Ecosystem Monitoring Program

Annual Report for Year 7

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Lower Columbia River Ecosystem Monitoring Program
Annual Report for Year 7 (September 1, 2010 to December 31, 2011)

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Executive Summary

The Lower Columbia Estuary Partnership (Estuary Partnership) implements elements of its Aquatic Ecosystem Monitoring Strategy (LCREP, 1999) to address needs for status and trends monitoring of the lower Columbia River ecosystem, toxic contaminants monitoring and data management through its Ecosystem Monitoring Program (EMP). Efforts for the EMP include the development of an estuarine ecosystem classification system and on-the-ground monitoring of vegetation, habitat, juvenile salmon, food web, and water quality. This monitoring was intended to address Action 28 of the Estuary Partnership's Comprehensive Conservation and Management Plan, Reasonable and Prudent Alternatives (RPAs) 161, 163, and 198 of the 2000 Biological Opinion for the Federal Columbia River Power System, and RPAs 58, 59, 60, and 61 of the 2008 Biological Opinion. The Estuary Partnership executes the EMP by engaging regional experts at the University of Washington (UW), Battelle-Pacific Northwest National Laboratory (PNNL), National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA-Fisheries), United States Geological Survey (USGS), Oregon Health and Sciences University (OHSU) and Columbia River Estuary Study Taskforce (CREST). Financial support for the EMP comes from the Bonneville Power Administration (BPA) and Northwest Power and Conservation Council (NPCC).

This report describes EMP accomplishments during September 1, 2010 to December 31, 2011, or Year 7 of this on-going project. For a background on the project since its inception in 2003, please see past Annual BPA reports. During the Year 7 period, the Estuary Partnership and monitoring partners:

- Completed mapping of the Columbia River Estuary Ecosystem Classification (Classification), including the following task: completed draft mapping of Classification Levels 4-6 for all Reaches (A-H). This data will go through the USGS technical review process in early 2012. Final edits and official release will be completed by May 2012. In 2011, we released the Columbia River Estuary Ecosystem Classification USGS open file report describing the Classification's conceptual basis, methods, and applications.
- Completed a high-resolution land cover mapping effort to support the Classification as well as an overall regional need for current estuarine land cover data.
- Facilitated 2010-2011 monitoring efforts by providing GIS support for site selection, coordinating discussions and site field trips, acquiring special use permits for site access, assisting sampling crews, creating a geodatabase of monitoring activities, and managing partner subcontracts (Estuary Partnership).
- Sampled 3 new sites in Reach E, 1 new site in Reach A, 1 previously sampled site in Reach F, 1 previously sampled site in Reach H, and 1 previously sampled site in Reach C, to assess habitat, fish, prey, and food web characteristics and inter-annual trends at previously sampled sites (PNNL, NOAA-Fisheries, USGS, OHSU and CREST).
- Compiled Classification and monitoring report contributions from partners into this annual report document (Estuary Partnership).
- Developed scopes of work for the 2011-2012 monitoring efforts (Estuary Partnership, PNNL, USGS, CREST, OHSU, and NOAA-Fisheries).
- Participated in regional monitoring coordination efforts, like Pacific Northwest Aquatic Monitoring Partnership (PNAMP) and Estuary Partnership's Science Work Group (Estuary Partnership).
- Presented findings at local, regional and national meetings and conferences (Estuary Partnership, PNNL, NOAA-Fisheries).
- Provided field support for PNNL and NOAA sampling crews during the 2011 field season.
- Conducted GIS analysis to support the 2010-2011 site selection process for on-the-ground monitoring in Reaches B and G, and updated geodatabase inventory of estuary RME efforts.
- Coordinated data sharing efforts in order to disseminate datasets, including those generated by the EMP, to public and private entities engaged in natural resource protection and restoration activities in the LCRE.

- Completed mapping of diked/tidally influenced areas of the LCRE, in support of the Classification.
- Coordinated with the USACE to develop a seamless terrain model for the LCRE based on recently acquired bathymetric and topographic data. Model was completed in fall 2010.
- Distributed terrain model and new elevation data to various research affiliates

2011 Results Summary

Habitat Structure Results

Monitoring data collected resulted in the further characterization or the spatial variability of Reach E sites and temporal variability of fixed sites in Reach A, C, F and H. This characterization continues to document the ranges and variation in hydrology and habitat structure of emergent marshes in the lower Columbia River Estuary (LCRE).

- Total organic carbon (TOC) content shows little variation between vegetation strata at any of the sites sampled. In general, sediments with greater than 12% TOC are considered organic sediments (Mitsch and Gosslink 2000), whereas all results presented here have less than 12% TOC.
- Sediment accretion rates were generally greater than 1.0 cm/year at the sites measured in 2011. A higher than average rate would be expected in this year due to the high inundation levels during the spring freshet.
- Hydrographs from the sites where water surface elevation (WSE) was collected during the 2010 to 2011 water year indicate that higher than average WSE resulting from the spring freshet was detectable in shallow water wetland habitats at least as far downriver as Whites Island (rkm72); however, this pattern was not observed at the outermost estuary site, Ilwaco (rkm 6).
- Vegetation cover and biomass was affected in 2011 by the higher than average water year by decreased cover and biomass. In general, species diversity was higher at the Reach C site than sites sampled in the remaining reaches.
- The sum exceedance value (SEV), representing the amount of water over a site in a given time period, was much higher at the upper estuary sites.

Water Quality and Food Web Results

In 2011, USGS monitored water quality and assessed food web resources at the four fixed sites: Ilwaco, Whites Island, Campbell Slough and Franz Lake (Reaches A, C, F and H).

- In 2011, all four sites experienced periods of “poor” water quality with respect to conditions for salmonid health, although the duration of poor water quality periods varied among sites.
- Whites Island had the best water quality conditions for juvenile salmonids among the sites during the monitoring period.
- Periphyton concentrations and phytoplankton concentrations (chlorophyll a) at Ilwaco were higher than at any of the other sites.

Fish and Macroinvertebrate Results

Sampling in 2011, as in previous years, found that unmarked juvenile Chinook, coho, and chum salmon are feeding and rearing in representative sites in Reaches A, C, E, F and H of the LCRE.

- Although we were successful in sampling most of the sites in late May (other than Franz Lake), extremely high water levels limited sampling of all sites until late July.
- In 2011, fish monitoring was extended through December for most of the sites to monitor salmon occurrence during the fall and winter months (Campbell Slough was monitored through October only due to permit constraints).
- All of Reach E sites had relatively high species diversity and richness, comparable to Reach C sites, and was dominated by stickleback. Reach E also supported multiple salmon species, including Chinook and coho salmon.
- At Ilwaco, the new sampling site in Reach A and the only site in the saltwater portion of the estuary, fish community composition was quite different from our observations in the tidal freshwater reaches (largely euryhaline species).

- At Ilwaco, large numbers of out-migrating chum salmon were present in April (47% of the total catch for that month), but aside from this, no coho and only one large Chinook salmon (90 mm) were caught at this site throughout the year.
- Looking at temporal trends at the fixed sites, high water temperatures, low dissolved oxygen and other conditions may have limited salmon use of some sites in July and August of 2009, as fish were present for a longer period in 2010.
- Temporal trends at the fixed sites also demonstrated that the condition factor values showed some variation among sites and years, but were generally within a healthy, normal range (0.92-1.25); however, it was lower in 2011 than previous years at the fixed sites.
- Juvenile Chinook are often described as opportunistic feeders, but prey selectivity results suggest that they select Dipteran larvae and pupae at greater rates than would be expected given their modest availability.
- With our more extended sampling period in 2011, we also observed that Chinook and coho salmon were present at some of the sites through December.
- The pilot results of the PIT tag array in Campbell Slough indicate that hatchery Chinook salmon from locations as far away as the Dworshak Hatchery on the Snake River remained in the slough for up to 12 days, feeding and rearing. The PIT tag array also detected the presence of fish we have never caught in our sampling efforts, including sockeye salmon.

Food Web (Phytoplankton, Zooplankton and Benthic) Results

In 2011, USGS, OHSU and CREST assessed food web resources at the four fixed sites: Ilwaco, Whites Island, Campbell Slough and Franz Lake Slough (Reaches A, C, F and H).

- Phytoplankton and zooplankton and benthic taxa were identified and enumerated at four shallow water sites (Ilwaco, Whites Island, Campbell Slough, and Franz Lake) between early April and late July 2011.
- Either linear chain-forming (e.g. *Stephanodiscus* spp., *Aulacoseira* spp., and *Fragilaria crotonensis*) or large colony-forming (mainly *Asterionella formosa*) diatoms dominated the phytoplankton assemblage during this period, particularly in early spring when abundances were the highest.
- A comparison of observations from the shallow water habitats monitored in this study with those of a concurrent study at Beaver Army terminal (BAT) suggested that phytoplankton abundances can be ten times higher in the shallow water habitats, as long as river discharge is low (relative to the freshet).
- Phytoplankton abundance (as inferred from chl *a*) and zooplankton species composition differed markedly pre- vs. post-freshet. The zooplankton community in the tidal freshwater sites was dominated by rotifers in spring (April-May) prior to the freshet, and by copepods and cladocerans later in the season (June-July), following the freshet.
- Rotifers were never abundant in brackish waters of Ilwaco, which were dominated by copepods at all times. The species composition of zooplankton at Ilwaco did not change markedly over the study, except that the abundance of ciliates increased from spring to summer.
- In July, a bloom of colonial cyanobacteria was noted at Campbell Slough (Ridgefield National Wildlife Refuge), which comprised many different taxa, including *Anabaena* spp., *Aphanizomenon* sp., and *Microcystis* sp., all of which are known to produce cyanotoxins with hepatotoxic effects.
- Adult benthic invertebrates were more prevalent than other life history stages throughout the sampling period (98% of invertebrates sampled).
- Species of the Annelida phyla (Oligochaetes, Nematodes and Polychaetes) are the most abundant benthic prey taxa throughout all of sample sets. Amphipoda and Dipteran orders represented the next highest proportion of invertebrates present within the benthic sample set.

1.0 EMP Efforts by the Estuary Partnership in 2010-2011

Ecosystem Monitoring Program Background

The lower Columbia River and estuary is designated as one of 28 "estuaries of national significance" or part of U.S. Environmental Protection Agency's National Estuary Program (NEP). Each NEP is required to work with regional partners (local, state, federal and tribal governments, industry, citizens, not-for-profits, and academia) to develop and then implement a Comprehensive Conservation and Management Plan (CCMP). US EPA requires each NEP to also establish a long term monitoring strategy to track status and trends of that estuary and assess efficacy of CCMP implementation by partners. Action 28 of our CCMP calls for the Estuary Partnership, with its partners, to implement sustained long term monitoring to understand conditions in the river and to evaluate the trends and impacts of management actions over time. Without sustained monitoring, assessing the lower river's health and gauging the success of restoration projects and other actions is extremely difficult. The Estuary Partnership's Ecosystem Monitoring Program was designed to address this need, specifically to provide the long term data needed to assess the status and trends of aquatic habitats, emphasizing those utilized by listed salmon populations, and to apply these data, as appropriate, to improving habitat restoration, toxic reduction, and salmon recovery strategies. The study area of the Ecosystem Monitoring Program covers the tidally influenced reach of the Columbia River from the river mouth to the Bonneville Dam.

From fiscal years 2004 through 2010, with funding from NPCC/BPA, the Ecosystem Monitoring Program has accomplished the following major tasks: 1) developed a statistically valid, ecosystem-based monitoring plan for the estuary focusing on salmon habitats; 2) developed and published a hierarchical estuarine ecosystem classification system (Classification) in which to base our sampling design and habitat restoration strategies; 3) mapped over 19,000 acres of high and medium priority shallow water bathymetry gaps; 4) mapped landcover of the lower river floodplain in 2000 and 2010; 5) collected water chemistry data and juvenile salmonids to support the creation of 3 models related to salmonid uptake, transport, and ecological risk of toxic contaminants; 6) collected habitat structure data at 23 sites and comprehensively monitored 11 sites throughout the lower river for habitat structure; salmon occurrence, diet, condition, stock, and growth; prey availability and preference, providing in some areas the only contemporary juvenile salmon use data available; 7) initiated the characterization of the salmon food web at 4 sites representing the estuarine-tidal freshwater gradient; 8) collected abiotic environmental/water column condition data at 1-4 sites annually; 9) provided technical assistance to the USACE in creation of a terrain model of the lower river, resulting in a seamless bathymetry/topography map which will be invaluable in mapping salmon habitat opportunity in combination with river flow data; 10) convened 5 technical workshops for researchers and managers on topics of interest such as landcover, bathymetry, toxic contaminants, and restoration; 10) provided monitoring coordination for entities involved in monitoring the lower river, exemplified by the estuary RME coordination meeting in spring 2010 involving NMFS, PNNL, CREST, USACE, BPA, LCRFB and others; 11) compiled information and presented overviews of on-going monitoring activities at various events, including the Estuary and Ocean Subgroup, EPA Toxics Reduction Working Group; and regional and national conferences; 12) played a key role in efforts supporting regional monitoring coordination, including Pacific Northwest Aquatic Monitoring Partnership's Integrated Status and Trends Monitoring group, an inventory of on-going effectiveness monitoring at restoration sites, and refinements to standardized protocols for restoration effectiveness monitoring; 13) acted as a central clearinghouse for GIS data while developing mapping website to house monitoring data collected in estuary.

In addition, NPCC/BPA funding provides leverage that allowed the Estuary Partnership to accomplish these additional estuary RME-related activities: 1) supported on-going regional toxic contaminants reduction efforts, such as preparing the State of the River Report, presenting monitoring information at the workshops, developing a basin-wide contaminant monitoring strategy with EPA's Toxics Reduction Workgroup, and supporting the institution of an Oregon Drug Take Back Program; 2) presented monitoring efforts at several regional and national conferences, including the Coastal and Estuarine Research Federation and National Conference on Ecosystem Restoration; 3) chaired an all day session on monitoring and restoration efforts in Pacific Northwest estuaries at the 2009 Coastal and Estuarine Research Federation conference with co-chairs, PNNL and South Slough National Estuarine Research Reserve; and 4) participated in regional forums, such as Pacific Estuarine Research Federation (PERS), NANOOS, American Fisheries Society, and Pacific Joint Venture, to share information and coordinate RME and restoration efforts. Information exchanged and gained and networking with other researchers doing related work during these events provide invaluable insight and guidance for future RME efforts in the lower river.

Activities Performed in the Year 7 Contract (September 1, 2010 through December 31, 2011)
Funding for the EMP by the NPCC/BPA supports the Estuary Partnership's Research Scientist. As part of 2010-2011 EMP efforts, funding supported her efforts to do the following:

- Coordinated development of the Columbia River Estuary Ecosystem Classification and work timelines.
- Facilitated discussions and planning for 2010-2011 monitoring efforts.
- Coordinated site field trips.
- Acquired special use permits and landowner permission for accessing monitoring sites.
- Provided field support for EMP monitoring partners.
- Coordinated Science Work Group meetings dedicated to the ecosystem monitoring efforts
- Managed EMP subcontracts with UW, PNNL, USGS, OHSU, CREST, Environment International (EI) and NOAA-Fisheries.
- Coordinated meetings, provided technical guidance, compiled results of data analyses (between 2005 and 2010) and edited draft report to complete a five-year synthesis for the EMP program with PNNL, NOAA-Fisheries and USGS.
- Compiled annual data collection summary report contributions from EMP subcontractors into this annual report to BPA.
- Summarized yearly activities and results per individual RPA for BPA in a separate 60 page reporting format.
- Completed preliminary program protocols in MonitoringMethods.org.
- Coordinated discussions on goals, objectives, actions and candidate indicators for an estuarine indicator system.
- Researched other estuarine indicator systems and provided recommendations to the Science Work Group.
- Developed new scopes of work with EMP subcontractors for the 2011-2012 EMP activities.
- Prepared and presented materials for several meetings with BPA, NOAA Fisheries, PNNL, and other regional monitoring partners to determine scope of EMP activities for 2011-2012.

EMP funds also support the Research Scientist's work on the Estuary Partnership's Action Effectiveness Monitoring (AEM) program funded by BPA. For this program, the Research Scientist:

- Refined site monitoring plans for 2010-2011 AEM efforts.
- Coordinated a Science Work Group meeting dedicated to AEM.
- Developed and managed AEM subcontracts with NOAA-Fisheries, CREST, Scappoose Bay Watershed Council (SBWC), and Ash Creek Forest Management (ACFM) for 2010-2011.
- Coordinated meetings, provided technical guidance and compiled of results of data (between 2008 and 2010) to complete a three-year synthesis for the EMP program with SBWC, NOAA-Fisheries and ACFM and CREST.
- Developed new scopes of work with AEM subcontractors for 2011-2012.

- Organized and facilitated site trips with subcontractors to discuss AEM methods and challenges and ensure data comparability between sites.
- Compiled AEM reports from subcontractors for the Restoration Program's 2010-2011 annual report to BPA.
- Coordinated meetings, provided technical guidance and compiled of results of data (between 2008 and 2011) to complete a synthesis for each site in the AEM program with NOAA-Fisheries, ACFM, SBWC and CREST.
- Compiled restoration AEM data, coordinated contract and provided review on the Reference Site Study vs. AEM Data Comparison with PNNL. The project also looked for regional patterns in hydrology, inundation and vegetation to recommend design considerations for restoration projects.

In addition to the work described above for the EMP and AEM programs, the Research Scientist contributed to regional monitoring efforts, such as:

- Coordination and communication amongst parties by staying abreast of RME activities in the LCRE and sharing this information and principal contacts.
- Coordination with Pacific Northwest Aquatic Monitoring Partnership (PNAMP) workgroups related to the estuary, Action Effectiveness Monitoring, and Integrated Status and Trends Monitoring.
- Development of an inventory of on-going effectiveness monitoring at restoration sites.
- Refinements to standardized protocols for restoration effectiveness monitoring.

Funding for the EMP also provides partial support for the Estuary Partnership's GIS/Data Management Specialist. For the 2010-2011 EMP efforts, the GIS/Data Management Specialist:

- Coordinated Columbia River Ecosystem Classification System (Classification) development efforts between the Estuary Partnership, USGS and UW.
- Provided development support for the Classification, which included QA/QC on the initial map products for completed Reaches, as well as assistance with refinement of the Classification scheme.
- Provided field support for PNNL and NOAA sampling crews during the 2011 field season.
- Conducted GIS analysis to support the 2010-2011 site selection process for on-the-ground monitoring in Reaches B and G, and updated geodatabase inventory of EMP monitoring efforts.
- Coordinated data sharing efforts in order to disseminate datasets, including those generated by the EMP, to public and private entities engaged in natural resource protection and restoration activities in the LCRE.
- Completed mapping of diked/tidally influenced areas of the LCRE, in support of the Classification.

In addition to the work described above for the EMP program, the GIS/Data Management Specialist contributed to the following regional monitoring efforts:

- Coordinated with the USACE to develop a seamless terrain model for the LCRE based on recently acquired bathymetric and topographic data. Model was completed in fall 2010.
- Distributed terrain model and new elevation data to various research affiliates.

2.0 Study Area

The LCRE is designated an "Estuary of National Significance" and as such is part of the National Estuary Program, established in Section 320 of the Clean Water Act. The EMP's study area encompasses all tidally influenced waters of the LCRE, extending from the plume of the Columbia at river mile (RM) 0 upstream to the Bonneville Dam at RM 146. The Estuary Partnership and monitoring partners collect data for the EMP on habitats supporting juvenile salmonids, including shallow emergent wetlands, tidally influenced sloughs adjacent to the Columbia River, scrub/shrub forested wetlands, and mud/sand flats.

The Estuary Partnership and monitoring partners use a multi-scaled stratification sampling design for the emergent wetland component of the EMP based on the Classification. The sampling has been organized according to Level 3 of the Classification (described below), which divides the LCRE into eight major hydrogeomorphic transitions. Previous habitat monitoring efforts for the EMP have concentrated on Reaches D and F (2004-2005), G and F (2005-2006), E and F (2006-2007), H and F (2008-2009), C, F and H (2008-2009) and C and F (2009-2010). In 2010-2011, the Estuary Partnership and partners monitored emergent wetland habitats in Reaches A, C, H, E, and F (Figure 1).

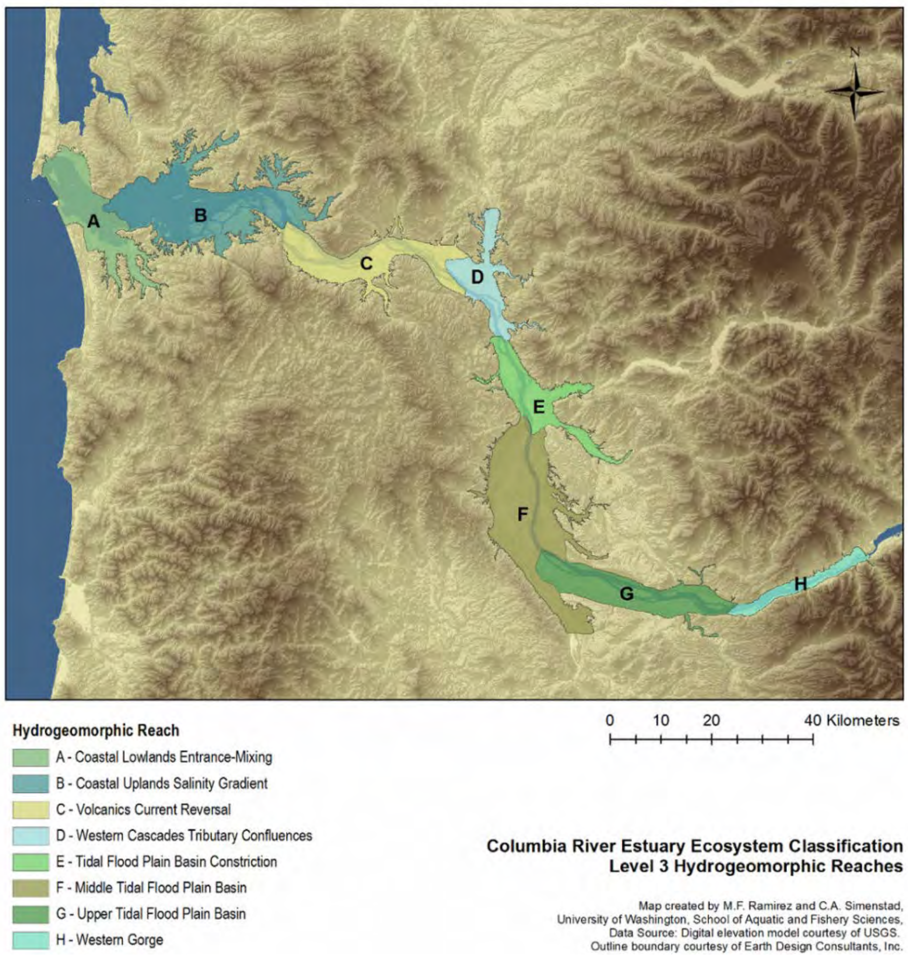


Figure 1. Lower Columbia River and estuary (LCRE) with hydrogeomorphic reaches (A-H) outlined and specified by color (2009 version of hydrogeomorphic reaches).

3.0 Columbia River Estuary Ecosystem Classification (Classification)

The 2010-2011 project period is the eighth year developing and refining the Classification. This GIS based data set is a six tier hierarchical framework that will allow delineation of the diverse ecosystems and component habitats across different scales in the LCRE. Its primary purpose is to enable systematic monitoring of diverse, scale-dependent, and scale-independent ecosystem attributes. The Classification, however, also provides a more utilitarian framework for understanding the underlying ecosystem processes that create the dynamic structure of the LCRE. As such, it aims to provide the broader community of scientists and managers with a larger scale perspective in order to better study, manage, and restore LCRE ecosystems. Hence, the Classification should also provide an important framework for habitat restoration and protection strategies.

3.1 Classification Background

Based on classification schemes developed for other estuarine ecosystems and concepts of ecosystem geography (Bailey, 1996), UW and USGS developed a classification scheme for the LCRE that has 6 hierarchical levels:

1) Ecosystem Province (based on EPA Ecoregion Level II)
2) Ecoregion (based on EPA Ecoregion Level III)
3) Hydrogeomorphic Reach (based on modified EPA Ecoregion Levels III and IV)
4) Ecosystem Complex (based on Primary Cover Class and geomorphic setting within each hydrogeomorphic reach)
5) Geomorphic Catenae (based on Stanford et al., 2005)
6) Primary Cover Class (based on cover data from LANDSAT or other remote sensing datasets)

Levels 1 and 2 were taken directly from the EPA Ecoregion dataset, and required no additional mapping. Mapping of the Level 3 hydrogeomorphic reaches was completed in 2007. Eight distinct reaches were defined, representing the intersection of broad-scale geologic processes and events over the last 50 million years with more modern or recent geologic and hydrologic processes of the Holocene period. The major hydrologic processes influencing reach boundaries include locations of current reversal, salinity intrusion, confluences of major tributaries, as well as maximum tide levels. The eight reaches are illustrated in the study area map above (Figure 1).

Since Year 5, Levels 4-6 have been the remaining levels of the Classification to be completed. Completion of these levels for the entire LCRE has been dependent on the availability of recent and high quality bathymetric and land cover data. Collection and delivery of bathymetric data was finalized at the end of Year 6. Collection and delivery of land cover data began in Year 6, and was completed in Year 7. Availability of this data allowed for mapping of Levels 4 and 5 of the Classification to proceed in Year 7 (the land cover dataset itself actually constitutes Level 6, which does not require further mapping). In addition, the USGS Open File report describing the concept and organization of the Classification was published in Year 7. This document can be accessed at http://pubs.usgs.gov/of/2011/1228/. For additional background information on the Classification, readers are encouraged to refer to this report.

Mapping of Levels 4 and 5 has been organized by hydrogeomorphic reach, beginning with upriver reaches (F, followed by E, D, G and H), and extending down river (Reaches C, B, and then A). As the mapping has extended into different reaches, refinements to the classification scheme have been required as new features and processes unique to certain reaches were encountered. This refinement process was required in Year 6, and extended into Year 7 as well. Thus, the classification scheme has been continuously evolving, resulting in a more robust and systematic organization of the landforms and processes.

The Classification has been a joint effort between the Estuary Partnership, USGS, and UW. The organization of tasks for mapping of Levels 4 and 5 is as follows, consistent with the Year 6 efforts:

1. Delineation of Levels 4 and 5 terrestrial features (complexes and catenae). Primary data sources include LiDAR elevations, aerial imagery, historical maps, soils data, and wetlands data. USGS
2. Delineation of cultural features using similar sources as step 1. USGS

3. Delineation of Levels 4 and 5 aquatic features using updated bathymetric data. UW
4. Merge Levels 4 and 5 terrestrial features with Levels 4 and 5 aquatic features. USGS.
5. Multivariate analysis of merged Level 5 data and Level 6 land cover data to create Level 5 sub-classes which reflect information contained in the land cover data. UW.
6. Review of all draft data as it is delivered. Estuary Partnership, USGS, UW.
7. Revisions of draft data based on reviews. USGS, UW.
8. Ongoing refinements to classification scheme as needed. Estuary Partnership, USGS, UW.

Year 7 saw the completion of Levels 4 and 5 drafts mapping for all hydrogeomorphic reaches (A-H), essentially completing the mapping for the project. This completed data set will then undergo a formal USGS technical review, followed by final edits and release projected for May 2012. In addition, FGDC (Federal Geographic Data Committee) compliant metadata will be generated and reviewed by USGS in early 2012.

3.2 Classification Level 4: Ecosystem Complexes

Ecosystem complexes comprise biophysical patches that reflect both antecedent processes that establish long-term geomorphic templates in the estuary and its floodplain but also reflect continuous processes and changing landscapes. Thus, they include the overlapping of the massive Holocene disturbances (e.g., landslide and volcanic sediment pulses, large floods and storm surges, and tectonic movement) with shorter-term biophysical processes (e.g., more localized flooding, sediment accretion, vegetation succession, local extinction and recruitment events) as well as the reflections of anthropogenic modifications on the landscape such as diking and filling, channel hardening, and urban and suburban development on the floodplain.

Refinements to the classification scheme in Year 7 resulted in modifications at the complex level. Three major changes were incorporated, as follows: 1) Removed the depth criteria from the complex level, and moved it to Level 5 (catena). This greatly reduced the overall number of complexes. For example, instead of having ‘primary channel, deep water’, ‘primary channel, permanently flooded’, primary channel, intermittently exposed’, and ‘primary channel, depth unknown’ complexes, we now have only a ‘primary channel’ complex, with the 4 depth ranges being described at the catena level; 2) Removed the ‘island’ criteria, and made this a separate attribute field. This further reduced the number of complexes that were needed; 3) Created a ‘surge plain’ complex, to describe floodplain areas that are regularly inundated by tide. We realized the need for this feature as mapping extended into the lower reaches of the river, where daily tidal influence increases. This complex was used to describe features in Reaches A, B, and C.

As in Year 6, USGS elected to first map terrestrial features at the catenae level (Level 5), and then derive the complexes from these features. With the completion and delivery of the bathymetric data set at the end of Year 6, UW was finally able to delineate the aquatic complexes and catenae for the entire estuary. Again, the aquatic complexes were derived from the aquatic catenae. As mentioned above, depth criteria, derived from the new bathymetry data, were incorporated at the catena level (Level 5), and removed from the complex level (Level 4). For a description of the depth criteria that were used, refer to the Year 6 report or the open file report.

3.3 Classification Level 5: Geomorphic Catenae

Geomorphic catenae form the mosaic of features nested within ecosystem complexes. Because they vary and change over space and time as a function of both natural ecosystem processes and intrinsic, moderate or minor disturbances, the catenae constitute a 3-dimensional shifting mosaic of ecosystems along the river-ocean continuum (Stanford et al., 2005).

Refinements to the classification scheme in Year 7 resulted in modifications at the catena level. Some of the major changes included are as follows: 1) Created a ‘tie channel’ catena, to describe channels which connect a main channel to a floodplain lake; 2) Created a ‘tidal channel’ catena, to describe dendritic channels in the lower estuary which are dominated by tides; 3) Created a ‘side channel’ catena, to describe secondary channels of major tributaries; 4) Created a ‘channel bar’ catena, to describe active accumulations of fluvial sediment adjacent to channels and intermittently exposed; 5) removed the ‘island’ criteria, and made this a separate attribute field; 6) Added catenae describing channel depths, which were previously included at the complex level (Level 4).

Geomorphic catenae are classified and delineated in two steps: 1) Use of multiple mapping criteria and sources to distinguish water body and geologic and geomorphic floodplain and adjoining terrestrial features (units) occurring within each complex; and, 2) Application of Level 6 Primary Cover Class data in order to delineate discrete biological associations within the geologic/geomorphic units delineated in step 1. Land cover data required for step 2 was delivered during the middle of Year 7, in May, 2011. The procedure for step 2 involved a multivariate analysis, using the PRIMER v6.0 statistical software package, to group land cover composition into statistically distinct categories. This was performed only for the following catenae: floodplain; wetland; surge plain, lower flooded; surge plain, upper flooded; surge plain, undifferentiated flooded.

Year 7 efforts included application of step 2 to Reaches D, E, F, G, and H. This step completes the mapping for these reaches, subject to revisions based on results of the USGS technical review. In addition, step 1 mapping was completed for Reaches A, B, and C, followed by application of step 2.

3.4 Classification Year 7 Results

Table 1 provides a detailed timeline for the actions that have been required to complete mapping of Levels 4 and 5. The delivery of bathymetry data and land cover data represent significant landmarks, as these data constitute critical information from which the mapping is derived. The actions listed in the table mirror tasks 1-8 listed in 3.1 above.

Table 1. Timeline for completion of tasks required for mapping of Classification Levels 4 and 5 (Complex and Catenae).

	Year 6												Year 7														
	2009				2010												2011										2012
Action	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct - Dec	Jan – May
Bathymetry data: collection (cont'd from Year 5)																											
Bathymetric data: compile and merge (USACOE)																											
Bathymetric data: delivery of model												X															
Land cover data: planning (RFP process, develop contract)																											
Land cover data: collection																											
Land cover data: delivery																					X						
Revisions to Classification Scheme																											
[1]All Reaches: Aquatic CO (based on new bathymetry)																draft			final rev								
Reach F: Terrestrial Co/Ca (cont'd. from Year5)	draft																rev 1										
Reach F: Cultural Features																		draft									
[1]Reach F: Merged Terrestrial & Aquatic Co/Ca.																		draft	rev 1			rev 2					
[2]Reach F: MV analysis, land cover SC																									draft and rev.		
Reach E: Terrestrial Co/Ca									draft					rev 1													
Reach E: Cultural Features														draft													
[1]Reach E: Merged Terrestrial & Aquatic Co/Ca.																									draft and rev.		
[2]Reach E: MV analysis, land cover SC																									draft and rev.		

Table 1 continued.

	Year 6												Year 7														
	2009				2010												2011										2012
Action	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct - Dec	Jan - May
Reach D,G,H: Terrestrial Co/Ca														draft								rev 1	rev 2				
Reach D,G,H: Cultural Features																						draft	rev 1				
[1] Reach D,G,H: Merged Terrestrial & Aquatic Co/Ca.																									draft and rev.		
[2] Reach D,G,H: MV analysis, land cover SC																									draft and rev.		
Reach C: Terrestrial Co/Ca																									draft	rev.	
Reach C: Cultural Features																									draft	rev.	
[1] Reach C: Merged Terrestrial & Aquatic Co/Ca.																										draft and rev.	
[2] Reach C: MV analysis, land cover SC																										draft and rev.	
Reach A,B: Terrestrial Co/Ca																										draft and rev.	
Reach A,B: Cultural Features																										draft and rev.	
[1] Reach A,B: Merged Terrestrial & Aquatic Co/Ca.																										draft and rev.	
[2] Reach A,B: MV analysis, land cover SC																										draft and rev.	
Generate metadata																											Jan
USGS metadata review																											Feb–Mar
USGS technical review of all map data																											Feb–Apr
Product release																											May

Key:
1: Action requires completed bathymetry data. 2: Action requires completed land cover data
Co = Level 4 Complex Ca = Level 5 Catenae
MV = Multivariate SC = Level 5 Sub-catenae

Table 2 shows the refined Levels 4-5 classification scheme, based on mapping of Reaches A–H. It is not expected that additional modifications will be required based on feedback from the technical review. Thus, this table should represent the final list of possible complexes and catenae.

Table 2. Crosswalk of Complexes and associated Catenae used in the Classification

Complex	Backwater Embayment	Bedrock	Crevasse Splay	Developed	Dune Deposit	Floodplain	Floodplain Backswamp
Possible Catenae	- Intermittently Exposed - Permanently Flooded - Unknown Depth	- Bedrock - Lake/Pond - Wetland	- Floodplain - Floodplain Channel - Lake or Wetland - Lake/Pond - Natural Levee - Tie Channel - Wetland - Tributary (minor) - Filled Areas	- Artificial Water Body - Developed Floodplain - Floodplain Channel - Lake/Pond - Wetland - Tributary (minor) - Filled Areas	- Dune Deposit - Lake/Pond - Wetland - Filled Areas	- Artificial Beach/ Bar - Artificial Water Body - Channel Bar - Floodplain - Floodplain Channel - Lake or Wetland - Lake/Pond - Natural Levee - Tie Channel - Wetland - Tributary(minor) - Filled Areas	- Artificial Beach/ Bar - Artificial Water Body - Channel Bar - Floodplain - Floodplain Channel - Lake or Wetland - Lake/Pond - Natural Levee - Tie Channel - Wetland - Tributary (minor) - Filled Areas

Complex	Floodplain Bar & Scroll	Landslide	Primary Channel	Secondary Channel	Surge Plain	Terrace
Possible Catenae	- Floodplain - Floodplain Channel - Lake or Wetland - Lake/Pond - Natural Levee - Tie Channel - Wetland - Tributary (minor) - Filled Areas	- Lake/Pond - Landslide Deposit - Wetland - Tributary (minor)	- Artificial Water Body - Deep Channel - Intermittently Exposed - Permanently Flooded - Unknown Depth	- Artificial Water Body - Channel Bar - Deep Channel - Intermittently Exposed - Permanently Flooded - Unknown Depth	- Channel Bar - Lower flooded - Tertiary channel, intermittently exposed - Tertiary channel, permanently flooded - Tidal channel - Tributary delta - Undifferentiated flooded - Upper flooded	- Floodplain - Lake/Pond - Terrace

Complex	Tributary Channel	Tributary Fan	Tributary Floodplain	Tributary Secondary Channel	Unknown	Volcanogenic Delta
Possible Catenae	- Artificial Water Body - Channel Bar - Deep Channel - Intermittently Exposed - Intermittently Exposed Bedrock - Permanently Flooded - Side Channel - Tributary Delta - Unknown - Unknown Depth	- Floodplain - Floodplain Channel - Lake/Pond - Tributary Fan - Wetland - Tributary (minor) - Filled Areas	- Channel Bar - Floodplain - Floodplain Channel - Lake/Pond - Natural Levee - Tributary Valley (outside floodplain) - Wetland - Tributary(minor) - Filled Areas	- Deep Channel - Intermittently Exposed - Permanently Flooded	- Floodplain - Lake/Pond - Natural Levee - Unknown - Wetland - Filled Areas	- Artificial Beach/Bar - Floodplain - Floodplain Channel - Lake or Wetland - Lake/Pond - Natural Levee - Volcanogenic Delta - Volcanogenic Delta affected by Col. R. floods - Wetland - Tributary(minor) - Filled Areas

The series of maps shown below (Figures 2-5) illustrate complete extents of the final draft mapping for the Classification. All data are subject to revision based on USGS technical review.

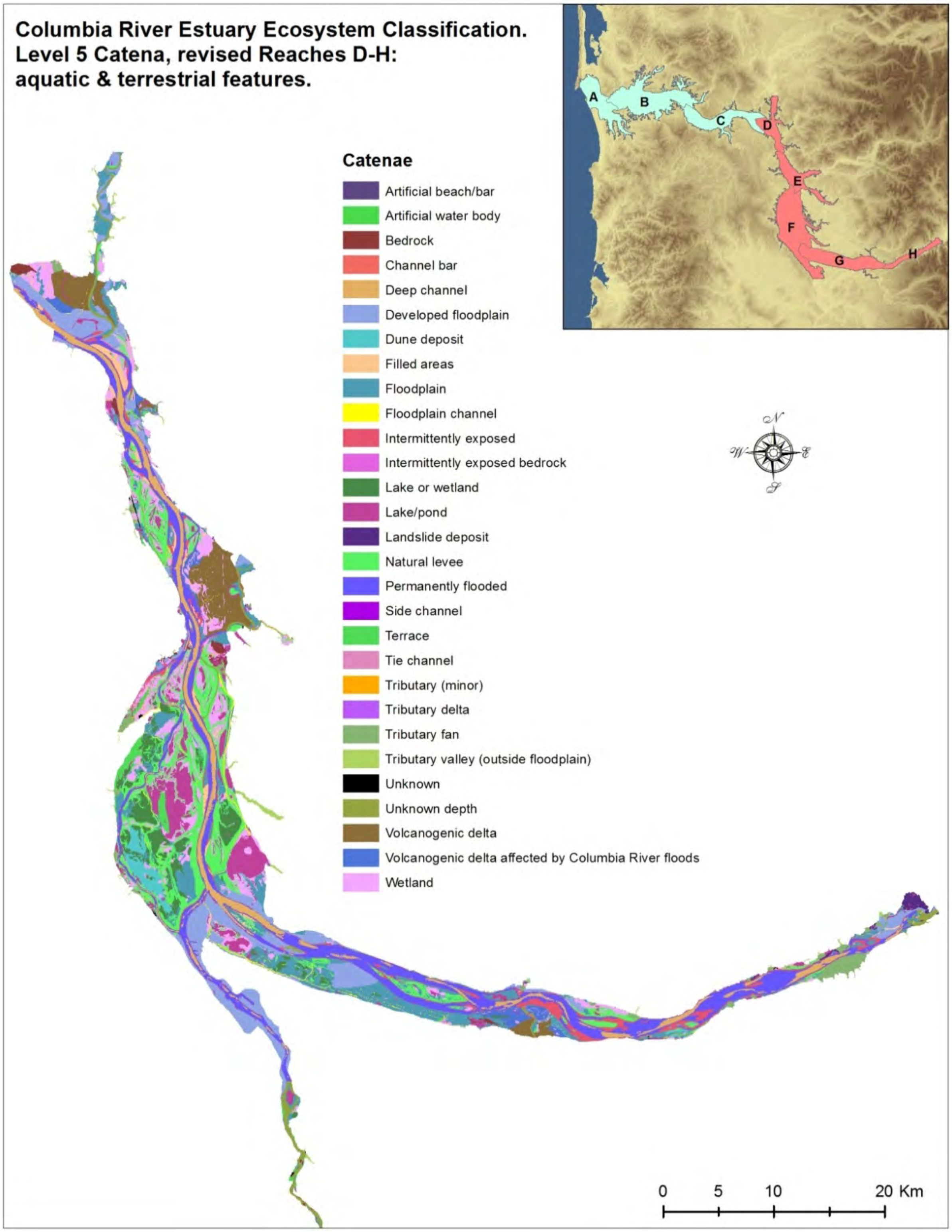


Figure 2. Map of Final Level 5 Geomorphic Catenae for Reaches D–H.

