similarity
5Steamboat (54.02)		
stickle	3.89	23.58
starry	3.29	18.14
Chinook UM	3.80	14.99
coho	2.96	13.52
prickly	2.24	11.92
staghorn	1.71	7.76
peamouth	2.33	5.17
6Steamboat (50.94)		
stickle	4.14	24.06
starry	4.06	22.24
Chinook UM	3.45	16.69
staghorn	2.20	8.41
coho	1.99	7.83
prickly	1.30	5.59
chum	1.92	4.29
shiner	1.79	3.66
6Union (52.28)		
stickle	5.11	30.46
Chinook UM	3.05	15.96
starry	3.03	15.51
staghorn	2.13	9.81
chum	2.57	7.12
coho	2.19	6.87
peamouth	1.86	5.77
8PriestPoint (43.70)		
surf smelt	4.27	28.61
shiner	3.98	16.89
starry	1.94	15.29
staghorn	1.44	10.78
chum	3.15	9.21
Chinook UM	1.16	6.13
stickle	0.96	3.62
9Mukilteo (47.39)		
sand lance	5.84	36.25
shiner	3.28	11.45
starry	1.87	9.11
staghorn	1.25	8.13
chum	2.15	4.73
saddleback	1.15	4.66
stickle	1.11	3.85
Chinook UM	0.72	3.67
surf smelt	0.69	3.38
bay pipefish	0.87	2.95
English sole	0.41	1.66
sharpnose	0.29	1.63

Juvenile salmon timing, density, and size

Density and timing in beach seines

Juvenile Chinook and coho salmon were present in sites throughout the estuary and nearshore shorelines in all months sampled during 2013 (Figure 5.8). However, the duration and timing of peak densities differed by species and/or origin (hatchery v. wild). Unmarked Chinook salmon had the longest duration and the highest peak mean density during 2013. Mean densities of UM Chinook steadily increased from Feb – Jun with a peak at 712 fish/ha in Jun. The prolonged duration of wild Chinook throughout the year emphasizes the importance of estuarine rearing for juvenile Chinook within the basin.. Juvenile coho showed a similar pattern though they appeared in catches slightly later and peaked earlier (May) at lower mean density (442 fish/ha) than unmarked Chinook. However, after June, coho had the highest mean densities for the remaining months of sampling. Such prolonged residence of coho in the estuary later in the year may represent delayed migration timing from freshwater habitats (Kubo et al. 2013 and/or suggests a significant estuarine rearing component of the coho life history in the system. Hatchery reared Chinook were represented in the catch for least amount of time and at the lowest densities compared to both unmarked Chinook and coho salmon. Marked Chinook were caught at very low densities until the peak in June and then showed a steady decrease through August. The peak of marked fish density in June likely reflects the release of sub-yearling Chinook from Wallace River hatchery facility. Similarly, the very low densities of marked Chinook early in the year represent a much smaller program of yearling releases from the same facility while also highlighting the potential lack of estuarine residence/dependence by that particular life history type.

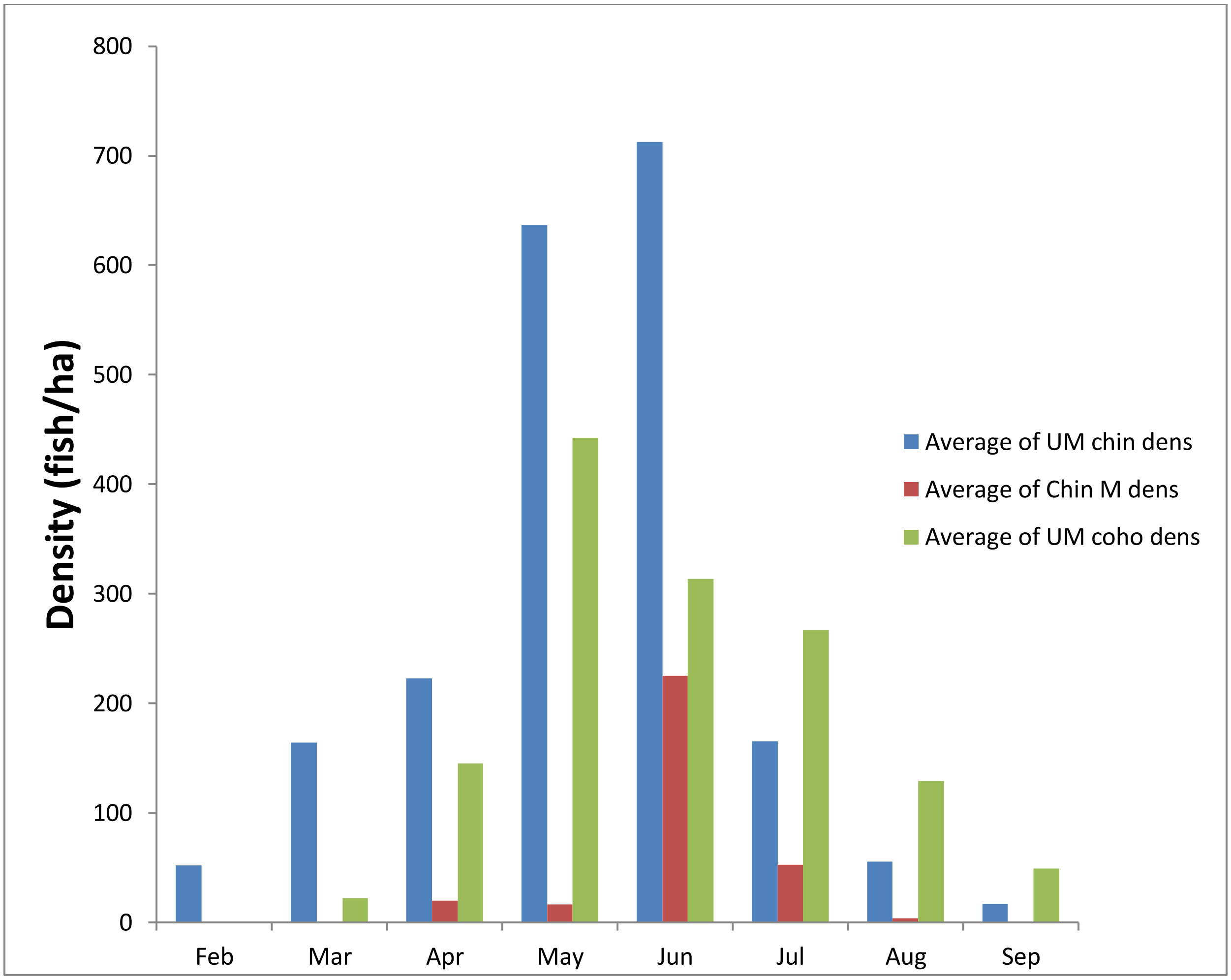

Figure 5.8. Mean juvenile salmon densities (fish/ha) from all beach seine sets throughout the system by month.

Mean densities of juvenile salmon were also variable among zones and/or channels throughout the system (Figure 5.9). Unmarked Chinook were captured in higher densities in all zones compared to both juvenile coho and hatchery reared Chinook. In general, observed patterns of Chinook density were closely related to mean zone connectivity through the system with a notable exception in zone 5 (Figure 5.10). Densities in zone 5 were markedly higher than all other zones. Higher densities in zone 5 were also associated with higher variability suggesting the pattern may reflect abnormally large, yet isolated, catches during some period or may be associated with unique hydrological conditions as discussed above. In contrast, coho densities were not highly correlated to mean connectivity and were highly variable across the landscape (Figure 5.10). Again zone 5 had the highest observed mean coho densities though there were also elevated densities in zones 3 and 7 compared to other areas in the system. The variable densities of coho may be related to hydrology, habitat types, and/or locations of source populations. Zone 5 showed a unique pattern of hydrological conditions that may have affected coho densities much the same as the observed densities of unmarked Chinook. This area of the estuary also contains the most in-tact forested estuary habitat (Otter Island) where coho have been observed in high abundance during past monitoring activities (Fresh, unpublished data). Lastly, unlike the Chinook populations in the system which are primarily from sources above the estuary complex, there are two notable coho populations (Quilceda and Allen Creeks) that enter the estuary in zone 7. Therefore the perceived lack of relationship to landscape connectivity and elevated densities may be indicative of where these fish enter the estuary.

In addition to the variability to the overall spatial variability in densities among species, there was considerable variability between estuary zones through time (Figure 5.11). For unmarked Chinook the patterns of cumulative densities were tightly correlated among the zones associated with the estuary proper (zones 1-7). However, in zones 8 and 9 (north and south nearshore areas, respectively) unmarked Chinook densities varied inversely and were not indicative of the rest of the system. Zone 8 (Priest Point) saw large proportion of unmarked Chinook very early in the season before gradually tapering off throughout the rest of the year. In contrast, zone 9 (Mukilteo shoreline) had relatively low densities until July when densities increased rapidly before falling off again in August. The patterns observed for marked Chinook salmon were highly indicative of a uniform distribution of fish throughout the system that coincided with hatchery releases in June. The spatial/temporal patterns of coho distribution were the most variable. While the overall pattern was reflective of the long estuary residence period beginning in March, there was considerable variability in both space and time. There was clear zone-specific timing for peak coho densities across the landscape. Such variability may indicate potentially complex life history patterns as well as the effect of source population location.

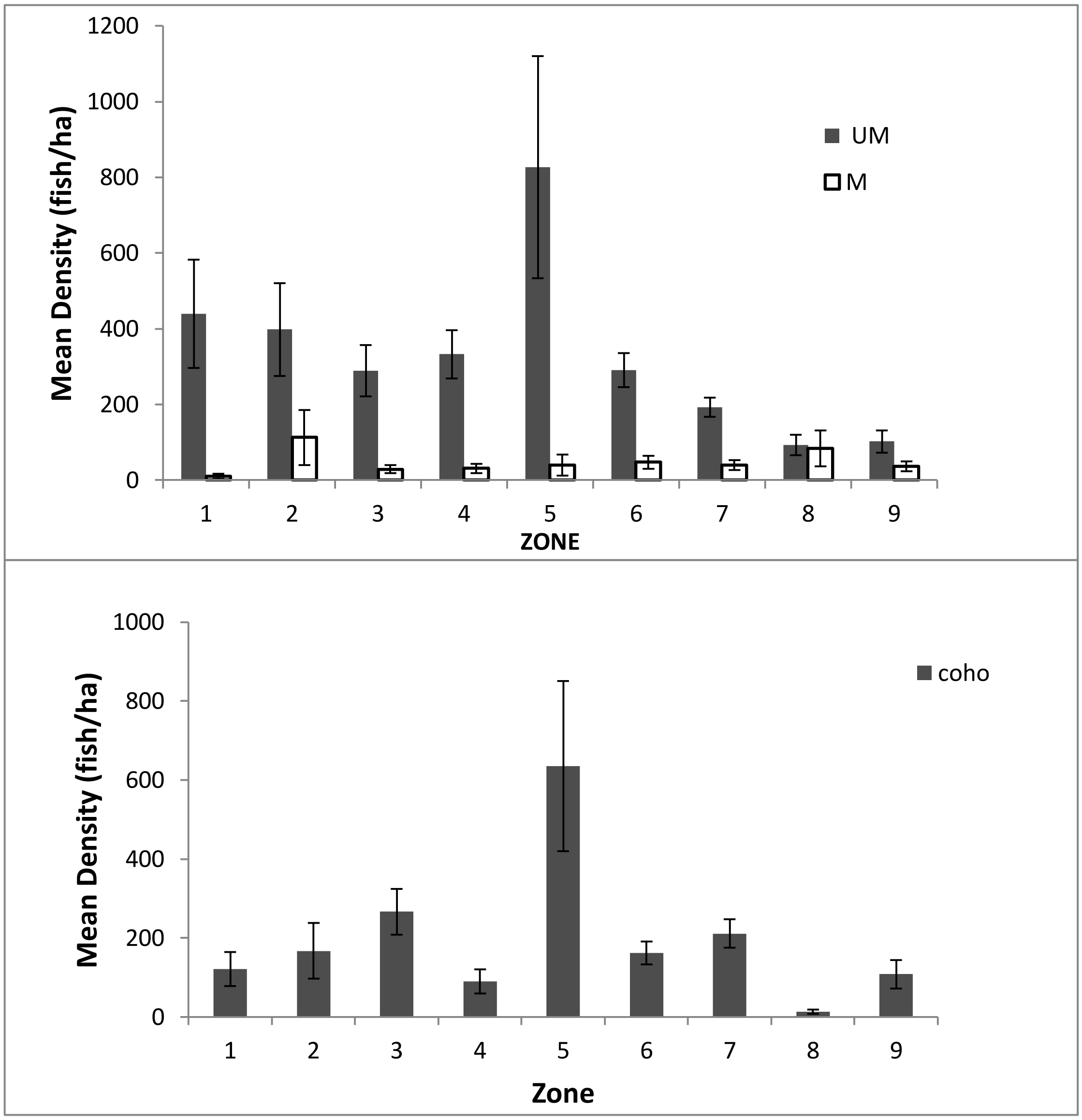

Figure 5.9. Mean densities of marked (M) and unmarked (UM) Chinook salmon and coho salmon by estuary zone from all beach seine sets.

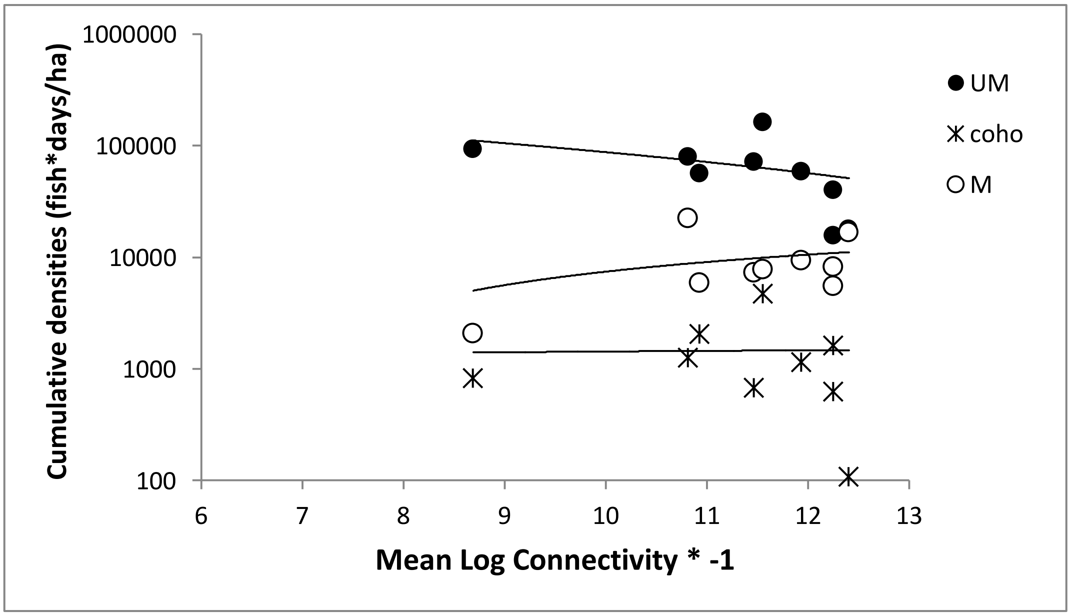

Figure 5.10. Total cumulative densities relative to mean log connectivity by species. Each point represents the values for each specific estuary zone.