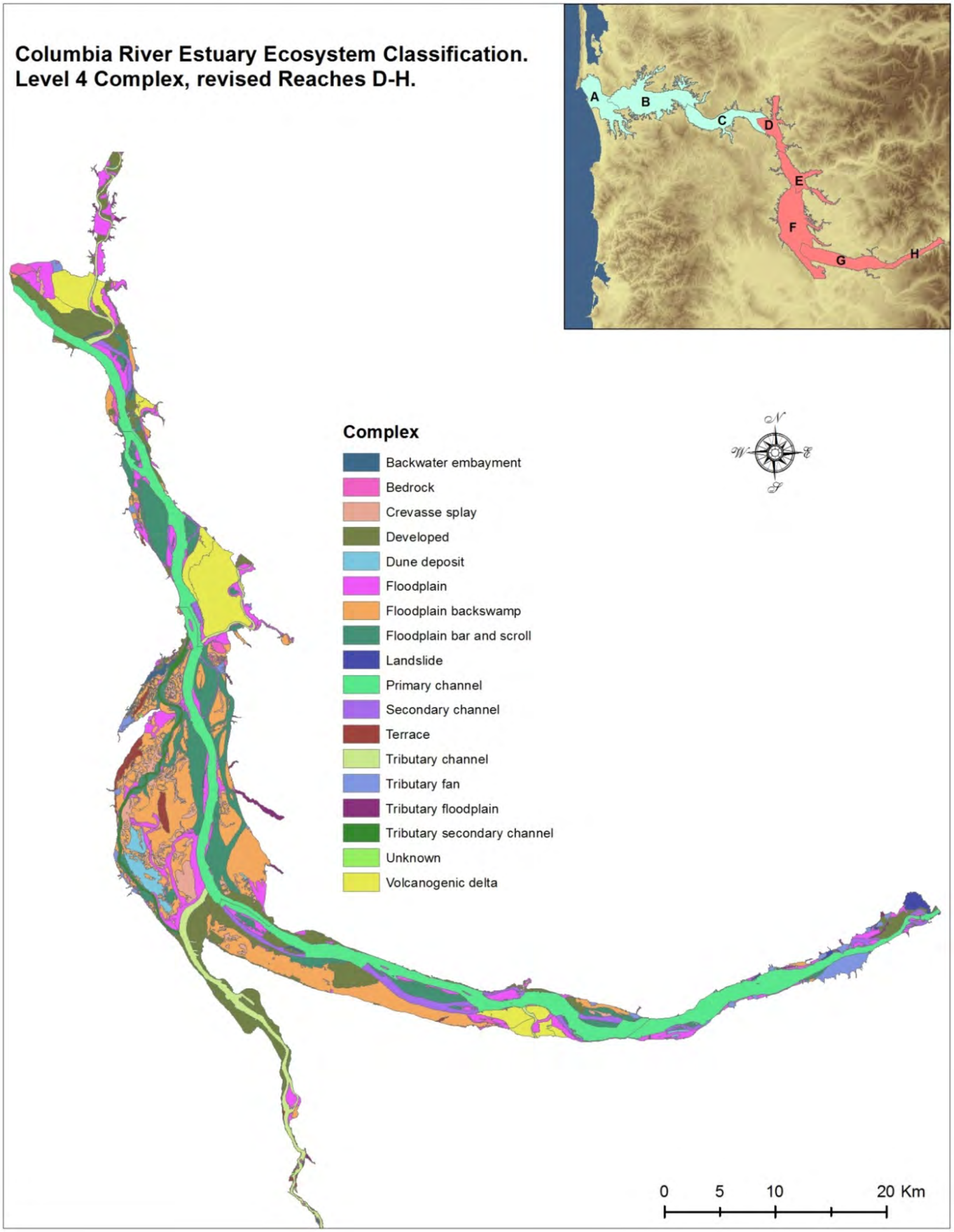


Figure 3. Map of Final Level 4 Geomorphic Complexes for Reaches D–H.

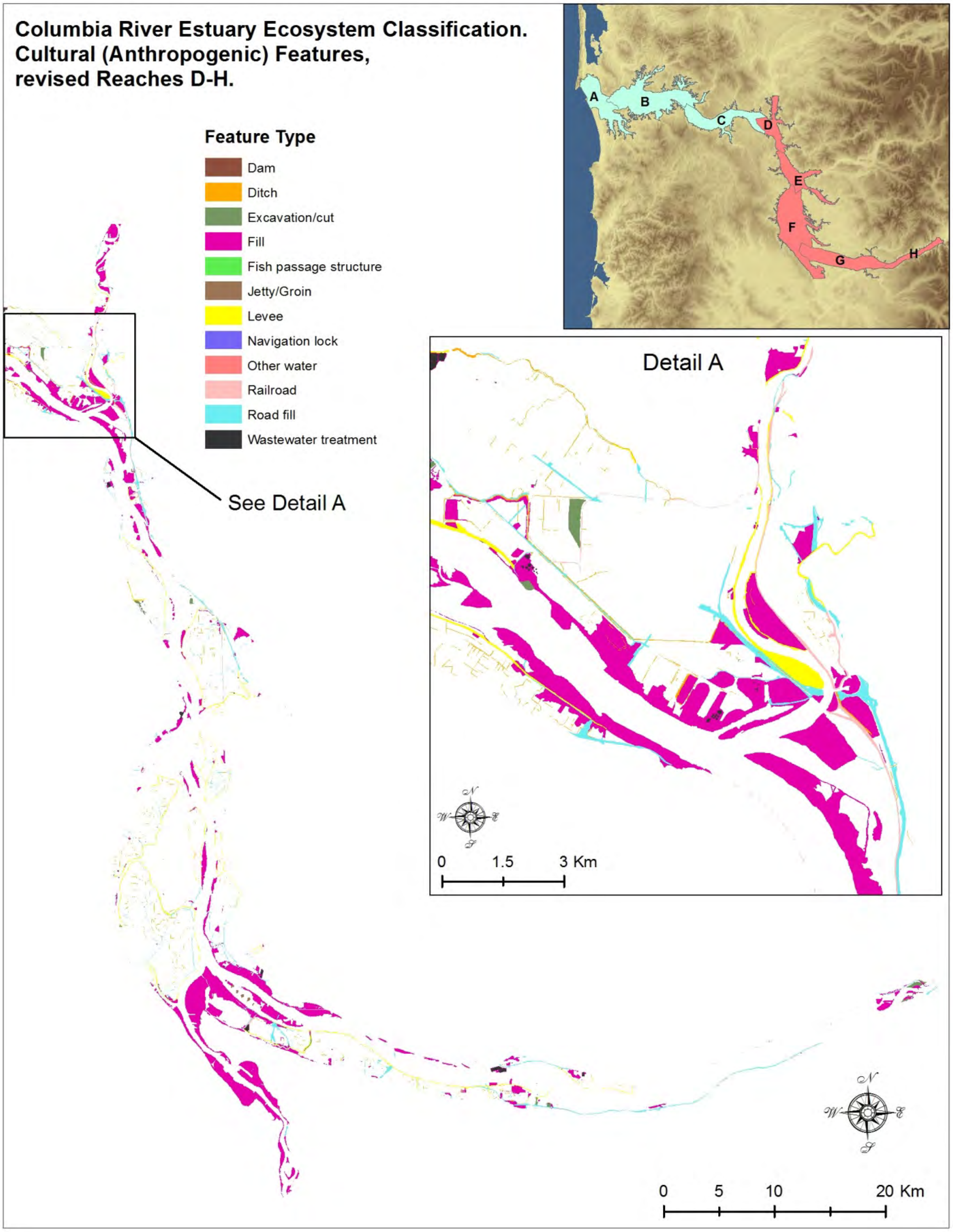


Figure 4. Map of Final Cultural Features for Reaches D–H.

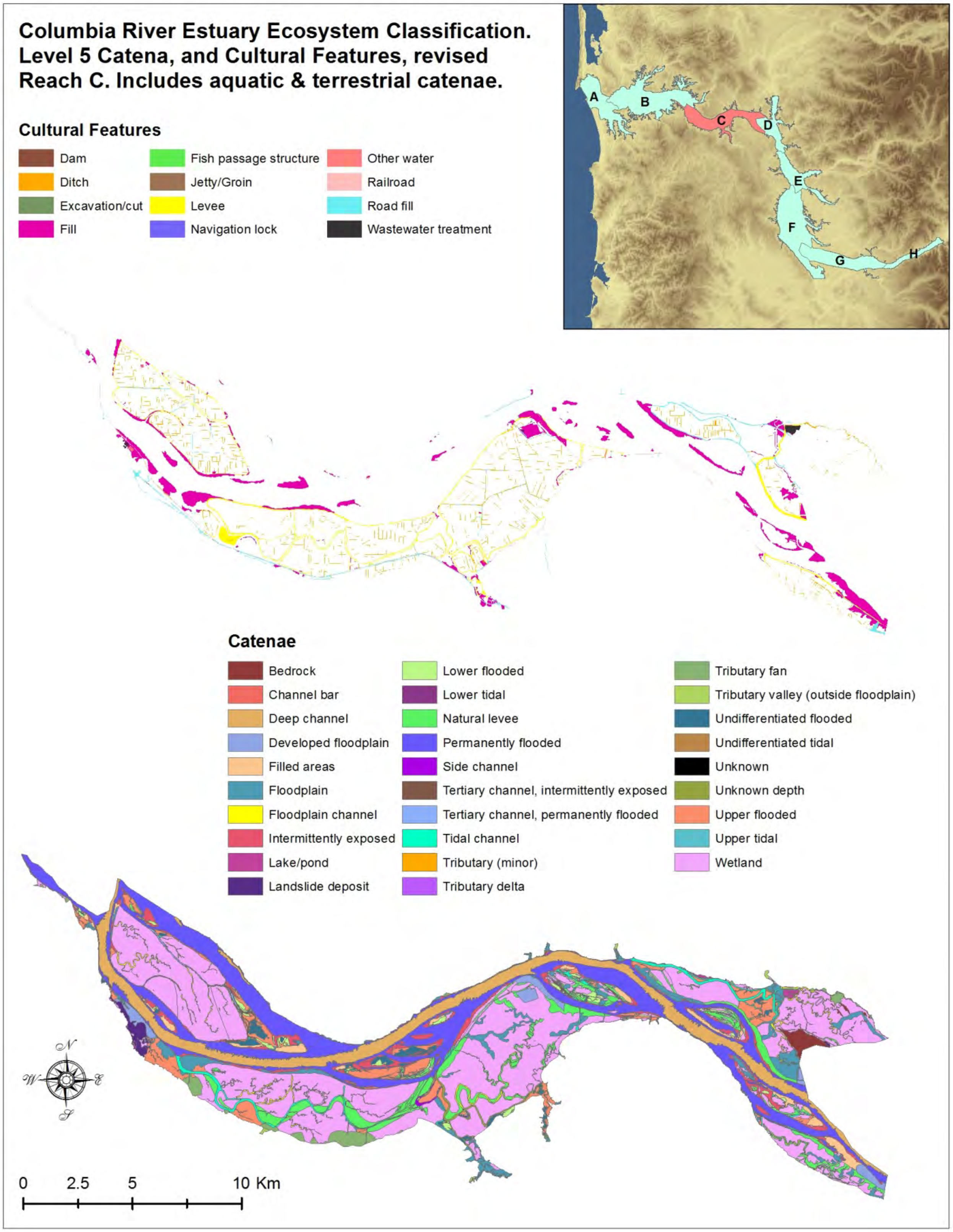


Figure 5. Map of Final Cultural Features and Level 5 Geomorphic Catenae for Reach C.

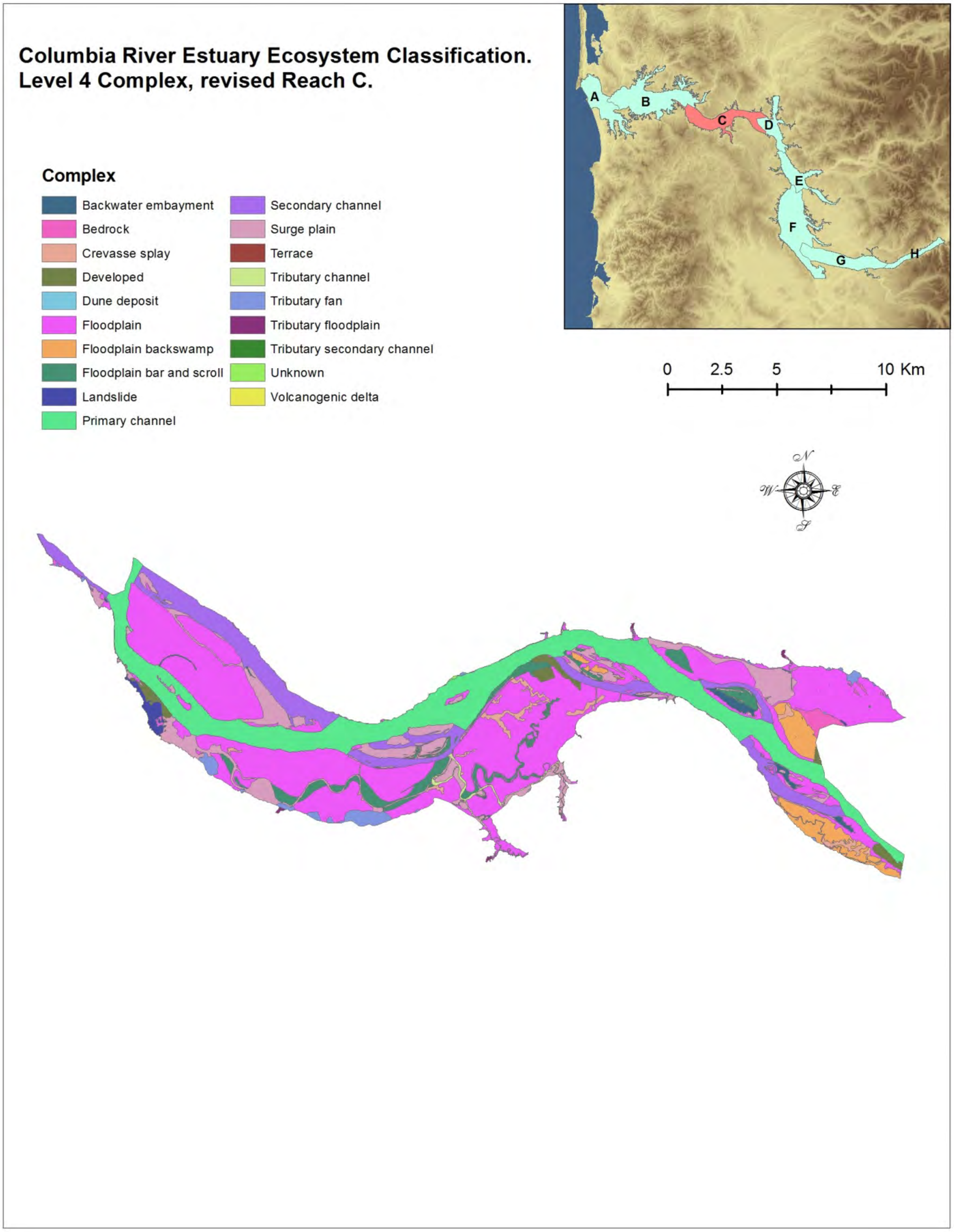


Figure 6. Map of Final Level 4 Geomorphic Complexes for Reach C.

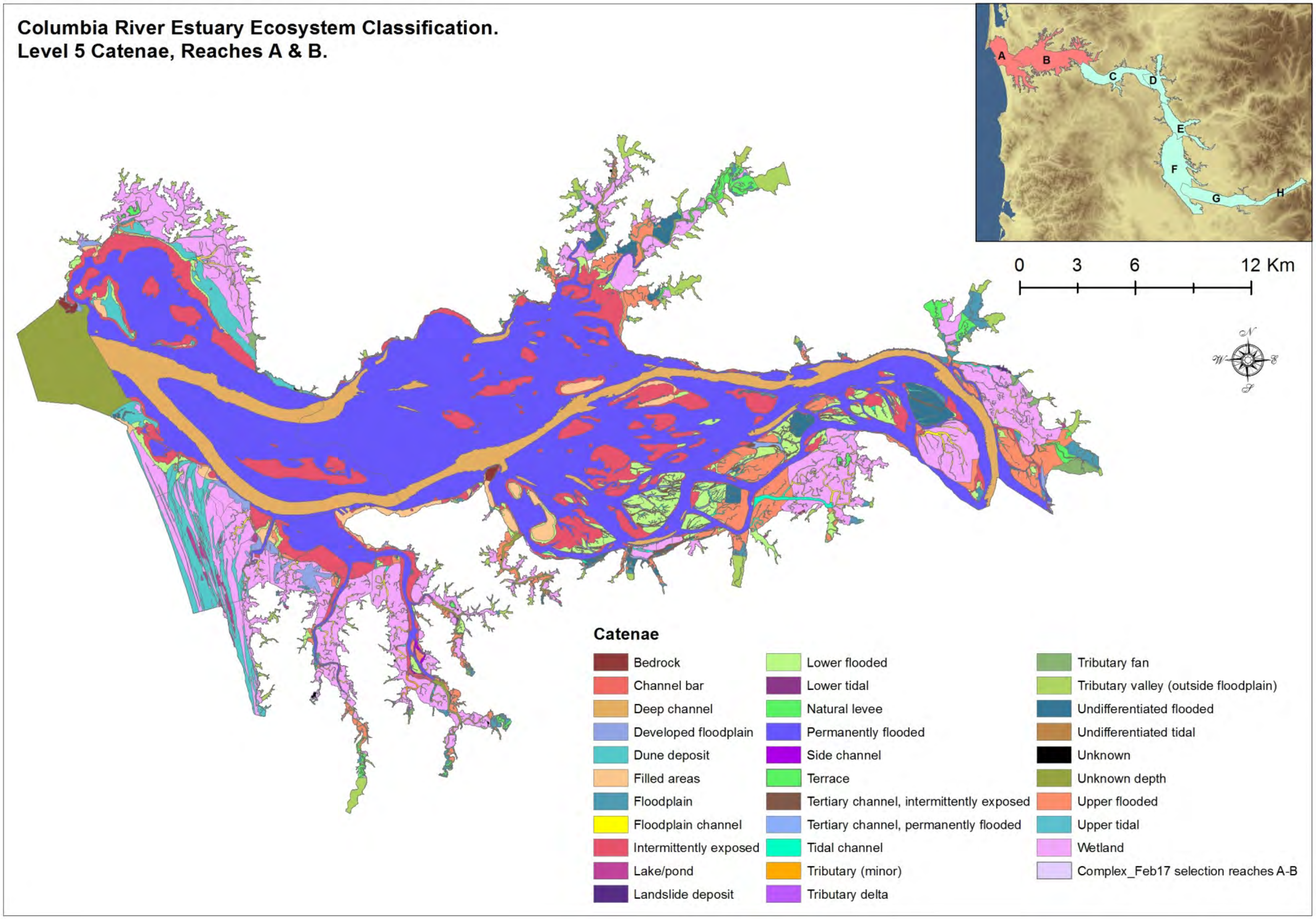


Figure 7. Map of Final Level 5 Geomorphic Catenae for Reaches A & B.

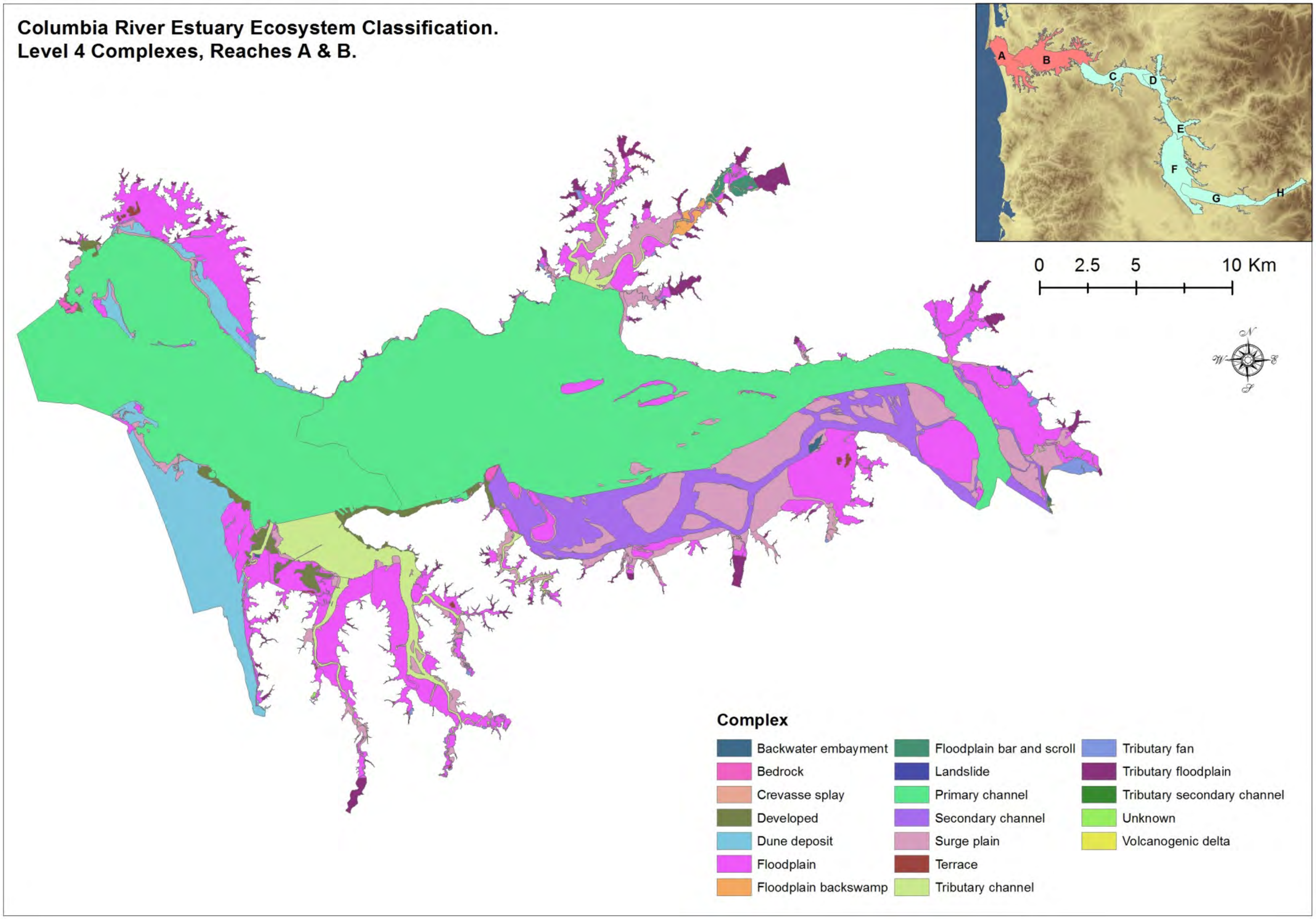


Figure 8. Map of Final Level 4 Geomorphic Complexes for Reaches A & B.

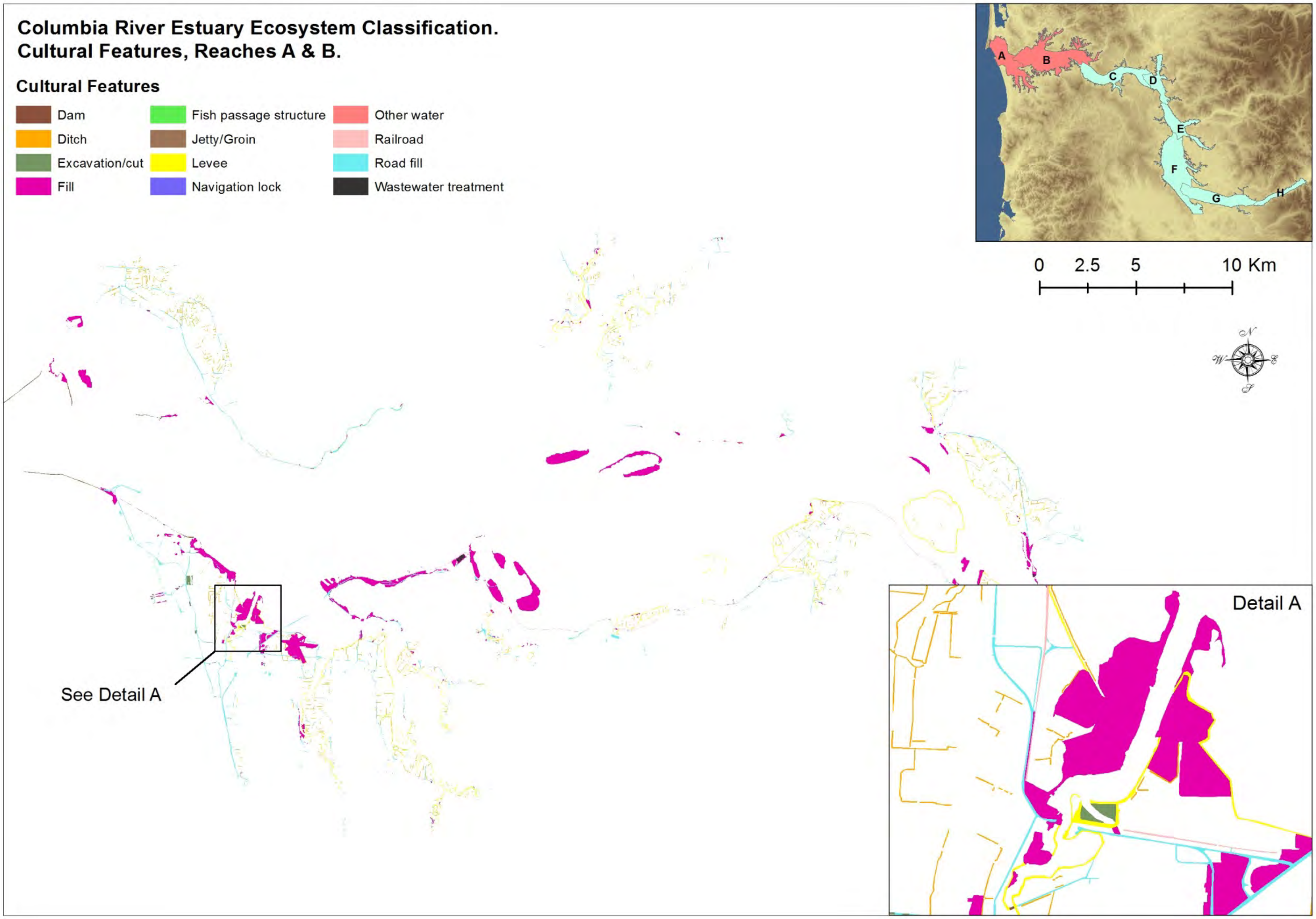


Figure 9. Map of Final Cultural Features for Reaches A & B.

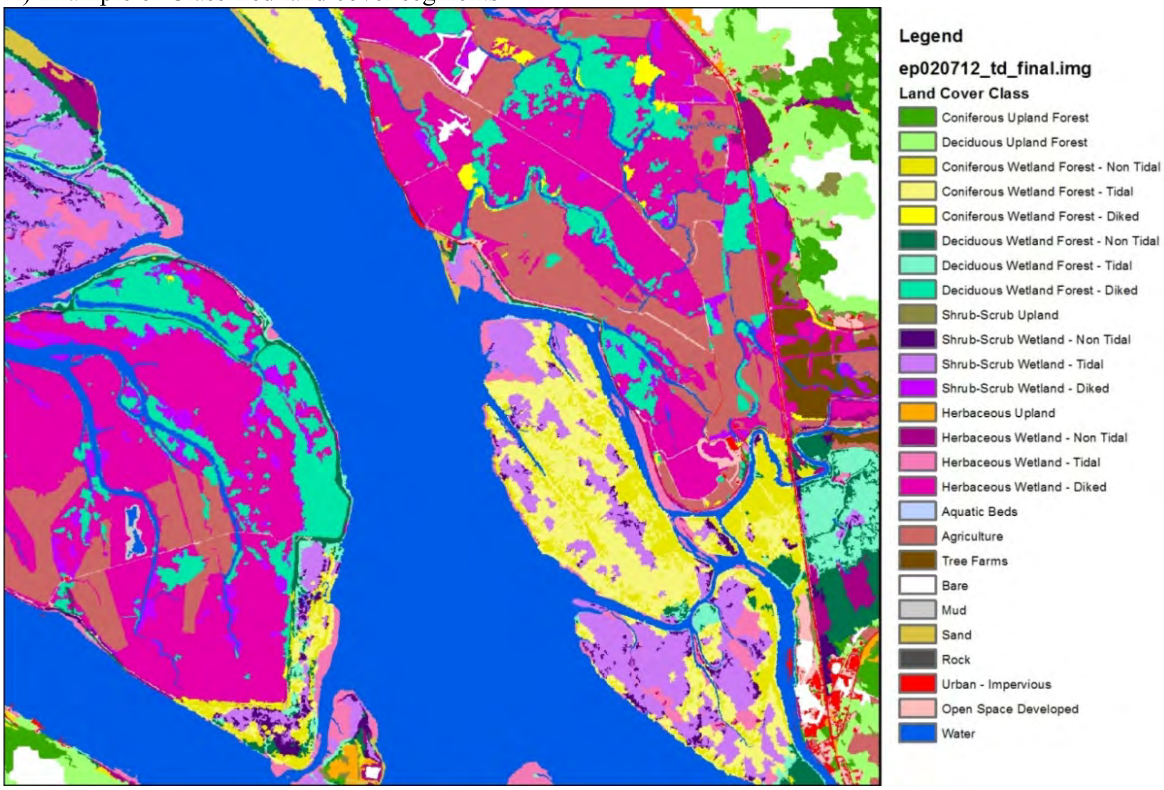
3.5 Land Cover Data

Delivery of the land cover data in Year 7 fills the last critical data gap necessary for completing the Classification. Specifically, land cover assists in the delineation of Level 5 (Geomorphic Catenae) and also serves as the stand alone Layer 6 (Primary Cover Class). The previously existing 2000 LANDSAT classification is nearly 10 years old and is functionally limited with regard to the Classification. For instance, the 2000 landcover data does not differentiate well between tidal and non-tidal wetlands, uplands and wetlands, and forest classes like mixed, coniferous, and deciduous forests. To address this data gap, the Estuary Partnership contracted with the Sanborn Map Company in January 2010 to generate a new data set. The contract period for this project extended over the Year 6 and Year 7 BPA contract periods, with data scheduled for delivery midway through Year 7. Additional details regarding the 2009 land cover workshop and the competitive bid process to select a contractor for the new land cover data can be found in the Year 6 report.

Sanborn has done extensive work of similar nature for the NOAA Coastal Change Analysis Program (C-CAP), and has developed an innovative, polygon based approach to high resolution land cover mapping that offers some advantages relative to more traditional techniques. Sanborn subcontracted with SWCA, a local consulting firm, to complete the field sampling portion of this project, while they themselves handled the image classification tasks. In addition, the NOAA C-CAP program partnered in this effort, providing extensive technical and field support.

The final dataset consisted of a polygon based, GIS data set with 26 land cover classes representative of typical estuarine habitats. In addition to vegetation information, this classification also characterizes the landscape with regard to the extent of tidal/fluvial influence. Wetland areas are further classified as being either tidal (influenced by the main stem Columbia by a combination of ocean tides and river stage), diked (low lying areas which are blocked from the influence of ocean tides and river stage by manmade barriers such as levees or tidegates), or non-tidal (areas of the floodplain whose elevation is higher than typical inundation levels resulting from the combination of ocean tides and river stage). A final report for the project is available from the Estuary Partnership. The digital data and metadata are currently available from the NOAA C-CAP data portal, and will be available from the Estuary Partnership website later in 2012. The data has been distributed to several restoration and monitoring partners throughout the region. Figure 6 shows a segment of the 2010 land cover data set, and an aerial image of the area that is classified.

A) Example of Classified land cover segments



B) Aerial Image of classified area shown in A

Figure 10. 2010 Land cover classification.

Table 3 shows the results of the accuracy assessment that was generated for this data set, which provides a measure of the quality of the data. The accuracy assessment reflects the difference between classified and reference data, for a randomly selected group of reference data obtained from field observations. Values in the diagonal boxes indicate the number of correctly classified segments for each land cover class. Four measures of accuracy are provided, as follows:

1) Overall accuracy – the number of correctly classified segments divided by the total number of reference observations. For these results, the value is 100* (649/749), or 86.2%.

2) Kappa coefficient – this is a multivariate statistical measure of overall accuracy, which is a more robust measure of the overall accuracy.

3) Producer's accuracy (errors of omission) – the probability that a certain land cover for an area is actually classified as such. Using the upland coniferous forest class as an example, the producer's accuracy for this class is calculated as 100 * (45/54) = 83%. This indicates that 83% of the upland coniferous forest reference samples were classified correctly in the map.

4) User's accuracy (errors of commission) – the probability that a segment that is labeled as a certain land cover class in the map is really in this class. Again using the upland coniferous forest example, the user's accuracy can be calculated as 100* (45/50) = 90%. This indicates that users of the map can expect roughly 90% of all segments that are classified as upland coniferous forest actually belong to this class.

Table 3. Error matrix for the 2010 land cover classification accuracy assessment:

	Reference (Ground Truth) Data: # of ground truth samples																
Map Data: # of segments classified in map as	Upland Coniferous Forest	Upland Deciduous Forest	Wetland Coniferous Forest	Wetland Deciduous Forest	Upland Shrub-Scrub	Wetland Shrub-Scrub	Upland Herbaceous	Wetland Herbaceous	Agriculture	Tree Plantations	Bare	Mud	Sand	Urban – Impervious	Water	**Total**	**User's Accuracy (%)**
Upland Coniferous Forest	**45**	4	1													50	90
Upland Deciduous Forest	8	**45**		7	2											62	73
Wetland Coniferous Forest		1	**30**													31	97
Wetland Deciduous Forest	1	4	4	**42**		3				2						56	75
Upland Shrub-Scrub					**33**	5	1		1							40	83
Wetland Shrub-Scrub				1	4	**38**		3								46	83
Upland Herbaceous					5		**37**				3					45	82
Wetland Herbaceous					4	5	3	**52**	2		1	2	1			70	74

Agriculture					2	1	8		**52**	2	1					66	79
Tree Plantations										**39**						39	100
Bare											**45**					45	100
Mud												**40**	2			42	95
Sand							1					6	**47**			54	87
Urban – Impervious														**50**		50	100
Water												2			**51**	53	96
Total	**54**	**54**	**35**	**50**	**50**	**52**	**50**	**55**	**55**	**43**	**50**	**50**	**50**	**50**	**51**	**749**	
Producer's Accuracy (%)	83	83	86	84	66	73	74	95	95	91	90	80	94	100	100		

Overall Accuracy: 86%
Kappa Coefficient: 0.85

3.6 Classification Work Efforts Planned for 2012

As follow up to the final draft mapping, and in order to officially release the Classification dataset, the following tasks will be required in early 2012, in order to complete this multi-year project:

1) Generate metadata for the complete mapping project. (Feb. 2012)
2) USGS technical review of GIS draft map data sets. (Mar. – Apr. 2012)
3) USGS internal review of metadata. (Mar. – Apr. 2012)
4) Edits to final draft data as necessary based on review process. (May 2012)
5) Official release of all GIS data and metadata which constitute the completed Classification. (June 2012).

4.0 Characterization of Emergent Wetlands in the LCRE

4.1 Sites

The on-going objective of the EMP is to characterize estuarine and tidal freshwater habitats and monitor salmon occurrence and health in those habitats in the LCRE. Based on funding levels, the EMP has largely concentrated on characterizing relatively undisturbed emergent wetlands and tidal forested wetlands that provide important rearing habitat for juvenile salmonids. Since 2007, we have co-located monitoring of vegetation, fish, fish prey, and some basic water conditions at emergent wetlands sites in order to have similar datasets for multiple sites throughout the LCRE. Starting in 2011, the Estuary Partnership added food web and abiotic site conditions (i.e., conditions influencing productivity such as temperature, water clarity, dissolved oxygen, nutrients) sampling and analysis to the EMP.

4.1.1 Selection

For the 2011 data collection efforts, the Estuary Partnership used the National Wetland Inventory (NWI, available at http://www.fws.gov/nwi/) for Reach E (Figure 11) to generate a list of potential sampling sites. This initial list was filtered using the following criteria applied in previous years to select the vegetation monitoring sites:

1. The site's wetland vegetation is classified as "emergent" in the NWI layer.
2. The site has tidal connectivity with the mainstem Columbia River.
3. The site's wetland is minimally disturbed (e.g., no diking, active grazing, tide-gate modifying flow regime present at the site).
4. The area of wetland is greater than 5 acres.
5. A backwater slough or other off-channel habitat thought key for juvenile salmon rearing is present.

During this process, EMP partners determined that a random sampling design was not appropriate for current monitoring efforts because:

1. Monitoring was focused on a specific habitat type (undisturbed emergent wetland) and reach.
2. Only a limited number of relatively intact, emergent wetlands occur on the landscape due to past land use activities.
3. Future management activities that would likely modify site conditions (logging, farming, construction) constrains long term data collection at site.
4. Site access from landowner permission or other constraints further limits the number of sites.
5. Data collected in 2011 should be consistent and comparable with data collected from 2005 to 2010.

In fall 2010, the Estuary Partnership, NOAA-Fisheries, PNNL, and USGS visited the potential sampling sites during a reconnaissance trip (Appendix A). In the end, the final habitat criteria used to select the 2011 monitoring sites were:

1. The site's wetland vegetation is classified as "emergent" in the NWI layer.
2. The site has tidal connectivity with the mainstem Columbia River.
3. The site's wetland is minimally disturbed (e.g., no diking, active grazing, tide-gate modifying flow regime present at the site).
4. The area of wetland is greater than 5 acres.
5. Wetlands at the site are shallow water.
6. The site is mainstem fringing or off-channel habitat.
7. The site is not located near immediate stressors or disturbance like industry, grazers, or recreational use.
8. Site sediments are generally smaller particle sizes, which are characteristic of lower-energy systems and more likely to support emergent marsh habitats than habitats with larger particle sizes.

Additional logistical criteria included:

1. Stream channels are present at the site to facilitate the collection of cross-section and fish data.
2. The site is fishable by beach seine or similar gear-type.
3. The site is accessible for sampling purposes and with landowner permission.

The final criteria for 2011-site selection were selected based on funding levels, the desire for data comparability with previously collected data, and reasons outlined above. This strategy focused the monitoring effort and facilitated the collection of data comparable with previous efforts. This strategy, however, does not meet the original goal for the EMP contract, which calls for a probabilistic sampling design, because current monitoring can only focus on one habitat type (undisturbed emergent wetlands) and not multiple habitat strata as a result of limited funding levels. At this time, data collected by the EMP will not support an assessment of ecosystem condition nor overall wetland condition within individual reaches due to its limited scope. The strategy does not support the collection of data that represents variation within and between different wetland types across the entire reach (es) being sampled or at an estuary-wide scale. At this time, it is not feasible to collect data facilitating the extrapolation of sampling results to the reach scale and considerations of statistical issues like the optimal size of the sampling unit, sources of error, and measures of variation. Instead, data collected in 2011 characterize a subpopulation of Reach E's wetlands (undisturbed emergent wetland), which are likely important habitat for juvenile salmon. The remaining wetland types in Reach E may have less salmon and lower abundances of marsh vegetation and wider ranges in sediment particle size and other physical attributes. While the 2011 effort provides initial information useful for understanding habitat conditions and salmonid use of undisturbed emergent wetlands in Reach E (and fixed-site reaches), sampling at a larger number of sites and habitat types throughout the 8 reaches is necessary to extend results to the estuary at large, assess system-wide ecosystem "health," and obtain the adequate statistical power needed for such analyses.

In 2011, the EMP partners selected 3 sites in Reach E for status monitoring: Deer Island, Goat Island and Burke Island (Table 4; Figure 12). Partners re-sampled 3 fixed sites for trends monitoring (Campbell Slough and Cunningham Lake in Reach F, Franz Lake in Reach F and Whites Island in Reach C) where data were previously collected and added a new fixed site in Reach A (Ilwaco) (Table 4; Figure 11).

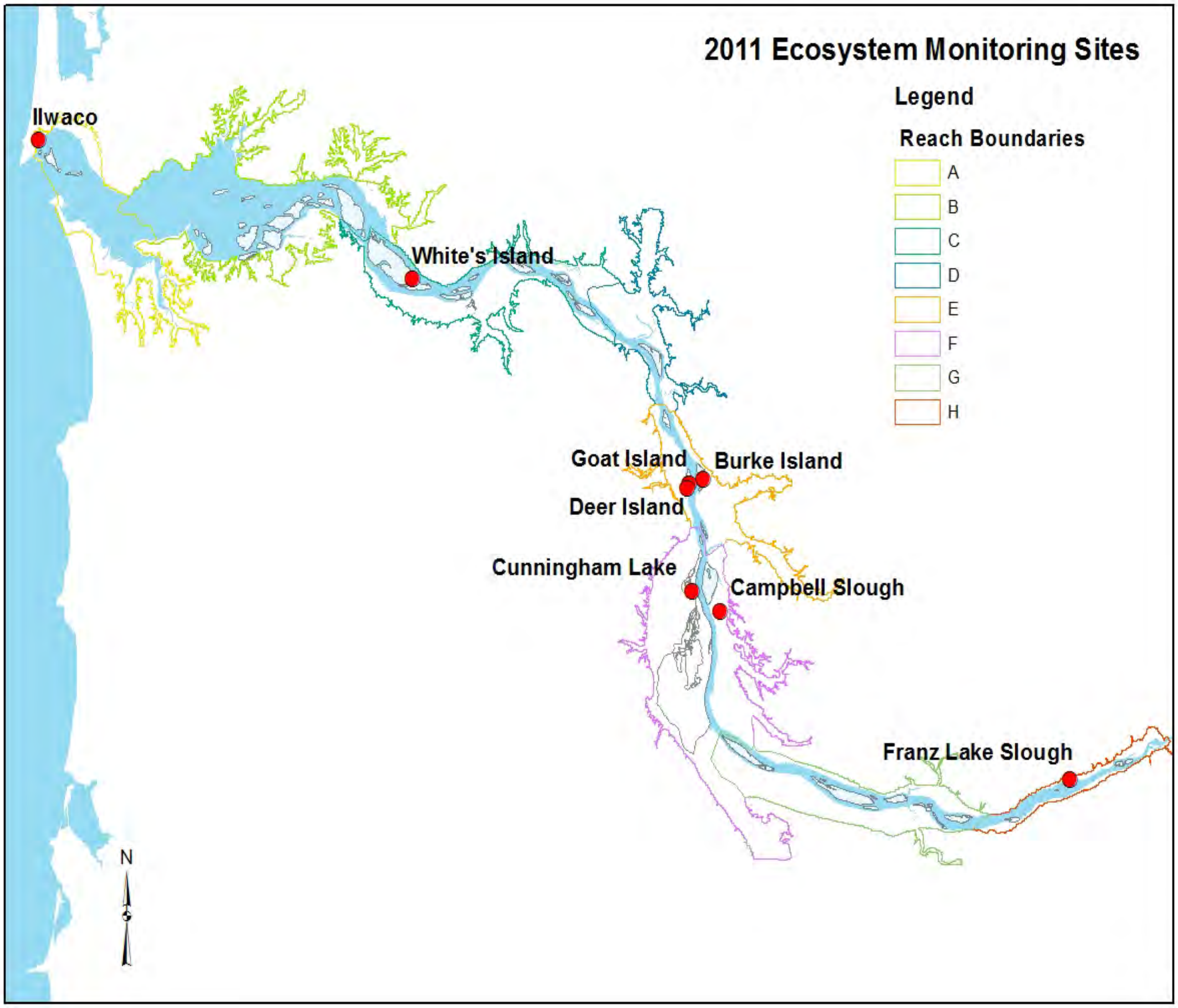


Figure 11. Map of Reaches A to H, showing the location of the 2011 monitoring sites.

Table 4. Summary of sampling effort by site and year(s) for sites; where data were collected in 2011 site is in **bold**. *Lord-Walker Island 2 was sampled by the EMP in conjunction with the Reference Site Study; thus, only vegetation and habitat data were collected at Lord-Walker 2.

Reach	Type of Site	Site	Vegetation & Habitat	Fish & Prey	Water Quality & Depth	Food Web
A	Trend	**Ilwaco**	2011	2011	2011	2011
C	Status	Ryan Island	2009	2009		
	Status	Lord-Walker Island 1	2009	2009		
	Status	Lord-Walker Island 2*	2009			
	Trend	**White Island**	2009-2011	2009-2011	2009	2011
	Status	Jackson Island	2010	2010		
	Status	Wallace Island	2010	2010		
	Status	Bradwood Landing	No access permission	2010		
D	Status	Cottonwood Island small slough	2005			
	Status	Cottonwood Island large slough	2005			
	Status	Dibble Slough	2005		2005	
E	Status	Sandy Island 1, 2	2007	2007		
	Status	Lewis River Mouth	2007			
	Status	Martin Island	2007			
F	Status	Sauvie Cove	2005			
	Status	Hogan Ranch	2005			
	Status	**Goat Island**	2011	2011		
	Status	**Deer Island**	2011	2011		
	Status	**Burke Island**	2011	2011		
	Trend	**Cunningham Lake**	2005-2011	2007-2009		
	Trend	**Campbell Slough**	2005-2011	2007-2011	2008- 2011	2011
G	Status	Water Resources Center				
	Status	McGuire Island	2006			
	Status	Old Channel Sandy River	2006			2006
	Status	Chattam Island	2006			
H	Trend	**Franz Lake**	2008-2009, 2011	2008-2009, 2011	2011	2011
	Status	Sand Island	2008	2008	2008	
	Status	Beacon Rock	2008	2008		
	Status	Hardy Slough	2008	2008		

4.1.2 Site Description

Ilwaco. Located in Reach A, southeast of the entrance of Ilwaco Harbor, is Baker Bay marsh. The property is currently owned by Washington Department of Natural Resources. Recently selected as a long-term monitoring site, the Ilwaco marsh is dominated by lush fields of Lyngby's sedge (*Carex lyngbyei*) with higher portions occupied by Tufted hairgrass (*Deschampsia cespitosa*) and cattail (*Typha angustifolia*). Being so close to the mouth of the river, the slough is regularly inundated with brackish water (Figure 4a).

Whites Island. The Whites Island site is located on Cut-Off Slough at the southern (upstream) end of Puget Island, near Cathlamet, Washington. A portion of the island is owned by Washington Department of Fish and Wildlife (WDFW) and is maintained as Columbia white-tailed deer habitat. Whites Island is not present on the historical maps from the 1880s and was likely created from dredge material placement. The monitoring site, located at the confluence of a large tidal channel and an extensive slough system, is approximately 0.2 km from an outlet to Cathlamet Channel; however, according to historic photos, this outlet was not present prior to 2006 and the River connection was approximately 0.7 km from the monitoring site. The site is characterized by high marsh and a few willows, with numerous small tidal channels.

Burke Island, Goat Island, and Deer Island. Three rotating sites for this sampling year occur in Reach E. Burke Island slough, located furthest downstream at river kilometer 131, is the only historically present marsh of the three (Figure 12). Located on private property, the slough and associated marsh are wedged between agriculturally managed fields. The Burke Island marsh consists mostly of wapato (*Sagittaria latifolia*) and sparse reed-canary grass (*Phalaris arundinacea*), with the reed-canary grass becoming more dense in the higher areas. Located across the river on the Oregon side is Goat Island slough, a created site composed of dredge material deposited within the last 50 years. The monitoring site, located at the upstream end of the island, is a fringing emergent marsh surrounded by steep banks populated by cottonwood (*Populus balsamifera*) and Pacific willow (*Salix lucida*). Adjacent to the Goat Island slough is Deer Island south slough, which hugs the Oregon bank. The lower portion of the site is dominated by sparse creeping spike-rush (*Eleocharis palustris*) and sparse reed-canary grass (*Phalaris arundinacea*), with reed-canary grass becoming more dense in the higher areas.

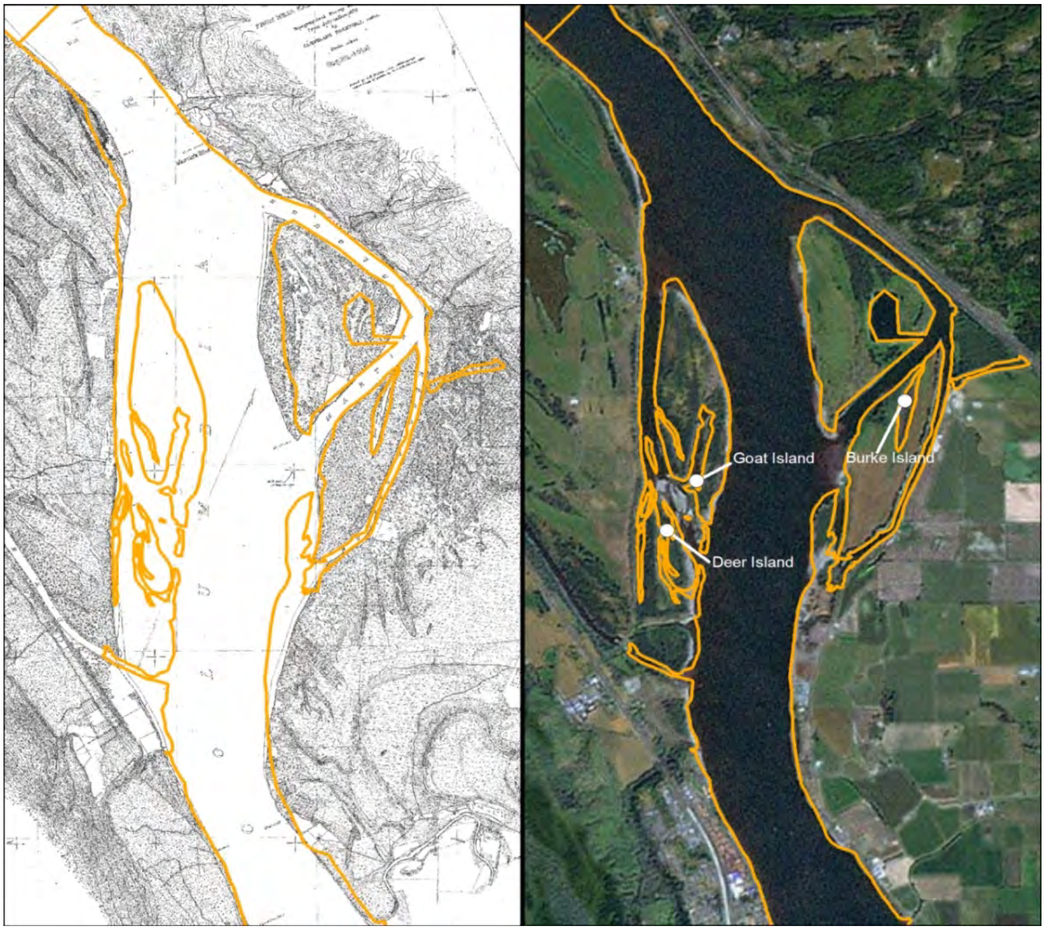


Figure 12. Close-up maps of Reach E depicting historical conditions and the current shoreline.

Cunningham Lake and Campbell Slough. Cunningham Lake and Campbell Slough sites are located in Reach F. These sites have been surveyed annually for habitat structure since 2005. While the 2004 rotational-panel sampling design has never be fully implemented due to program funding levels, these two sites have been included with each annual survey to help better understand inter-annual variability in vegetation patterns. Cunningham Lake is located on Sauvie Island in the Oregon DFW Wildlife Area at the end of Cunningham Slough, approximately 6.4 km from the mainstem of the Columbia River. The site is a fringing emergent marsh bordering the extremely shallow "lake" (Figure 13f) that in some years is covered with wapato (*Sagittaria latifolia*). Campbell Slough is located on the Ridgefield National Wildlife Refuge in Washington. The monitoring site is an emergent marsh adjacent to the slough, approximately 1.4 km from the mainstem of the Columbia River. The site grades from wapato up to reed canary grass and is adjacent to fenced-in pasture land. Extensive grazing occurred at the site in 2007 but vegetation has been recovering since then. In 2010 and 2011, slight evidence of grazing was again observed.

Franz Lake. Located the furthest up river in Reach H is Franz Lake, which is part of the Pierce National Wildlife Refuge. The site has an expansive area of emergent marsh extending 2 km from the mouth of the slough to a large, shallow ponded area. The sample site was located approximately 350 m from the channel mouth. Several beaver dams have created a series of ponds along the length of the channel resulting in large areas of shallow water wetland with fringing banks gradually sloping to an upland ecosystem.

Figure 13. 2011 Ecosystem Monitoring sites: (a) Ilwaco ; (b) Whites Island, Cut-Off Slough; (c) Burke Island slough; (d) Goat Island slough; (e) Deer Island south slough; (f) Cunningham Lake; (g) Campbell Slough; and (h) Franz Lake.

4.2 Vegetation and habitat monitoring

The EMP is a collaborative effort between the Estuary Partnership, USGS, NOAA-Fisheries, PNNL, OHSU and CREST. PNNL's role in this multi-year study is to monitor the habitat structure (e.g., vegetation, topography, channel morphology, and sediment type) as well as hydrologic patterns. Each year the monitoring program strives to monitor a number of core sites for "trends" analysis and a number of rotating sites for "status" analysis. The number of sites has been limited by available funds in the past; however, the number of core sites has gradually been increasing to allow for a more comprehensive evaluation of the LCRE. To date, 29 sites have been sampled as part of this program (Table 4). This report summarizes the 2011 field effort and provides the results for multi-site data analysis including data collected at emergent wetland sites from 2005 – 2010 as part of this and other studies in the estuary.

4.2.1 Metrics Monitored

This study is using standard monitoring protocols developed for the LCRE (Roegner et al., 2009). Five metrics are included in this part of the monitoring program. These metrics have been determined to represent important structural components, which can be inferred to provide habitat functions. The rationale for choosing these metrics is discussed below.

Elevation, hydrology, and substrate are the primary factors that control wetland vegetation composition, abundance, and cover. Knowing the elevation, soil, and hydrology required by native tidal wetland vegetation is critical to designing and evaluating the effectiveness of restoration projects (Kentula et al., 1992). Sediment accretion is important for maintaining wetland elevation. Accretion rates can vary substantially between natural and restored systems (Diefenderfer et al., 2008); therefore, baseline information on rates is important for understanding potential evolution of a reference or restoration site. Evaluating vegetation composition and species cover provides an indication of the many functions provided by wetland vegetation. These functions include the production of organic matter (macrodetritus), food web support, habitat for many fish and wildlife species including salmon, and contributing to overall biodiversity of the Columbia River estuarine ecosystem. Likewise, collection of vegetation biomass is being conducted at the core sites to begin to quantify the contribution of organic matter from these wetlands to the ecosystem.

Assessment of channel cross sections and channel networks provides information on the potential for many important estuarine functions including fish access (Simenstad and Cordell 2000) and export of prey, organic matter, and nutrients. This information is also necessary to develop the relationship between cross-section dimensions and marsh size, which aids in understanding the channel dimensions necessary for a self-maintaining restored area (Diefenderfer et al., 2009). The primary objective associated with the channel data collection effort is to determine how unmodified channels may differ between reaches within the region with regard to habitat opportunity (Bottom et al., 2005).

4.2.2 Water Year

The water year from 2010 to 2011 began with the water surface elevation (WSE) below average in the fall followed by above average water levels through the spring and summer (Figure 14). The WSE resulting from the spring freshet in 2011 was 2.5 m higher than the 29-year average, starting with a peak in early April then sustained at that level or higher from mid-May to mid-July. During our usual sampling period in the last 2 weeks of July, WSE was still higher than average and precluded sampling at any 2011 monitoring sites until late July, and at the Franz

Lake site (nearest the dam at river kilometer [rkm] 221) until late August. Even at these late dates, water was present in the vegetation at all sites during sampling, and at some lower elevation areas the water was too deep to see the bottom.

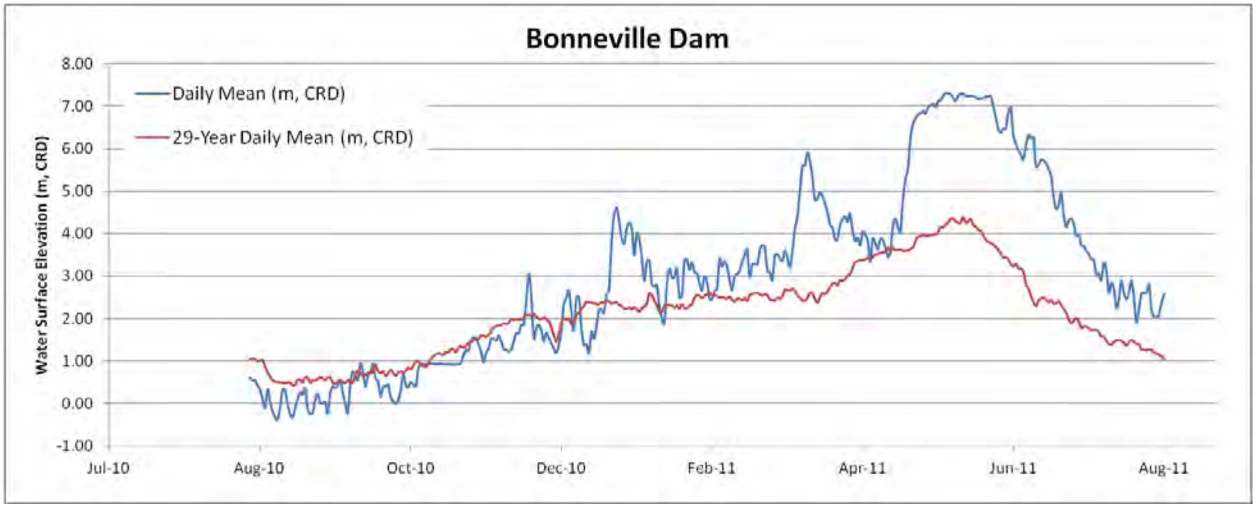


Figure 14. Water surface elevation at Bonneville Dam (rkm 233) from August 2010 to August 2011 compared to the 29-year daily average water surface elevation (Data from USGS National Water Information System at: http://waterdata.usgs.gov/nwis/).

4.2.3 Methods

The methods outlined below detail 1) the annual monitoring methods employed at the core and rotational sites; 2) the methods used to synthesize data collected since 2005 at multiple monitoring sites; and 3) the methods used to update the temporal analysis of the core sites that was originally conducted in 2010 (Borde et al., 2011a)

As in previous years (i.e., 2005-2010), we surveyed sites for elevation, determined percent cover of vegetation along transects, and mapped prominent vegetation communities within the marsh. Since 2009, we have also measured channel cross sections, installed sediment accretion stakes at all sites, and collected sediment samples at new sites. New in the 2011 sampling year, biomass collection was performed at all of the core sites, excluding Cunningham Lake. A photo point was also designated at each site from which photographs were taken to document the 360-degree view. Methods generally follow the restoration monitoring protocols developed by Roegner et al. (2009) for the LCRE.

The vegetation monitoring schedule was delayed this year by an extended high water period (see Section 4.2.2 above). Biomass retrieval was also delayed at Campbell Slough, as was all vegetation monitoring at Franz Lake. The high water also influenced several of the metrics recorded, including vegetation percent cover. At the upper river sites, lower portions of the marshes were inundated during the entire monitoring period. Sampling occurred between 7/26/2011 and 8/26/2011 (Table 5).

Table 5. Sampling dates for each site monitored in 2011.

Site	Sampling Date
Goat Island	7/26/2011
Deer Island	7/27/2011
Burke Island	7/28/2011
Campbell Slough	7/29/2011*
Cunningham Lake	7/30/2011
Ilwaco	8/1/2011
Whites Island	8/2/2011
Franz Lake	8/25/2011

* The biomass samples at Campbell Slough were collected on 8/26/11.

Sediment Composition

Sediment samples were collected within each major vegetation community strata at Ilwaco, Burke Island, Deer Island and Goat Island. Sediment samples were collected in 2008 at Campbell Slough and Cunningham Lake, and at Franz Lake and Whites Island in 2009 and therefore were not recollected this year. Two 10-cm cores were collected within each stratum and homogenized in a large metal bowl, placed in a clean plastic bag, and kept in a cooler until shipment to the analyzing lab. Samples were analyzed by Columbia Analytical Services in Kelso, Washington for total organic carbon (TOC) following the ASTM D4129-82M method and grain size following PSEP (1986) methods. Samples were analyzed within 17 days from the time of collection.

Sediment Accretion Rates

At each site, PVC stakes separated by one meter were driven into the sediment and leveled. The distance from the plane at the top of the stakes to the sediment surface is measured as accurately as possible every 10 cm along the one meter distance. The stakes are measured at deployment and again, one year later at recovery. The stakes, termed sedimentation stakes, are used to determine gross annual rates of sediment accretion or erosion (Roegner et al., 2009). Sedimentation stakes are measured annually at each of the core sites and were installed and measured at the Burke, Deer and Goat Islands sites this year, where they will be measured and retrieved in 2012. The accretion or erosion rate is calculated by averaging the 11 measurements from each year and comparing the difference.

Hydrology

In 2010, pressure transducers (HOBO Water Level Data Loggers, Onset Computer Corporation) were deployed at each of the core sites as a means of logging in situ water level data for one year. Sensors were redeployed at Whites Island, Cunningham Lake, Campbell Slough and Franz Lake in the summer of 2010. During the fall of 2010, a sensor was deployed at Ilwaco that turned out to be faulty, and was replaced in April 2011. For the Reach E sites, sensors were deployed at Burke and Goat Islands in July 2011 and will be retrieved during the summer of 2012. The sensor at Goat Island will also be used for Deer Island.

Salinity

In order to better assess the influence of salinity on habitat, a conductivity data logger (Onset Computer Corporation) was deployed at the Ilwaco site in August of 2011. The data logger will be recording conductivity and temperature within the slough and deriving salinity on-the-fly from those two measurements, based on the Practical Salinity Scale of 1978 (see Dauphinee 1980 for description of conversion).

Vegetation Assemblage Structure
The vegetation sample areas at each site were selected to be near a tidal channel and to be representative of the elevations and vegetation communities present at the site. This was easier in the upper portions of the estuary, where the sites were generally narrower and the entire elevation range could be easily covered in the sample area. In the lower estuary, the sites were broad and covered a larger area, so in some cases multiple sample areas were surveyed if possible to cover different vegetation communities (e.g., low marsh and high marsh).

Along each transect, vegetative percent cover was evaluated at 2-5 meter intervals. Interval length was based on the transect length and/or the vegetation homogeneity. At each interval on the transect tape, a 1-m^2 quadrat was placed on the substrate and percent cover was estimated by observers in 5% increments. If two observers were collecting data then they worked together initially to ensure their observations were "calibrated." Species were recorded by four letter codes (1st two letters of genus and 1st two letters of species, with a number added if the code had already been used, e.g., LYAM is *Lysichiton americanus* and LYAM2 is *Lycopus americanus*). In addition to vegetative cover, features such as bare ground, open water, wood, and drift wrack were also recorded. When plant identification could not be determined in the field, a specimen was collected for later identification using taxonomic keys or manuals at the laboratory. If an accurate identification was not resolved, the plant remained "unidentified" within the database. Where visibility through the water column allowed, the degree of submerged aquatic vegetation coverage was estimated to the extent possible by the observers.

Vegetation Biomass
Beginning this year, above ground biomass was sampled to estimate the primary productivity at the core sites. For the emergent marsh biomass sampling, a 1-m square plot was randomly placed along the established vegetation transect, making sure that the biomass plots did not intersect the vegetation percent cover plots, with two biomass plots evenly spaced per transect. Within the 1-m square biomass plot, a 0.1 m^2 quadrat was placed in a randomly selected corner and all rooted vegetation, live or dead, was removed using shears. Each sample was placed in a uniquely numbered bag, and held in a cooler for the remainder of the sampling trip. For the submerged aquatic vegetation (SAV) plots, similar methods were employed with the exception of the placement of the plots. Either existing transects were extended past the baseline or new transects were created to reach the main slough. In some instances, an existing transect intersected the slough and an SAV plot was randomly placed along it. Depending on the width of the channel, either one or two SAV plots were randomly placed along each transect. Vegetation species were recorded in field notebooks along with the corresponding biomass sample number. In the laboratory, the biomass samples were stored in a cold room until processing could begin. The samples were then individually rinsed of all non-organic material, and obvious root material was removed. Pre-weighed pieces of tinfoil were used to secure the individual biomass samples, a wet weight was then measured, and the samples were placed in an oven set at 90° C for three to four days. When the samples were deemed completely dry, a second weight was then measured for each sample, and entered either into a datasheet or directly into a spreadsheet software program.

Vegetation Community Mapping
Using Trimble GeoXT and GeoXH handheld global positioning system (GPS) units, a representative portion of each site (using reasonable natural boundaries) was mapped and major vegetation communities were delineated within the site. Additionally, features of importance to the field survey (e.g., transect start/end points, depth sensor location, and photo points) were also mapped. All data were input to a GIS, and maps of each site showing major communities and features were created (Appendix B).

Elevation
At all sites, elevation was measured at each of the following locations: vegetation quadrats, the water level sensor, sediment accretion stakes, vegetation community boundaries, and in the channels. Elevation was surveyed using a Trimble real time kinematic (RTK) GPS with survey-grade accuracy. All surveying was referenced to the NAVD88 vertical datum; horizontal position was referenced to NAD83. Data collected from the base receiver were processed using the automated Online Positioning User Service (OPUS) provided by the National Geodetic Survey. OPUS provides a Root Mean Squared (RMS) value for each set of static data collected by the base receiver, which is an estimate of error. A local surveyed benchmark was located whenever possible and measured with the RTK to provide a comparison between the local benchmark and OPUS derived elevations.

Trimble Geomatics Office (TGO) software was used to process the data. Each survey was imported and overviewed by a scientist. Benchmark information was entered into TGO and rover antenna heights were corrected for disc sink (measured at each survey point to the nearest centimeter) at each point. The survey was then recomputed within TGO and exported in a GIS shapefile format. Surveys were visually checked within TGO and GIS software for validity. Elevations were then converted from NAVD88 to the Columbia River Datum (CRD) based on conversions developed by the USACE (unpublished). Using the CRD alleviates elevation differences associated with the increasing elevation of the river bed in the landward direction. Sites below RKM 37, the lower limit of the CRD, were converted to mean lower low water (MLLW).

All survey notes were recorded on data sheets during site visits, and subsequently transferred into Microsoft Excel at the laboratory. Quality assurance checks were performed on 100% of the data entered. Elevations from the RTK survey were entered into the Excel spreadsheet to correspond to the appropriate transect and quadrat location. All elevations in this report are referenced to CRD unless noted otherwise.

Channel Metrics
Elevation surveys were conducted for channel cross-sections at all sites. Five channel cross-sections were surveyed at most sites starting near the mouth of the channel and continuing past the marsh vegetation survey area. The mouth of the channel is described as the point where the vegetated banks start. Channel cross-sections were distributed evenly along the channel. Exceptions were made where a major side-channel met with the main channel. In these cases, the cross-section was moved above the confluence. Site maps identify the locations of all cross-sections (Appendix B). Additional notes were made for features of interest located at the cross-section: top and bottom of bank, vegetation edges, and thalweg. Data from the elevation surveys were used to calculated channel depth. The elevation data were also combined with hydrology data to calculate inundation times for the channel and bank edge.

Inundation
The data from the water level sensors were used to calculate inundation metrics from the marsh and channel elevations collected at those sites. Inundations were calculated for only the core sites, with the exception of Franz Lake, where the sensor could not be found at the time of retrieval because of beaver activity. Due to the faulty sensor at Ilwaco, inundation metrics were only calculated from April 2011 to August 2011.

The percent of time each marsh was inundated was calculated for the entire period of record (approximately one year) and for the growing season, April 22-October 12. The growing season is based on the number of frost-free days for the region, as determined by the Natural Resource

Conservation Service (NRCS) in the wetland determination (WETS) table for Clark County, WA (NRCS 2002). The Clark County growing season is used for all the sites in the estuary so that the inundation calculations are standardized to one period. The inundation frequency during the growing season was only calculated during daylight hours (between 0900 and 1700). This limitation was employed primarily for tidal areas where the timing of the daily high tide can be a factor in the amount of time available for plants to photosynthesize.

The percent of time each channel was inundated was calculated for the thalweg and top-of-bank elevations and for two time periods. In order to estimate habitat opportunity for juvenile salmonids, water depth of 50cm was added to the thalweg elevation of each cross-section as an indicator of the amount of water adequate for fish use of the channel (Nicole Sather, personal communication). Likewise, a 10cm water depth was added to the top of bank elevation at each cross-section to represent a minimum amount of water needed for fish to access the vegetation at the edge of the bank (Bottom et al., 2005; Kurt Fresh personal communication). The periods assessed were 1) the deployment period (generally July to July) and 2) the period from March 1 through July 31, which represented the peak juvenile Chinook migration period as determined from data collected as part of this Ecosystem Monitoring Program and other studies (Bottom et al., 2005; Sather et al., 2011).

In order to better assess hydrologic patterns and to make sites comparable over time and space, we needed a single measurement that would incorporate magnitude, timing, and duration of surface water flooding. Following work conducted in the US and in Europe (Gowing et al., 2002; Simon et al., 1997; Araya et al., 2010) we calculated the sum exceedance value (SEV) using the following equation:

$$\text{SEV} = \sum_{i=1}^{n} (d_{\text{elev}})$$

where n is the number of hours present in the time period evaluated, and d_{elev} is the hourly water surface elevation above the average marsh elevation. This differs from previous LCRE studies (Borde et al., 2011a and Borde et al., 2011b) in which the daily mean water surface elevation was used in the calculation rather than the hourly water level elevation used here. The latter was chosen to ensure we captured daily inundation fluctuations that occur in the more tidally dominated sites. The time periods evaluated were the annual deployment period and the growing season. Both periods were standardized to include the same days in each year, as follows:

Growing season: April 22 to June 21 and August 20 to October 12 (115 days)
Annual deployment period: August 20 to June 21 (of the next year; 306 days)

This standardization was necessary because in the past, the deployment and retrieval dates for sensors varied between June 21 and August 20 and to compare calculations from past and present data required that the same time periods be used.

4.2.4 Results

Sediment Composition

Total organic carbon (TOC) content shows little variation between strata at any of the sites sampled. TOC values at Ilwaco were higher than the other sites, with the *Typha angustifolia* (TYAN) stratum showing the highest TOC value of all data presented here. Burke Island has the next highest set of values for the site followed by Goat and Deer Islands. Differences in TOC can be caused by numerous controlling factors including the extent of tidal hydrology (greater tidal inundation resulting in greater TOC), marsh age (the older the marsh the greater the TOC), sediment composition, and the species of vegetation present (Thom et al., 2001). Goat, Deer, and Burke Islands are located in the tidal, fluvial portion of the LCRE with less tidal inundation than at Ilwaco. In addition, Goat and Deer Islands are relatively young (~50-80 yrs), created marshes, while Burke Island was present on historical maps from 130 yrs ago. The age of the Ilwaco marsh is uncertain, as it was not present on the historical maps and likely developed due to changes in hydrology and sediment deposition in Ilwaco caused by the construction of the CR north jetty and creation of islands on the perimeter of the Bay. Vegetation species differed between some of the sites (Table 6), which could potentially affect the TOC content. The highest TOC was from areas with *Typha angustifolia* (TYAN) and *Carex lyngbyei* (CALY) and the lowest from areas with *Phalaris arundinacea* (PHAR) and *Eleocharis palustris* (ELPA). In general, sediments with greater than 12 percent TOC are considered organic sediments (Mitsch and Gosslink 2000), whereas all results presented here have less than 12 percent TOC.

Table 6. Vegetation strata associated with sediment samples at the 2011 monitoring sites.

Site	Sample	Vegetation Strata
Ilwaco	CALY	*Carex lyngbyei*
	Channel	Bare mud within channel
	DECE	*Deschampsia cespitosa*
	TYAN	*Typha angustifolia*
Burke Island	PHAR	*Phalaris arundinacea*
	SALA	*Sagittaria latifolia*
	SALA/PHAR	*Sagittaria latifolia/Phalaris arundinacea*
Deer Island	Sparse ELPA	Sparse *Eleocharis palustris*
	Dense PHAR	Dense *Phalaris arundinacea*
	Sparse PHAR	Sparse *Phalaris arundinacea*
Goat Island	Sparse ELPA	Sparse *Eleocharis palustris*
	Dense PHAR	Dense *Phalaris arundinacea*
	Sparse PHAR	Sparse *Phalaris arundinacea*

Sediment data for grain size show a similar trend in variation as the TOC data. There is little variation between strata at each site. Ilwaco has the highest variation of grain sizes with a higher clay and coarse sediment content than the other sites. Burke Island has the highest percent of silt throughout the strata. Deer Island has the highest percent of very fine sand. Sediment composition at Deer and Goat Islands is very similar. As with the TOC data, this could be related to their age, but also their proximity to each other.

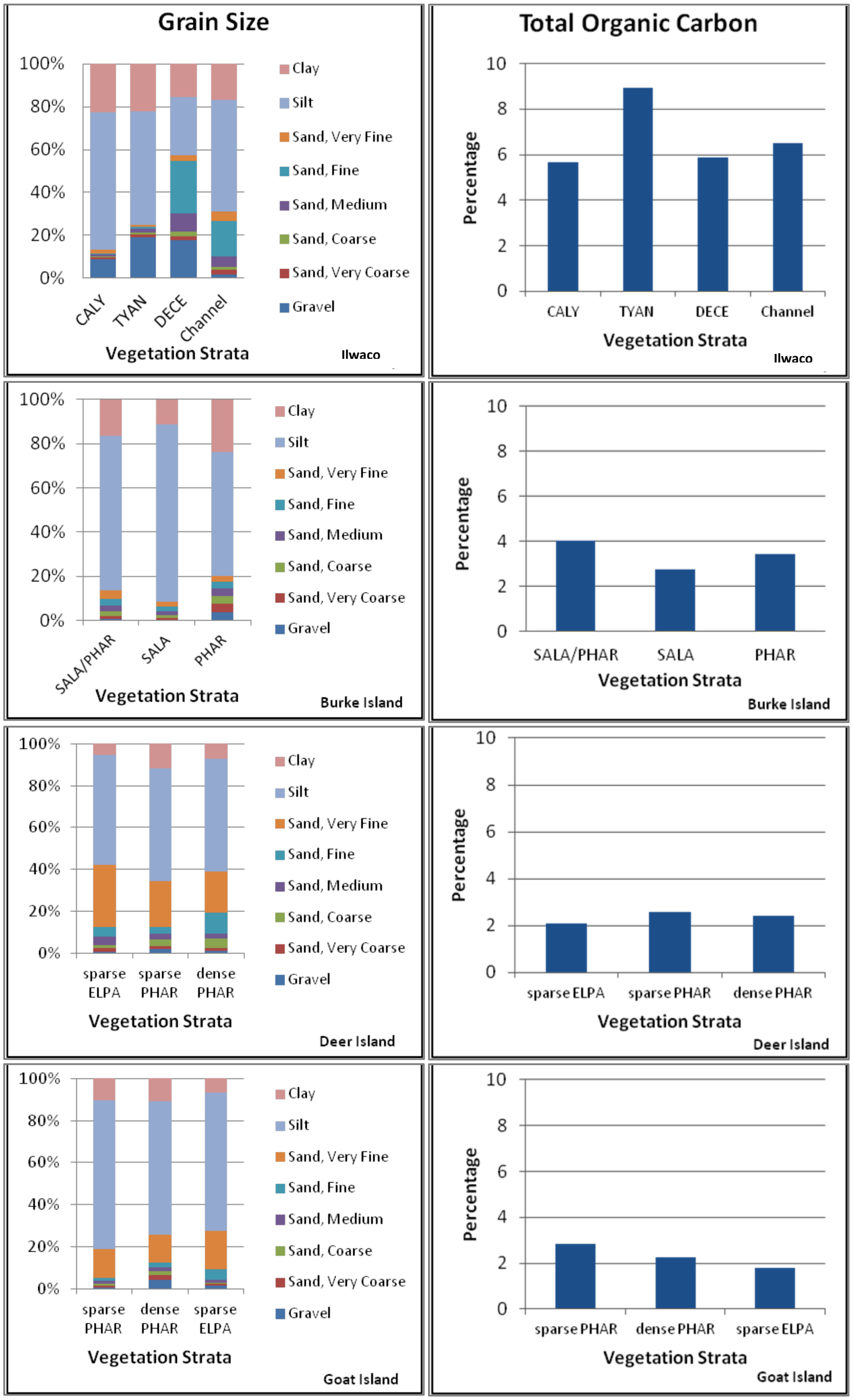


Figure 15. Grain size (on the left) and total organic carbon (TOC; on the right) at Ilwaco and the Reach E sites.

Sediment Accretion Rates

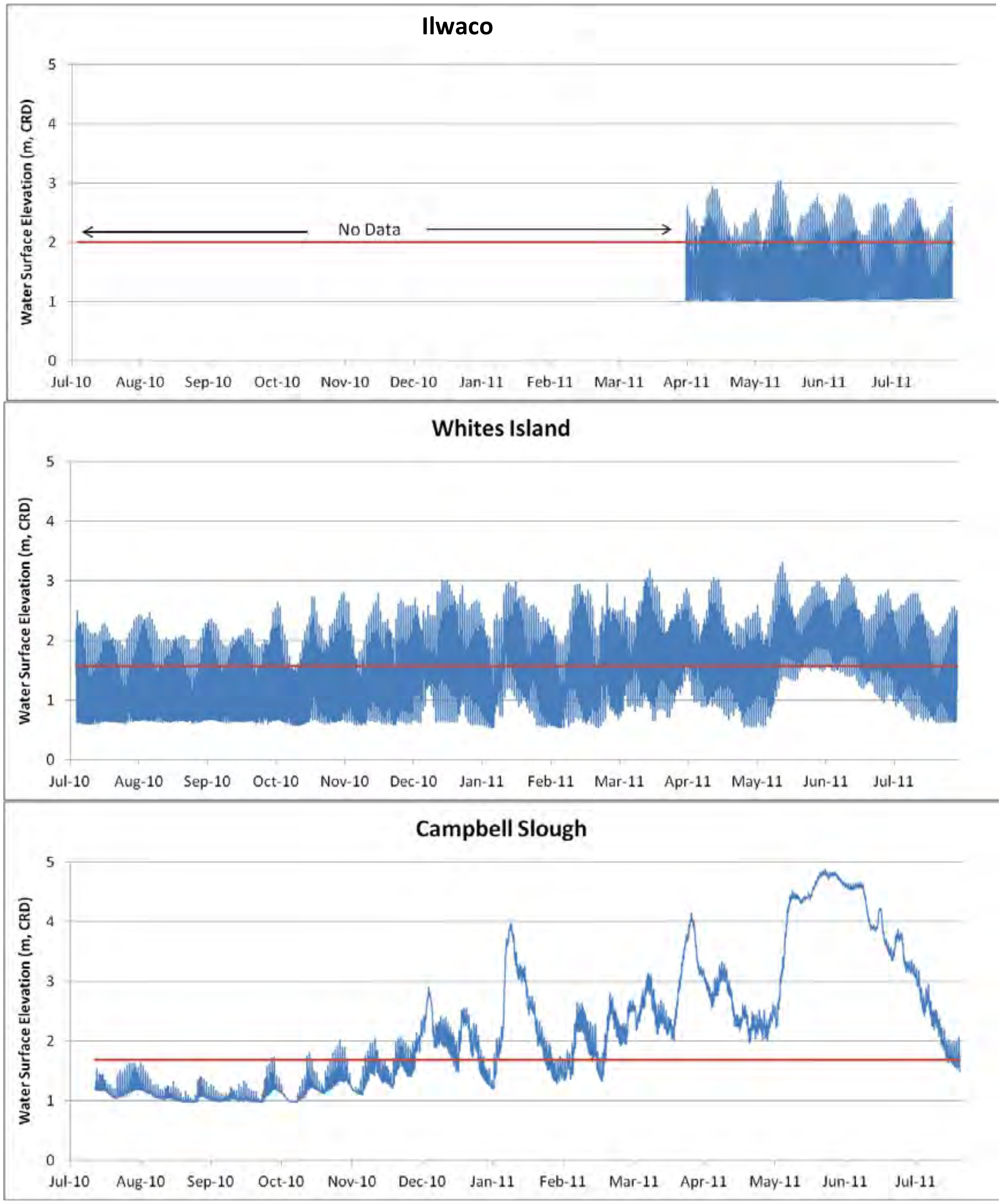
Sediment accretion rates were generally greater than 1.0 cm/year at the sites measured in 2011. A higher than average rate would be expected in this year due to the high inundation levels during the spring freshet. The highest levels of sediment accretion are often associated with flood events (Hensel et al., 1999). Observations at the sites in Reaches E, F, and H, where mud was noted covering up to 20% of the vegetation, also corroborate these findings. In the lower, tidally dominated part of the estuary, river flooding is not likely a cause of increased accretion rates, and in fact, Whites Island had a very low accretion rate. This could be explained by the higher elevation of the site or the position of the site in the landscape (i.e., an island in the lower part of the floodplain). Conversely, the Ilwaco site appears to be a depositional area based on an assessment of historical maps and imagery, potentially explaining the higher accretion rate at this site. Stakes were installed in the Reach E sites (BIM, DIC, and GIC) in 2011 and will be measured again in 2012 to calculate the annual rates.