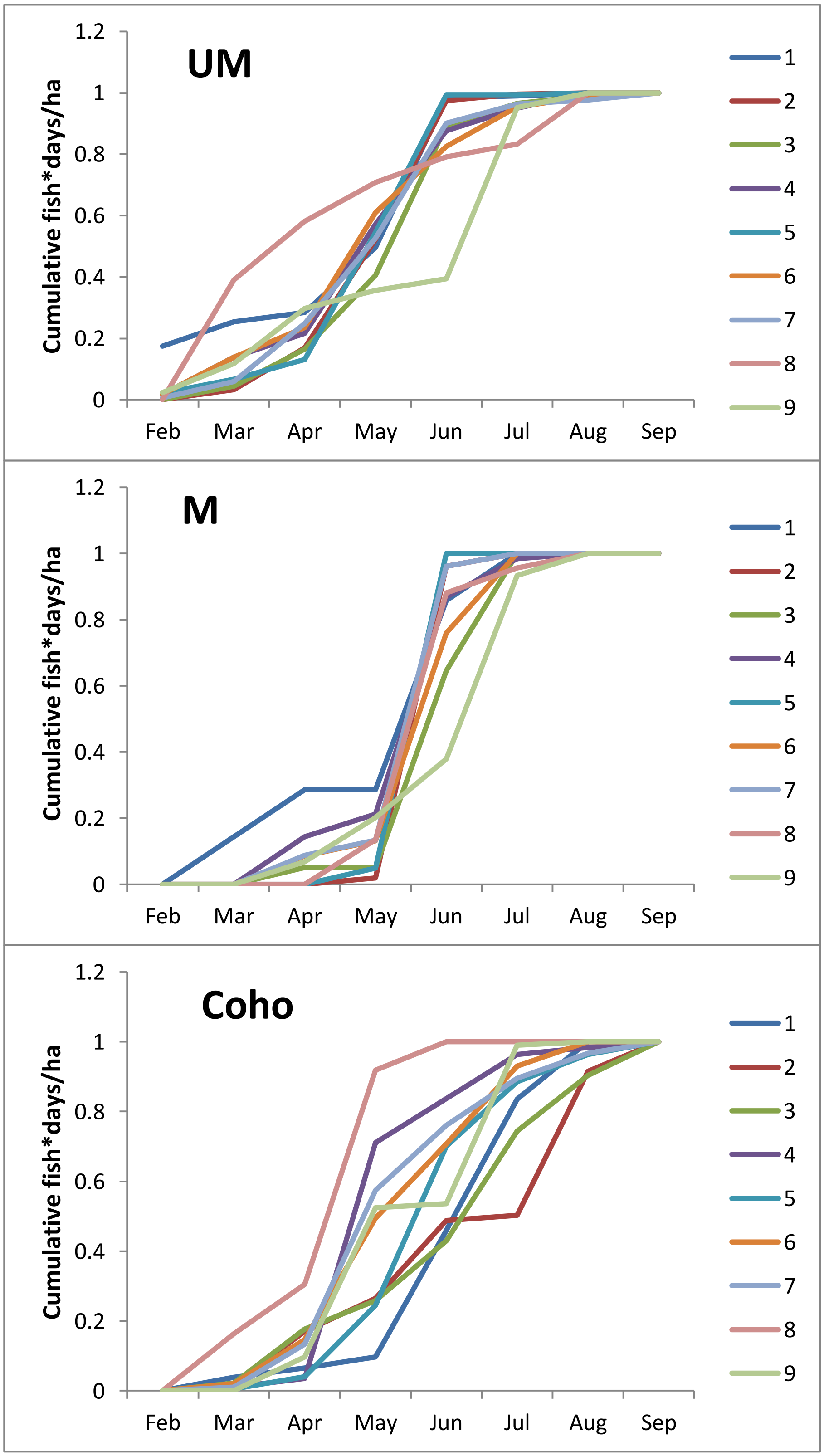

Figure 5.11. Cumulative densities (fish/ha) by zones over time for each species. Marked Chinook (M), unmarked Chinook (UM), and coho salmon.

Size distribution of juvenile salmon in beach seines

Size of juvenile salmon also varied among species and through time (Figure 5.12). The majority of unmarked Chinook were captured at sizes ranging between 40 and 100 mm. Unmarked Chinook showed a steady increase in size with relatively little variability from early to late periods in 2013. Fish caught earlier in the season were primarily less than 50mm FL though the presence of larger fish in April is indicative of a yearling component to the population (Figure 5.13). Unmarked Chinook caught after April steadily increased in size as densities peaked and began to decrease. Size of marked Chinook salmon throughout the sampling period was indicative of hatchery rearing and release practices. The increasing size and corresponding increases in densities of unmarked Chinook likely indicate the presence of multiple life history types within the basin. Marked Chinook encountered early in the season were significantly larger than the unmarked Chinook during the same time period (Figure 5.14). This reflects the small release of yearling Chinook in the system as densities of these larger fish remained very low. As densities increased in June with the sub-yearling release size was more or less uniform with low variability as it gradually increased before the end of the summer. Overall patterns of coho size distribution over time were more variable than either marked or unmarked Chinook, especially early in the sampling period. Similar to the early pattern of unmarked Chinook size, early season coho size distributions are indicative of a yearling life history type present during the late winter and early spring (Figure 5.15).

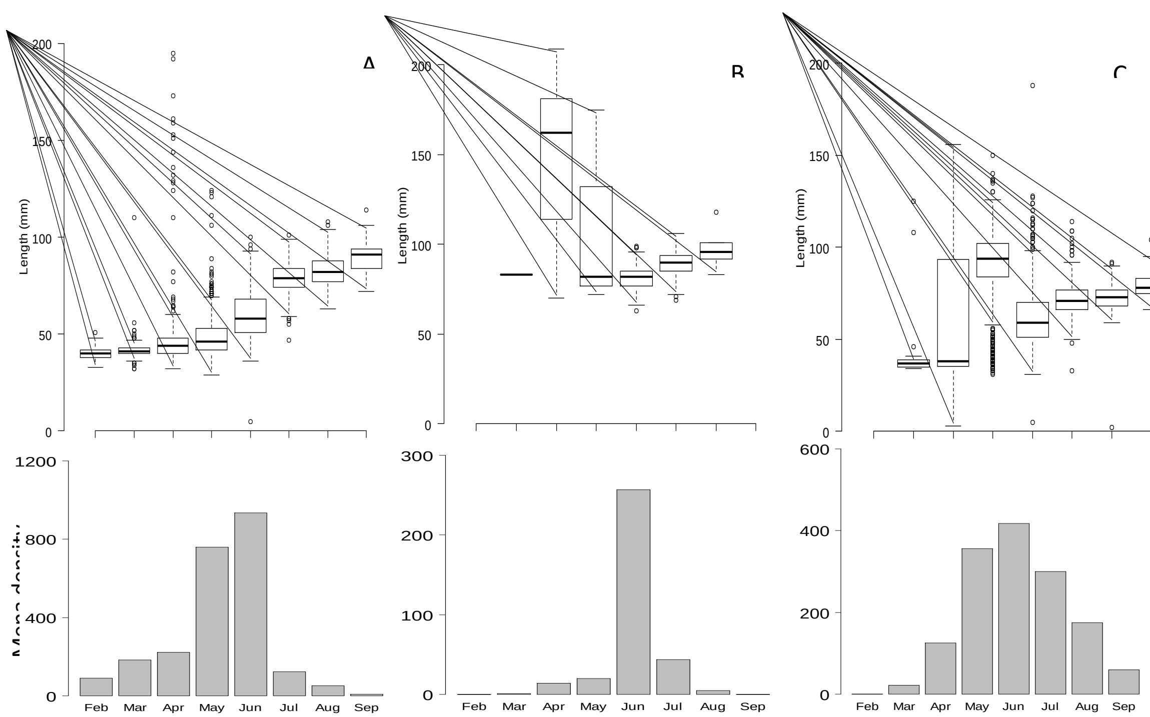

Figure 5.12. Size distribution by month and associated mean densities for unmarked Chinook (A), marked Chinook (B), and coho salmon (C) captured in beach seines. Horizontal lines in each box represent the median, boxes the 25 and 75% quartiles,

whiskers represent the upper and lower 95%, and circles are outliers. Note different y-axis values on barplots.