Table 7. Sediment accretion rates measured at sites in 2011.

Reach	Site	Rkm	Sediment Stake Elevation (m, CRD)	Year	Accretion/Erosion Rate (cm/year)
A	Ilwaco	6	1.81	10-11	1.7
C	Whites Island	72	2.05	10-11	0.1
F	Cunningham Lake	145	1.49	10-11	1.6
	Campbell Slough	149	1.54	10-11	1.7
H	Franz Lake	221	1.87	10-11	3.0

Hydrology

Hydrographs from the sites where WSE was collected during the 2010 to 2011 water year indicate that high WSE resulting from the spring freshet was detectable in shallow water wetland habitats at least as far downriver as Whites Island (rkm72); however, this pattern was not observed at the outermost estuary site, Ilwaco (rkm 6) (Figure 16). Also of interest, is that the amount of time the marshes were exposed at each site during the growing season varied considerably. By comparing the average marsh elevation at each site (as denoted by the red line on the hydrographs) to the WSE we can see the variability. For example, the Ilwaco site is exposed consistently every day due to the tidal regime and is likely exposed for more of the day than it is inundated. Similarly, Whites Island follows a consistent tidally driven pattern of inundation and exposure except that there are periodic events where the WSE does not reach a level low enough to expose the marsh. This inundation event occurred for over a month in May and June of 2011 during the spring freshet. Farther upriver at the Campbell Slough and Cunningham Lake sites the pattern is very different, with the marsh exposed during the end of growing season, typically from July through October, and inundated for the early growing season to varying degrees. In 2011, these upriver sites were inundated with greater than a meter of water for most of April and from mid-May through mid-June.


Ilwaco
Water Surface Elevation (m, CRD)
No Data
0
1
2
3
4
5
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Whites Island
Water Surface Elevation (m, CRD)
0
1
2
3
4
5
Jul-10
Aug-10
Sep-10
Oct-10
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Campbell Slough
Water Surface Elevation (m, CRD)
0
1
2
3
4
5
Jul-10
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May-11
Jun-11
Jul-11

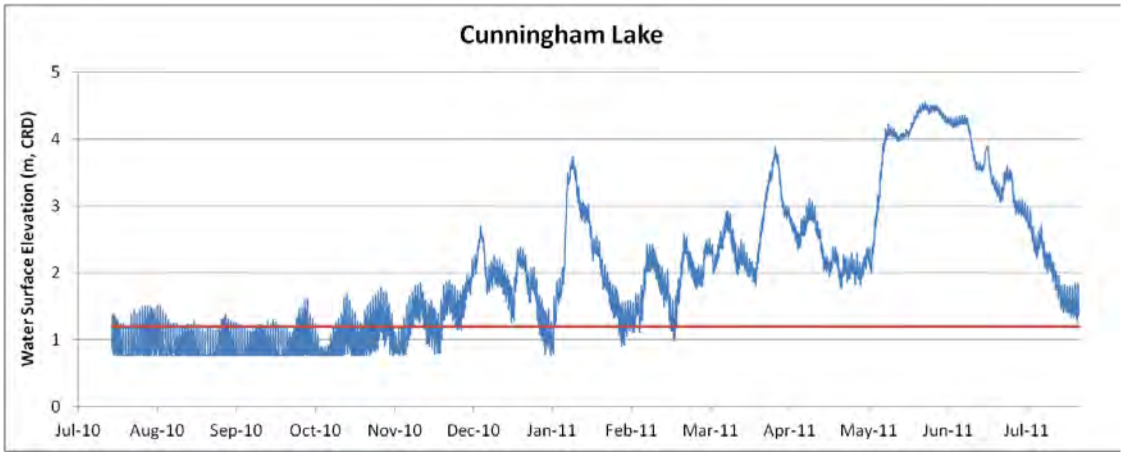


Figure 16. Water surface elevation data from the study sites where sensors were deployed 2010-2011. The red line represents the average elevation of the marsh sampling area.

Vegetation Assemblage Structure

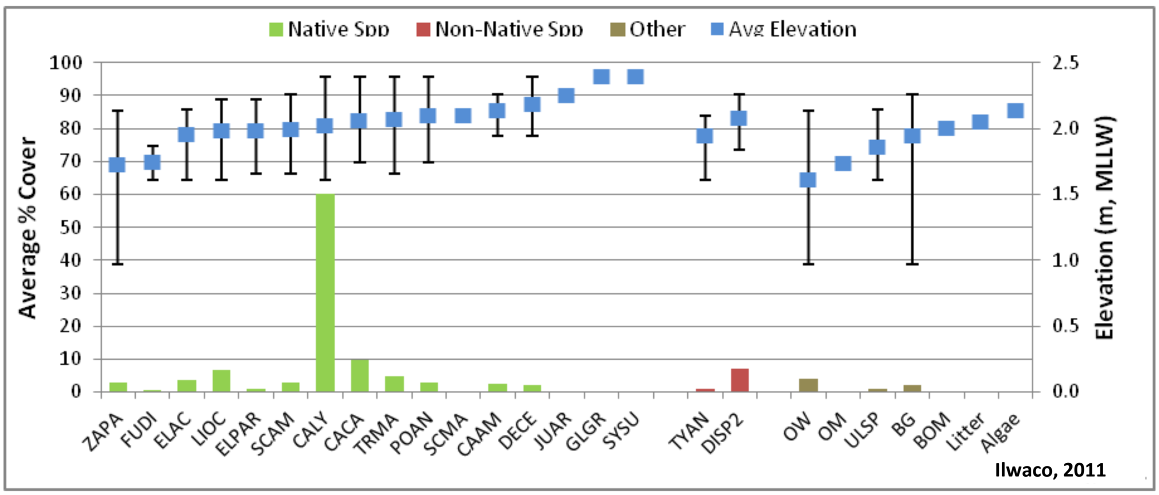
Vegetation cover and biomass was affected in 2011 by the higher than average water year. The prolonged high water coupled with mild fall temperatures resulted in a very late growing season, particularly in the upper portions of the estuary. All sites in Reaches E and F had stunted and sparse vegetation. We were unable to conduct our monitoring during the period established in prior years at the Reach H site (Franz Lake) because the vegetation was underwater. When we were able to monitor the site one month later the vegetation was recovering, however, peak biomass had not yet been reached. A site visit was made in late October at which time much denser vegetation was observed at the site.

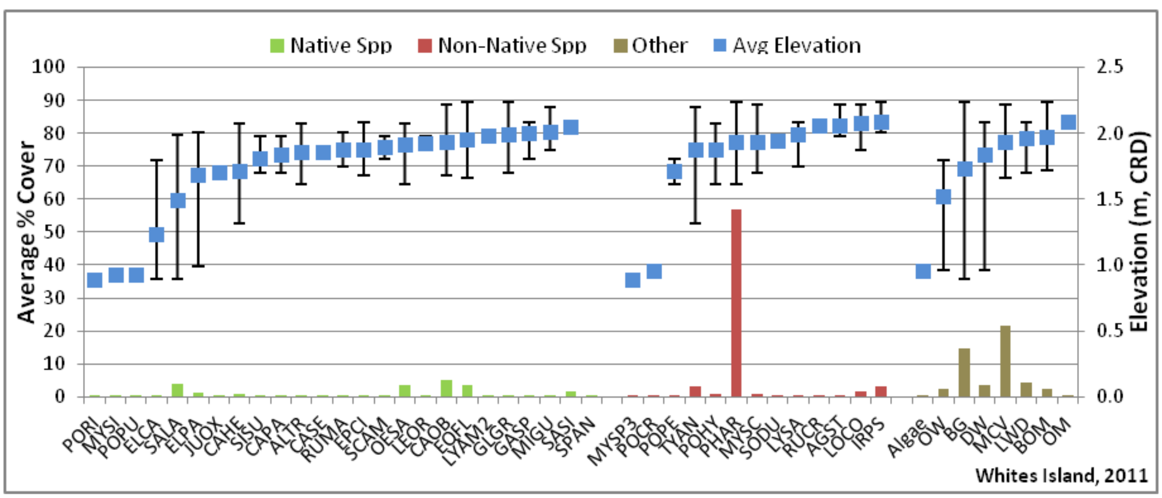
In general, species diversity was higher at the Reach C site than sites sampled in the remaining reaches. Elevation and percent cover of species observed during 2011 sampling are shown in Figure 17. The Ilwaco site had very high cover of native vegetation, with only one non-native species comprising one percent of the cover (Table 8). The marsh was dominated by CALY and was the only site where PHAR was not observed. In contrast, Whites Island had <25% native cover and was dominated by PHAR (>55% cover).Whites Island had the highest species richness of any of the sites at 38 species. The upland border at all upriver sites, which was not part of the sample area, was comprised of willows (*Salix* spp.), cottonwood (*Populus balsamifera)*, and ash (*Fraxinus latifolia*). At Ilwaco, the upland area was dominated by conifers. Maps of vegetation distributions at each site illustrate vegetation patterns and the spatial distribution of each major species communities relative to tidal channels at each site (Appendix B).

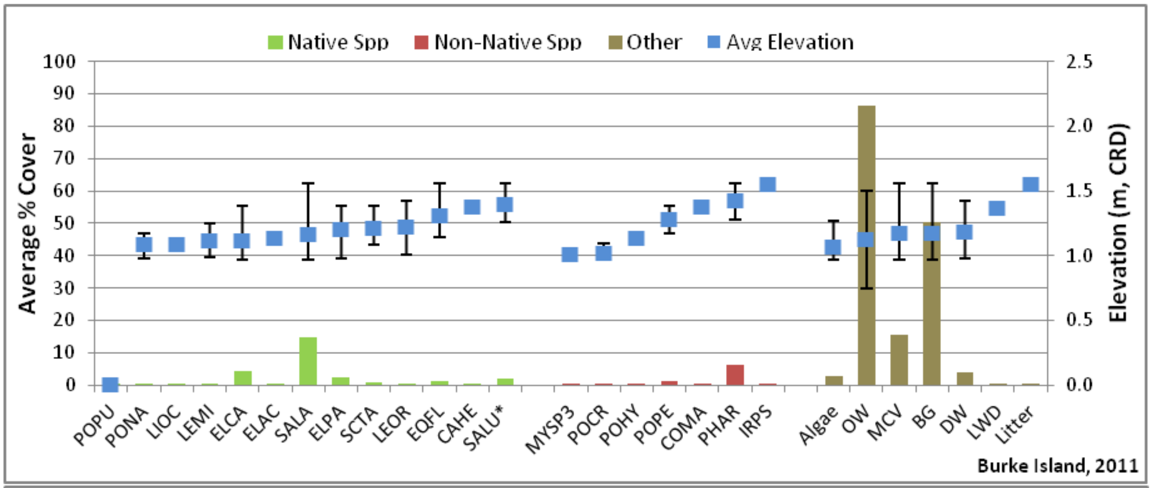
The upriver sites all shared some common vegetation traits in this high-water year. The upriver sites had higher cover in the categories of open water (>40%) and bare ground (>20%) and generally lower vegetative cover than previous years (Borde et al., 2011b). PHAR cover is in the top 5 species at all of the upriver sites. ELPA, *Sagittaria latifolia* (SALA), and *Salix lucida* (SALU) are the primary native species at all of the upriver sites. Campbell Slough and Cunningham Lake showed decreased species diversity cover from previous years, again probably due the high water.

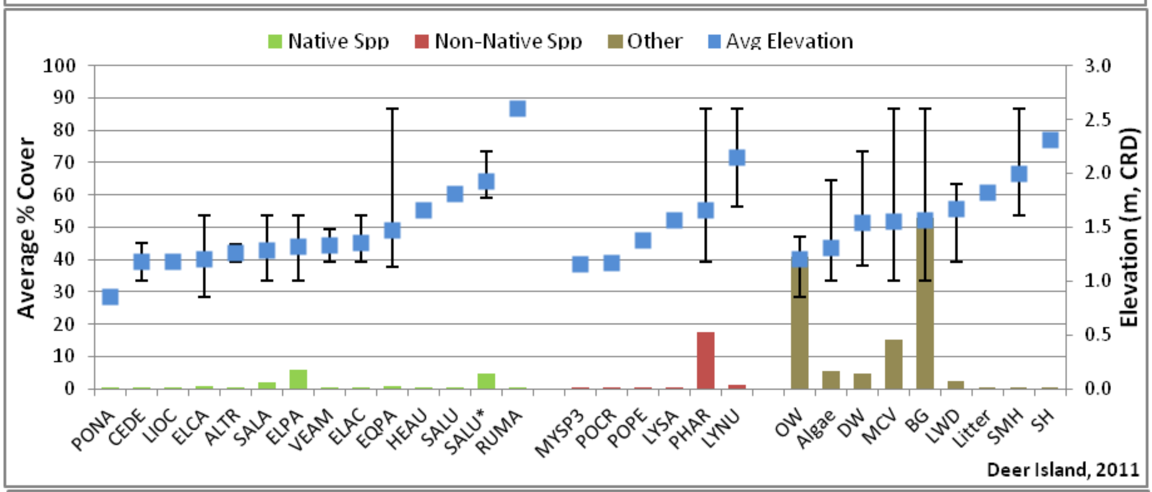
Table 8. Species richness and areal cover of native and non-native species at the 2011 monitoring sites.

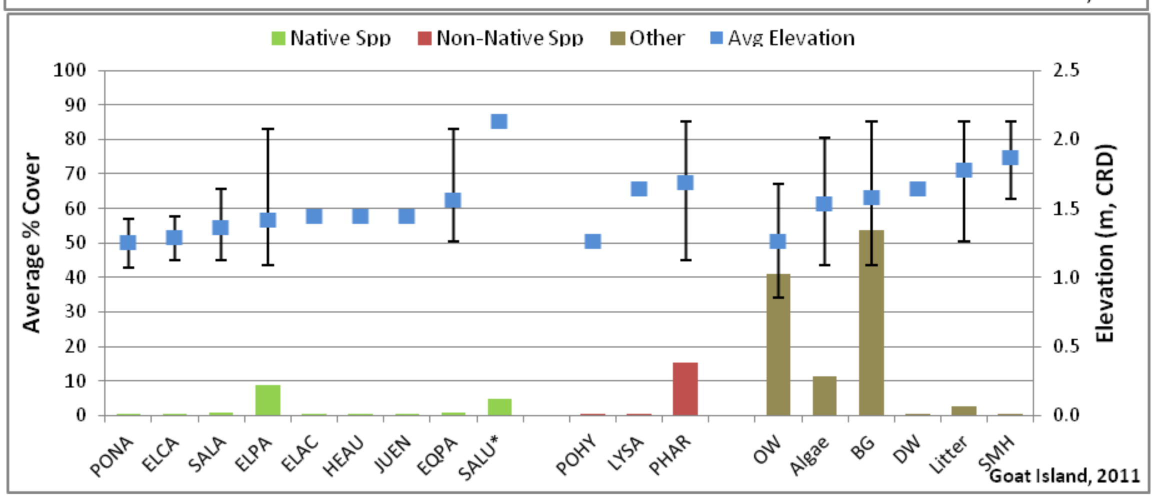
Site	# Native species	Native species percent cover	# Non-native species	Non-native species percent cover
Ilwaco	17	107.6	1	1.1
Whites Island	25	24.6	13	68.6
Burke Island	13	25.8	7	8.5
Goat Island	9	16.1	3	15.5
Deer Island	14	15.9	6	19.3
Campbell Slough	12	21.6	3	34.9
Cunningham Lake	9	13.0	4	40.6
Franz Lake	16	33.8	3	32.2






Native Spp
Non-Native Spp
Other
Avg Elevation
Average % Cover
Elevation (m, CRD)
POPU PONA LIOC LEMI ELCA ELAC SALA ELPA SCTA LEOR EQFL CAHE SALU*
MYSP3 POCR POHY POPE COMA PHAR IRPS
Algae OW MCV BG DW LWD Litter
Burke Island, 2011


Native Spp
Non-Native Spp
Other
Avg Elevation
Average % Cover
Elevation (m, CRD)
PONA CEDE LIOC ELCA ALTR SALA ELPA VEAM ELAC EQPA HEAU SALU SALU* RUMA
MYSP3 POCR POPE LYSA PHAR LYNU
OW Algae DW MCV BG LWD Litter SMH SH
Deer Island, 2011


Native Spp
Non-Native Spp
Other
Avg Elevation
Average % Cover
Elevation (m, CRD)
PONA ELCA SALA ELPA ELAC HEAU JUEN EQPA SALU*
POHY LYSA PHAR
OW Algae BG DW Litter SMH
Goat Island, 2011

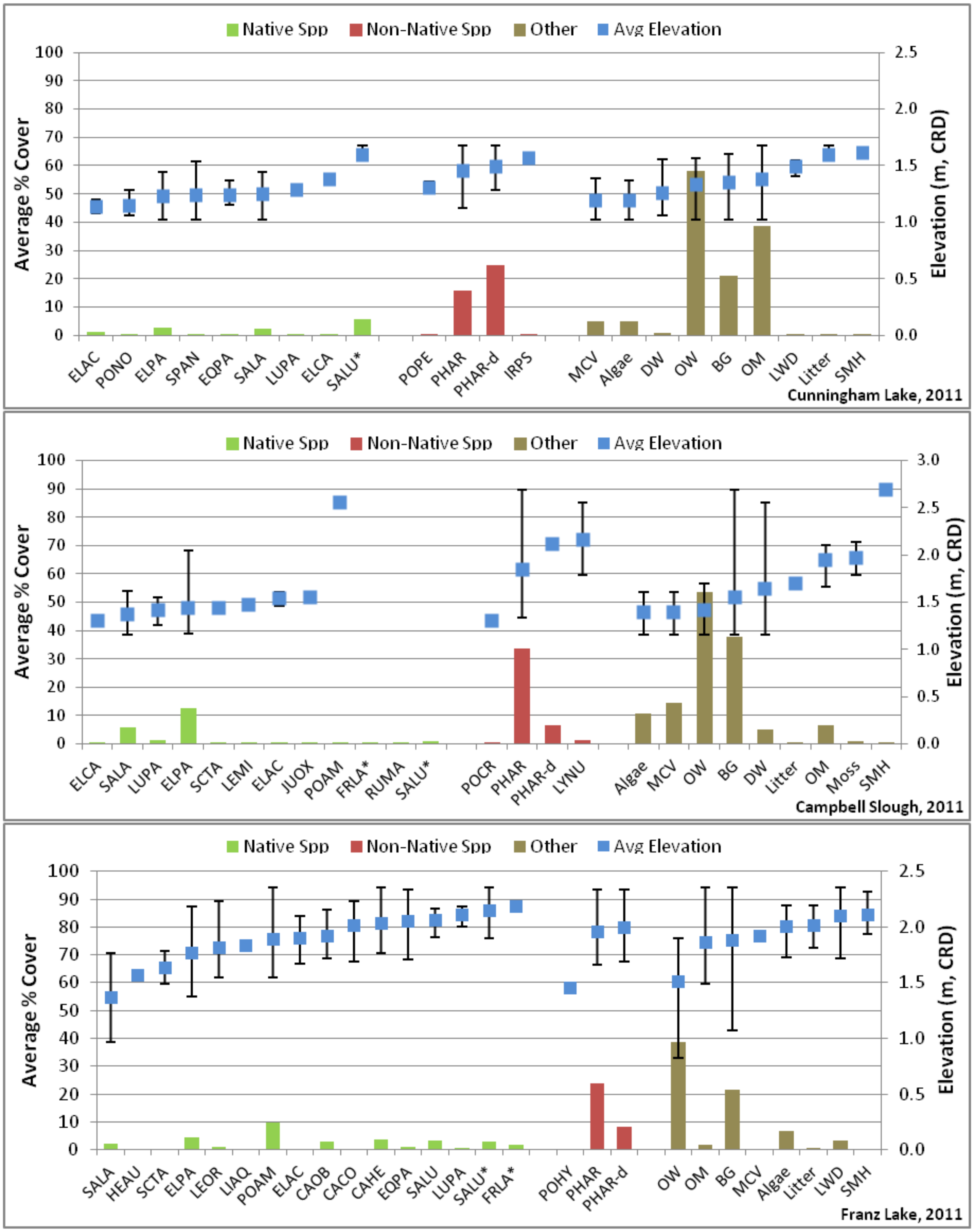


Figure 17. Vegetation species cover and elevations for sites sampled in 2011. Bars represent the minimum and maximum elevations at which the vegetative species occurred within the sample area (See Appendix C for species names associated with codes along the x-axis). Note slightly higher elevation scale for Campbell Slough plot and Deer Island plot.

Biomass

The biomass sample design is such that samples are collected in the summer at peak biomass and then again in winter, just prior to the initiation of primary production in the next growing season. In this way, the annual primary production can be estimated as well as the potential amount of biomass exported from the wetland. The four core sites were sampled for summer biomass in 2011 (Table 9) and the winter biomass will be collected at the same sites in early 2012. Due to high water in the two upriver sites the timing of peak biomass was delayed. Sampling of the biomass was delayed until late August, however, the mild fall weather likely delayed the peak season until late fall. Therefore, the results shown in Table 9 portray the effect of the high water on biomass production, however they are perhaps not indicative of potential or realized biomass production at all the sites. The two lower estuary sites (BBM and WHC) have the highest emergent and SAV biomass. These results are likely representative of peak biomass at the BBM site and possibly at WHC, however, the total vegetation cover was slightly lower at the time of sampling in 2011 than it had been in the previous two years: 107, 101, and 93 percent in 2009, 2010, and 2011 respectively (numbers greater than 100 occur when multiple layers of vegetation are present).

Table 9. Average dry weight per site of emergent and submerged aquatic vegetation biomass for the summer 2011 sampling period.

Site	Vegetation Strata	Average (Dry Wt., g/m^2)
Ilwaco (BBM)	Emergent	864.5
	Submerged	81.8
Whites Island (WHC)	Emergent	802.6
	Submerged	51.8
Campbell Slough (CS1)	Emergent	256.8
	Submerged	1.8
Franz Lake (FLM)	Emergent*	203.2

*No SAV was observed or collected at the site due to high water.

Elevation, Inundation, and Vegetation Interactions

Average elevations of each vegetation sampling area and their location in the River are provided in Table 10 and Figure 18. The elevations of the sites monitored in 2011 cover a narrow range between 0.85 m and 2.69 m with the average site elevations between 1.0 and 2.0 m. Although the elevations are similar, the inundation patterns are very different. The percent of time the average marsh elevations were inundated varied from 20 percent at BBM to 65 percent at CLM during the deployment periods and between 14 and 54 percent at WHC and CLM, respectively, during the growing season (see Figure 16 for hydrographs from the sites). Similarly, the sum exceedance value (SEV), representing the amount of water over a site in a given time period, was much higher at the upper estuary sites (Figure 20 and Table 11) than at WHC. The difference between years is also very noticeable at the two upper estuary sites, whereas the SEV at WHC was only slightly elevated in 2011 (278 versus 230 in 2010).

Table 10. Average elevation of vegetation survey areas (relative to CRD).

Reach	Site	Site Code	Rkm	Average Elevation (m, CRD)
A	Ilwaco	BBM	6	2.00
C	Whites Island	WHC	72	1.95
E	Burke Island	BIM	131	1.18
	Goat Island	GIC	131	1.57
	Deer Island	DIC	132	1.51
F	Cunningham Lake	CLM	145	1.37
	Campbell Slough	CS1	149	1.66
H	Franz Lake	FLM	221	1.85

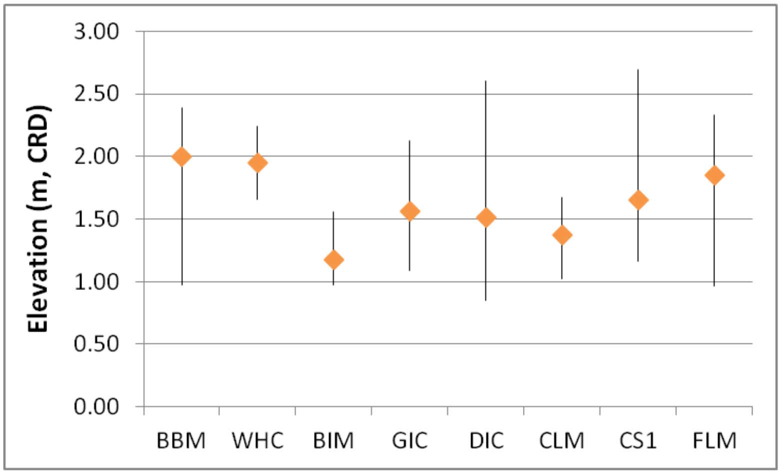


Figure 18. Average elevation of the vegetation survey area (points) with the range of elevations measured in the vegetated survey area (lines).

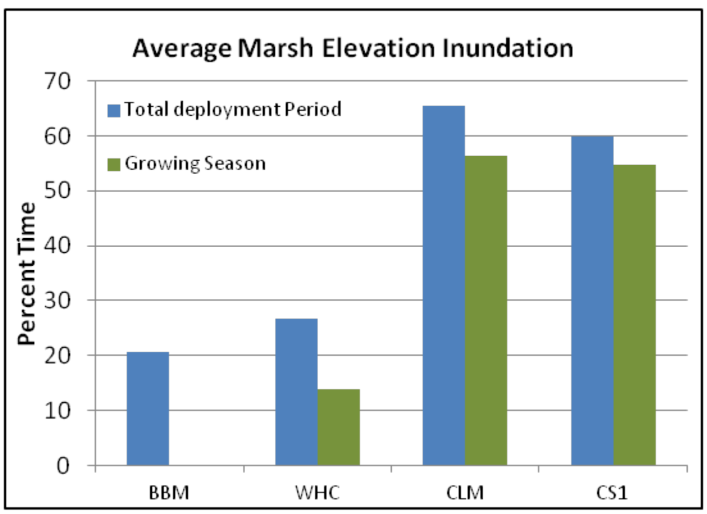


Figure 19. Percent of time the average marsh elevation was inundated at each site during the deployment period and during the growing season.

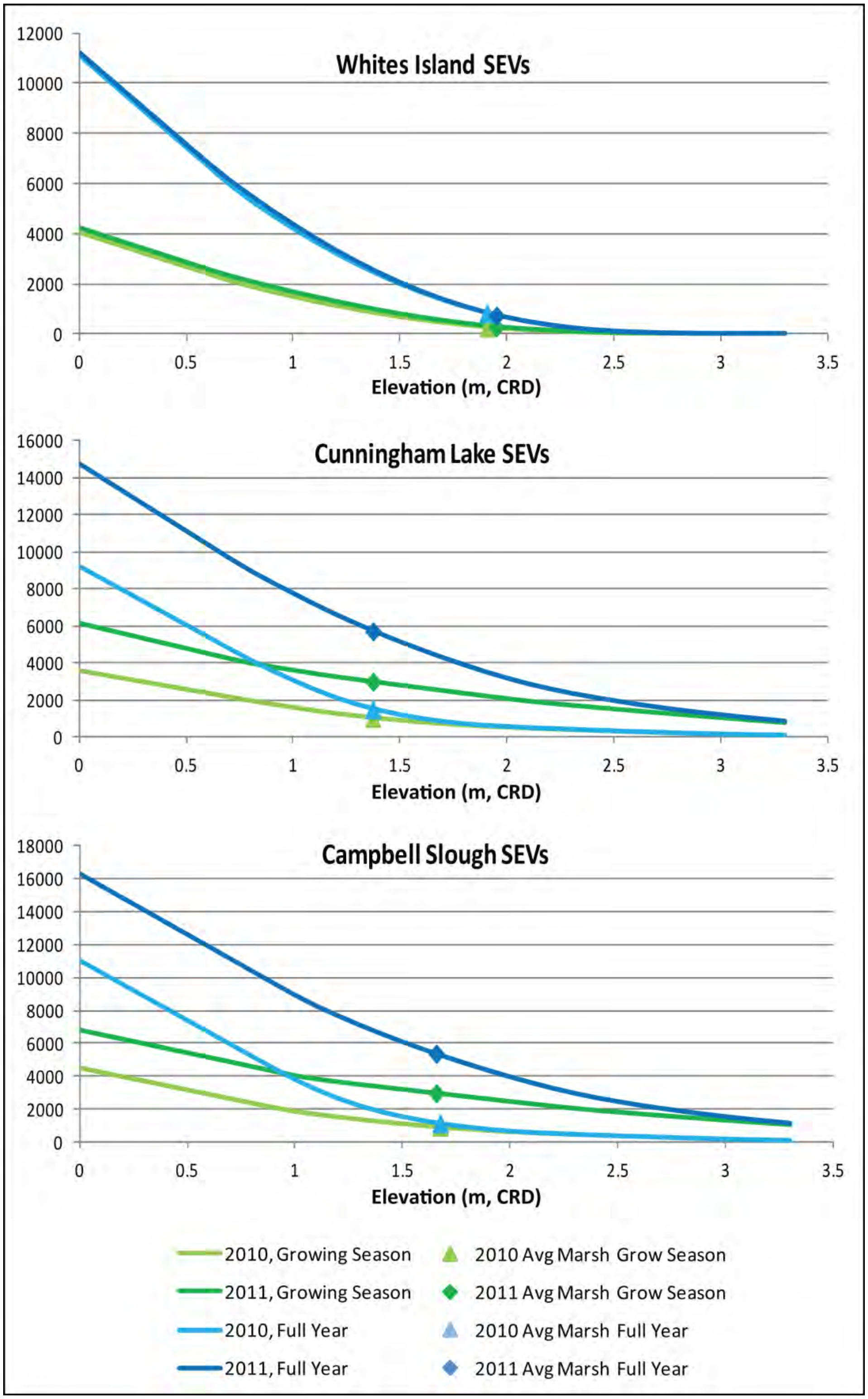


Figure 20. Sum Exceedance Values for the 2009-2010 period compared with the 2010-2011 period.

The lower vegetation cover in the upper estuary sites noted in Table 8 is undoubtedly a result of the higher inundation at these sites during the growing season. The difference in inundation as measured by the SEV is an order of magnitude greater at the upper estuary sites as shown in Table 11. The duration of the effect of higher growing season inundation is uncertain. Observations at sites later in the 2011 growing season indicate that the vegetation may have eventually reached biomass production levels equivalent to lower-water years, however we currently have no data to determine the timing or extent to which this happens.

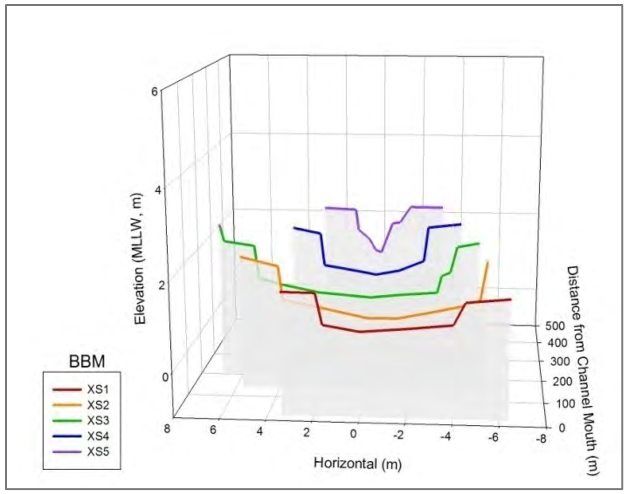
Table 11. Sum exceedance values for the sites where water level data were collected from 2010-2011.

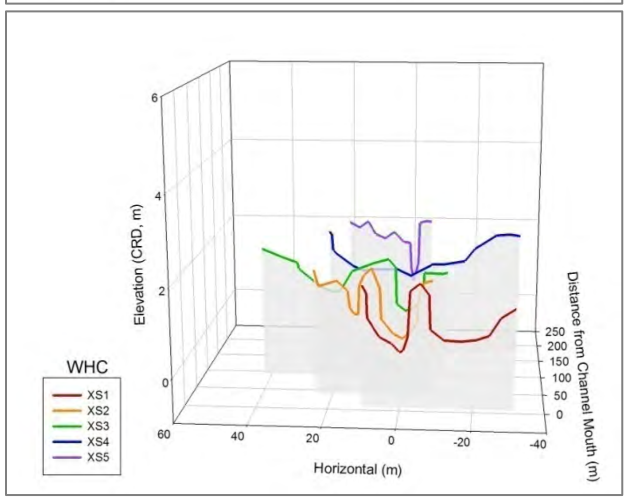
Site	Average Marsh Elevation (m, CRD)	Growing Season SEV (m-hours)
Whites Island	1.95	278.3
Cunningham Lake	1.37	2997.6
Campbell Slough	1.66	2994.8

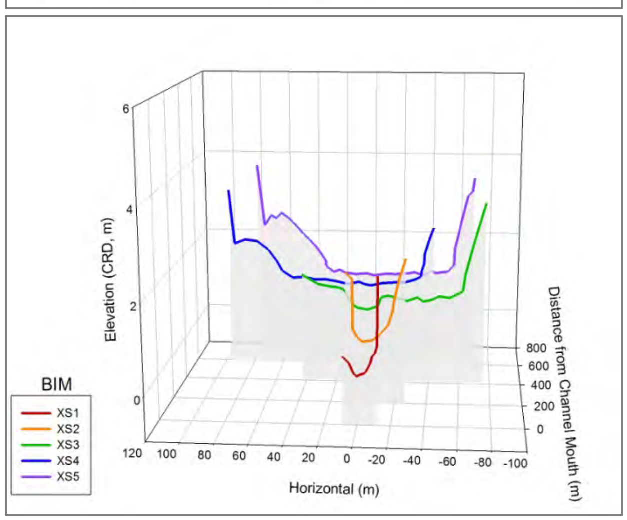
Channel Morphology and Inundation

Channel cross-section morphologies are shown in Figure 21 and channel morphometrics and inundation times are provided in Table 12. For the purposes of the EMP, the channel mouth is generally defined as the location where vegetation begins along the channel bank, and this location is usually designated as channel cross section 1 (XS1). Exceptions based on site configuration necessarily occur. For example, Whites Island and Goat Island do not have a cross-section at channel mouth noted because the channel at the site is a secondary channel to a main channel where vegetation is growing along then entire bank. The site at Cunningham Lake is approximately 6.5 km from Multnomah Channel and the mouth has not been surveyed as part of this program. At Deer Island and Franz Lake, the cross-section designated as "XS0" is the XS that would typically be designated as XS1, but because the initial survey did not include a XS at the outer edge of the bank vegetation, XS0 was added later to ensure the mouth was surveyed.

In some cases, the channel mouth cross-section is shallower than the next cross-section upstream (e.g., BBM and DIC). This sill effect controls hydrologic connectivity during low water. Campbell Slough has a rip rap weir across the mouth which restricts access once the WSE of the Columbia River is below 0.89 m (Table 12; this was surveyed in 2010 and is discussed in Borde et al 2011b). The sill effect is observable in the frequency of inundation; at BBM and CS1, inundation of the 1st channel is noticeably less than the inundation period of the next cross-section up-channel. Channel inundation for Reach E will be discussed in detail in the following year when the hydrology data has been collected.


Elevation (MLLW, m)
Distance from Channel Mouth (m)
Horizontal (m)
BBM
XS1
XS2
XS3
XS4
XS5


Elevation (CRD, m)
Distance from Channel Mouth (m)
Horizontal (m)
WHC
XS1
XS2
XS3
XS4
XS5


Elevation (CRD, m)
Distance from Channel Mouth (m)
Horizontal (m)
BIM
XS1
XS2
XS3
XS4
XS5

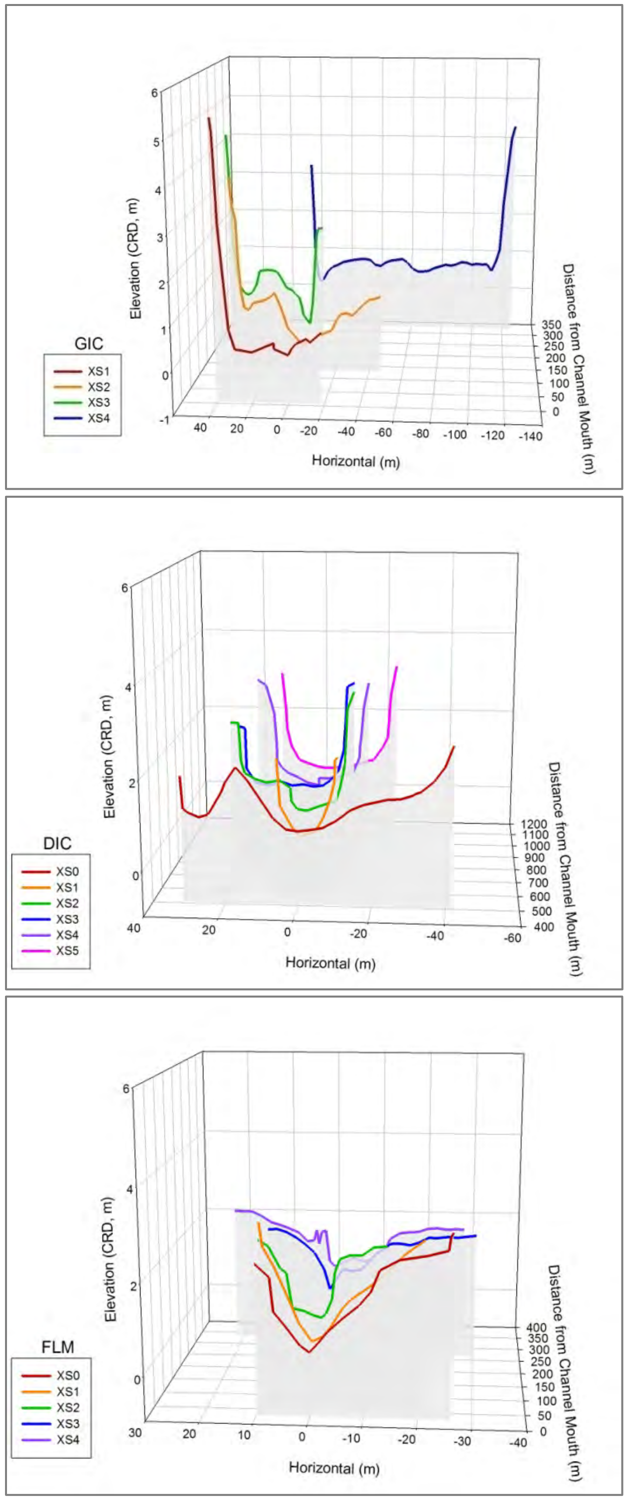


Figure 21. Relative elevations of the channel cross sections for the 2011 sites with multiple cross sections.

Table 12. Channel metrics and inundation frequencies during the annual deployment period and during the peak juvenile Chinook salmon migration period (March 1st to July 31st). .*

					Annual Deployment Period		Peak Salmon Migration Period	
Site (sensor elevation m, CRD)	**Cross Section Location**	**Bank Elevation (m, CRD)**	**Thalweg Elevation (m, CRD)**	**Channel Depth (m)**	**Frequency WSE >thalweg +50 cm**	**Frequency WSE >top channel bank +10 cm**	**Frequency WSE > thalweg +50 cm**	**Frequency WSE >top channel bank +10 cm**
Ilwaco (0.83)	1 (mouth)	1.59	0.90	0.68	48	35	48	35
	2	1.86	0.70	1.16	56	22	57	22
	3	2.12	0.90	1.22	48	10	48	10
	4	2.00	1.01	0.99	43	16	43	16
	5	2.26	1.17	1.09	36	7	36	6
Whites Island (0.65)	1	1.10	0.28	0.82	83	65	94	80
	2	1.41	0.34	1.07	81	49	93	64
	3	1.53	0.61	0.92	69	43	83	57
	4	1.93	0.92	1.00	54	23	69	32
	5	1.45	0.44	1.01	76	47	89	61
Burke Island (0.83)	1 (mouth)	0.53	0.09	0.44				
	2	1.89	0.46	1.43				
	3	1.22	0.74	0.48				
	4	1.78	0.98	0.80				
	5	1.75	1.05	0.70				
Goat Island (0.67)	1	0.64	0.11	0.53				
	2	0.84	-0.37	1.21				
	3	2.11	-0.31	2.42				
	4	2.29	0.20	2.09				
Deer Island (0.67)	0 (mouth)	1.84	0.66	1.18				
	1	2.15	0.43	1.72				
	2	2.64	0.63	2.01				
	3	2.18	0.79	1.39				
	4	2.28	0.48	1.80				
	5	2.43	0.51	1.92				
Cunningham Lake (0.75)	1	1.02	0.75	0.27	70	77	98	99
Campbell Slough (0.97)	1 (mouth)*	2.009	0.891	1.118	69	47	97	90
	2 (mouth)*	1.854	-0.308	2.162	100	52	100	94
	3	1.30	0.79	0.51	73	68	97	97
Franz Lake (0.81)	0 (mouth)	2.03	0.42	1.61				
	1	1.24	0.48	0.75				
	2	1.53	0.48	1.05				
	3	1.47	0.60	0.87				
	4	1.42	0.82	0.59				

* Inundation frequency is only calculated for the sites where on-site water surface elevation (WSE) data was collected for the 2010-2011 monitoring period.

4.2.5 Conclusions and Recommendations

Conclusions

In this report, we begin to document the ranges and variation in hydrology and habitat structure of emergent marshes in the LCRE. Temporal and spatial variability in these systems affect the vegetation communities and their capacity for storing carbon, providing habitat for salmon, and contributing to the food web of the greater LCRE. As such, quantifying the expected ranges and variability can start to reduce uncertainties and inform research focus areas to improve the capacity of the LCRE to provide these important functions.

Spatial patterns we have been able to discern with the existing dataset fall into the primary categories contributing to wetland structure and process, specifically sediment, hydrology (elevation), and vegetation. Sediment TOC is a means of measuring the organic content in the sediments and varies over time and space depending on inundation, vegetation communities present, age of the marsh, and other sediment constituents such as grain size. Given this complexity, the factors contributing to the variability in sediment TOC at our study sites is difficult to ascertain. All samples from the study area had values less than 10 percent TOC, with the highest values in the high marsh areas, which is a pattern consistent with measurements elsewhere (Odum et al. 1984). However, the values measured can generally be considered low for tidal wetlands, with overall lower TOC at known created sites. While little data has been collected on organic content in tidal freshwater and brackish marshes in the northwest, one study in a tidal freshwater marsh in the region found TOC between 16 and 26 percent (Thom et al. 2001) while Craft (2007) has documented that tidal freshwater marsh sediments often have higher organic content than salt marshes. One study in the LCRE has documented TOC levels ranging from 13 to 30 attributing the variation to marsh age and landscape position (Elliot 2004). Studies in other areas have seen patterns of higher organic content in high marshes and lower in low marshes (Odum et al. 1984); we have noted similar but limited patterns in our data as well. While we cannot conclude the factors contributing to low TOC levels at our study sites at this time, we can hypothesize that likely a combination of vegetation type, landscape position, and marsh age may be factors contributing to the lower than expected levels. Further analysis of marsh age through evaluation of historical records will hopefully inform this theory.

Sediment grain size follows a pattern in the estuary that may be partially be explained by proximity to the main channel of the River or the main stem of a tributary. The hypothesis regarding this landscape pattern is that finer sediments would be present in more backwater settings, away from the higher flows associated with the River. Sherwood et al., (1984) found similar results, with finer sediments found in the peripheral bays as compared to the main channel. This hypothesis does not completely explain the observed patterns however. Additional factors such as elevation and history of dredge material placement may also be factors. We will continue to evaluate these patterns as more data become available.

Sediment accretion is largely dependent on the sediment load of the contributing watershed, which is variable but estimated to average approximately 10 million metric tons annually in the Columbia (Sherwood et al. 1984). However, sediment transport has changed dramatically in the estuary and has been reduced an estimated 61 percent from historic levels (Bottom et al. 2005). Altered sediment budgets, variable transport patterns, and historical changes due to dredging and entrapment by the reservoirs interact to create a complex sediment transport environment. Likewise, marsh sediment accretion rates fell within a narrow range in our study area, but were variable in time and space throughout the estuary. For comparison, salt marsh sediment accretion rates measured in the region fell within a similar range between 0.2 to 1.7cm/yr (Jefferson 1975; Thom 1992). In the Fraser Estuary, sediment deposition was most often associated with the occurrence of the spring freshet with deposits of 5 cm/yr common (Seliskar and Gallagher 1983). Rates can be also be affected by local site factors including elevation, plant density, landscape position, and sediment type. More data on accretion rates over a longer period of record and throughout the estuary will help to expand our understanding of sedimentation and erosion patterns on multiple scales.

The hydrologic variability and the resulting inundation of the marshes varies dramatically along the estuarine gradient, with high inundation and seasonal variability in the fluvial dominated upper estuary and lower inundation and daily variability in the tidal dominated lower estuary. In the mesohaline zone (5 to 18 ppt; ~0 to 15 rkm) near the mouth of the estuary the vegetation cover is high, however, the number of species is limited by salinity. Few non-native species are found in this zone. In the oligohaline zone (0.5 to 5 ppt; ~16 to 40 rkm), species diversity starts to increase as there becomes an overlap in the number of species that can tolerate brackish and freshwater conditions. The highest species diversity occurs in the portion of the River that is tidal freshwater, but not affected by the high seasonal inundation associated with the spring freshet (~41 to 135 rkm). In the fluvial dominated tidal freshwater zone (above 135 rkm) vegetation cover and species diversity appear to be variable depending on the timing and magnitude of the spring freshet.

Vegetation was also evaluated as a function of elevation and indirectly inundation, as we have shown inundation is correlated with elevation when compared in hydrologically similar portions of the LCRE. The highest species diversity occurs between the elevations of approximately 1.5 m CRD and 2.5 m CRD, consistent with other studies that have shown increased species diversity in high versus low marshes (Elliot 2004; Leck et al. 2009). Of particular interest in this analysis is the determination of the lower elevation limit of reed canarygrass throughout the estuary. This aggressive non-native invasive species lowers species diversity and has the potential to affect the food web by reducing invertebrate prey diversity as well (Spyreas et al. 2010). As such, information regarding the limiting factors for growth and success are important to determining management actions. Elevation and inundation appear to be such limiting factors. The lower depth limit varied along the estuarine gradient; affected by salinity in the oligohaline portion of the estuary and therefore only present at higher elevations where the sediments are often fresh (Seliskar and Gallagher 1983). In the tidally dominated freshwater portion of the estuary, the lower elevation ranges from approximately 1.2 m to 1.6 m CRD. This range increases to approximately 1.4 to 1.8 m CRD in the fluvial dominated portion of the estuary as seasonal inundation increases and likely limits the lower elevation range.

We have found that the hydrologic variability observed between years is a primary factor driving variability in vegetation cover, composition, and biomass. This interannual variability associated with varying water levels was documented in our trends analysis at the three up-river core sites (located at 145, 149, and 221 rkm); however the same patterns were not as discernible at the core site located at 72 rkm. The boundaries between the major species at the core sites were generally stable over time even with varying water levels. In the highest water year we did observe an increase in the lower elevation of all species at CLM, the lowest elevation site, indicating the potential for an effect on the elevation ranges from this level of hydrological variability. The implications of this kind of change include a potential loss of wetland area and a reduction in biomass production (discussed below).

Another trend we observed in this analysis was the interannual variability of PHAR cover due to varying water levels; however, reductions were not persistent between years. At the lower-river core site (WHC), where interannual hydrologic variability does not appear to be a primary controlling factor, the trend over three years has been a gradual increase in cover of PHAR and a decrease in the cover of all other species. This trend could be attributed to the invasive nature of the species or could be due to interannual variability; additional data will provide a better understanding. The slight increase in the number of species over time was likely caused by an increase in the number of quadrats each year in an attempt to adequately represent the diverse site.

Preliminary data on primary productivity and biomass export show similar results to other estuarine areas in the region for the lower estuary (i.e., sites BBM and WHC) however, the upper estuary sites (i.e., CS1 and FLM) had low values compared to other studies (Berg et al. 1980; Seliskar and Gallagher 1983; Small et al. 1990; Thom et al. 2001). Although high variability in both salt marshes and tidal freshwater marshes make comparisons difficult (Odom 1988), the low values observed in the upper estuary are likely due to the effects of the high water in 2011. Because the interannual variability in water level and position in the estuary affect the timing of peak biomass, we need to evaluate these differences and potentially modify future sampling efforts.

Inundation of the marsh channel mouths varies longitudinally and as expected between sites with varying channel elevations and morphologies. This affects the potential for fish access and is important for understanding the contribution of these marshes for refuge, feeding, and cover. Most channels were accessible for at least 60 percent of the time and most channel banks accessible for at least 40 percent of the estimated peak juvenile salmonid migration period. These elevations can be useful for informing restoration projects to ensure that salmon access is maximized at the site.

In general, the emergent marshes of the LCRE that were evaluated in this study are diverse, productive systems with channels that are providing the opportunity for juvenile salmonids access throughout the LCRE. Additional research evaluating the capacity differences between these emergent wetlands will further reduce the uncertainties regarding the quality of these systems for juvenile salmon. Further research on TOC in the sediment, biomass export, site history, sedimentation rates, and non-native species will help to better understand other ecosystem processes and functions such succession, carbon storage, and food web support.

Recommendations

Sedimentation and Elevation

Surface elevation tables (SET) could be installed at some or all of the core monitoring locations to evaluate accuracy of the current method for measuring wetland accretion or erosion and to allow for better characterization of overall elevation changes due to sediment dynamics and shallow subsidence (Rybczyk and Cahoon 2003). In addition, multiple sediment accretion stakes could be placed at core sites to look at site-scale patterns of sediment dynamics.

Hydrology

Timing of sensor deployment should be changed so the entire growing season is recorded in one year (e.g., deploy and retrieve in late October).

Vegetation

In future years, the mapping effort could be reduced at core sites unless obvious change is observed; maybe every 3-5 years. More time should be focused on the biomass collection effort to ensure we are getting representative results and to better our understanding of the variability associated with this metric. As such, additional seasonal sampling may be needed to further evaluate cover and biomass changes throughout the year and the addition of more biomass samples would reduce the variability we are seeing within sites, especially in the SAV zone.

Channel Morphology

In future years, single cross sections at the channel mouth could probably be measured at the core sites to evaluate change, with the whole channel being surveyed less frequently. Changes in the channel morphology would likely be detected by measurements at the channel mouth. If change was observed at the mouth then a full survey should be completed in the following year. Otherwise, the channel could be surveyed at a regular interval such as every 5 years. In addition, at core sites the channel cross sections need to be surveyed at exactly the same start points and at consistent intervals to be able to evaluate change over time. Initial surveys of the rotating sites should still have the full channel surveyed as part of the characterization of the site.

4.3 Fish and Prey Monitoring

4.3.1 Introduction

In 2011, NOAA Fisheries, USGS, PNNL,OHSU, CREST and the Estuary Partnership, with support from BPA, monitored salmon and salmon habitats primarily in Reach E of the LCRE, with more limited sampling at fixed sites in other reaches of the river. As part of this monitoring effort, NOAA Fisheries focused on the following 6 work elements:

1) A survey of prey availability and habitat use by salmon and other fishes at three sites in Reach E of the LCRE and data collection on fish habitat use in relation to physical habitat characteristics (monitored by PNNL and USGS). This effort also included re-sampling of the fixed monitoring sites: Franz Lake site at reach H, Campbell Slough site in the Ridgefield National Wildlife Refuge (NWR) in Reach F, and the Whites Island site in Reach C, in order to examine year-to-year trends in fish use of these sites. In 2011, Ilwaco site in Reach A was added as one of the fixed monitoring sites.
2) Taxonomic analyses of prey in Chinook salmon (*Oncorhynchus tshawytscha*) stomach contents in order to identify preferred prey types at different sites and times, and to compare these with prey identified at the sites.
3) Analyses of otoliths collected from juvenile Chinook salmon at 2011 sites for determination of growth rates.
4) Analyses of biochemical measures of growth and condition for juvenile Chinook salmon collected at the 2011 sites.
5) Identification of genetic stock for juvenile Chinook salmon collected at 2011 sites.
6) Compilation of data and annual report preparation.

4.3.2 Study Sites

In 2011, we monitored prey availability and habitat use by juvenile Chinook salmon and other fishes at three new tidal freshwater sites in Reach E: Deer Island, Goat Island, and Burke Island (Figure 22 and Figure 23). Additionally, we re-sampled fish and prey at the Franz Lake site in Reach H (sampled in 2008 and 2009) (Figure 22 and Figure 24), Ridgefield Wildlife Refuge site (Campbell Slough) in Reach F (sampled from 2007-2009) (Figure 22 and Figure 25), White Island site in Reach C (sampled in 2009 and 2010) (Figure 22 and Figure 26), and Ilwaco site in Reach A (2011) (Figure 22 and Figure 27), in order to examine year-to-year trends in fish use and prey availability at the sites. Photographs of the sites are shown in Figure 28. Our objectives were to collect preliminary information on fish habitat use that may be related to physical habitat characteristics and availability of prey organisms. At these fish sampling sites, PNNL conducted vegetation and habitat characterization surveys and USGS collected sediment samples.

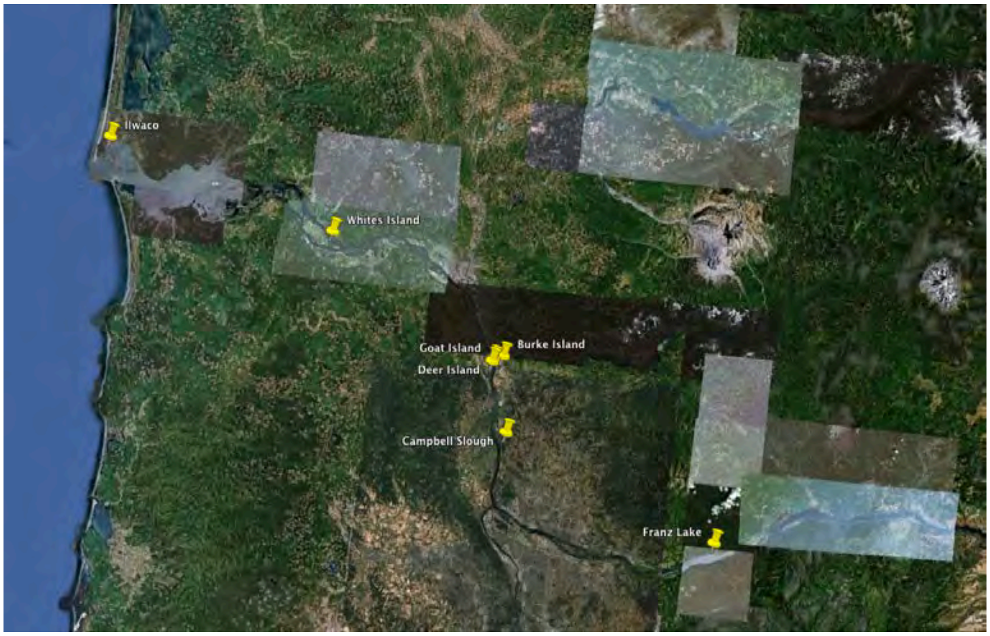


Figure 22. Locations of Ecosystem Monitoring sites in sampled in 2011.

Figure 23. Locations of Ecosystem Monitoring sites in Reach E sampled in 2011.

Figure 24. Location of Franz Lake long-term monitoring site in Reach H of the Lower Columbia River and Estuary.

Figure 25. Location of Ridgefield National Wildlife Refuge (NWR) long-term monitoring sites in Reach F of the Lower Columbia River and Estuary.

Figure 26. Location of Whites Island long-term monitoring sites in Reach C of the Lower Columbia River and Estuary.

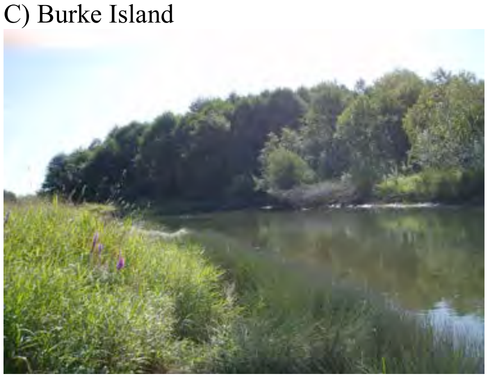
Figure 27. Location of Ilwaco long-term monitoring site in Reach A of the Lower Columbia River and Estuary.


A) Deer Island


B) Goat Island


C) Burke Island


D) Franz Lake


E) Whites Island


F) Campbell Slough


G) Ilwaco

Figure 28. Photographs of 2010 fish sampling Sites A) Deer Island; B) Goat Island; C) Burke Island D) Franz Lake, E) Campbell Slough F) Whites Island, and G) Ilwaco

4.3.3 Methods

Fish Sampling

Fish use of the sites was assessed by analysis of catch data. Fish were collected from April 2011 through December 2011. Table 13 shows the coordinates of each site.

Table 13. Coordinates of the sites sampled in 2011.

Site Name	Latitude	Longitude
Ilwaco	46°18.035'N	124° 2.784'W
Whites Island	45° 9.561'N	123° 20.408'W
Deer Island	45° 55.775'N	122° 49.209'W
Goat Island	45° 55.952'N	122° 48.974'W
Burke Island	45° 56.427'N	122° 47.376'W
Campbell Slough	45° 47.032'N	122° 45.291'W
Franz Lake	45° 36.035'N	122° 6.184'W

Fish were collected using a Puget Sound beach seine (PSBS) (37x2.4m, 10mm mesh size). PSBS sets were deployed using a 17 ft Boston Whaler or 9 ft inflatable raft. Up to three sets were performed per sampling time as conditions allowed. Sampled fish were identified to the species level and counted. Salmonid species (up to 30 specimens) were measured (fork length in mm) and weighed (in g) and checked for adipose fin clips and coded wire tags to distinguish between marked hatchery fish and unmarked, presumably wild fish. At each sampling event, as conditions allowed, the coordinates of the sampling locations, the time of sampling, water temperature, weather, habitat conditions, tide conditions, salinity, and vegetation were recorded.

When Chinook salmon were present, up to 30 individual juvenile Chinook were collected for necropsy at each field site at each sampling time. Salmon were measured (to the nearest mm) and weighed (to the nearest 0.1 g), then sacrificed by anesthesia with a lethal dose of MS-222. The following samples were collected from the field-sampled fish: stomach contents for taxonomic analysis of prey; whole bodies (minus stomach contents) for measurement of lipids and persistent organic pollutants (POPs), including polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethanes (DDTs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and various organochlorine pesticides; fin clips for genetic stock identification; otoliths for aging and growth rate determination, and, when sufficient fish were available, bile for measurement of metabolites of polycyclic aromatic hydrocarbons (PAHs); stomach contents for measurement POPs, including PAH, DDTs, PCBs, PBDEs, and various organochlorine pesticides. These samples were not collected for coho salmon (*Oncorhynchus kisutch*) or other salmonid species because our permits did not authorize this type of sampling for these species.

Samples for chemical analyses were frozen and stored at –80°C until analyses were performed. Samples for taxonomic analyses were preserved in 10% neutral buffered formalin. Fin clips for genetic analyses were collected and preserved in alcohol, following protocols described in (Myers et al. 2006). Otoliths for age and growth determination were also stored in alcohol. The number and type of samples collected at each site and sampling time are listed in Table 14.

Table 14. Samples collected from juvenile Chinook salmon in 2011.

	otolith	bile*	stomach taxonomy	stomach chemistry	body chemistry	genetics	USGS muscle
Ilwaco	0	0	0	0	0	0	1
Whites Island	47	1*	35	0	47	61	10
Deer Island	24	0	23	0	23	24	0
Burke Island	10	0	10	0	10	12	0
Campbell Slough	31	1*	22	0	31	31	10
Total	112	55	90	0	91	128	21

*These individual samples were composited at the time of sample collected to produce one composite sample at each site. The bile sample from Whites Island contained bile from 28 individual fish, while the sample from Campbell Slough contained bile from 27 individual fish.

Prey Sampling

For the invertebrate prey sampling, the objective was to collect aquatic invertebrate samples and identify the taxonomic composition and abundance of salmonid prey available at sites when juvenile salmonids were collected. These data could then be compared with the taxonomic composition of prey found in stomach contents of fish collected concurrently.

In 2011, NOAA Fisheries conducted the following types of invertebrate collections at the monitoring sites:

1) Open water column Neuston tows (2 tows at each site at each sampling time). These tows collect prey available to fish in the water column and on the surface of open water habitats. For each tow, the net was towed for a measured distance of at least 50 m. Invertebrates, detritus, and other material collected in the net were sieved, and invertebrates were removed and transferred to a labeled bottle. The sample was preserved with 95% ethanol.
2) Emergent vegetation Neuston tows (2 tows at each site at each sampling time). These vegetation tows collect prey associated with emergent vegetation and available to fish in shallow areas. For each tow, the net was dragged through water and vegetation at the channel margin where emergent vegetation was present and where the water depth was < 0.5 m deep for a recorded distance of at least 10 m. The samples were then processed and preserved in the same manner as the open water tows.

In addition to the invertebrate sampling along the channel margin, the density and type of emergent vegetation at the sampled sites were noted and photographed. The objective of surveying the % cover of emergent vegetation was to determine if there are correlations between the diversity and abundance of invertebrate prey and the extent of emergent vegetation across sites. To quantify vegetation, a surveyor placed a 0.5x0.5m PVC frame at 5 sites evenly spaced along each 10 m transect. The surveyor then photographed the complete frame and the aquatic area and any vegetation within that frame so that standardized photos could be analyzed later (to ensure analysis is as objective as possible, photos from all sites will be analyzed in random order after code names have been assigned). The surveyor also visually assessed and recorded estimates of % cover and type of vegetation within each frame, and photographed the larger area sampled (upstream and downstream from the transects). The number and type of samples collected at each site and sampling time are listed in Table 15.

Table 15. Prey Samples collected from juvenile Chinook salmon in 2011.

site	date	emergent vegetation tows	open water tows	total tow samples	salmon diet sample s
Burke Island	5/2/11	2	2	4	10
Burke Island	7/27/11	0	0	0	2
Campbell Slough	5/4/11	2	2	4	22
Deer Island	5/2/11	2	2	4	10
Franz Lake	5/4/11	0	2	2	0
Goat Island	5/2/11	2	2	4	13
Ilwaco	4/4/11	0	2	2	0
Ilwaco	5/3/11	0	2	2	0
Ilwaco	5/31/11	3	3	6	0
Ilwaco	6/22/11	1	3	4	0
Total		12	20	32	57

Sample Analyses
Genetic analysis. Genetic stock identification (GSI) techniques (see Manel et al. 2005) were used to investigate the origins of juvenile Chinook salmon using the EMP sites, as described in Teel et al. 2009 and Roegner et al. 2010. The stock composition of juveniles was estimated with a regional microsatellite DNA data set (Seeb et al. 2007) that includes baseline data for spawning populations from throughout the Columbia River basin (described in Teel et al. 2009). The overall proportional stock composition of EMP site samples was estimated with the GSI computer program ONCOR (Kalinowski et al. 2007), which implemented the likelihood model of Rannala and Mountain (1997). Probability of origin was estimated for the following regional genetic stock groups (Seeb et al. 2007; Teel et al. 2009): Deschutes River fall Chinook; West Cascades fall Chinook; West Cascades Spring Chinook; Middle and Upper Columbia Spring Chinook; Spring Creek Group fall Chinook; Snake River Fall Chinook; Snake River Spring Chinook; Upper Columbia River Summer/Fall Chinook; and Upper Willamette River Spring Chinook. West Cascades and Spring Creek Group Chinook are Lower Columbia River stocks.

Lipid Determination. As part of our study we determined lipid content in salmon whole bodies. Lipid content can be a useful indicator of salmon health (Biro et al. 2004), and also affects contaminant uptake and toxicity (Elskus et al. 2005). Studies show that the tissue concentration of a lipophilic chemical that causes a toxic response is directly related to the amount of lipid in an organism (Lassiter and Hallam, 1990; van Wezel et al. 1995); in animals with high lipid content, a higher proportion of the hydrophobic compound is associated with the lipid and unavailable to cause toxicity.

Prior to analyses, salmon whole body samples from the field were composited by genetic reporting group and date and site of collection into a set of composite samples, each containing 3-5 fish each. In salmon whole bodies composite samples from the total amount of extractable lipid (percent lipid) was determined by Iatroscan and lipid classes were determined by thin layer chromatography with flame ionization detection (TLC/FID), as described in Ylitalo et al. (2005).

Otolith Analyses. Otoliths of juvenile Chinook collected from the 2011 EMP sites were extracted and will be processed for microstructural analysis of recent growth in the coming months. Specifically, sagittal otoliths are embedded in Crystal Bond© and polished in a transverse plane using 30-3μm lapping film. Using Image Pro Plus© (version 5.1), with a media cybernetics (evolutionMP color) digital camera operating at a magnification of 20 x, the average fish daily growth rate (i.e., mm of fish length/day) is determined for three time periods: a) the last 7 days of their life, b) the last 14 days of their life, and c) the last 21 days of their life. Average daily growth (DG, mm/day) is calculated using the Fraser-Lee equation:

$$La = d + [(Lc - d)/Oc] \times Oa$$

$$DG = [(Lc - La)/a]$$

where La and Oa represents fish length and otolith radius at time a (i.e., last 7, 14, or 21 days), respectively, d is the intercept (13.563) of the regression between fish length and otolith radius, Lc and Oc are the fish length and otolith radius at capture, respectively.

Chemical Contaminants in Chinook salmon bodies. Composite body samples, with stomach contents removed, were extracted with dichloromethane using an accelerated solvent extractor. The sample extracts were cleaned up using size exclusion liquid chromatography and analyzed by gas chromatography/mass spectrometry (GC/MS) for PCB congeners; PBDE congeners; organochlorine (OC) pesticides including DDTs, hexachlorocyclohexanes (HCHs), chlordanes, aldrin, dieldrin, mirex, and endosulfans; and low (2-3 ring) and high (4-6 ring) molecular weight aromatic hydrocarbons as described by Sloan et al. (2004, 2006). Summed PCBs were determined by adding the concentrations of 45 congeners (PCBs 17, 18, 28, 31, 33, 44, 49, 52, 66, 70, 74, 82, 87, 95, 99, 101/90, 105, 110, 118, 128, 138/163/164, 149, 151, 153/132, 156, 158, 170/190, 171, 177, 180, 183, 187, 191, 194, 195, 199, 205, 206, 208, 209). Summed DDT levels (∑DDTs) were calculated by summing the concentrations of *p,p'*-DDT, *p,p'*-DDE, *p,p'*-DDD, *o,p'*-DDD, *o,p'*-DDE and *o,p'*-DDT. Summed chlordanes (∑CHLDs) were determined by adding the concentrations of heptachlor, heptachlor epoxide, g-chlordane, a-chlordane, oxychlordane, *cis*-nonachlor, *trans*-nonachlor and nonachlor III. Summed hexachlorocyclohexanes (∑HCHs) were calculated by adding the concentrations of a-HCH, b-HCH, g-HCH, and lindane. Summed low molecular weight aromatic hydrocarbons (∑LAHs) were determined by adding the concentrations of biphenyl, naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, 2,6-dimethylnapthalene, acenaphthene, fluorene, phenanthrene; 1-methylphenanthrene, and anthracene. Summed high molecular weight aromatic hydrocarbons (∑HAHs) were calculated by adding the concentrations of fluoranthene, pyrene, benz[a]anthracene, chrysene, benzo[a]pyrene, benzo[e]pyrene, perylene, dibenz[a,h]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, indenopyrene, and benzo[ghi]perylene. Summed total aromatic hydrocarbons (∑TAHs) were calculated by adding ∑HAHs and ∑LAHs.

To adjust for the influence of lipid on toxicity, we normalized whole body contaminant concentrations for lipid, and relied primarily on lipid-normalized data to evaluate potential health effects of toxicants on juvenile salmon. Wet weight data are also presented to facilitate comparison with other studies, and to evaluate risks to predators who consume salmon that have accumulated toxicants.

PAH metabolites in salmon bile. Bile samples were analyzed for metabolites of PAHs using high-performance liquid chromatography/fluorescence detection (HPLC/fluorescence) method described by Krahn et al. (1986). Briefly, bile was injected directly onto a C-18 reverse-phase column (PhenomenexSynergi Hydro) and eluted with a linear gradient from 100% water (containing a trace amount of acetic acid) to 100% methanol at a flow of 1.0 mL/min. Chromatograms were recorded at the following wavelength pairs: 1) 260/380 nm where several 3-4 ring compounds (e.g., phenanthrene) fluoresce, and 2) 380/430 nm where 4-5 ring compounds (e.g., benzo[a]pyrene) fluoresce. Peaks eluting after 5 minutes were integrated and the areas of these peaks were summed. The concentrations of fluorescent PAHs in the bile samples of juvenile fall Chinook salmon were determined using phenanthrene (PHN) and benzo[a]pyrene (BaP) as external standards and converting the fluorescence response of bile to phenanthrene (ng PHN equivalents/g bile) and benzo(a)pyrene (ng BaP equivalents/g bile) equivalents.

To ensure that the HPLC/fluorescence system was operating properly, a PHN/BaP calibration standard was analyzed at least 5 times, and a relative standard deviation of less than 10% was obtained for each PAC. As part of our laboratory quality assurance (QA) plan, two QA samples [a method blank and a fish bile control sample (bile of Atlantic salmon, *Salmo salar*, exposed to 25 µg/mL of Monterey crude oil for 48 hours)] were analyzed with the fish bile samples (Sloan et al. 2006).

Biliary protein was measured according to the method described by Lowry et al. (1951). Biliary fluorescence values were normalized to protein content, which is an indication of feeding state and water content of the bile. Fish that have not eaten for several days exhibit higher biliary FAC values and higher protein content than fish that are feeding constantly and excreting bile more frequently (Collier and Varanasi 1991).

Fish Community Characteristics, Catch per Unit Effort, and Fish Condition Calculations

Fish species diversity was calculated using the Shannon-Weiner diversity index (Shannon and Weaver 1949):

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

Where

ni = the number of individuals in species i; the abundance of species i.

S = the number of species. Also called species richness.

N = the total number of all individuals

Pi = the relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community.

Catch per unit effort (CPUE) was calculated as described in Roegner et al. 2009, with fish density reported in number per 1000 m^2.

For all salmonid species, Fulton's condition factor (K) (Fulton 1902; Ricker 1975) was calculated as an indicator of fish health and fitness, using the formula:

$$K = [\text{weight (g)}/\text{fork length (cm)}^3] \times 100$$

4.3.4 Results

Water level and its effect on fishing

In 2011, as in other years (Jones et al. 2008, Johnson et al. 2009, 2010, 2011b) we encountered considerable variation in water level at all of our sampling sites (Figure 29). Extreme high water levels, especially in Reaches E, F, and H, made some sites difficult to access. Thus, while fish sampling took place every month, it was not always possible to fish all sites each month because of problems with accessibility and fishability (Table 16).

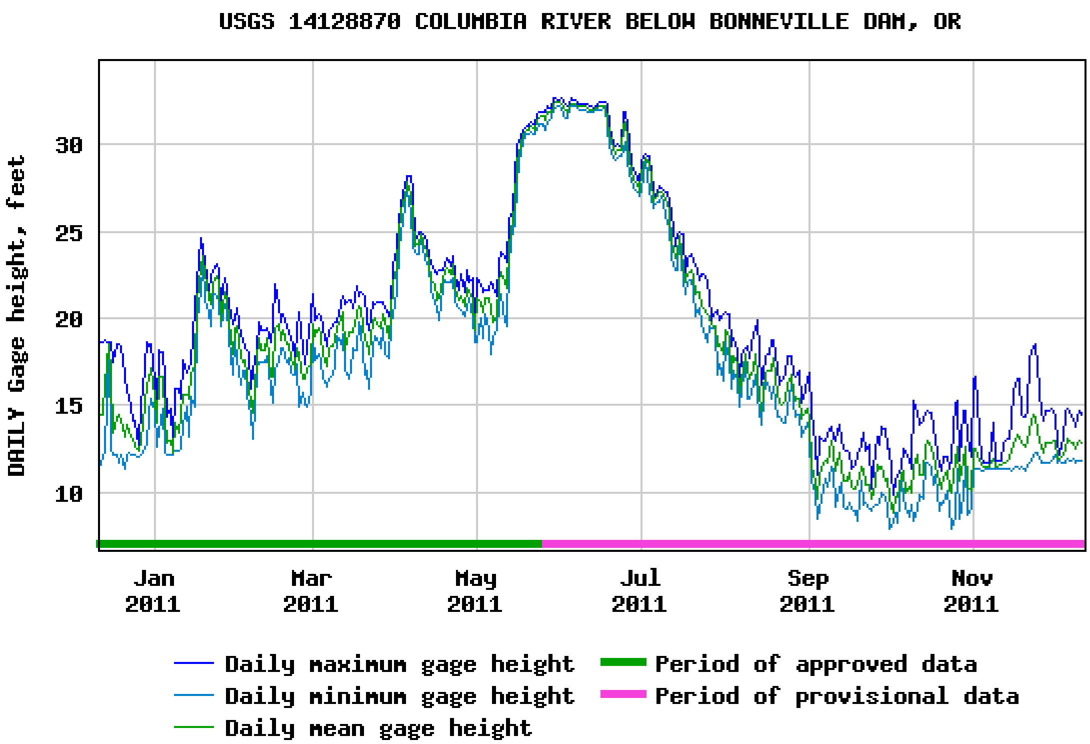


Figure 29. Water depth (ft) below Bonneville Dam (Lat 45° 38'00", long 121° 57'33") over the salmon sampling period. Data provided by USGS.

Table 16. Fishing attempts made at 2011 Ecosystem Monitoring sites.

	month								
site	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
Ilwaco	2	5*	3	2	3	3	3	3	3
Whites Island	a	5*	2	2	3	3	3	3	3
Deer Island	a	1	b	1	3	3	3	3	3
Goat Island	a	1	b	1	2	3	3	3	3
Burke Island	a	1	b	2	2	3	3	3	3
Campbell Slough	a	1	b	2	3	3	3	a	a
Franz Lake	a	b	b	1	3	3	3	3	3

* denotes sites where the site was sampled in early May and late May.
[a] denotes sites where sites were not sampled due to sampling permit issues.
[b] denotes sites where sites were not sampled due to extreme water levels

Water temperature

Due to sampling permit issues and extreme water levels described above, Ilwaco is the only site at which temperature data is available for all sampling months. At Ilwaco, the average water temperature of 8.9°C in April increased to 19°C in August, than decreased to 7°C in December.

Although temperature data for certain months were not available for some of the sites due to permit issues and extreme water levels, the rise and fall of water temperature for the remaining sites were similar to the profile observed in the Ilwaco (Figure 30, Table 17).

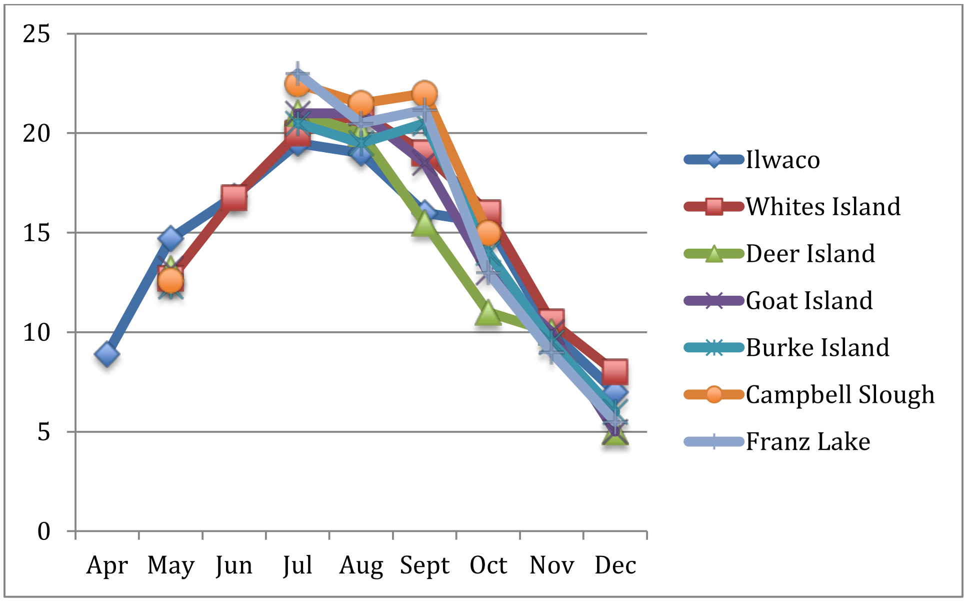


Figure 30. Mean water temperature in °C by month at each the 2011 Ecosystem Monitoring sites.

Table 17. Average monthly water temperature at 2011 Ecosystem Monitoring Project fishing sites.

	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Ilwaco	8.9	14.7	16.8	19.5	19	16	15.5	10	7
Whites Island		12.7	16.8	20	21	19	16	10.5	8
Deer Island		13.2		21	20	15.5	11	10	5
Goat Island		13.2		21	21	18.5	13	10	5
Burke Island		12.3		20.5	19.5	20.5	14	9.5	6
Campbell Slough		12.6		22.5	21.5	22	15		
Franz Lake				23	20.5	21.17	13	9	5.5

Salinity

Ilwaco was the only site sampled in 2011 with a saltwater influence. Figure 31 shows the surface water salinity profile at Ilwaco from July through December (salinity data from April through June are not available due to equipment malfunction). The salinity of the water did not change greatly throughout the study. The average value for the site over the entire sampling season was 9.97±0.72 ppt. Salinity was highest in November (11 ppt) and lowest in December (9 ppt).

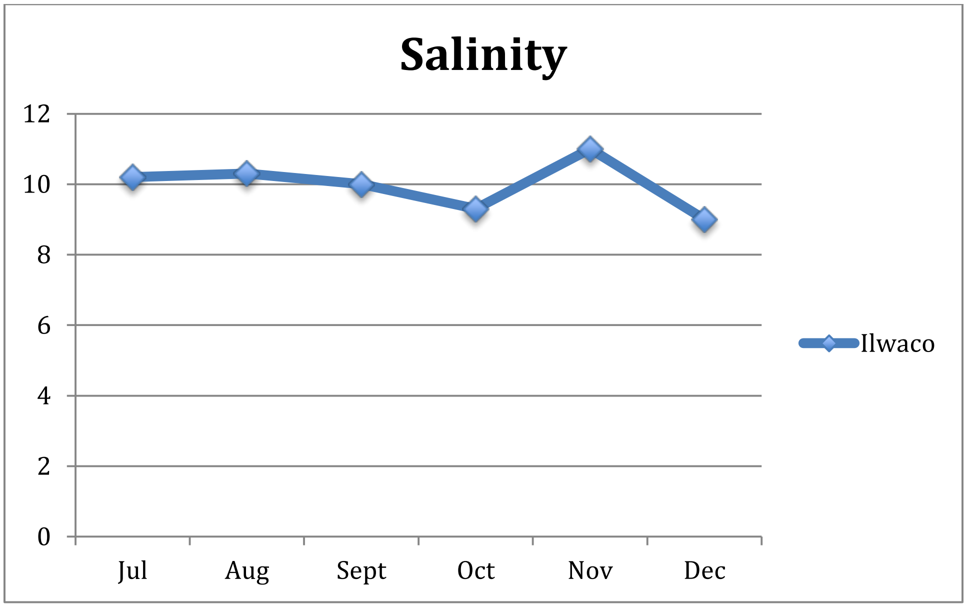


Figure 31. Salinity (ppt) at the Ilwaco 2011 Ecosystem Monitoring site.