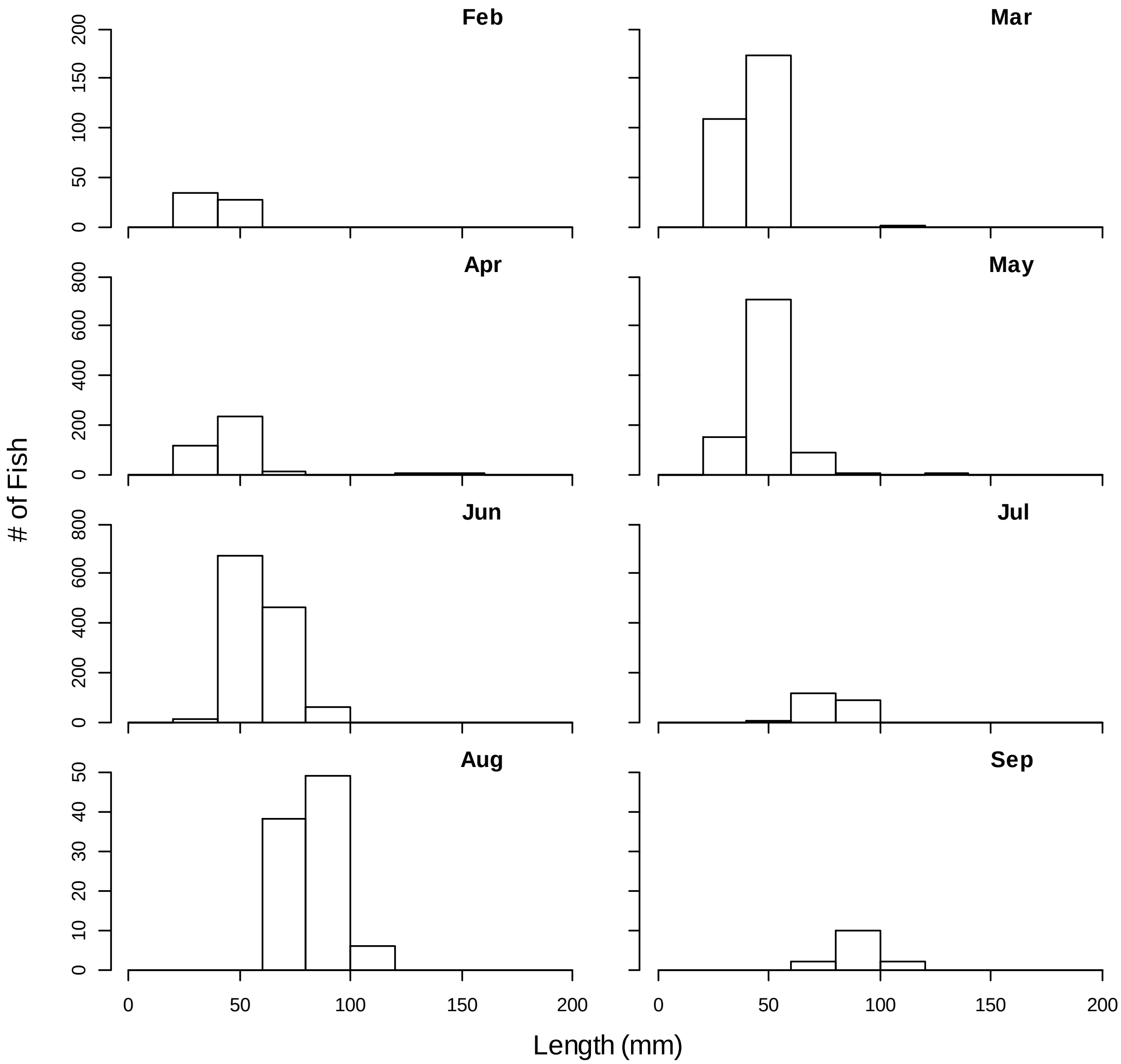

Figure 5.13. Length frequency histograms for unmarked Chinook captured in beach seines by month in 2013.

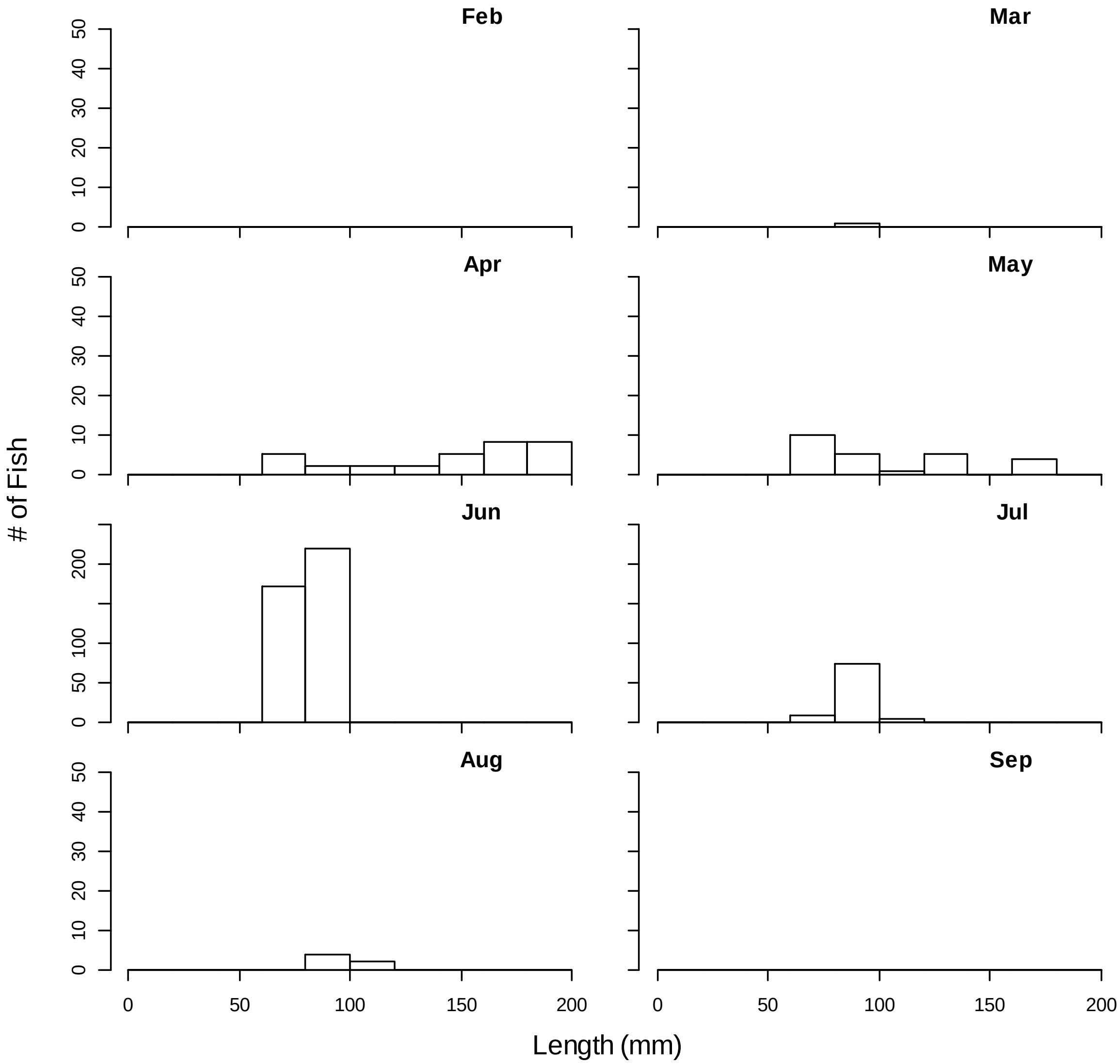

Figure 5.14. Length frequency histograms for marked Chinook captured in beach seines by month in 2013.

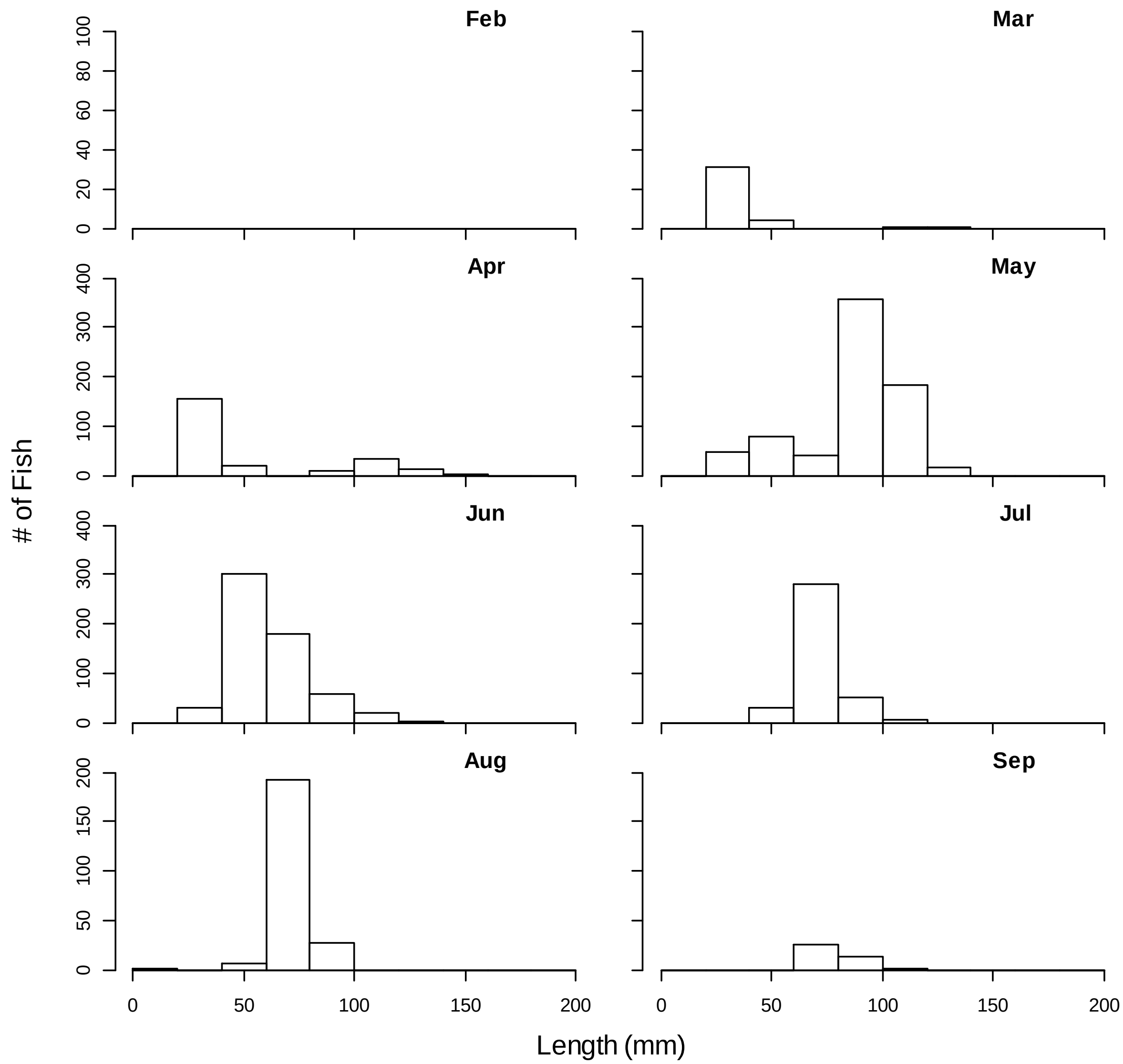

Figure 5.15. Length frequency histograms for unmarked coho salmon captured in beach seines by month in 2013.

Density and timing of juvenile salmon in fyke traps

Overall salmon densities at fyke trap sites were dominated by the presence of coho salmon throughout the sampling period (Figure 5.16). Both Chinook and coho appeared in fyke trap catches in March and remained until the end of the sampling period in July. Densities of coho salmon increased rapidly through May before steadily declining through July. Coho densities at fyke trap sites were consistently 6-10x higher than either marked or unmarked Chinook densities beginning in April. Unmarked Chinook salmon densities increased more consistently until the peak in June after which densities again decreased significantly. Marked Chinook densities were very low compared to coho and unmarked Chinook with a typical peak in June coincident with the hatchery release. Overall densities of coho and Chinook salmon also varied by location (Figure 5.17). Mean coho densities were higher than marked and unmarked Chinook at three of the four fyke trap sites. Differences were most pronounced at the Ebey fyke site and the Quilceda small site. These sites are adjacent to two source populations of coho in the lower estuary (Allen Creek and Quilceda Creek, respectively) therefore higher coho densities may be expected. Heron Point and Quilceda Big sites had very similar densities of coho and unmarked Chinook over the entire sampling period. Marked Chinook were present at relatively low densities across all sites during 2013.

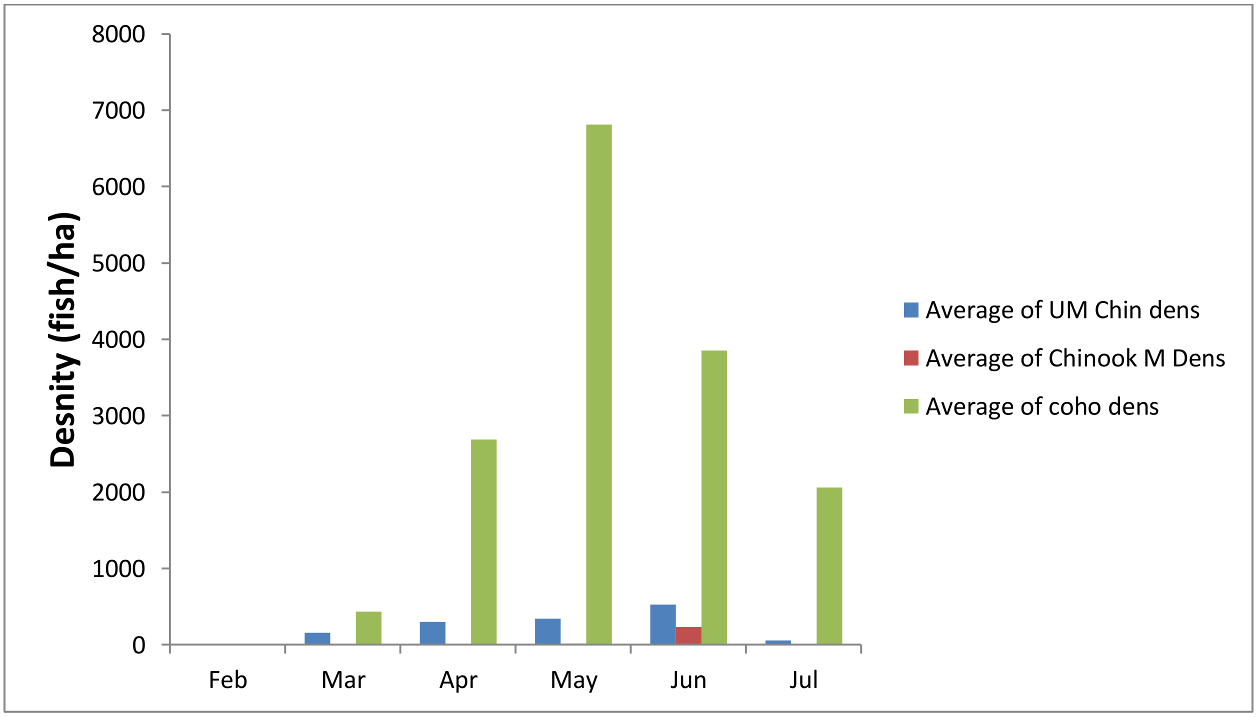

Figure 5.16. Mean juvenile salmon densities in fyke trap catches by month.

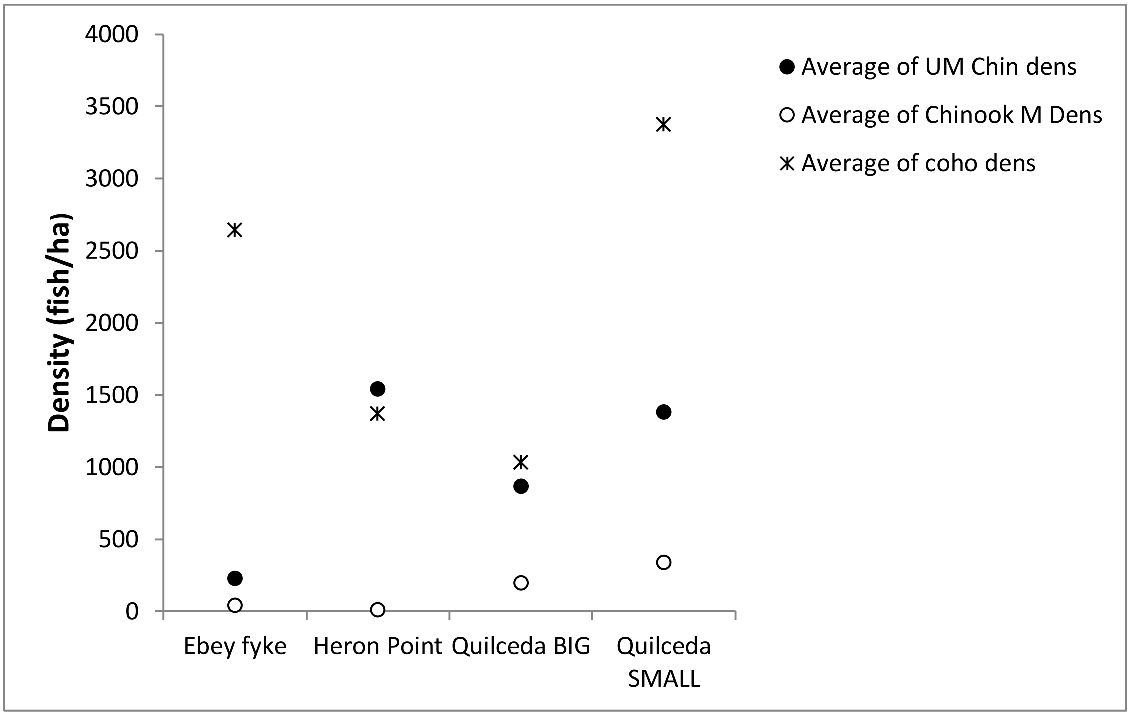

Figure 5.17. Mean juvenile salmon densities by site and species across all months.

The site specific temporal patterns of salmon densities were not uniform among species (Figure 5.18). Coho densities were the most uniform at all sites across all months. Coho densities peaked in May at all sites though the magnitude was considerably different; the highest densities at sites apparently closest to the source populations. Unmarked Chinook densities peaked in April at three of the four sites. Densities at the Ebey fyke site were both consistently lower and peaked later than all other sites. In general marked fish were encountered at significantly lower densities at all sites. Marked fish were not abundant at any site until June though there was a small pulse of Yearling marked Chinook at the Quilceda small site.

Size distributions of juvenile salmon in fyke traps

Size distributions of salmon captured at the fyke trap sites was largely similar to patterns observed in beach seine catches (Figure 5.19). Unmarked Chinook size steadily increased through time with very low variability within each month with the exception of April when a small number of yearling fish were encountered. Unmarked Chinook ranged in size from 38 to 120mm with the majority falling between 40 and 85mm (Figure 5.20). The size of marked Chinook salmon was again relatively uniform through time beginning in June with very little variability within months (Figure 5.21). Similar to coho in the beach seine catches, coho size distributions in the fyke traps were highly variable early in the season through the peak density in

May before becoming more uniform in June and July. Coho sizes during March ranged from 35-100mm before displaying a clear bimodal distribution during April and May indicative of both yearling and sub-yearling life history types (Figure 5.22).