Fish Species Composition

Monitoring efforts in 2011 showed that juvenile salmon and other fish species were present at all sites (Table 18, Figure 32). Salmonid species generally accounted for 5% or less of the total catch. Juvenile Chinook were captured at all seven sites, with the percentage of total catch for the entire sampling period ranging from 0.02% at the lowest catch site to 3.37% at the highest catch site. Coho salmon were captured at three of the seven sites (Deer Island, Burke Island, and Franz Lake) at percentages ranging from 0.02 to 2.81% of the total catch. Chum salmon (*Oncorhynchus keta*) were captured only at Ilwaco, and made up 4.77% of the total catch (47.22% of the catch in April).

Of the non-salmonid species captured, three-spined stickleback (*Gasterosteus aculeatus*) was the most abundant at all sites, followed by banded killifish (*Fundulus diaphanous)*, chiselmouth (*Acrocheilus alutaceus*), and largescale sucker (*Catostomus macrocheilus*) (Table 18, Figure 32). At Ilwaco , a saltwater site, 46.91% of the total catch was comprised of stickleback, followed by euryhaline species such as shiner perch (*Cymatogaster aggregata*, 24.87%), staghorn sculpin (*Leptocottus armatus*, 18%), surf smelt (*Hypomesus pretiosus*) (4.29%), sandlance (*Ammodytes hexapterus)*, 0.79%), and rosy sculpin (*Oligocottus rubellio*, 0.02%). At Whites Island, 95.34% of the total catch was comprised of stickleback followed by chiselmouth (1.87%), and killifish (0.63%, Table 18).

At the Reach E sites (Deer Island, Burke Island, and Goat Island), stickleback were the most abundant species (32.03-71.35% of the total catch) followed by killifish (3.14-18.09%), chiselmouth (0.02- 30.23%), and yellow perch (2.61-6.60%; Table 6). At Deer Island, although stickleback were the dominant species caught, stickleback were practically absent in the July-August sampling period. The percentage of stickleback increased again during the September-December sampling period. High numbers of chiselmouth were caught during the July-September sampling period (30.23% of catch), but they were absent in other sampling periods.

Additionally, Tui chub (*Gilia bicolor*) were observed only in the August sampling, when they made up 32.83% of the catch, but were absent in other sampling months. Goat Island catches were dominated by stickleback (53.35%), followed by killifish (18.09%) and chiselmouth (8.89%). Similar to Deer Island, Tui chub was only caught at this site in the August sampling period (8.4%). Interestingly, at Goat Island, an increase in the percentage of killifish was observed in conjunction with a decrease in the stickleback percentage. Burke Island was also dominated by stickleback (71.35%), followed by carp (11.79%), largescale sucker (5.83%) and killifish (4.07%). Slimy sculpin (*Cottus cognatus*), which was not observed in previous EMP efforts, was caught in July (0.89% of the total catch in July), and a low percentage of mosquitofish *(Gambusia affinis)* were also observed (0.86% of the total catch in September).

Stickleback were the dominant species found at Campbell Slough (33.71%). The highest proportion were found in July and October, but they were practically absent during the August and September sampling period (Table 18). Similar to Goat Island, the decrease in stickleback percentage was accompanied by increase in killifish percentage. Killifish accounted for 29.90% of the total at this site followed by carp (10.24%). Golden shiner *(Notemigonus crysoleucas)* was caught in the month of July (0.05% of the total catch in July), and warmouth *(Lepomis gulosus)* was observed in October sampling (0.17% of the total catch in October).

Proportions of stickleback at Franz Lake was 53.35%, followed by chiselmouth (26.99%), and killifish (16.86%; Table 18). Lake chub (*Couesius plumbeus*), another species not observed in previous Ecosystem Monitoring efforts, was caught in the month of December (0.25%).

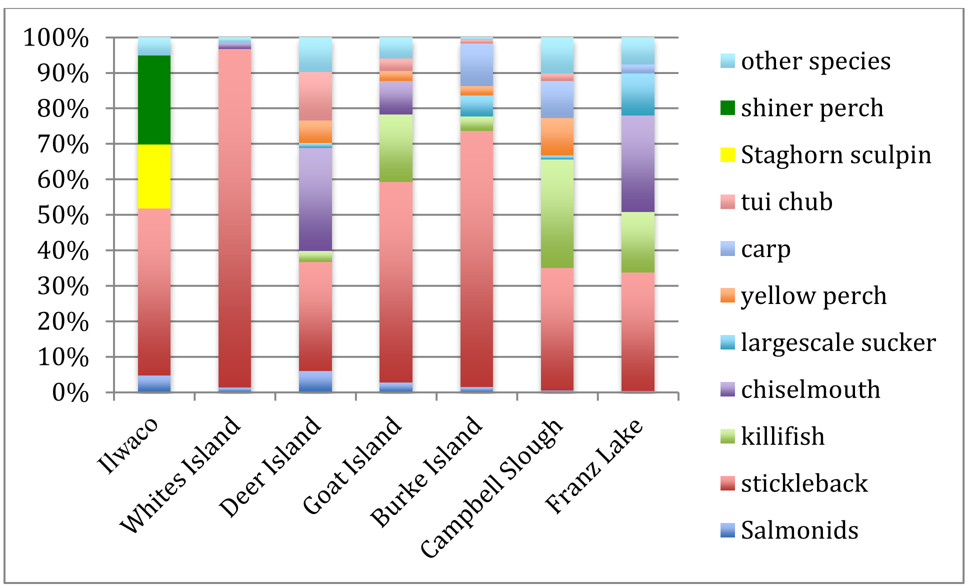


Figure 32. Fish community composition at the 2011 Ecosystem Monitoring sites over the full sampling season (April-December).

Table 18. Total of species captured, and relative abundance of each species as a percentage of the total number of all individual fish captured.

site	date	species count	total # of fish	Chinook	coho	chum	three spined stickleback	banded killifish	sculpin unknown	staghron sculpin	rosy sculpin	northern pikeminnow	yellow perch	surf smelt	pumpkinseed	bullhead	crappie	carp	bluegill	peamouth	chiselmouth	largescale sucker	smallmouth bass	American shad	shiner perch	tui chub	starry flounder	sandlance	mosquitofish	Slimy sculpin	golden shiner	lake chub	warmouth
	4/4/11	4	485	0.00	0.00	47.22	14.23	0.00	0.00	30.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.84	0.00	0.00	0.00	0.00	0.00
	5/3/11	1	336	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5/31/11	4	321	0.31	0.00	0.00	8.72	0.00	0.00	28.97	0.00	0.00	0.00	61.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6/27/11	3	338	0.00	0.00	0.00	57.99	0.00	0.00	39.35	0.00	0.00	0.00	2.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/25/11	3	1010	0.00	0.00	0.00	60.79	0.00	0.00	8.91	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8/30/11	3	284	0.00	0.00	0.00	73.24	0.00	0.00	4.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/18/11	3	860	0.00	0.00	0.00	28.14	0.00	0.00	6.51	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	65.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10/16/11	2	279	0.00	0.00	0.00	51.97	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	47.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11/14/11	4	704	0.00	0.00	0.00	80.40	0.43	0.14	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12/7/11	1	184	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ilwaco	**total**	**11**	**4801**	**0.02**	**0.00**	**4.77**	**46.91**	**0.08**	**0.02**	**18.20**	**0.02**	**0.00**	**0.00**	**4.29**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**24.87**	**0.00**	**0.00**	**0.79**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	5/3/11	2	521	4.41	0.00	0.00	95.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5/31/11	1	2	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	6/27/11	2	181	18.78	0.00	0.00	81.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/28/11	3	785	0.25	0.00	0.00	98.34	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8/30/11	4	961	0.00	0.00	0.00	97.09	0.42	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.08	0.10	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/18/11	4	1311	0.00	0.00	0.00	92.22	0.92	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10/16/11	2	643	0.00	0.00	0.00	99.38	0.16	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11/14/11	1	17	0.00	0.00	0.00	94.12	0.00	5.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12/7/11	1	21	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Whites Island	**total**	**9**	**4442**	**1.37**	**0.00**	**0.00**	**95.34**	**0.63**	**0.05**	**0.00**	**0.00**	**0.18**	**0.02**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.50**	**1.87**	**0.05**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	5/2/11	4	448	16.07	13.62	0.00	66.96	3.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/27/11	4	251	0.40	0.00	0.00	0.40	3.98	0.40	0.00	0.00	0.40	11.55	0.00	0.40	0.00	0.00	0.40	1.99	0.00	79.68	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8/31/11	10	926	0.00	0.00	0.00	1.51	2.38	0.00	0.00	0.00	0.00	12.31	0.00	0.00	0.00	4.43	1.30	6.16	0.00	36.07	2.48	0.43	0.00	0.00	32.83	0.11	0.00	0.00	0.00	0.00	0.00	0.00
	9/20/11	7	415	0.00	0.00	0.00	65.06	1.20	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.72	0.00	0.00	29.16	2.41	0.24	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00
	10/18/11	0	3	0.00	0.00	0.00	33.33	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	33.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11/15/11	2	57	0.00	0.00	0.00	77.19	22.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Deer Island	12/6/11	2	67	0.00	0.00	0.00	95.52	4.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	**16**	**2167**	**3.37**	**2.81**	**0.00**	**32.03**	**3.14**	**0.18**	**0.00**	**0.00**	**0.05**	**6.60**	**0.00**	**0.05**	**0.00**	**1.98**	**0.74**	**2.86**	**0.00**	**30.23**	**1.52**	**0.23**	**0.00**	**0.00**	**14.07**	**0.14**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	5/2/11	3	89	56.18	0.00	0.00	41.57	2.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/27/11	5	140	0.00	0.00	0.00	23.57	32.86	4.29	0.00	0.00	0.00	2.86	0.00	0.00	0.00	0.00	0.00	0.00	0.71	35.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8/31/11	11	762	0.13	0.00	0.00	21.52	32.68	0.52	0.00	0.00	0.00	5.91	0.00	0.00	0.00	7.87	0.26	0.26	0.00	8.14	1.44	0.00	12.86	0.00	8.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/20/11	5	208	0.00	0.00	0.00	47.12	18.27	5.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.44	2.40	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10/18/11	2	84	0.00	0.00	0.00	94.05	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.19	0.00	0.00	0.00	0.00	3.57	0.00	0.00	0.00	0.00	0.00	0.00
	11/15/11	1	232	0.00	0.00	0.00	99.14	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goat Island	12/6/11	2	365	0.00	0.00	0.00	99.18	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	total	**14**	**1880**	**2.71**	**0.00**	**0.00**	**53.35**	**18.09**	**1.12**	**0.00**	**0.00**	**0.00**	**2.61**	**0.00**	**0.00**	**0.00**	**3.19**	**0.11**	**0.11**	**0.05**	**8.88**	**0.90**	**0.00**	**5.32**	**0.00**	**3.40**	**0.16**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

Table 20. Continued.

site	date	species count	total # of fish	Chinook	coho	chum	three spined stickleback	banded killifish	sculpin unknown	staghron sculpin	rosy sculpin	northern pikeminnow	yellow perch	surf smelt	pumpkinseed	bullhead	crappie	carp	bluegill	peamouth	chiselmouth	largescale sucker	smallmouth bass	American shad	shiner perch	tui chub	starry flounder	sandlance	mosquitofish	Slimy sculpin	golden shiner	lake chub	warmouth
	5/2/11	3	186	69.89	0.54	0.00	26.88	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/27/11	11	1008	13.10	0.10	0.00	21.43	12.90	0.50	0.00	0.00	1.49	21.13	0.00	0.20	0.00	0.00	27.58	0.10	0.00	0.20	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.00
	8/31/11	7	4897	0.00	0.00	0.00	68.57	4.41	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	14.19	0.00	0.00	0.00	10.58	0.00	0.00	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/20/11	3	116	0.00	0.00	0.00	12.93	11.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.86	0.00	73.28	0.00	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.00
	10/18/11	1	9	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11/15/11	1	401	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12/6/11	2	2358	0.00	0.00	0.00	99.87	0.08	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Burke Island	**total**	**18**	**8975**	**2.92**	**0.02**	**0.00**	**71.35**	**4.07**	**0.11**	**0.00**	**0.00**	**0.17**	**2.38**	**0.00**	**0.02**	**0.01**	**0.14**	**11.79**	**0.01**	**0.00**	**0.02**	**5.83**	**0.01**	**0.00**	**0.00**	**1.03**	**0.00**	**0.00**	**0.01**	**0.10**	**0.00**	**0.00**	**0.00**
	5/4/11	1	34	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7/25/11	14	2114	0.00	0.00	0.00	72.75	0.09	0.05	0.00	0.00	0.09	22.75	0.00	0.28	0.09	2.08	0.47	0.47	0.28	0.05	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00
	8/30/11	15	1384	0.00	0.00	0.00	1.08	61.42	0.51	0.00	0.00	0.14	12.14	0.00	1.45	0.22	0.07	10.91	4.84	0.00	0.14	0.72	2.31	0.22	0.00	3.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/20/11	14	2000	0.00	0.00	0.00	0.00	47.75	0.05	0.00	0.00	1.20	5.95	0.00	6.55	0.55	0.50	23.25	2.60	0.00	0.05	2.15	5.25	0.95	0.00	3.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10/18/11	12	591	0.00	0.00	0.00	86.46	4.06	1.86	0.00	0.00	0.00	1.02	0.00	0.17	0.00	0.00	0.17	1.18	0.00	1.69	0.00	1.02	0.68	0.00	1.52	0.00	0.00	0.00	0.00	0.00	0.00	0.17
Campbell Slough	**total**	**19**	**6123**	**0.56**	**0.00**	**0.00**	**33.71**	**29.90**	**0.33**	**0.00**	**0.00**	**0.46**	**12.64**	**0.00**	**2.58**	**0.26**	**0.90**	**10.24**	**2.22**	**0.10**	**0.23**	**1.03**	**2.34**	**0.42**	**0.00**	**2.06**	**0.00**	**0.00**	**0.00**	**0.00**	**0.02**	**0.00**	**0.02**
	7/26/11	2	301	0.00	0.00	0.00	89.70	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	9.30	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8/29/11	13	211	0.00	0.00	0.00	15.17	13.27	5.21	0.00	0.00	0.00	0.95	5.21	1.42	6.16	11.85	9.00	3.32	5.69	11.37	0.00	0.00	11.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9/19/111	10	945	0.00	0.00	0.00	61.06	4.23	0.32	0.00	0.00	0.00	0.00	0.00	2.33	0.00	1.48	7.72	1.69	0.00	4.66	15.98	0.42	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	10/17/11	9	1178	0.00	0.08	0.00	8.23	45.93	0.00	0.00	0.00	0.08	0.08	0.00	0.51	0.00	0.25	0.00	1.27	8.83	9.59	24.45	0.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11/15/11	4	728	0.00	0.00	0.00	34.89	0.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	63.46	0.14	0.14	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12/5/11	6	397	0.50	2.52	0.00	4.79	4.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	86.65	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00	0.00	0.25	0.00
Franz Lake	**total**	**20**	**3760**	**0.05**	**0.29**	**0.00**	**33.22**	**16.86**	**0.37**	**0.00**	**0.00**	**0.05**	**0.08**	**0.29**	**0.82**	**0.35**	**1.12**	**2.50**	**1.01**	**3.09**	**26.99**	**11.73**	**0.35**	**0.64**	**0.00**	**0.16**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.03**	**0.00**

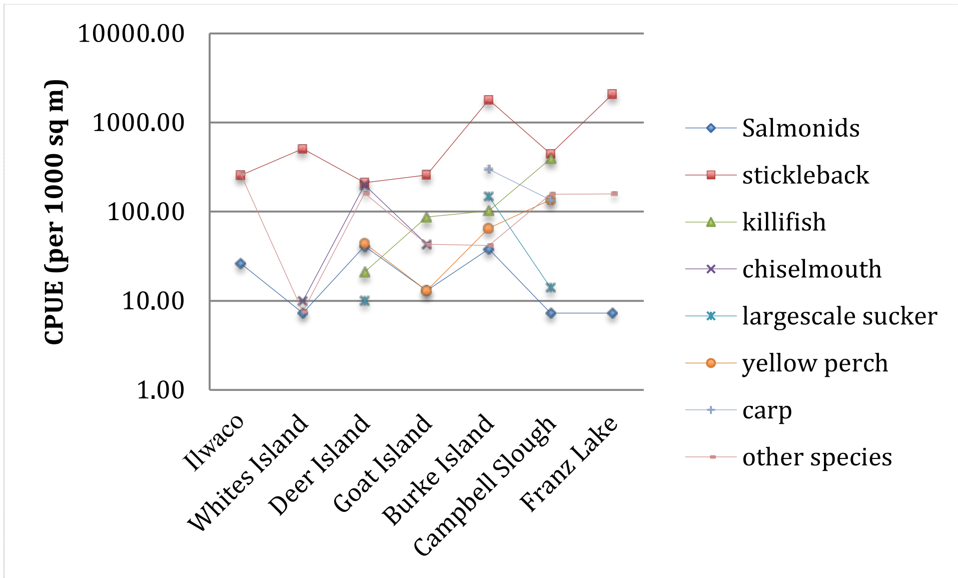
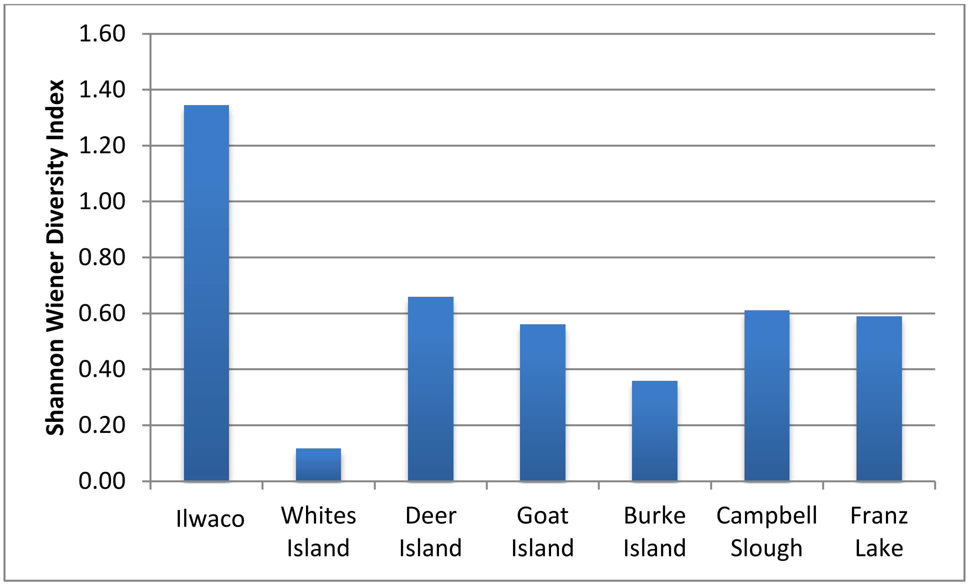


Figure 33. Catch per unit effort for salmonids vs. other species at 2011 Ecosystem Monitoring sites. Species with low CPUE were grouped as “other species”.

A)



B)

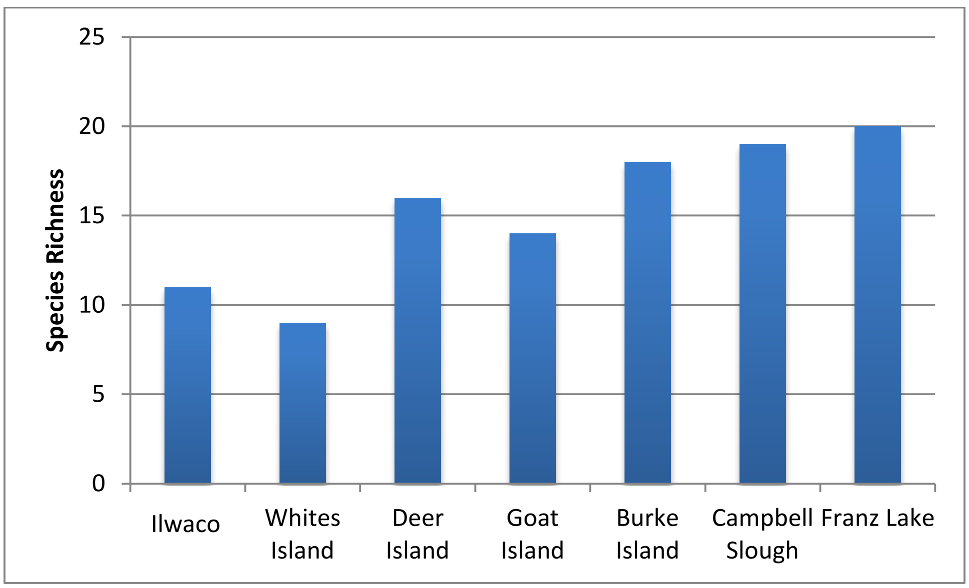


Figure 34. A) Species diversity (Shannon Weiner diversity index) and B) species richness (total number of species captured) at 2011 Ecosystem Monitoring sites.

Overall, Franz Lake and Campbell Slough had the greatest species richness or total number of species captured, 20 and 19 respectively, with number of species captured at other sites ranging from 9 to 18 (Table 18, Figure 34A). Fish assemblages were also analyzed for fish species diversity using the Shannon–Wiener diversity index (Shannon and Weaver 1949) (Figure 33). Ilwaco had the highest species diversity while Whites Island had the lowest (Figure 34B).

Chinook salmon were the most abundant juvenile salmon species overall, representing 54% of all salmon captured, as well as the most abundant salmon species at the majority of sites sampled (Figure 35). Chinook represented from 95-100% of the salmonid catch at Whites Island, Burke Island, and Campbell Slough, while at Deer Island and Franz Lake, 54%, and 18% of salmonids captured were Chinook. Overall, coho salmon made up 11% of the total salmonid catch. Coho were most abundant at Deer Island where they made up 46% of the total salmonid catch (Figure 35). They were absent from Campbell Slough, Whites Island and at Goat Island. Chum salmon accounted for 0.3% of the salmonid catch. They were most abundant at Ilwaco where they made up close to 100% of the total salmonid catch (Figure 35). We collected chum salmon only in April (Ilwaco); Chinook salmon mainly from April to August, with a small number of Chinook occurring again in December at Franz Lake; and coho salmon mainly from May through July, with a small number occurring in October and November at Franz Lake.

Overall, Chinook salmon density was highest at Burke Island (37 fish per 1000 m^2) and lowest at Franz Lake (1.1 fish per 1000 m^2; Figure 35). Deer Island had the highest density of coho salmon (19 fish per 1000 m^2), followed by Franz Lake (6.2 fish per 1000 m^2). No coho salmon were found at Burke Island, Goat Island, Campbell Slough, or Ilwaco (Figure 35). Chum salmon were only found at Ilwaco (26.1 fish per 1000 m^2; Figure 36).

Seasonal patterns in salmon density are shown in Figures 16-18. Ilwaco was the only site sampled in April due to sampling permit issues, and sites above Reach C were not sampled in late May through June due to extremely high water levels. The highest density of Chinook salmon was observed at Deer Island in Reach E in early May, followed by Campbell Slough in early May and Whites Island in early May and June (Figure 37). Low densities of Chinook were observed at Burke Island, Deer Island, and Whites Island in July, but Chinook density declined to zero at all sites by August. Chinook salmon were observed again at low densities (4.4 fish per 1000 m^2) at Franz Lake in December.

Coho salmon (Figure 38) was only found at significant densities at Deer Island in May, when a maximum of 281 fish per 1000 m^2 were collected. One unmarked coho was captured Burke Island in May, but otherwise coho salmon were not captured until October, when a few unmarked coho salmon were captured at Franz Lake. Chum salmon was found only at Ilwaco in April where a maximum of 440 fish per 1000 m^2 were collected (Figure 39).

Both marked (hatchery) and unmarked Chinook salmon were found at the EMP sampling sites (Figure 40). A limited number of Chinook salmon were caught at Franz Lake and Ilwaco site, but all were unmarked. Both unmarked and marked Chinook were caught at other sites. Overall, 40% of Chinook captured were unmarked. At Whites Island 90% of the catch were unmarked, while at Campbell Slough 9% of the catch were unmarked. Unmarked fish accounted for 80% of Chinook salmon at Deer Island, 46% at Goat Island, and 62% at Burke Island (Figure 40).

Figure 41 shows the relationship between unmarked and marked Chinook in terms of density (or CPUE). The number of unmarked fish caught per 1000 m^2 was much higher than the number of marked fish at Whites Island, Deer Island, Burke Island, and Franz Lake, but at Goat Island and Campbell Slough, the density of marked fish was higher than the density of unmarked fish.

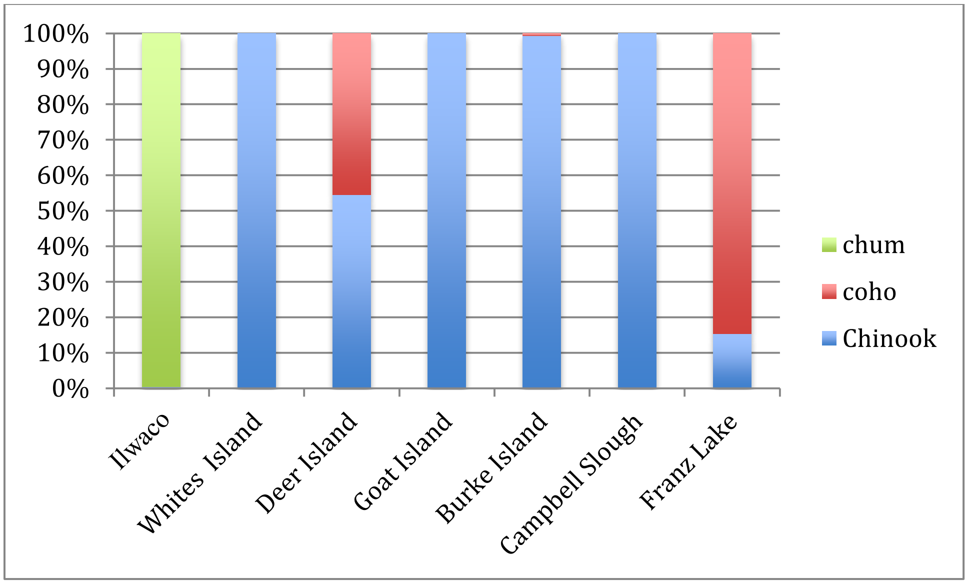


Figure 35. The composition of salmonid catch at 2011 Ecosystem Monitoring sites.

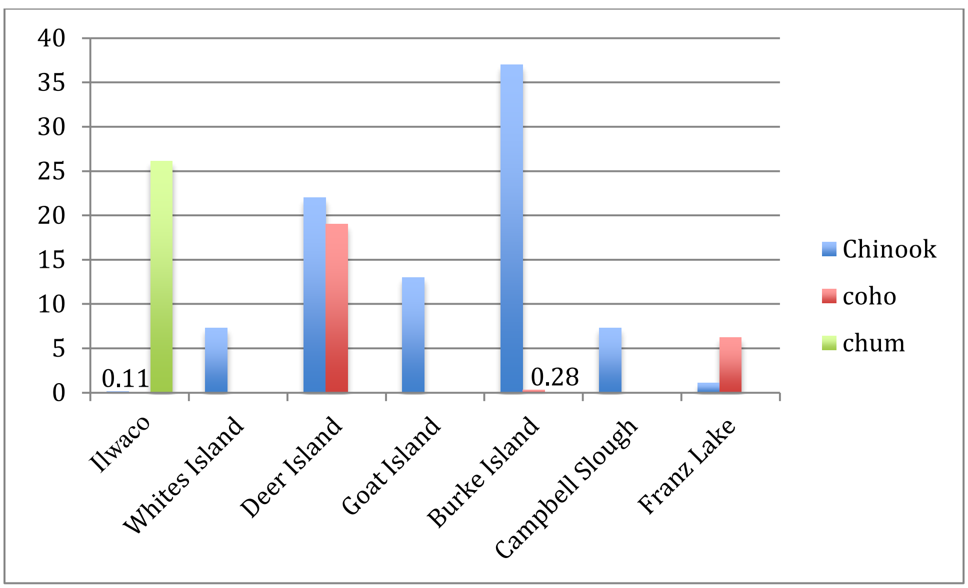


Figure 36. Salmonid catch per unit effort (CPUE) in fish per 1000 sq meters at the 2011 Ecosystem Monitoring sites.

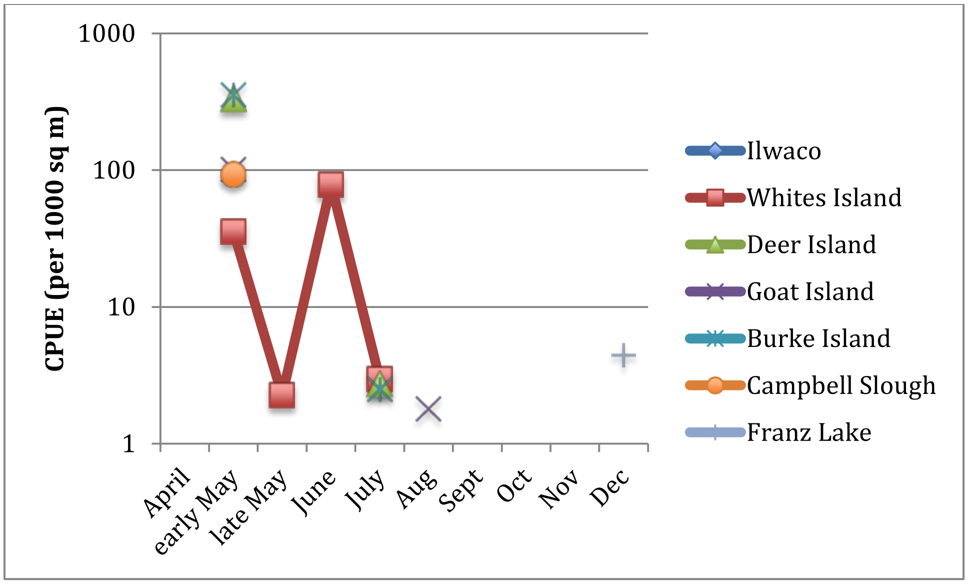


Figure 37. Seasonal trends in the capture of Chinook salmon at the 2011 Ecosystem Monitoring sites.

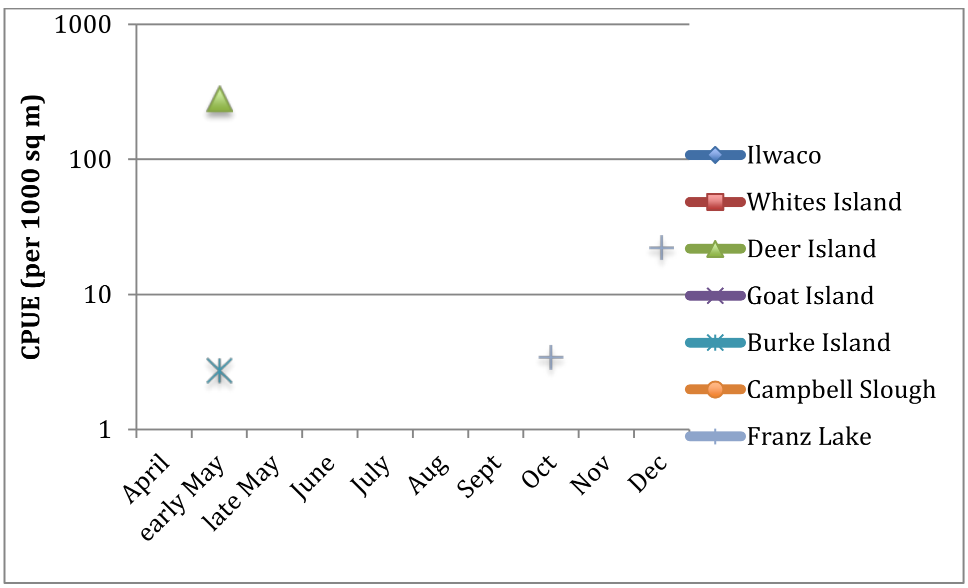


Figure 38. Seasonal trends in the capture of coho at 2011Ecosystem Monitoring sites.

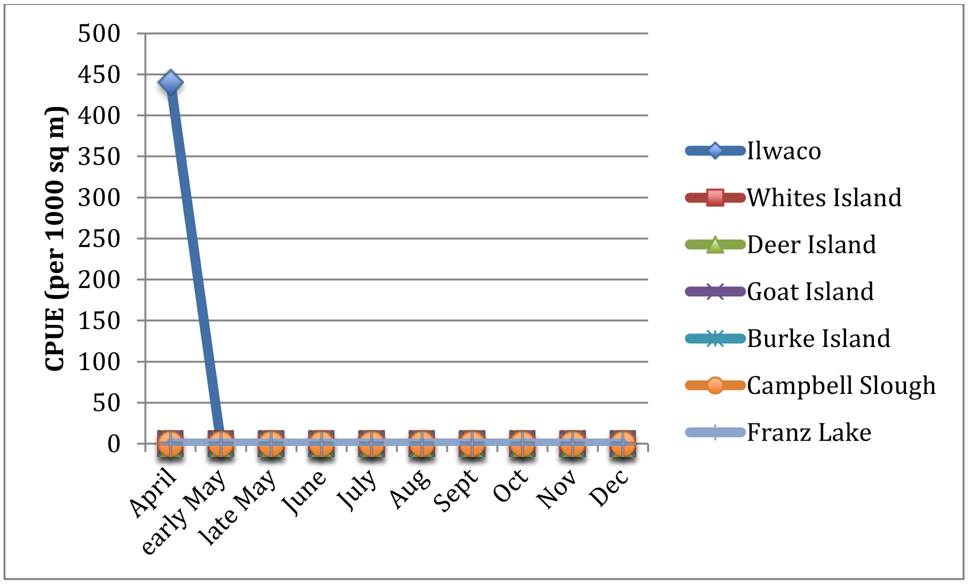


Figure 39. Seasonal trends in the capture of chum salmon at the 2011 Ecosystem Monitoring sites.

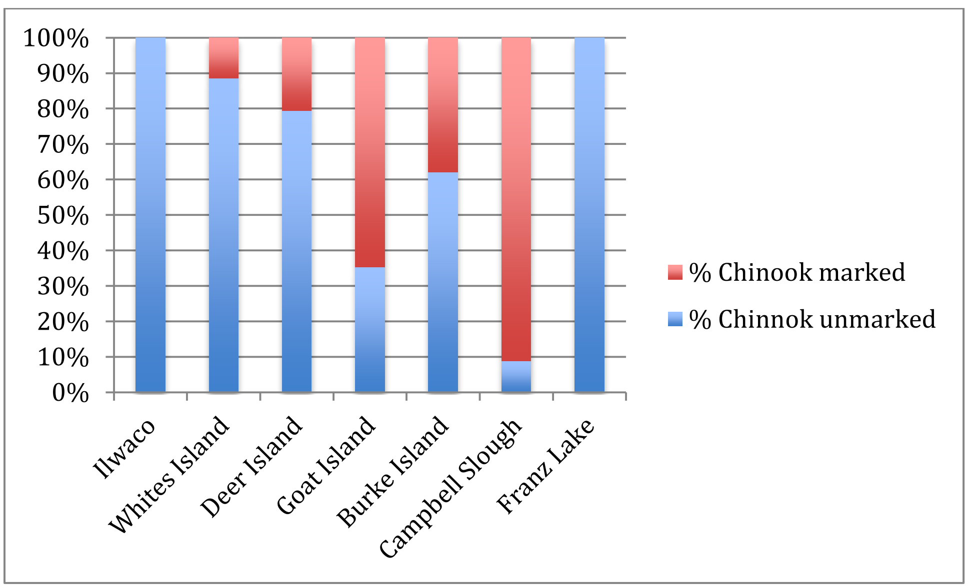


Figure 40. Proportions of unmarked and marked salmon species in salmon catches at the 2011 Ecosystem Monitoring sites.

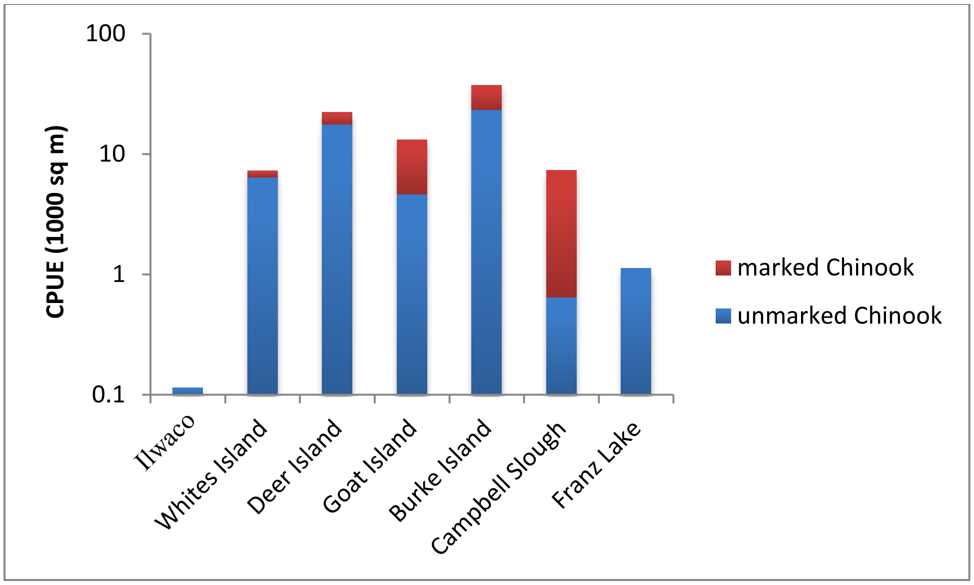


Figure 41. Catch per unit effort (Mean Density in fish per 1000 m^2) of marked (hatchery) versus unmarked Chinook salmon at the Ecosystem Monitoring sites.

Salmon Size and Condition

Chinook salmon. Several factors affected the length and weight of sampled Chinook salmon (Tables 7 and 6). Marked, hatchery Chinook salmon were larger than unmarked Chinook (the average length of the unmarked fish were 59 ± 11 compared to 76 ± 8, $p<0.0001$). Of the unmarked fish, 85% were ≤ 60 mm, in comparison to only 3% of marked fish. For the unmarked fish, length ranged from 39 to 105 mm and weight ranged from 0.4 to 15.8 g. For the marked fish, length ranged from 56 to 95 mm and weight ranged from 1.8 to 9.6 g. The fish that was 105 mm in length was likely a yearling Chinook, sampled from Whites Island in July. Condition factor was slightly higher in hatchery than in wild Chinook (1.02 ± 0.13 vs. 1.00 ± 0.19).

Franz Lake and Ilwaco were removed from statistical site comparisons since only one Chinook salmon was caught at each site. The mean length of unmarked Chinook (Table 19,Figure 42) differed significantly by site ($p = 0.0143$). Fish length at White Island was significantly higher than at Deer Island (one-way ANOVA, Tukey's LSD; < 0.05; Figure 21). The mean weights of unmarked Chinook (Table 19), however, did not differ significantly by site ($p = 0.097$). The mean length and weight of marked Chinook (Table 19, Figure 43) were not different among sites by ($p > 0.05$). Fish length and weight were higher for marked Chinook than unmarked Chinook (one-way ANOVA, Tukey's LSD; < 0.05).