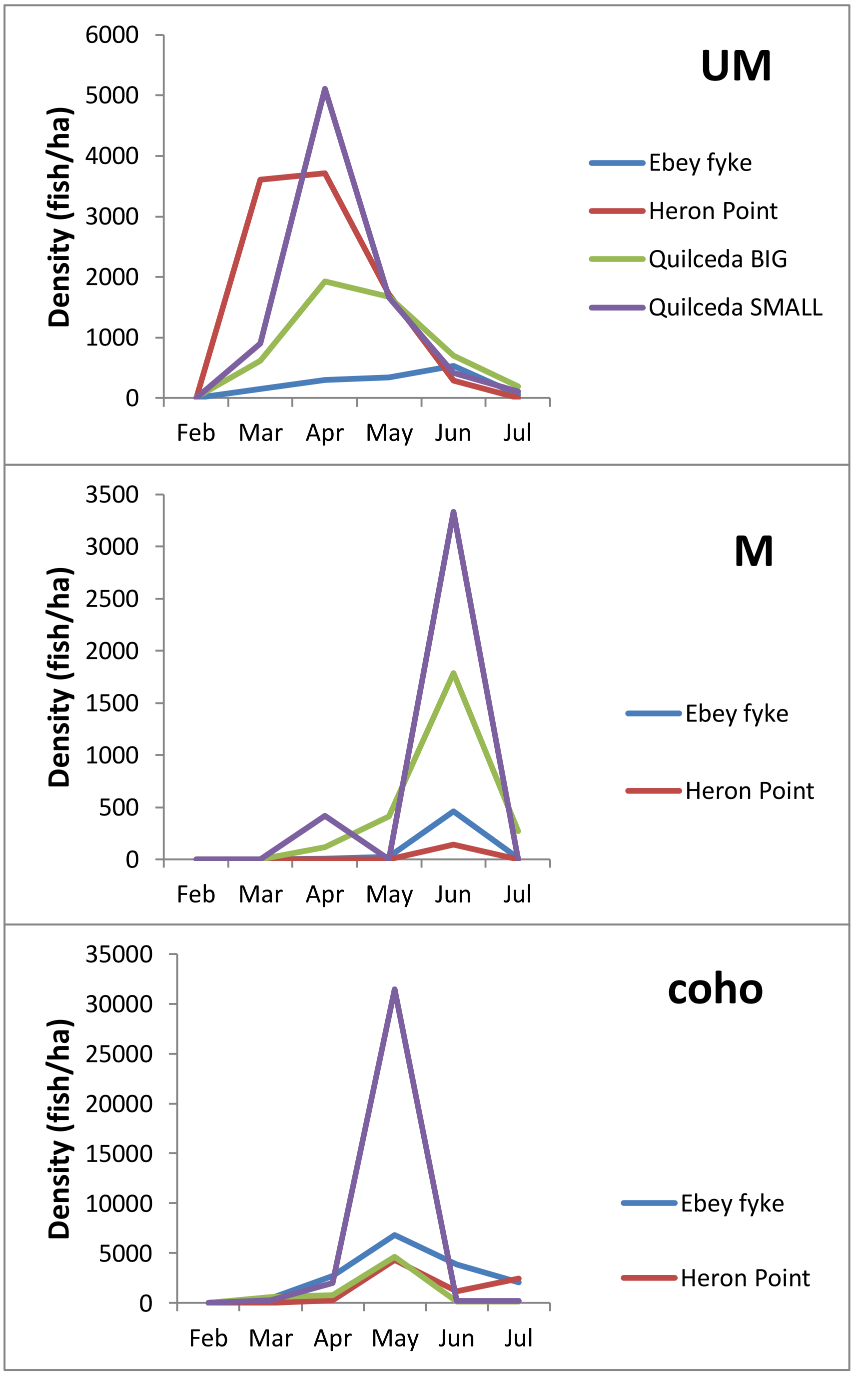

Figure 5.18. Species specific patterns of mean juvenile salmon density for each site by month.

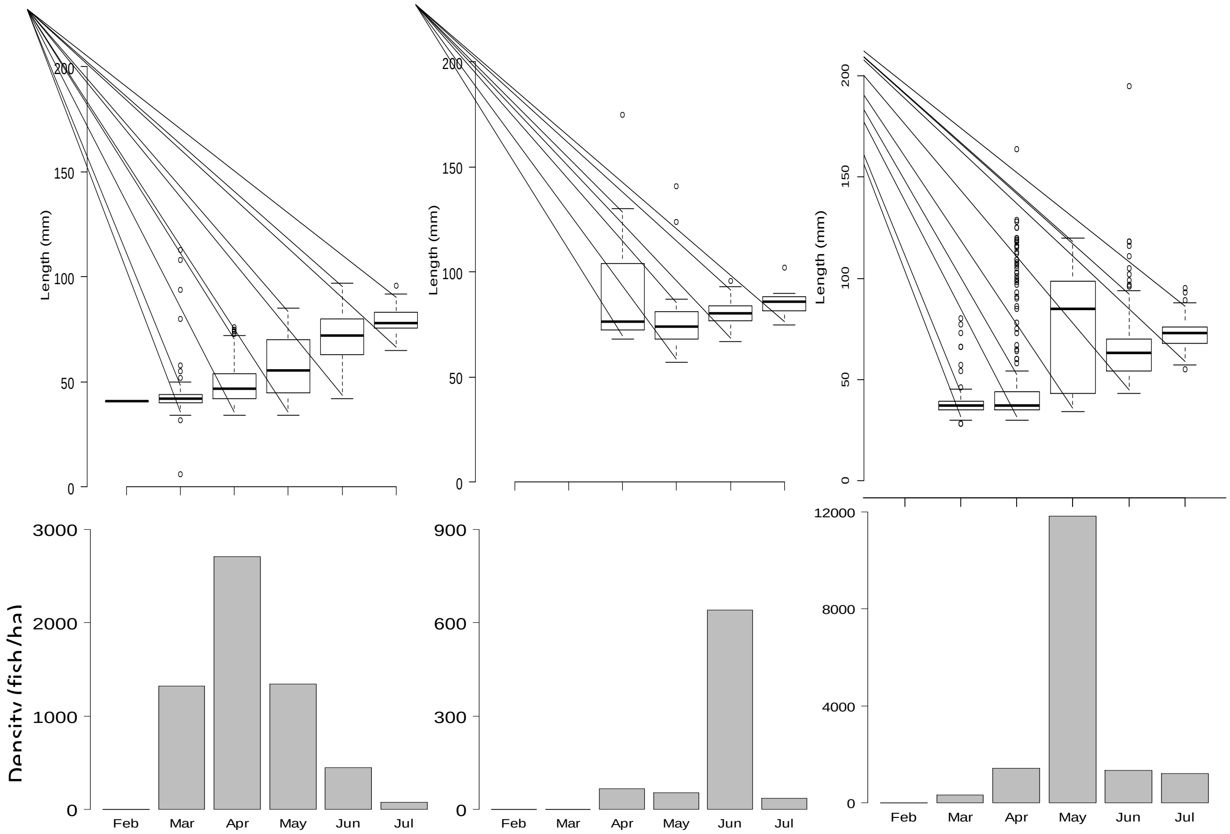

Figure 5.19. Size distribution by month and associated mean densities for unmarked Chinook (A), marked Chinook (B), and coho salmon (C) captured in fyke traps. Horizontal lines in each box represent the median, boxes the 25 and 75% quartiles, whiskers represent the upper and lower 95%, and circles are outliers. Note different y-axis values on barplots.