Table 19. Mean length, weight, and condition factor (CF) of Chinook salmon over the sampling season at the 2011 Ecosystem Monitoring sites.

		marked				unmarked			
site	month	n	length(mm)	weight(g)	CF	n	length(mm)	weight(g)	CF
Ilwaco	May					1	90	7.3	1.00
Whites Island	early May	2	64±11	2.8±1.3	1.03±0.01	22	53±6	1.4±0.7	0.90±0.15
	late May	2	94±2	9.3±0.5	1.13±0.02				
	June	3	72±8	3.8±1.3	1.02±0.1	31	68±8	3.6±1.3	1.09±0.07
	July	2	82±33	8.9±9.8	1.17±0.28				
Deer Island	early May	4	72±1.	4.5±0.6	1.25±0.18	21	50±14	1.6±1.1	0.95±0.34
	July	1	92	7.8	1.00				
Goat Island	early May	12	76±3	4.3±0.5	0.98±0.08	13	56±19	2.4±1.4	1.05±0.10
	Aug					1	68	3.4	1.08
Burke Island	May	6	78±3.	4.4±0.2	0.92±0.08	19	52±14	1.6±0.8	0.95±0.09
	July					2	82±6	6.3±1.9	1.11±0.11
Campbell Slough	early May	31	77±4	4.3±0.7	0.94±0.05	3	47±8	1.1±0.6	0.98±0.11
Franz Lake	Dec					1	68	3	0.95

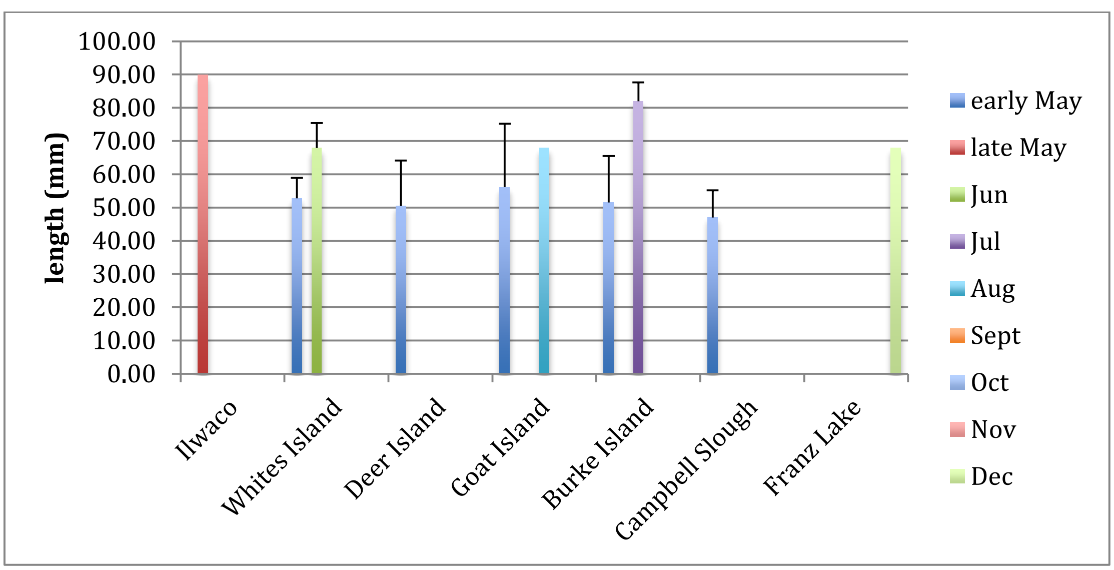


Figure 42. Mean length (± SD) of unmarked Chinook salmon over the sampling season at the 2011 Ecosystem Monitoring sites.

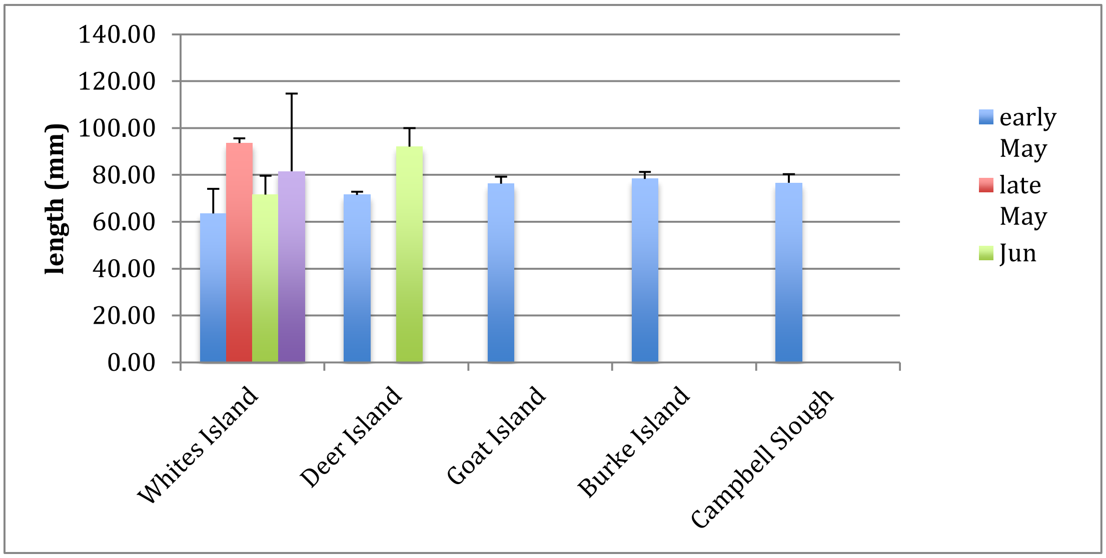


Figure 43. Mean length (± SD) of marked Chinook salmon over the sampling season at the 2011 Ecosystem Monitoring sites

Excluding three unmarked fish caught in late May (90mm), August (83mm), and December (83mm), the average length of unmarked juvenile Chinook increased steadily each month over the sampling season, from an average of 57 mm in May to 82 mm in July ($p<0.0001$, $n=111$). The two marked fish caught in late May were larger than marked fish caught in early May ($n=25$) and June ($n=3$); ($p=0.0014$). No increase in average length was observed between early May and June ($p>0.05$).

Coho salmon. Marked, coho salmon were larger than unmarked Coho (length was 140±10 mm for marked coho vs. 101±21 for the unmarked coho; Table 20). All of the coho captured in 2011 were larger than 60 mm in length. All of the coho captured from Deer Island were marked, whereas all of the coho captured from Burke Island and Franz Lake were unmarked (Table 20). For the unmarked fish, length ranged from 74 to 142 mm and weight ranged from 3.6 to 16.5 g. For the marked fish, length ranged from 136 to 153 mm and weight ranged from 23.9 to 32.9 g. Condition factor was slightly higher in marked than in unmarked coho (0.94+0.083 vs. 0.90+0.19).

Chum salmon. Chum from Ilwaco captured in April were unmarked and relatively small (Table 21). The length of the chum ranged from 38 to 50 mm and weight ranged from 0.4 to 1.0 g. Condition factor ranged from 0.54 to 0.94.

Table 20. Mean length, weight, and Condition Factor (CF) of coho salmon over the sampling season at the 2011 Ecosystem Monitoring sites.

		unmarked				marked			
site	month	n	length	weight	CF	n	length	weight	CF
Deer Island	May					15	143±3	27.2±3.0	0.94±0.08
Burke Island	May	1	131	26.0	0.92				
Franz	Oct	1	89	NA					
Lake	Dec	9	103±20	9.8±4.0	0.89±0.20				

Table 21. Mean length, weight, and CF of chum salmon over the sampling season at the 2011 Ecosystem Monitoring sites

site	month	n	length	weight	CF
Ilwaco	April	34	44±3	0.7±0.2	0.74±0.11

Genetics Analysis

In 2011, a total of 118 fin clip samples from juvenile Chinook salmon were collected for genetic stock identification, from Whites Island, Deer Island, Burke Island, and Campbell Slough. Analyses of these samples are now in progress, and results will be presented in a later report.

Growth Analyses

In 2011, a total of 102 otolith samples for growth rate estimation were collected from juvenile Chinook salmon at Whites Island, Deer Island, Burke Island, and Campbell Slough. These samples are still being analyzed.

Lipid content of juvenile Chinook salmon

As a biochemical indicator of salmon health and condition, we collected salmon whole bodies for analysis of lipid content and classes. A total of 102 bodies from juvenile Chinook salmon were collected for these analyses in 2011, from Whites Island, Deer Island, Burke Island, and Campbell Slough. The 2011 samples will be analyzed as soon as we have the genetic stock information needed to composite the samples.

Contaminants in Whole bodies of Chinook salmon

Because of the difficulty we have had in collected sufficient bile from juvenile Chinook salmon for PAH analyses, we began analyses of PAHs in whole bodies of Chinook salmon in 2011. These analyses have been completed for whole bodies of juvenile Chinook salmon collected in 2010 from Campbell Slough in Reach F, and from Bradford Slough, Jackson Island, and Wallace Island West in Reach C. The 2011 samples (a total of 102 bodies, which will be composited by site, date, and stock for analyses) will be analyzed for PAHs, as well as PCBs, DDTs, and PBDEs as soon as we have the genetic stock information needed to composite the samples.

Chinook salmon body concentrations of PAHs (ng/g wet wt) for the 2010 samples are shown in ng/g wet wt in Figure 23. Concentrations of PAHs were highest in both marked and unmarked salmon from Campbell Slough, although relatively high concentrations were also found in one sample of marked fish from Jackson Island. These differences were statistically significant for the unmarked fish, but not for the marked fish, probably in part due to low samples size (see Figure 44). In all samples, LAHs accounted for almost all of the PAHs observed in body samples. On average, HAHs accounted for less than 5% of PAHs in the samples.

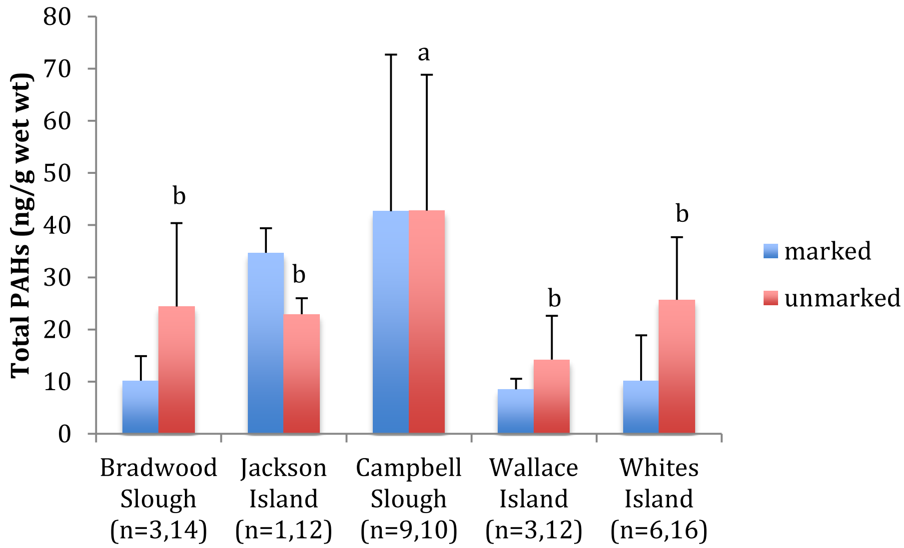


Figure 44. Mean concentrations of PAHs (ng/g wet wt) in bodies of juvenile Chinook salmon from the 2010 Ecosystem Monitoring sites. Number of samples of marked and unmarked fish are noted in parentheses, below the site names.

Salmonid Prey Availability Surveys and Diet Analyses for Juvenile Chinook Salmon

In 2011, 32 emergent vegetation and open water Neuston tow samples were collected at Ilwaco , Burke Island, Goat Island, Deer Island, and Franz Lake. Corresponding diet samples were collected from a total of 90 individual Chinook salmon. The 2011 samples are currently being processed by the Northwest Fisheries Science Center and by Rhithron Associates.

Pilot PIT Tag Array Effort at Campbell Slough

2011 Efforts. A pit tag detection system was installed in Campbell Slough on June 2. This system consists of a Destron-Fearing FS1001-MTS multiplexing transceiver, which simultaneously receives, records and stores tag signals from two antennas measuring 4’ by 20’. The system is powered by a 470W solar array with battery backup and is also connected to a wireless modem that allows daily data downloads. For this first year ‘pilot’ project, the antennas were anchored to the bottom without any mechanism for adjusting their height within the water column, nor did we attach any netting or barrier material around the antennas to direct fish though them. Water levels at the site on day of install were about 16’ and the antennas were placed at depth of about 5’ below the surface. On June 29 we replaced the modem with a new one and observed that the tops of the antennas were now about 10-12 inches below the surface, which correlated well with the approximately 4’ drop in water levels during this time period, recorded at nearby USGS Station (Figure 45).

We had continuous and uninterrupted data collection though June 29. Later that same day the modem stopped sending data and on July 7 we investigated and found the batteries were drained and the system was inoperable. At the time we suspected that the system was not receiving sufficient daily solar exposure to keep the batteries fully charged. The system was restored and operational again on July 12 but not sending daily reports. However, tag data was still being collected at this time and modem communications were later restored. Data was collected and reported though August 3 when the system failed again. On August 23 the entire system was disconnected and antennas removed from the slough. The observed water depth was about 4' feet at the site and the antennas were entirely floating on the surface, and likely had been in this state since around mid-July.

Figure 45. Water levels at Vancouver, WA USGS Monitoring station near Campbell Slough during deployment of PIT tag array.

In total, the system was operable and collecting tag data for about 7 weeks and recorded 69 detections, which corresponded to 23 unique tags. Using the PTAGIS database we were able to determine species and site origination info for all but 5 of these tags. Most of the detected fish were Chinook salmon, but we also detected a sockeye salmon and a Northern pike minnow (Table 22). The Chinook salmon originated from one of four hatcheries: Little White Salmon Hatchery in Stevenson, WA (above Bonneville Dam), Irrigon Hatchery near Irrigon, OR (above John Day Dam), Lyons Ferry Hatchery near Starbuck, WA (above Lower Monumental Dam on the Snake River) and Dworshak Hatchery near Orofino, ID (confluence of the North Fork and mainstem Clearwater River). In addition to the Chinook salmon, we detected one sockeye that had come from the Sawtooth Hatchery near Stanley, ID (on the Salmon River) and also a Northern pikeminnow that had been tagged and released near the mouth of the Lewis River.

Nearly half of all these tagged fish were detected multiple times at the site over multiple days or weeks. One Chinook from Little White Salmon Hatchery was detected 17 times over a 12 day period, while a couple of unidentified tags were detected multiple times over a range of 20 and 45 days. The time to travel from hatchery of origin to the Campbell Slough site varied tremendously. For example, the Dworshak Hatchery Chinook made the over 300 mile journey in just over two weeks, while fish from the much nearer Little White Salmon Hatchery took about 5 weeks and fish released from the Lyons Ferry Hatchery in mid-April took about 7 weeks to show at our site, assuming that tag dates are comparable to or the same as release dates. We are currently attempting to get information on the 5 unidentified tags from Biomark and the Pacific States Marine Fisheries Commission.

2012 Plan. For 2012, we are planning to move the receiver and solar array to the North shore (dike side) of the slough, as the present location of our solar panels on the opposite bank does not provide enough sunlight to reliably power the system. The job box (housing the reader, batteries and modem) and solar panels will be placed upon an elevated platform at the site which will keep all of the sensitive gear about 4 feet off the ground and protect it from the highest water levels observed in 2011. This work has been started and should be completed sometime in March. In addition to relocating the equipment, we will also be anchoring the 2 antennas in a manner that allows their height within the water column to be manually adjusted with lines. Finally, we are also considering the installation of some netting or other barricade material to the antennas, in an effort to better 'direct' fish though the antennas. We estimate that all this work should be completed and the entire system back up and running no later than April 1.

Table 22. PIT tag identifications from Campbell Slough PIT tag array for 2011

Tag IDs from Campbell Slough	1st detection	time	No. of detections	Days between first and last detection	Species	Tag Site	Tag date
3D9.1C2CF051BD	3-Jun-11	15:39:07	3	5	N. pikeminnow	mouth of Lewis River area	4/3/10
3D9.1C2CFD6E7A	6-Jun-11	10:21:39	2	9	N. pikeminnow	mouth of Lewis River area	4/25/11
3D9.1C2D48EA44	8-Jun-11	5:19:38	5	20	N. pikeminnow	mouth of Lewis River area	4/26/11
3D9.1C2D491816	3-Jun-11	21:36:14	1		N. pikeminnow	mouth of Lewis River area	4/25/11
3D9.1C2D492879	24-Jun-11	9:29:10	1		N. pikeminnow	Reach H Sand Island area	4/26/11
3D9.1C2D4939E5	4-Jun-11	23:14:19	4	45	N. pikeminnow	Bonneville area	4/27/11
3D9.1C2D618AC3	12-Jul-11	17:41:18	17	12	Chinook	Little White Salmon Hatchery[1]	6/6/11
3D9.1C2D6191F5	12-Jul-11	15:03:47	4	9	Chinook	Little White Salmon Hatchery	6/6/11
3D9.1C2D62ECCE	12-Jul-11	21:24:56	2	8	Chinook	Little White Salmon Hatchery	6/6/11
3D9.1C2D637992	13-Jul-11	9:28:01	4	10	Chinook	Little White Salmon Hatchery	6/6/11
3D9.1C2D63799A	20-Jul-11	7:58:50	1		Chinook	Little White Salmon Hatchery	6/7/11
3D9.1C2D640053	13-Jul-11	9:12:38	1		Chinook	Little White Salmon Hatchery	6/6/11
3D9.1C2D640F05	12-Jul-11	14:44:43	1		Chinook	Little White Salmon Hatchery	6/7/11
3D9.1C2D93FBC4	9-Jun-11	13:55:50	2	1	Chinook	Lyons Ferry[2]	4/16/11
3D9.1C2D94585F	9-Jun-11	8:19:11	1		Chinook	Irrigon Hatchery[3]	4/20/11
3D9.1C2D955E80	13-Jun-11	11:36:29	1		Chinook	Lyons Ferry	4/17/11
3D9.1C2D956D63	8-Jun-11	14:50:17	1		Chinook	Lyons Ferry	4/17/11
3D9.1C2D9808AA	7-Jun-11	20:05:37	6	3	Chinook	Lyons Ferry	4/13/11
3D9.1C2D99548B	8-Jun-11	20:13:17	1		Chinook	Lyons Ferry	4/15/11
3D9.1C2D9FECF3	4-Jun-11	3:57:30	1		sockeye	Sawtooth Hatchery[4]	4/6/11
3D9.1C2DA07A5C	23-Jun-11	21:00:12	1		Chinook	Dworshak[5]	6/6/11
3D9.1C2DC618ED	10-Jun-11	18:19:13	1		Chinook	Dworshak	5/26/11
3D9.1C2DC71089	20-Jun-11	17:59:52	8	8	Chinook	Dworshak	6/2/11
		Total	69				

[1]Little White Salmon National Fish Hatchery is located 12.5 miles east of Stevenson, Washington, on State Highway 14
[2]Lyons Ferry Hatchery is 13780 Highway 261 Starbuck, Washington 99359-0278
[3]Irrigon Hatchery is located along the Columbia River above John Day Dam 3 miles west of Irrigon, Oregon.
[4]Sawtooth Hatchery is located five miles south of Stanley, Idaho just off state Highway 75 next to the Salmon River.
[5]Dworshak National Fish Hatchery Complex is located at the confluence of the North Fork and mainstem Clearwater River in Ahsahka, Idaho, 3 miles west of Orofino, Idaho

4.3.5 Discussion

The EMP is designed to characterize tidal freshwater and estuarine habitats in the Lower Columbia River and Estuary, and to monitor salmon occurrence and health in those habitats. For the past five years, the primary focus of the fish monitoring component of the program has been on tidal freshwater habitats with emergent marsh vegetation. To date, we have monitored sites in Reaches C, E, and H, as well as four fixed stations: Ilwaco in Reach A (2011), Whites Island in Reach C (2009 to 2011), Campbell Slough in Reach F (2007 to 2011), and Franz Lake in Reach H (2008, 2010, and 2011). Our findings to date indicate that while juvenile salmon are utilizing tidal freshwater and estuarine habitats in all of these reaches for migration, feeding and rearing, the salmonid species and stocks present, as well as the non-salmonid fish community, show distinctive patterns moving downriver from the Columbia Gorge (Reach H) toward the estuary (Reach A).

We started out the 2011 sampling season at Ilwaco in April, and caught high numbers of chum salmon, well exceeding the maximum number allowed in our Washington and Section 10 ESA sampling permits. Our permit was revoked, and therefore, little data from the EMP sites for April could be collected. The sampling permit for 2011 was reinstated in early May, when we proceeded with our normal sampling plan. However, we encountered high water levels at several sites, including the new Reach E sites, limiting successful fishing. Although we were successful in sampling most of the sites in late May (other than Franz Lake), extremely high water levels again limited sampling of all sites until late July. In 2011, the fish monitoring effort, which normally lasts only through August or early September, was extended through December for most of the sites to monitor salmon occurrence during the fall and winter months. Fish monitoring of Campbell Slough lasted through October only due to permit constraints.

Our sampling efforts in 2011 allowed us to better characterize fish community characteristics and patterns of salmon occurrence in Reach E. Generally, fish community composition at the new Reach E sites was very similar to Sandy Island in Reach E and Campbell Slough in Reach F, which we sampled previously (Johnson et al. 2011b). Three-spine stickleback was the most abundant species at all sites, followed by killifish, chiselmouth, and largescale sucker. The sites supported a variety of native species (salmonids, pikeminnow, sucker, sculpin) as well as non-native species (carp, chiselmouth, killifish, yellow perch and peamouth), and species richness was comparable to that previously observed at Sandy Island. Species diversity was somewhat lower, but diversity values were also lower than normal at the fixed sampling sites in 2011 (Johnson et al. 2011b), perhaps because of the disrupted sampling season. All three sites were utilized by both marked and unmarked Chinook salmon from early May through August, but higher proportions of unmarked Chinook were observed at two of the three sites (Deer Island and Burke Island), while at Goat Island the proportions were about the same. Coho salmon were observed at Deer Island and Burke Island during the May sampling, but were absent from Goat Island. No chum salmon were observed at any of the new Reach E sites, probably because these sites were not sampled until May, when most juvenile chum salmon have completed their outmigration to the ocean (Salo 1991).

Densities of Chinook salmon at Burke, Deer, and Goat Island were higher than densities observed at Whites Island and Campbell Slough in 2011, and generally comparable with densities of Chinook salmon that we have observed at the EMP sites in Reach C (Johnson et al. 2011b). Coho salmon densities at Burke and Goat Island were low, similar to many sites in Reach C and Campbell Slough (Johnson et al. 2011b). Coho density was higher at Deer Island, similar to densities observed at Bradwood Slough where, in previous samplings, the highest densities of coho were found outside of Reach H (Johnson et al. 2011b). However, the coho salmon caught in May at Deer Island were mainly marked fish, so may have been part of a local hatchery release. There are several hatcheries in the area, including the Washington Department of Fish and Wildlife (WDFW) Lewis River hatchery, the WDFW Kalama Falls hatchery, and the WDFW Cowlitz Hatchery that release coho salmon into the Columbia River (Columbia River DART; http://www.cbr.washington.edu/dart/hatch.html). Overall, our efforts suggest that Reach E is a productive habitat that juvenile salmonids utilize during their outmigration.

At Ilwaco , our new sampling site in Reach A and the only site in the saltwater portion of the estuary, fish community composition was quite different from our observations in the tidal freshwater reaches. While stickleback were a predominant species, as at many of the other sites, the other common fish present were euryhaline species such as shiner perch, staghorn sculpin, surf smelt, sandlance, and rosy sculpin, found only rarely at other sites. Although the number of species found at Ilwaco was not especially high in comparison to tidal freshwater sites, species diversity was higher because species were more evenly distributed. Roegner et al. (2008) also report relatively high species diversity at their sampling sites in the lower estuary, and the presence of species such as surf smelt, sand lance, shiner perch, and staghorn sculpin. However, Roegner et al. (2008) observed juvenile Chinook, coho, and chum salmon at their lower estuary sites. In contrast, at our Ilwaco site, large numbers of out-migrating chum salmon were present in April (47% of the total catch for that month), but aside from this, no coho and only one large Chinook salmon (90 mm) were caught at this site throughout the year. This suggests that juvenile Chinook and coho salmon do not utilize this site as much as other sites studied in the EMP or lower estuary sites sampled by other investigators. This may be in part due to the location of Ilwaco . Ilwaco is situated close to the mouth of the Columbia River, protected by a dike on the west side (see Figure 7). The whole area can be flooded during high tide, but is muddy and bare at low tide, which would interfere with the ability of the fish to access and utilize the site for extended periods of time. Additionally, the work of Roegner et al. (2008) suggests that juvenile Chinook salmon density in the lower estuary is lowest during high tides and periods of high salinity. The salinity at Ilwaco during fish sampling was consistently in the 10-12 ppt range, which may be above the level preferred by the fry and fingerlings that are typically found in emergent marsh habitats, and may not yet have undergone smoltification. The Chinook salmon collected by Roegner et al. (2008) in the lower estuary were larger than those we usually find in emergent marsh habitats (80-100 mm as compared to 50-70 mm). These larger fish that are closer to ocean entry tend to prefer deeper water, pelagic habitats (McCabe et al. 1986) and so would be unlikely to utilize a shallow water emergent marsh site such as Ilwaco . Similarly, coho salmon in the final stage of outmigration may also prefer deeper and saline water, and would not utilize the area. Chum salmon, on the other hand, tend to utilize the inner part of the estuary before their ocean migrations (Johnson et al 1997), so would be more likely to be found at Ilwaco .

Our observation of chum salmon at the Ilwaco site in April is consistent with other studies. For example, Roegner et al. (2004, 2008) found chum salmon in beach seine samples in lower estuary from February through May, with peak numbers occurring in April. Also, the mean length of the chum we collected (44 mm) is within the typical size range (37-63 mm) at which size juvenile chum outmigrate to the ocean (Salo 1991). However, it should also be noted that the timing of our chum catch in Ilwaco coincided with a two day prior release of chum salmon fry into Big Creek by Oregon Department of Fish and Wildlife's Big Creek Hatchery as part of the reintroduction and recovery process for Lower Columbia River chum (T. Murtaugh, ODFW, pers. comm.; see also http://www.dfw.state.or.us/news/2011/april/041111e.asp). This release could account for the very high density of chum salmon we encountered at the site.

Currently the only information we have on salmon health and condition at the new 2011 sites is condition factor (K). For Chinook salmon, values of K at Deer, Burke, and Goat Island were somewhat variable, with mean monthly values ranging from 0.92 to 1.25, but generally comparable to values found for Campbell Slough and Sandy Island, as well as other previously sampled EMP sites (Johnson et al. 2011). Only one Chinook salmon was caught at Ilwaco , with a value of K (1.0), also within the same range. For coho salmon, mean monthly values ranged from 0.92-1.0, typical of the range observed for coho salmon at other EMP sites (Johnson et al. 2011). For chum salmon, which were found only at Ilwaco , the mean value of K was 0.74, within the lower range of values previously observed at other EMP sites (Johnson et al. 2011). Overall, these data suggest that fish condition at the new sites is within the normal range of values for these species and for the EMP sites.

At our long-term trend sites (Whites Island, Campbell Slough, and Franz Lake) the species present were generally consistent with our observations from previous years. Overall, Chinook density in 2011 tended to be lower than values observed in previous years, but this could be due in large part to the lack of data for April and June when large numbers of Chinook salmon are typically observed at the EMP sites (Johnson et al 2012). No chum or coho salmon were observed at either Whites Island or Campbell Slough in 2011, although they had been encountered in small numbers is previous years. The absence of chum is likely because we did not sample these sites until May, when most chum have left the Lower Columbia River Estuary (Salo 1991). In the past, coho salmon have only been found in small numbers at Whites Island and Campbell Slough (Johnson et al. 2011) so their absence in 2011 was not unusual.

At Whites Island and Campbell Slough, Chinook salmon condition factor (K) tended to be lower in 2011 than in other years (1.02 vs. 1.04-1.09 at Whites Island and 0.95 vs. 1.02-1.14 at Campbell Slough). For the one Chinook salmon sampled from Franz Lake, K was 0.95, intermediate between values for 2008 and 2009 (0.86-1.01). The reasons for the relatively low K values at Whites Island and Campbell Slough are uncertain, though the unusually high water levels and the sporadic sampling may have contributed. Also, while somewhat lower than in previous years, these values may not be outside the normal range of variability found for this measurement at the EMP sites.

Overall, we encountered few salmonids during our extended fall and winter sampling in 2011. However, we observed a small number of Chinook and coho at Franz Lake during late fall sampling. We have not sampled any of these sites during late fall months previously, so we cannot compare these data with previous results. However, our observations are similar to reports of Sather et al. (2009) and Johnson et al. (2011a) showing the presence of juvenile Chinook and coho salmon at Sandy River Delta sites in December. Our results differ in that Johnson et al. (2011a) report higher numbers of Chinook salmon than coho salmon during the late fall months, whereas we observed higher number of coho salmon. This is consistent with observations that coho salmon are especially common in tributaries along the Washington side of the Columbia River (Sandercock 1991). However, in a restoration monitoring study at Mirror Lake Complex in Reach G, in Columbia River, Oregon, where a large population of juvenile coho is present at one of the upstream sites, we also found a small number of coho downstream closer to mainstem Columbia during the fall months (Olson et al. 2012). While we do not yet know the genetic origin of the Chinook salmon we observed at Franz Lake, genetics data from Johnson et al (2011) suggest that the Chinook salmon collected in December are predominantly spring Chinook overwintering prior to outmigration as yearlings.

In summary, our sampling confirmed that unmarked juvenile Chinook, coho, and chum salmon are feeding and rearing in representative sites of the LCRE, although our findings may have been influenced by data gaps resulting from permit issues and our inability to fish due to extremely high water levels at some sites. Patterns of fish community composition and salmon occurrence at the new Reach E sites were generally similar to our previous observations at Sandy Island and Campbell Slough in Reaches E and F. Like Campbell Slough and Sandy Island, the Reach E sites had relatively high species diversity and richness in comparison to the sites we have sampled in other reaches, and were dominated by stickleback. The Reach E sites supported multiple salmon species, including Chinook and coho salmon. Ilwaco in Reach A supported high numbers of chum salmon as well as many euryhaline species. With our more extended sampling period in 2011, we also observed that Chinook and coho salmon were present at some of the sites through December. This is consistent with reports of Sather et al. (2009) and Johnson et al. (2011a) showing the presence of juvenile salmon at Sandy River Delta sites in December. Chinook salmon densities at all of the sites were relatively low compared to densities for other years, but this may be due to lack of data for April-early May, when high numbers of Chinook salmon would normally be present. Overall, the 2011 sampling results highlight emergent marsh tidal freshwater habitats in Reach E as productive rearing areas for juvenile salmonids.

The pilot results of the PIT tag array in Campbell Slough indicated that hatchery Chinook salmon from locations as far away as the Dworshak Hatchery on the Snake River were using Campbell Slough for feeding and rearing, and are remaining in the area for up to 12 days. These data are consistent with our genetics information from previous years (Johnson et al. 2011b) showing multiple Chinook salmon stocks at Campbell Slough. The PIT tag array also detected the presence of fish we have never caught in our sampling efforts, including sockeye salmon. This information provides further evidence for the importance of tidal freshwater habitat for juvenile salmon from throughout the Columbia Basin.

4.4 Water Quality and Food Web

4.4.1 Introduction

One aspect of the Estuary Partnership's EMP is to describe food web characteristics at representative shallow water and vegetated sites within the estuary, tidal freshwater, and tributary confluence areas. While USGS efforts in earlier years were concentrated on measuring only water quality conditions at selected sites, the efforts in 2010 focused on developing and testing methods for assessing food web resources in addition to examining water quality conditions. In 2011, USGS monitored water quality and assessed food web resources at the four fixed sites: Franz Lake Slough, Campbell Slough, Whites Island, and Ilwaco (Table 23, Figure 46).

Table 23: Site information for locations of water quality monitors in 2011. *In order to be consistent with site names used by other monitoring partners, site names used in this report differ from official USGS site names.

Site name*	USGS site number	USGS site name*	Reach	Latitude	Longitude	Monitor deployment date	Monitor retrieval date
Franz Lake Slough	453604122060000	Franz Lake Slough Entrance, Columbia River, WA	H	45° 36' 04"	-122° 06' 00"	March 29	July 25
Campbell Slough	454705122451400	Ridgefield NWR, Campbell Slough, Roth Unit, WA	F	45° 47' 05"	-122° 45' 15"	April 25	July 26
Whites Island	460939123201600	Birnie Slough, White's Island, Columbia River, WA	C	46° 09' 39"	-123° 20' 16"	March 29 June 21	-- July 19
Ilwaco	461802124024400	Columbia R. at Port of Ilwaco Marina at Ilwaco, WA	A	46° 18' 02"	-124° 02' 43"	April 12	July 25

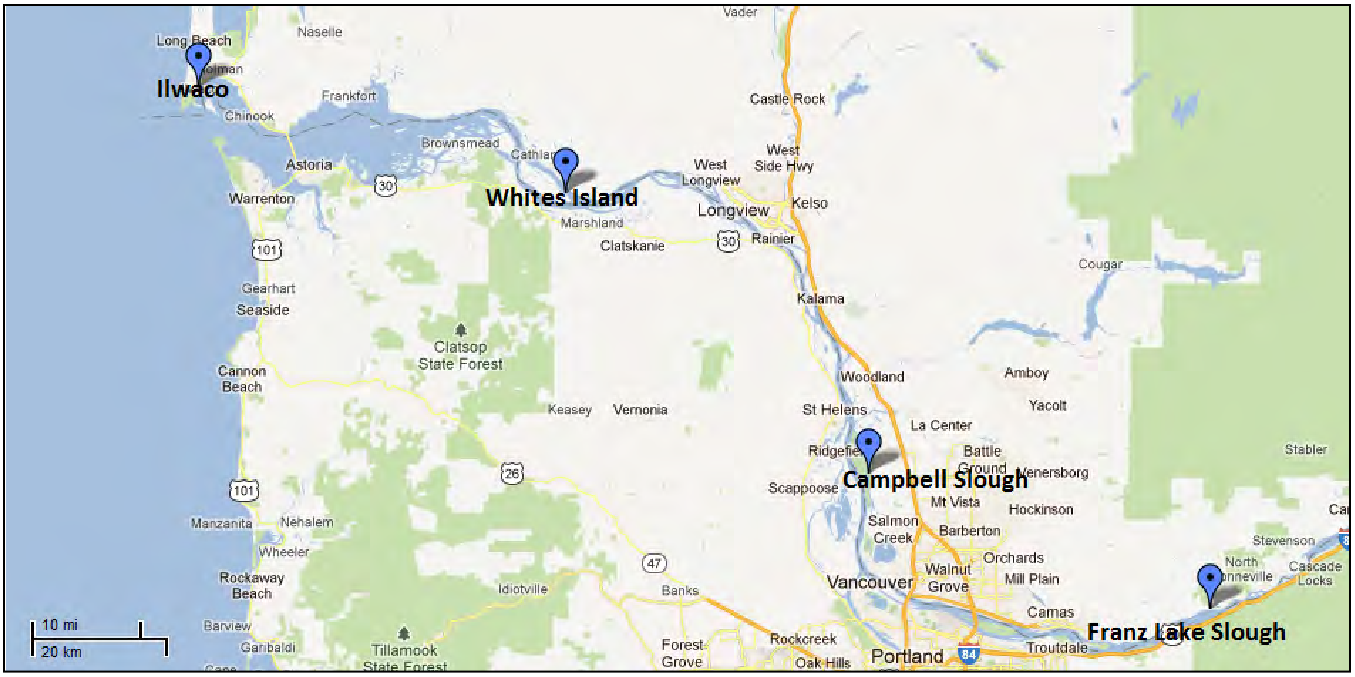


Figure 46: Map of the four fixed water quality monitoring sites monitored in 2011

The main components of the monitoring included:

- Seasonal water quality monitoring
- Food web resource assessment:
    - Water-column nutrient concentrations and photosynthetically available radiation (PAR)
    - Algal biomass and species composition
    - Algal productivity rates
    - Stable isotope ratios of algae, plants, insects, and juvenile salmonids
    - Plankton and benthic-invertebrate species composition (samples collected for other partners)

The goal of the food web assessment is to characterize the food web resources supporting juvenile salmonids in tidal freshwater emergent wetlands, which provide important rearing habitat. This assessment addresses a knowledge gap identified by NOAA's National Marine Fisheries Service as important for salmonid recovery and ecosystem restoration in the lower Columbia River and estuary (Bottom and others, 2005). As part of the food web assessment, an understanding of algal production is important because it is at the base of the food chain. Moreover, some evidence suggests that algal production has recently become a more important component of the Columbia River food chain in comparison to a pre-development food chain that was based more on wetland and intertidal production (Lower Columbia River Estuary Partnership, 1998).

Water-Column Nutrient Concentrations and Photosynthetically Available Radiation (PAR) and Algal Biomass

Light at wavelengths of 400-700 nanometers can penetrate the water column and be absorbed by photosynthetic pigments in algae and plants and used for photosynthesis (Day and others, 1989). Light in this range is called photosynthetically available radiation, or PAR. Nitrogen and phosphorus are the nutrients that are most commonly limited in the environment relative to the amounts required for algal growth. PAR and concentrations of biologically available forms of nitrogen and phosphorus are therefore important factors that can influence rates of algal growth. Algal biomass can be estimated by measuring the concentration of chlorophyll *a*, a photosynthetic pigment that is common to all types of algae, or as ash-free dry mass (AFDM), which measures carbon biomass (Hambrook Berkman and Canova, 2007). Biomass of phytoplankton (suspended algae) and periphyton (attached algae) were measured in concert to provide a more complete assessment of algal availability at the sites.

Algal Productivity Rates

Estimation of algal productivity is important in the assessment of aquatic food web resources because algae provide the energetic base of the food chain. In order to characterize algal productivity as representatively as possible, both phytoplankton (suspended algae) and periphyton (attached algae) productivity were assessed.

Stable Isotope Ratios of Algae, Plants, Insects, and Juvenile Salmonids

The ratios of carbon and nitrogen stable isotopes in tissues of consumers reflect the stable isotope ratios of their food sources (Neill and Cornwell, 1992; France, 1995), and therefore, can be useful to determine major food sources, provided that the food sources have distinct isotopic ratios. The stable isotope ratios of carbon and nitrogen were measured from juvenile salmonid muscle tissue and several potential food sources to provide information on the food web supporting juvenile salmonids. Isotopic signatures of more metabolically active tissues such as liver, mucus, or blood turn over more quickly than those of muscle, otoliths, or scales, so liver is a good medium with which to examine relatively recent dietary sources (Phillips and Eldridge, 2006; Church and others, 2009; Buchheister and Latour, 2010). It was planned that samples of salmonid liver or mucus would be collected in addition to muscle tissue in order to characterize more recent dietary information than can be determined using muscle samples. However, only muscle samples were collected in 2011. Juvenile salmonids were only available from two sites in 2011: Whites Island and Campbell Slough.

4.4.2 Methods

Seasonal Water Quality Monitoring

For the fourth consecutive year, USGS deployed a continuous water quality monitor at Campbell Slough in the Roth Unit of the Ridgefield National Wildlife Refuge in 2011. This site in Reach F has been sampled for vegetation since 2005 (PNNL) and for fish since 2007 (NOAA Fisheries). USGS also deployed a monitor in a tidal slough in Whites Island in the Columbia River. This site in Reach C was monitored for water quality in 2009 and 2011 and sampled for vegetation (PNNL) and fish (NOAA Fisheries) since 2009. Franz Lake Slough in Franz Lake National Wildlife Refuge in Reach H was monitored for water quality for the first time in 2011 and for vegetation (PNNL) and fish (NOAA Fisheries) in 2008-09 and 2011. Water quality was also monitored in a tidal channel of the Columbia River near Ilwaco marina in Baker Bay, WA. This site in Reach A was new to all partners in 2011.

The monitors deployed were Yellow Springs Instruments (YSI) models 6600EDS and 6920V2 equipped with water temperature, specific conductance, pH, dissolved oxygen, and depth probes. Table 24 provides the specifics on the accuracy and effective ranges for each of these probes. The deployment period for these monitors was designed to characterize water quality conditions while juvenile salmonids were present, during the period of time when they migrated away from the sites, and shortly thereafter. In 2011, the monitors were deployed as early as possible, starting the last week of March, through the last week of July, with visits roughly every 4 weeks to change the batteries, check the calibration of the variables, and make any adjustments needed. Due to issues accessing the Campbell Slough site, the monitor was not deployed until April 26. The targeted monitoring period in 2010 and 2011, April through July, was approximately one month earlier than in previous years to capture conditions during months when salmonids were found at the site in recent years.