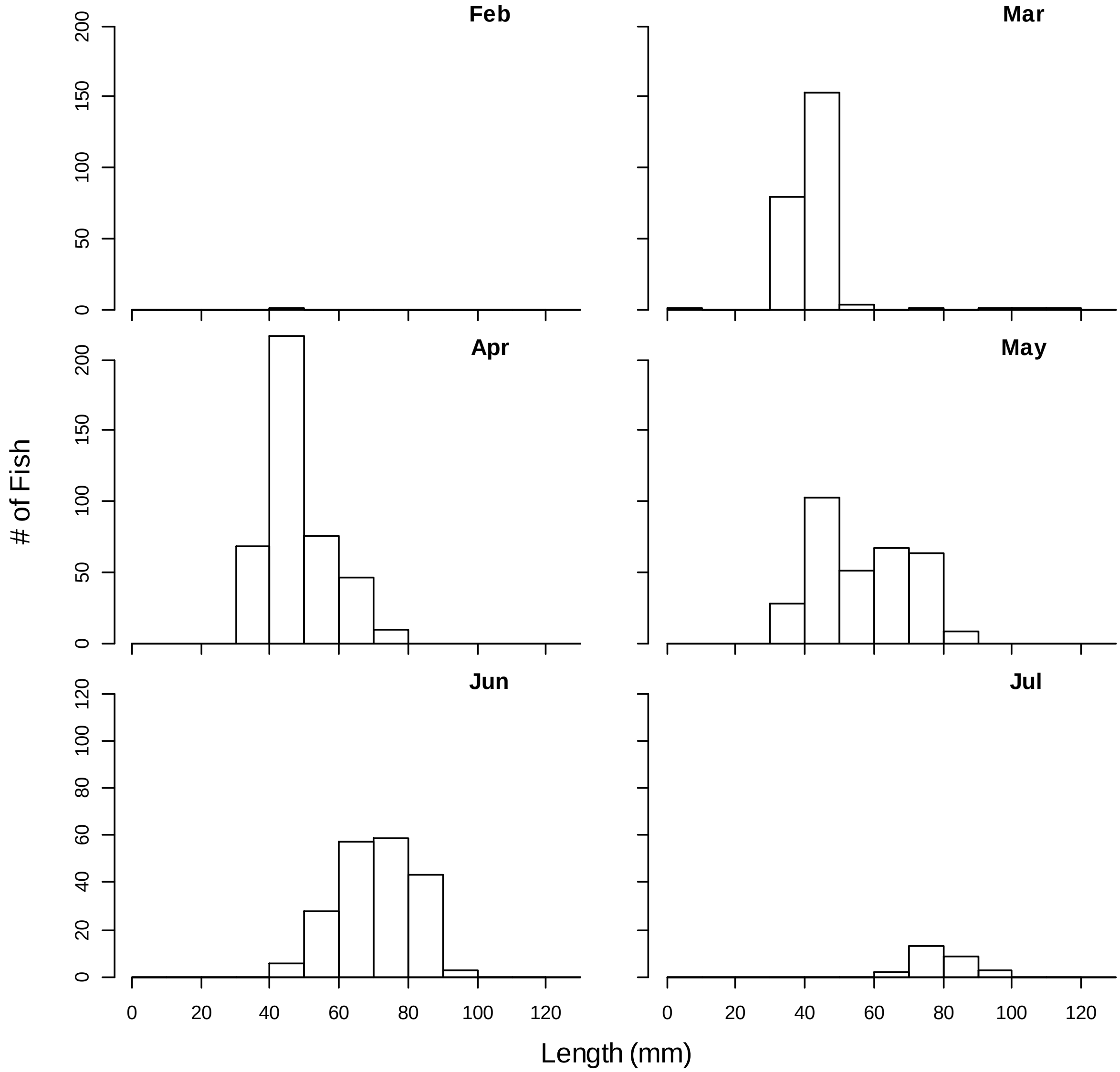

Figure 5.20. Length frequency histograms for unmarked Chinook captured in fyke traps by month in 2013.

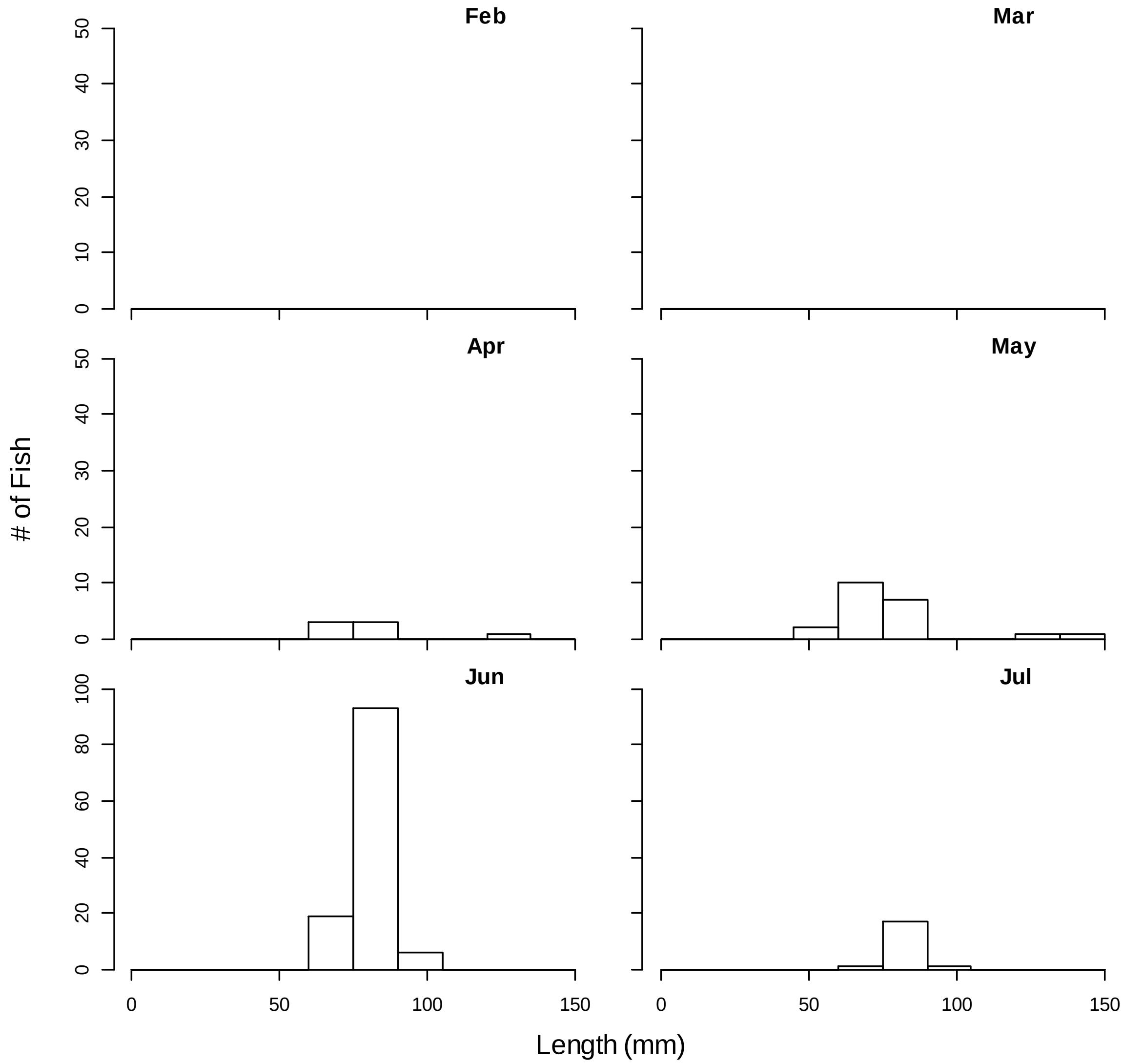

Figure 5.21. Length frequency histograms for marked Chinook captured in fyke traps by month in 2013.

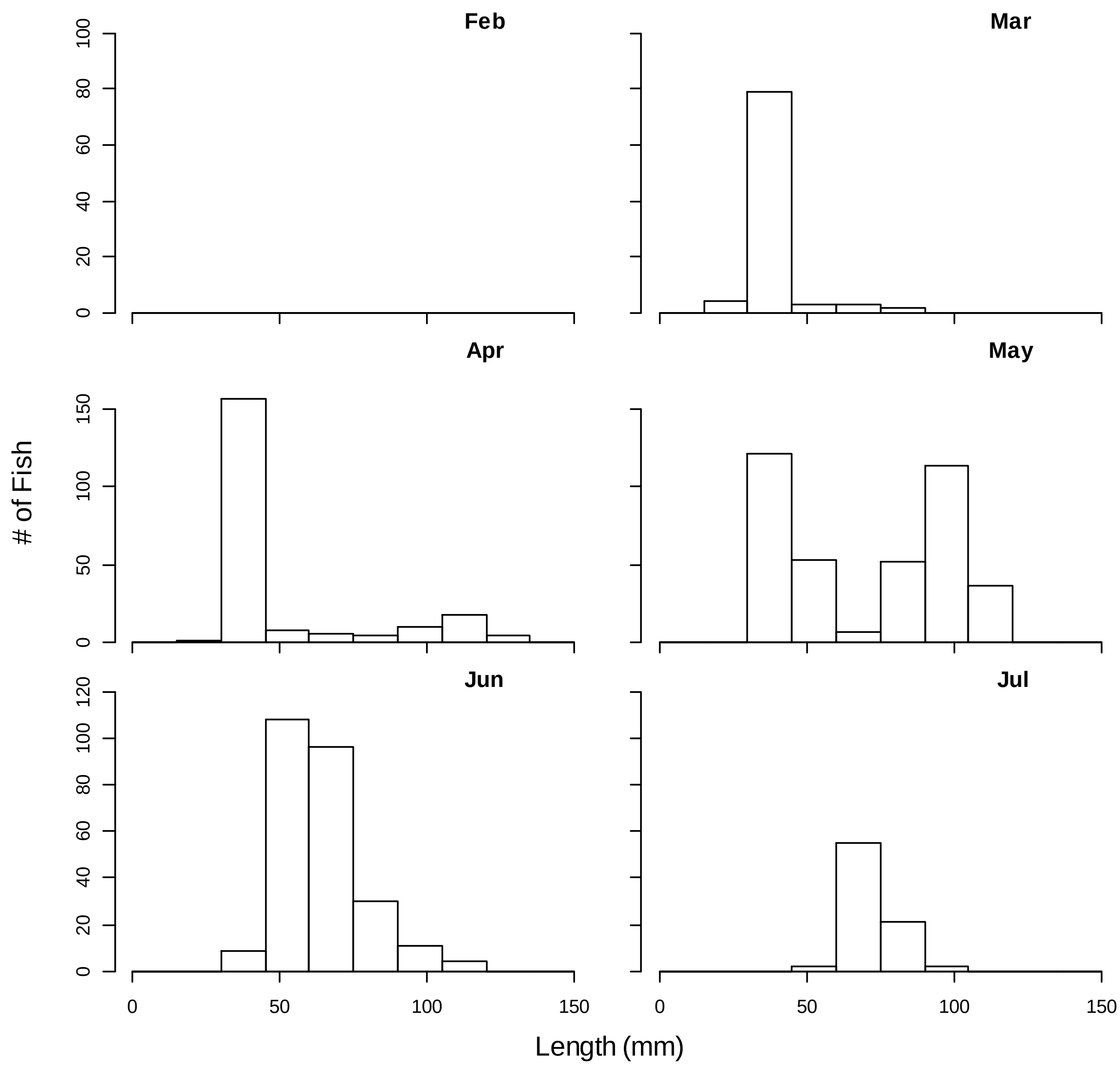

Figure 5.22. Length frequency histograms for unmarked coho salmon captured in fyke traps by month in 2013.

6) RECOMMENDATIONS

General

Overall we believe that the Snohomish estuary has great potential for both basic ecosystem studies as well as applied scientific assessments of wild salmon recovery efforts, and the scientific infrastructure and efforts recently in placed by this and other projects efficiently provide invaluable information. Our general recommendations are to at a minimum maintain existing data logging equipment and data collection, as well as fish monitoring. These general goals can be achieved through increased funding, but also through expanded collaboration. Our specific recommendations follow.

Continuous Water Sensors:

We recommend maintaining the current system-wide continuous water sensor monitoring plan in the Snohomish River estuary. This monitoring component requires relatively little time to maintain (e.g., two-person crew with a boat for one day every three months) and provide very high spatial and temporal resolution data for the Snohomish River estuary. The preliminary analysis of these data presented in this report indicate that these data series provides information that would be missed if we relied on our discrete sampling of surface water and water column profiles, which are restricted by our sampling frequency.

Given the high failure rate of Solinst sensors, we also recommend that these sensors be replaced with a different sensor package. We currently are testing a more expensive, and hopefully more reliable, instrument package (CTD Diver). The reliability of these new sensors will be assessed in January 2014 when the system-wide sensors are cleaned, downloaded, and calibrated. If these new sensors prove reliable, we recommend that the Solinst sensors be replaced as budgets allow.

Continuous water sensors can also be used to understand the dynamics of shallow groundwater in tidally flooded systems, and responses to dike breaching at Qwuloolt. Feasibility and proof of concept testing for shallow groundwater monitoring in the Snohomish River estuary has not been completed. Test wells have been installed at the Quilceda project site, and these test wells have provided useful information. However, final recommendations on monitoring design cannot be made until the test wells are monitored in parallel with the adjacent surface water monitoring point at the Quilceda fyke trap site. The Quilceda fyke trap site monitoring point is now actively being monitored by a continuous water sensor. Final testing and evaluations of well design can now be completed, although sensor failures have prevented deployments at the test wells in order to maintain the continuous system wide surface water measurements. We recommend that evaluation of the test wells be completed when additional sensors become available.

FVCOM Simulations:

FVCOM solutions for the Snohomish River estuary provide a number of opportunities for understanding hydrology and hydrological impacts. Output from the FVCOM simulations can be used to inform restoration planning/design as well as restoration effectiveness monitoring. In addition, FVCOM output can be used for status and trends analyses and hydrological impacts scenario testing (e.g., climate change scenarios). While the current simulation data is currently providing useful information, these simulations are limited to the 2006 calendar year. To maximize the utility of this tool, we recommend that the FVCOM simulations be expanded to include more years for which we have system-wide discrete surface water samples (2001 – present) and continuous water sensors (2013 – present). Data from these monitoring components can be used to calibrate and validate FVCOM simulations over multiple years, which would increase our ability to describe hydrological conditions over a range of forcing conditions that vary over interannual or interdecadal time scales (e.g., precipitation, snowfall, and flow). These multiyear simulations would also allow us to test future hydrologic loads based on projected climate change effects on precipitation in the Pacific Northwest (e.g., IPCC A1b and B2 emission scenarios).

In addition to basic hydrodynamic simulation output (e.g., temperature, salinity, and flow), the FVCOM simulations can be expanded to include biogeochemical and water quality output. In the Whidbey Basin near the mouth of Snohomish River estuary, the Washington State Department of Ecology's marine monitoring program has conducted monthly water quality profile measurements of nutrients, Chlorophyll, salinity, temperature, and DO since 1990. NOAA-NMFS also conducted detailed monitoring of Puget Sound and Whidbey basin in 2011 and 2012. However, assimilation of these data sets into a biogeochemical modeling framework for the Snohomish River estuary has not been done. Associated with the hydrodynamic models listed above, PNNL has completed a carbon based biogeochemical model of Salish Sea with 19 constituents, which reproduces annual cycles of phytoplankton growth, nutrient consumption, grazing by zooplankton, and DO (Khangaonkar et al. 2012). A nested application to Snohomish River estuary similar to the hydrodynamic model is proposed to provide multiyear water quality and biogeochemical simulations for the Snohomish River estuary.

Watershed response to estuary restoration

We recommend adding a case-study component to the restoration monitoring plan to investigate watershed-level effects from estuary restoration. Monitoring estuary restoration projects is often limited to measuring site level responses despite the fact that offsite (e.g. watershed) effects may be significant and positive. The Qwuloolt levee breach project provides a unique opportunity to document such offsite impacts; specifically, the effects of increased spawning activity by wild salmon. The Allen Creek watershed drains southwest from the cascade foothills through the city of Marysville and connects to Ebey Slough through tide gates at the southwest corner of the Qwuloolt project. The tide gates severely restrict connectivity to the watershed for both outmigrating juvenile and returning adult coho salmon (*O. kisutch*), but Allen Creek still supports a small, naturally spawning population of coho. Upon completion, the Qwuloolt project will reconnect Allen Creek to Ebey slough through the proposed levee breach and vastly improve access to the watershed and estuary by returning adults and juvenile coho, respectively. We propose to evaluate the population and ecosystem effects of this increased access by measuring adult and juvenile coho abundance; fish and invertebrate assemblage composition; and changes in sources of nutrients and organic matter in the aquatic food web. Observed changes would be compared with conditions observed in Quilceda Creek; a relatively in-tact watershed just downstream of the project site which supports a thriving population of naturally spawning coho salmon. A proposed two year study plan would allow for direct before/after comparisons of the above metrics to ensure the documentation of pre-breach conditions and provide a foundation for post-breach and longer term monitoring of restoration effectiveness within the system.

Comprehensive sample size power analysis

Nuff said…

Fyke trap efficiency estimates

A priority recommendation for future monitoring work is to acquire efficiency estimates for all fyke trap sites in the Snohomish River estuary. Current estimates used for determining density and catch per unit effort for each fyke trap site are derived from similar work conducted in the Skagit River estuary. We apply an overall mean recapture efficiency from all sites in the Skagit program to the sites sampled in Snohomish estuary. Efficiency estimates for our specific sites would provide further confidence around our current and future density estimates. Site specific efficiency estimates would be calculated from a mark-recapture procedure implemented at least monthly during sampling at each site. The procedure would likely require attaining surplus Chinook from the Tulalip hatchery, n=50-75, for each site estimate. Individuals would be clearly marked with Bismark Brown®, a non-lethal dye, for identification among the total catch. Marked fish would be placed in the channel ~100m upstream of the trap at or near high water. The number of marked individuals captured and processed after net retrieval would be divided by the number of marked individuals placed into the channel after the trap was set resulting in the overall catch efficiency for that site/event.

Analysis of archived samples

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