Table 24: Range, resolution, and accuracy for water quality monitors deployed by USGS [ft, feet; m, meters; °C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter]

Monitoring Metric	Range	Resolution	Accuracy
Water depth	0–30 ft, 0–9 m	0.001 ft, 0.0003 m	±0.06 ft, ±0.02 m
Temperature	-5–70 °C	0.01 °C	±0.15 °C
Specific conductance	0–100,000 µS/cm	1 µS/cm	±1 µS/cm
ROX optical dissolved oxygen	0–-50 mg/L	0.01 mg/L	±0–20 mg/L
pH	0–14 units	0.01 units	±0.2 units

Food Web Resource Assessment

In 2010, USGS tested methods to assess food web resources supporting juvenile salmonids at the Campbell Slough site in order to refine protocols to be applied at multiple sites in later years. In 2011, USGS used those methods at the four sites where water quality was monitored. Brief descriptions of methods used to collect these data are provided below. Refer to Table 25 for sample dates of each component.

Table 25: Water quality monitor and primary productivity sampling schedule at four sites in 2011 [PAR, photosynthetically available radiation; chl-a, chlorophyll *a*; AFDM, ash-free dry mass; POM, particulate organic matter]

Task ↓ / Week of →		March 28	April 11	April 25	May 9	May 24	June 20	July 4	July 25
Water quality monitor		Deploy (3 sites)	Clean	Service (3 sites) Deploy (Campbell Slough)	Clean	Service	Service	Service	Retrieve
Nutrient samples					X	X	X		
PAR			X		X	X	X	X	
Periphyton productivity experiment: Periphytometers			Deploy	Retrieve	Deploy	Retrieve	Deploy	Retrieve	
Phytoplankton productivity experiment: Carbon-14 uptake					X		X		
Phytoplankton biomass (chl-a, AFDM)			X		X		X		
Periphyton biomass (chl-a, AFDM)			X		X		X		
Samples for stable isotope analysis	**Algae / POM**		X		X		X		
	Vegetation		X		X		X		
	Periphyton		X		X		X		
	Aquatic Insects		X		X		X		

Week of → / Task ↓	March 28	April 11	April 25	May 9	May 24	June 20	July 4	July 25
Phytoplankton species composition samples for OHSU	X	X	X	X	X	X	X	X
Zooplankton species composition samples for OHSU		X	X	X	X	X	X	
Benthic-invertebrate samples for CREST		X		X		X		

Water-Column Nutrient Concentrations and Photosynthetically Available Radiation (PAR) and Algal Biomass

One-liter water grab samples were collected from representative areas within the sites and composited in a plastic churn. Water was subsampled and analyzed for concentrations of nitrogen and phosphorus species and algal biomass during three sampling events. During every sampling event, PAR was measured approximately 0.5 feet below the water surface.

Subsamples were filtered to collect particulate organic matter (POM) for stable isotope analysis on three sample dates. During three sampling events, periphyton was scraped from measured areas of rocks, submerged wood, or artificial substrates. It was then filtered and analyzed for chlorophyll *a* and AFDM analyses.

Algal Productivity Rates

^{14}C Uptake Experiment

The uptake of radioactive tracer carbon during photosynthesis can be used to determine the in-situ rate of phytoplankton productivity in the environment (Wetzel and Likens, 1991). Using this approach, water samples with a measured concentration of dissolved inorganic carbon-12 ($DI^{12}C$) are spiked with a known amount of radioactive tracer carbon-14 (^{14}C) and incubated in bottles in the stream. After 2 to 4 hours, the amount of ^{14}C incorporated into the algal biomass during photosynthesis is measured. An isotopic correction factor of 1.06 is used in the calculation of ^{14}C assimilated to account for the preferential uptake of the lighter ^{12}C isotope over ^{14}C isotope by phytoplankton (Wetzel and Likens, 1991). The uptake of ^{14}C relative to the total ^{14}C that is available is assumed to be equivalent to the proportion of $DI^{12}C$ that is incorporated during photosynthesis, relative to the total $DI^{12}C$ available, as follows:

$$\frac{\text{14C available (known spike concentration)}}{\text{14C assimilated (measured at end of experiment)}} = \frac{\text{12C available (measured DIC)}}{\text{12C assimilated (calculated)}}$$

(modified from Wetzel and Likens, 1991). Therefore, the calculated $DI^{12}C$ assimilated value is used to determine the rate of primary production in mass of carbon assimilated per volume per time. ^{14}C assimilation by phytoplankton was measured using a liquid scintillation counter at Oregon Health & Science University in 2011. Two ^{14}C uptake experiments were done at each site, except for Campbell Slough, where limited site access only allowed for one experiment.

Periphytometers

Nutrient-diffusing substrate (NDS) periphytometers can be used to estimate periphyton productivity. Micro-NDS periphytometers, as described by Wise and others (2009), were used to estimate periphyton accrual during a two-week period three times during the monitoring period. For each deployment, eight 40-milliliter glass vials were filled with each treatment solution: deionized water (control treatment), sodium nitrate solution (nitrogen [N] treatment, 350 micromolar [µM] as N), sodium hydrogen phosphate solution (phosphorus [P] treatment, 100 µM as P), or N+P solution (N+P treatment, 350 µM as N and 100 µM as P). The control treatment was used to determine the ambient periphyton productivity rate, while the nutrient treatments were used to assess nutrient limitation or co-limitation. Vials were capped with a 0.45-micron nylon barrier membrane and a glass-fiber filter, which served as the artificial substrate for periphyton growth. Half of the replicates of each treatment were covered with 18 x 14 mesh fiberglass window screen to test for the effect of grazers on phytoplankton accrual.

Stable Isotope Ratios of Algae, Plants, Insects, and Juvenile Salmonids

Algae. Samples of POM and periphyton collected as described above were filtered and analyzed for stable carbon and nitrogen isotopes. Additional replicates of the periphytometer control treatments were also used as substrate for periphyton for stable isotope analysis.

Macrophytes (Plants). Samples of dominant emergent vegetation species were collected from representative areas within each site. Plant samples were not collected from the Franz Lake site in 2011 because the site was inundated during the whole sampling period and emergent plants could not be found. Plants were rinsed at least five times in deionized water to remove external material, such as invertebrates and periphyton, and were kept frozen for later processing.

Insects and Juvenile Salmonids

Juvenile salmonid muscle tissue was collected by NOAA Fisheries staff. Wild juvenile salmonids were collected using a seine and skinned muscle tissue samples were collected. Aquatic insects were collected by USGS staff in open water and in emergent vegetation at the water's margin using a 500-micrometer net. Salmonid and aquatic insect samples were frozen for later processing.

Frozen salmonid tissue, insects, and plant material were freeze dried using a lyophilizer. Freeze-dried plants of the same species from the same sample date were composited and ground using a clean coffee grinder. Freeze-dried insect bodies of the same taxa were composited, ground using a clean glass mortar and pestle, and subsampled.

4.4.3 Results

Seasonal Water Quality Monitoring

Franz Lake Slough. Franz Lake Slough is an approximately two-kilometer channel connecting Franz Lake to the Columbia River, approximately 12 river kilometers downstream of Bonneville Dam. The monitoring site is approximately 300 meters upstream of the confluence with the Columbia River. High river levels in the spring of 2011 flooded the vegetated strip of land between the slough and the main stem, laterally connecting the channels throughout the monitoring period (Figure 47). Water quality parameters at this site reflect inputs from Franz Lake and from the Columbia River. The 2011 monitoring period at this site was March 29–July 18, 2011.

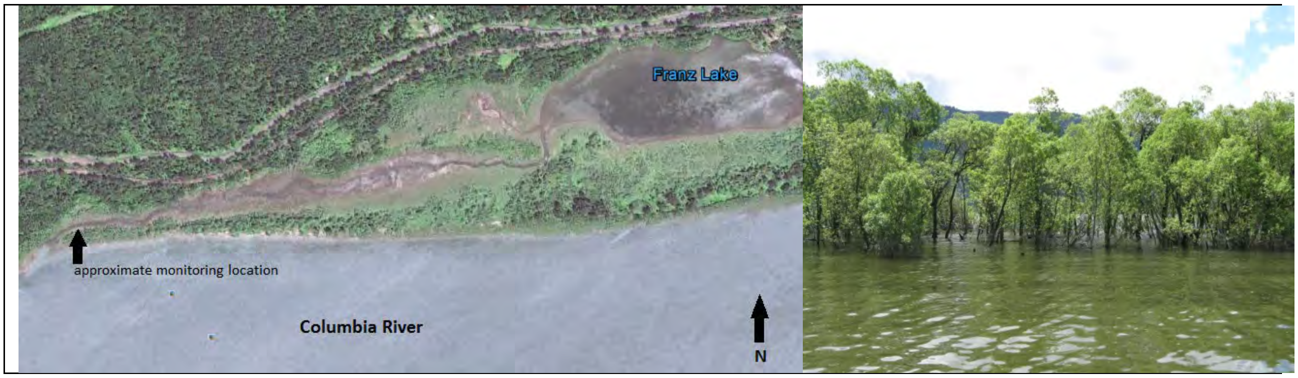


Figure 47: (A) Google Earth image showing Franz Lake Slough location in relation to Franz Lake and the Columbia River. This image was taken on July 5, 2010, when water in the slough was within its channel. (B) Photo of Franz Lake Slough taken on June 20, 2011 showing the Columbia River (behind the trees) flooding into Franz Lake Slough in the foreground.

Water temperature increased steadily throughout the monitoring period, only exceeding the Washington state weekly maximum standard of 17.5 degrees Celsius (° C) at the end of July (Figure 48). The standard was exceeded on seven percent of days during the monitoring period. Temperature ranged from 7.1 to 20.6° C, with daily average temperatures increasing two to three degrees per month. During July 2011, average daily temperatures ranged from 16.9 to 17.7° C, with average daily median temperatures of 17.1° C (Table 26).

pH ranged from 6.6 to 9.5 standard units during the 2011 monitoring period. It increased during April, peaking in May, and dropped through July. Unlike at some of the downstream monitoring sites, daily fluctuations were larger in April and May than in June and July. The Washington state maximum standard of 8.5 was violated on 26 percent of days, all during April and May. The minimum standard was not violated during the monitoring period.

Dissolved oxygen concentrations were steadily high in April and through most of May, decreasing slowly but steadily through July. The range during the monitoring period was 3.6 to 15.7 milligrams per liter (mg/L). The average daily minimum concentration ranged from 11.9 mg/L in April to 6.5 mg/L in July. The minimum daily concentration dropped below the Washington state minimum standard of 8.0 mg/L occasionally at the end of May through June, and during much of July; overall the standard was violated on 18 percent of monitored days (Figure 49).

Specific conductance ranged from 50 to 172 microsiemens per centimeter (µS/cm) during the monitoring period. During April and the first half of May, specific conductance fluctuated daily with no distinct pattern, and often large differences between minimum and maximum measured values each day; the greatest differences were over 100 µS/cm per day (Figure 50). By mid-May, daily variation in specific conductance decreased to less than 10 µS/cm per day. The differences correlate well to Columbia River levels below Bonneville Dam (USGS site number 14128870) (U.S. Geological Survey, 2011); when river levels were high, the specific conductance varied less during the day, whereas, there was greater daily variation when river levels were lower. This could reflect relatively greater contributions of water from Franz Lake when the river levels were lower.

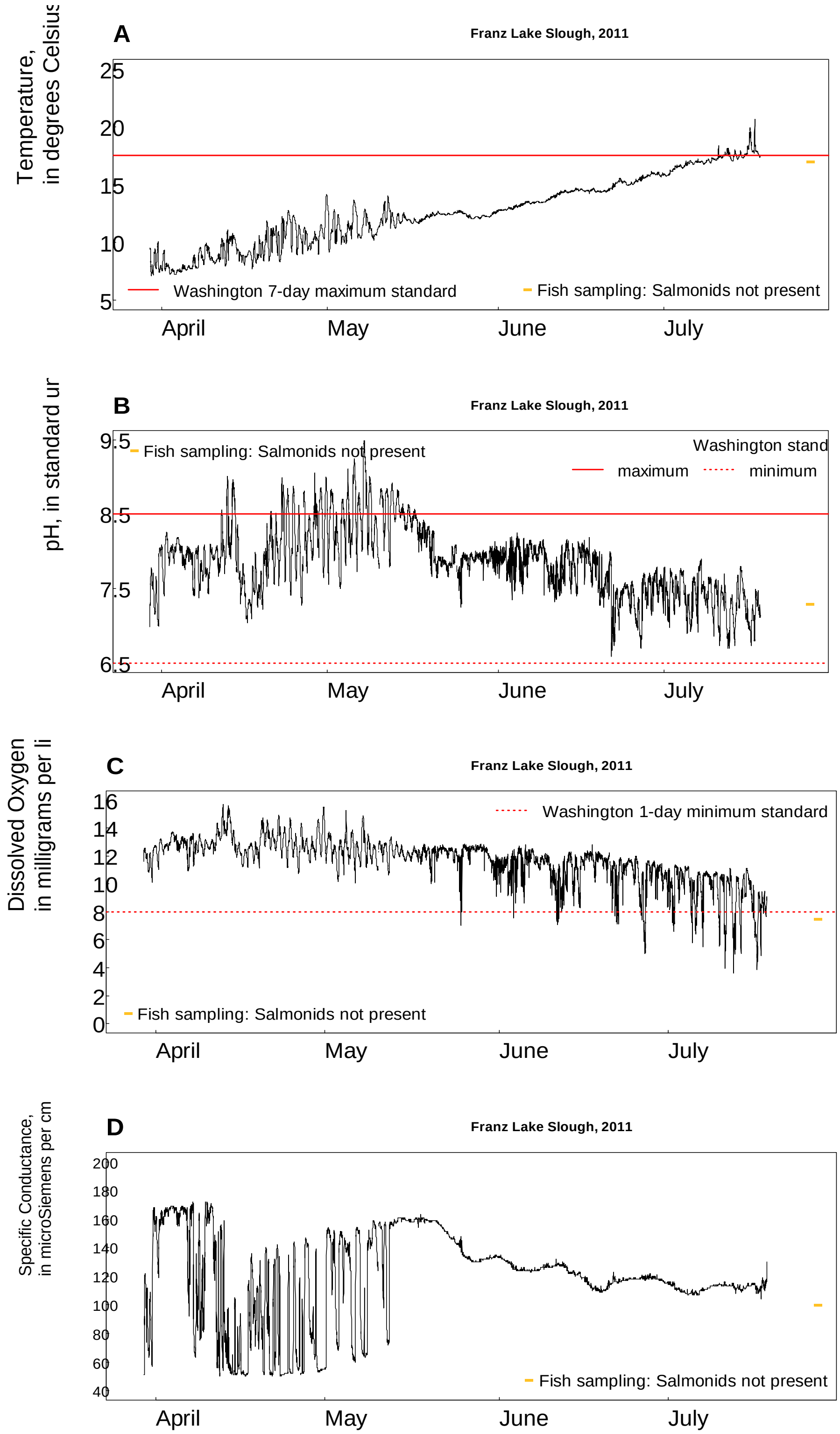


Figure 48: Continuous water quality monitor data: (A) water temperature, (B) dissolved oxygen, (C) pH, and (D) specific conductance measured at Franz Lake Slough, WA, March 29–July 25, 2011. Measurements were taken every 15 minutes while the monitor was submerged. The presence or absence of salmonids during NOAA fish sampling events is also shown.

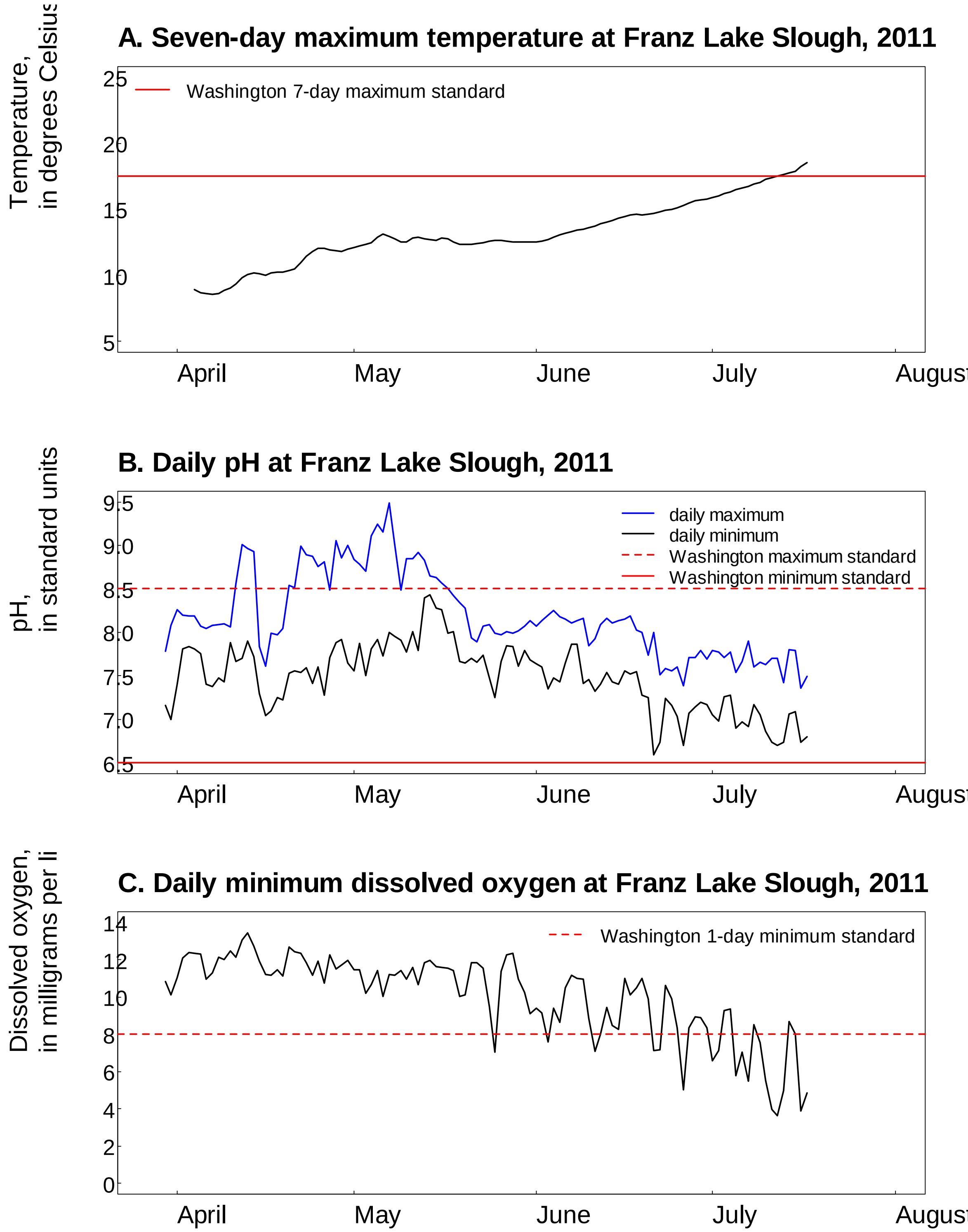


Figure 49: Calculated weekly maximum temperature (A), daily minimum and maximum pH (B), and daily minimum dissolved oxygen (C), at Franz Lake Slough, WA, March 29–July 25, 2011, and comparable Washington State water quality standards.

Table 26: Average daily minimum, mean, median, and maximum water quality values by month, Franz Lake Slough, WA, March 29–July 25, 2011
[°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter]

Franz Lake		April	May	June	July
Temperature (° C)	daily min	8.4	11.4	14.2	16.9
	daily mean	9.4	12.0	14.4	17.2
	daily median	9.4	11.9	14.4	17.1
	daily max	10.5	12.6	14.6	17.7
pH (standard units)	daily min	7.6	7.8	7.3	7.0
	daily mean	8.0	8.2	7.7	7.4
	daily median	8.0	8.2	7.7	7.4
	daily max	8.4	8.5	7.9	7.7
Dissolved Oxygen (mg/L)	daily min	11.9	11.0	9.1	6.5
	daily mean	13.0	12.3	11.0	9.3
	daily median	13.0	12.4	11.2	9.6
	daily max	14.0	13.1	12.0	10.7
Specific Conductance (µS/cm)	daily min	76	121	120	110
	daily mean	103	138	121	112
	daily median	103	141	121	112
	daily max	142	151	123	115

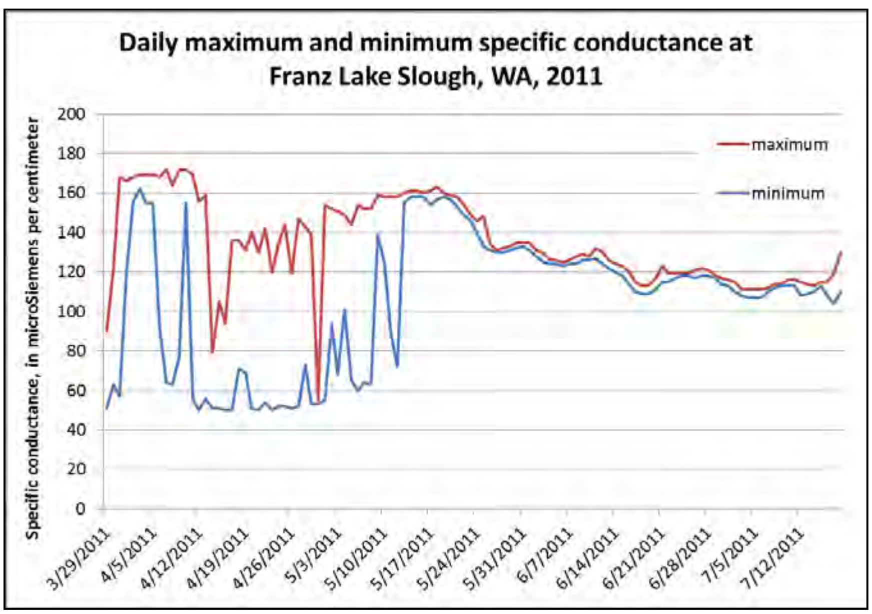


Figure 50: Graph of daily maximum and minimum specific conductance measured at Franz Lake Slough, WA, March 29–July 25, 2011.

Campbell Slough. The monitoring site at Campbell Slough is approximately 1.4 kilometers off the main stem of the Columbia River in Ridgefield National Wildlife Refuge (NWR) near Ridgefield, WA. This site is farther off the main stem than the other water quality monitoring sites. This site is influenced by inputs from Campbell Lake as well as tidal flows from the Columbia River. The site was slower-draining than other monitoring sites following the high water in the spring of 2011. The 2011 water quality monitoring period at Campbell Slough was April 26–July 25, 2011. Monitor data from this site were recorded every 30 minutes in order to have sufficient memory on the monitor in case the site could not be accessed for prolonged periods due to high water, as was the case the previous year.

Measured water quality parameters showed daily and seasonal variation. Water temperature ranged from 9.0 to 24.3° C during the 2011 monitoring period. The temperature increased steadily over the monitoring period, with larger daily fluctuations during May and July than in June (Figure 51). The period of smaller daily fluctuations occurred when the site was flooded during the spring freshet. The Washington seven-day maximum standard of 17.5° C was exceeded for most of July. The standard was exceeded on 25 percent of days for which there are data during May through July 2011 (n=85), compared to 60 percent of days during those months in 2010 (n=81), and 91 percent in 2009 (n=80).

pH ranged from 6.8 to 8.5 standard units, with a median value of 7.3. The Washington maximum water quality standard for pH was exceeded during two days in May. The average daily maximum pH was highest in May, at 8.1 standard units (Table 27). Washington's minimum pH standard was not violated during the monitoring period. There were larger daily fluctuations in pH during May and July compared to June, showing patterns indicating greater algal productivity in May and July. The trends were similar in 2010 and 2011, which could indicate lower productivity due to the cooler spring and early summer temperatures, as opposed to the trend in pH observed in 2009, a warmer year. However, insufficient algal biomass data are available to be certain.

Dissolved oxygen concentrations were generally highest in May, lowest in June, and moderate in July. This pattern was also similar to that in 2010, but the peak concentrations were higher in 2010. As with other water quality parameters, the magnitude of daily fluctuations was lower in June when the site was inundated and the sonde was in deeper water (at this site, the sonde was at a fixed location relative to the channel bottom). Dissolved oxygen concentrations dropped below the Washington daily minimum standard of 8.0 milligrams per liter (mg/L) on 67 percent of days (Figure 52). The measured concentration was below the standard for nearly all of June and much of July, although diel fluctuations in July peaked above the standard on most days. Water levels on the main stem of the Columbia River at Vancouver (the nearest gaging station, USGS site number 14144700) were on average 7 feet higher in June 2011 compared to the June average of the previous four years (Figure 53) (U.S. Geological Survey, 2011). In Campbell Slough, decomposing organic matter consumed dissolved oxygen from the stagnant water, keeping the dissolved oxygen concentrations less than 4 mg/L for more than two weeks. During June, the average daily maximum dissolved oxygen concentration was 3.9 mg/L.

Specific conductance ranged from 116 to 191 µS/cm during the 2011 monitoring period. Despite daily fluctuations, the measured specific conductance of Campbell Slough was fairly steady through May. It decreased during the high water in June, which would be expected with the input of lower conductance water from the main stem of the Columbia. Average daily median values were consistent among months, although the difference between average daily minima and maxima increased in July. This change in specific conductance coincides with the decreasing water levels at the site, after being flooded all spring. The increased daily variation is assumed to reflect higher conductance inputs from upstream Campbell Lake and lower conductance tidal inputs from the Columbia River.

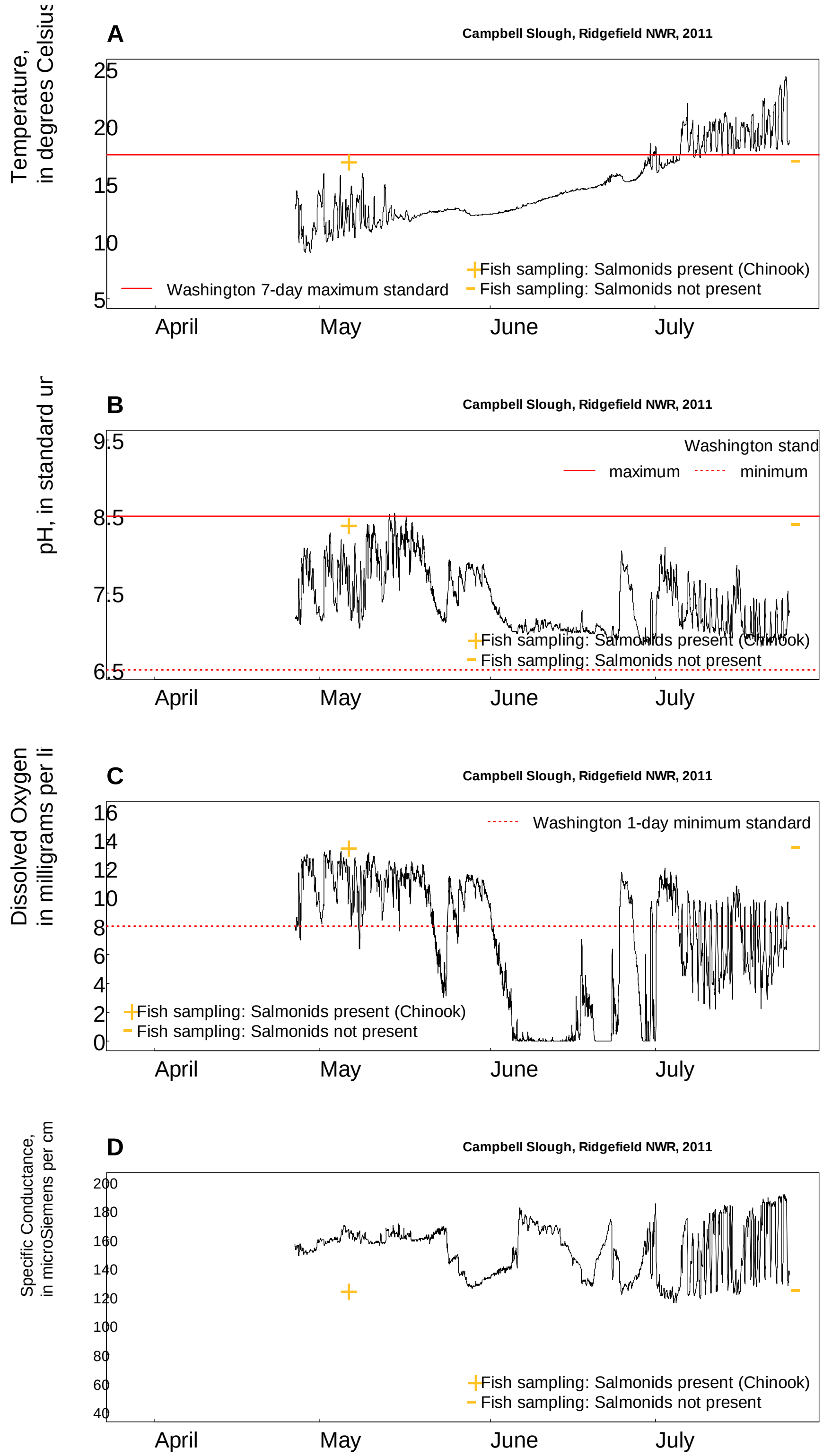


Figure 51: Continuous water quality monitor data: (A) water temperature, (B) dissolved oxygen, (C) pH, and (D) specific conductance measured at Campbell Slough, Ridgefield, WA, April 26–July 25, 2011. Measurements were taken every 30 minutes while the monitor was submerged. The presence or absence of salmonids during NOAA fish sampling events is also shown.

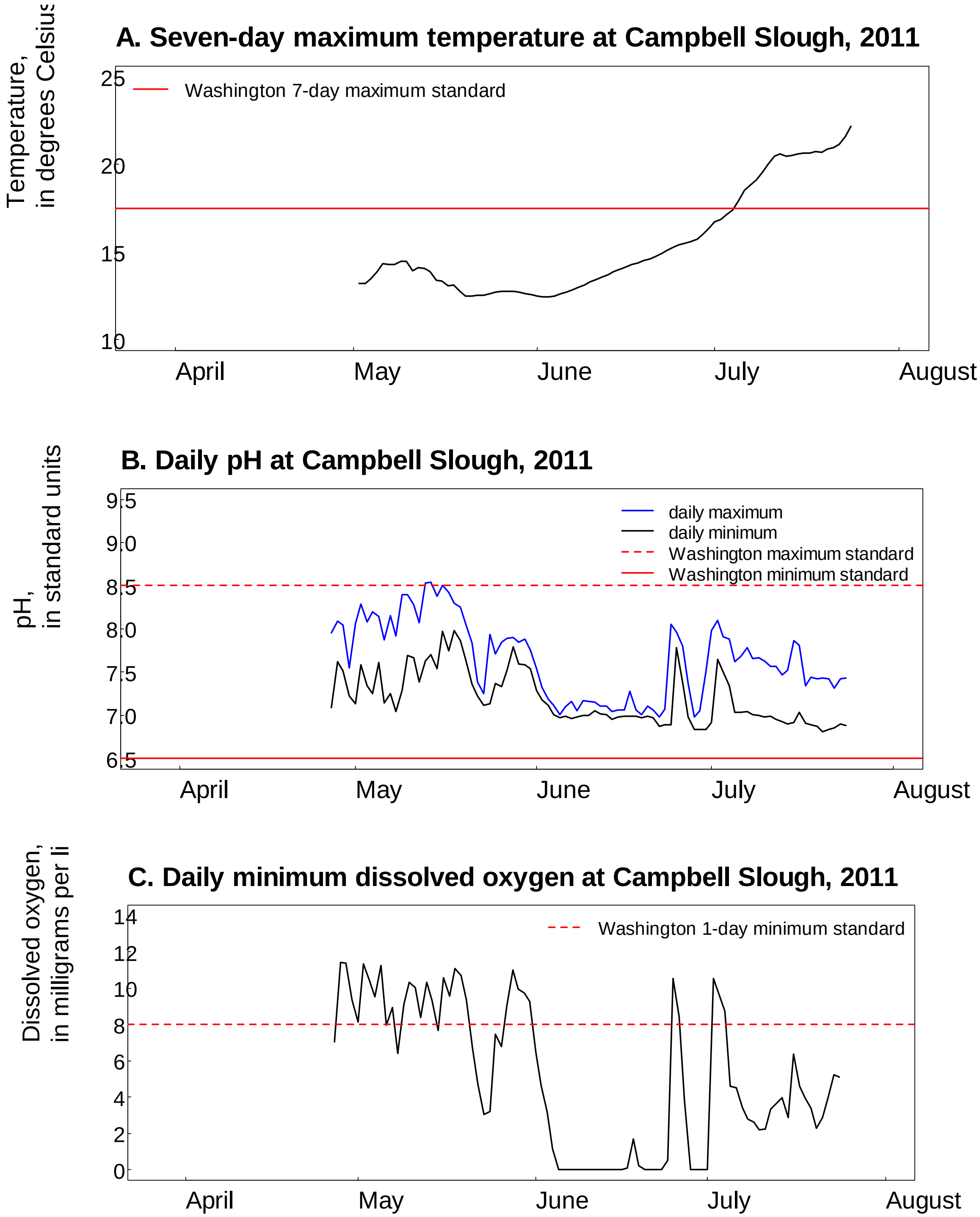


Figure 52: Calculated weekly maximum temperature (A), daily minimum and maximum pH (B), and daily minimum dissolved oxygen (C), at Campbell Slough, Ridgefield, WA, April 26–July 25, 2011, and comparable Washington State water quality standards.

Table 27: Average daily minimum, mean, median, and maximum water quality values by month, Campbell Slough, Ridgefield, WA, April 26–July 25, 2011. [°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter]

Campbell Slough		April	May	June	July
Temperature (° C)	daily min	10.2	11.6	14.2	17.6
	daily mean	11.5	12.3	14.3	19.0
	daily median	11.3	12.3	14.3	19.0
	daily max	13.0	13.3	14.5	20.5
pH (standard units)	daily min	7.3	7.5	7.0	7.0
	daily mean	7.5	7.8	7.1	7.2
	daily median	7.5	7.8	7.1	7.2
	daily max	7.8	8.1	7.2	7.6
Dissolved Oxygen (mg/L)	daily min	9.4	8.7	1.4	4.4
	daily mean	10.6	10.5	2.4	7.3
	daily median	10.8	10.6	2.2	7.1
	daily max	11.7	11.7	3.9	10.2
Specific Conductance (µS/cm)	daily min	151	152	143	125
	daily mean	153	155	150	150
	daily median	153	155	151	153
	daily max	156	159	156	170

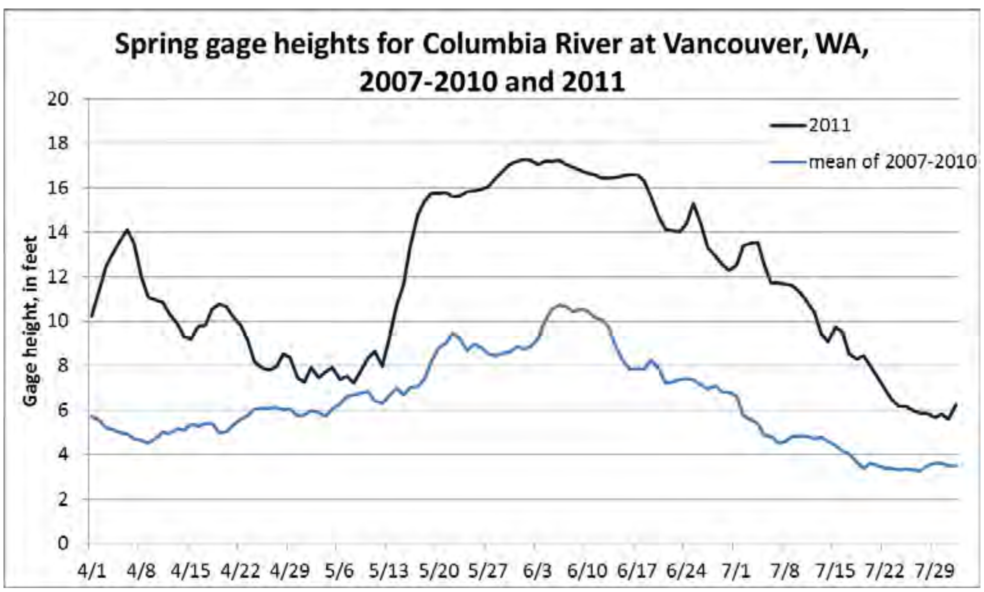


Figure 53: Gage heights at the Columbia River at Vancouver, WA (USGS site number 14144700) during the monitoring period in 2011 and on average for those dates in 2007–2010.

Whites Island. The monitor at Whites Island is located at the confluence of a large tidal channel and an extensive slough system that cuts through Whites Island, which is in the main stem of the Columbia River near Cathlamet, WA. Water quality parameters at the site show a strong tidal influence, with a short lag time between tidal changes in the main stem of the river and the slough. The Whites Island water quality monitor was missing from the site during the May 11 visit and was not replaced until June 21. Therefore, data were not available between April 25 (the previous visit, when data were downloaded) and June 21. The 2011 monitoring period was March 29–April 25 and June 21–July 19.

Water temperature at Whites Island increased through April and in late June through July 2011 (Figure 54). In July, daily fluctuations peaked at temperatures greater than the Washington 7-day water quality standard of 17.5° C; the standard was violated on 30 percent of days for which data are available. The average daily maximum temperature in July was 17.9° C; the average daily minimum that month was 16.5° C (Table 28). In 2009, when the site was also monitored, the average daily maximum in July was 21.4° C and the average daily minimum was 18.7° C.

pH ranged from 7.15 to 8.35 standard units during the monitoring period, consistently within the acceptable range of 6.5 to 8.5 based on the Washington state water quality standards (Figure 55). In contrast, during late June and July 2009, pH oscillated above the standard of 8.5 to daily maxima between 9 and 10. In 2011, average daily minimum, median, and maximum values were slightly higher in April than in June and July. Daily fluctuations were greater in June and July than in April.

Dissolved oxygen concentrations at Whites Island ranged from 6.8 to 13.8 mg/L in 2011. Average daily ranges varied from 11.2–12.8 mg/L during April to 7.7–10.8 mg/L during July. As with pH, the daily ranges of dissolved oxygen concentrations were greater during July than earlier in the monitoring period. Daily fluctuations dipped below the Washington state minimum water quality standard of 8.0 mg/L starting July 5, although most of the measured values on those days were greater than the standard. Overall, dissolved oxygen concentrations at Whites Island were less than the Washington water quality standard on 25 percent of days with data in 2011. In 2009, daily fluctuations also dropped below the minimum standard throughout July.

Specific conductance ranged from 100 to 163 µS/cm during the 2011 monitoring period. This range was similar to that measured in 2009. The daily average values were approximately 20 µS/cm higher in April than in July.

Although there are no monitor data for May and most of June, interpolation of the trends of the available data gives no reason to expect that conditions were poor during the time when data are not available. Additionally, comparator data are available from a nearby upstream site on the main stem of the Columbia River; the Land-Ocean Biogeochemical Observatory (LOBO) monitoring site is administered by the Center for Coastal Margin Observation & Prediction and is located at a USGS gaging station (USGS site number 14246900, Columbia River at Beaver Army Terminal). A comparison of the Whites Island monitoring data to hourly monitor data from the LOBO site shows that the data match well, except that the Whites Island data fluctuate more in response to tidal changes than do the main-stem data (Figure 56). The LOBO data are available at http://columbia.loboviz.com/. For this comparison, dissolved-oxygen data from the LOBO site were converted to mg/L. The comparison of data from the two sites appears reasonable given the close proximity of the monitor site to the main stem, the regularity of daily tidal flushing in the slough as exemplified by the existing monitor data, the lack of major tributaries into the Columbia River between the two monitoring sites, and the consistent relationship between water quality parameters monitored at the two sites during the time when data from both monitors are available.

During April and at the end of June, temperature measurements from the LOBO match the daily minimum temperature from Whites Island, with Whites Island daily maximum temperatures approximately 2° C higher than the temperature from the LOBO station. If the trend was the same during the period for which there are no data from Whites Island, then there would not have been temperatures exceeding the standard of 17.5° C during May or early June at Whites Island. Similarly, the measured daily maximum dissolved oxygen at Whites Island matches well with the main-stem data from the LOBO station during April and the day of June for which data were available from both monitors. However, the daily minimum dissolved oxygen at Whites Island was approximately 2 to 2.5 mg/L lower than the data from the LOBO. If this trend was consistent, during the period of missing data at Whites Island, then it would be expected that dissolved oxygen at Whites Island remained greater than the standard of 8 mg/L during that period.

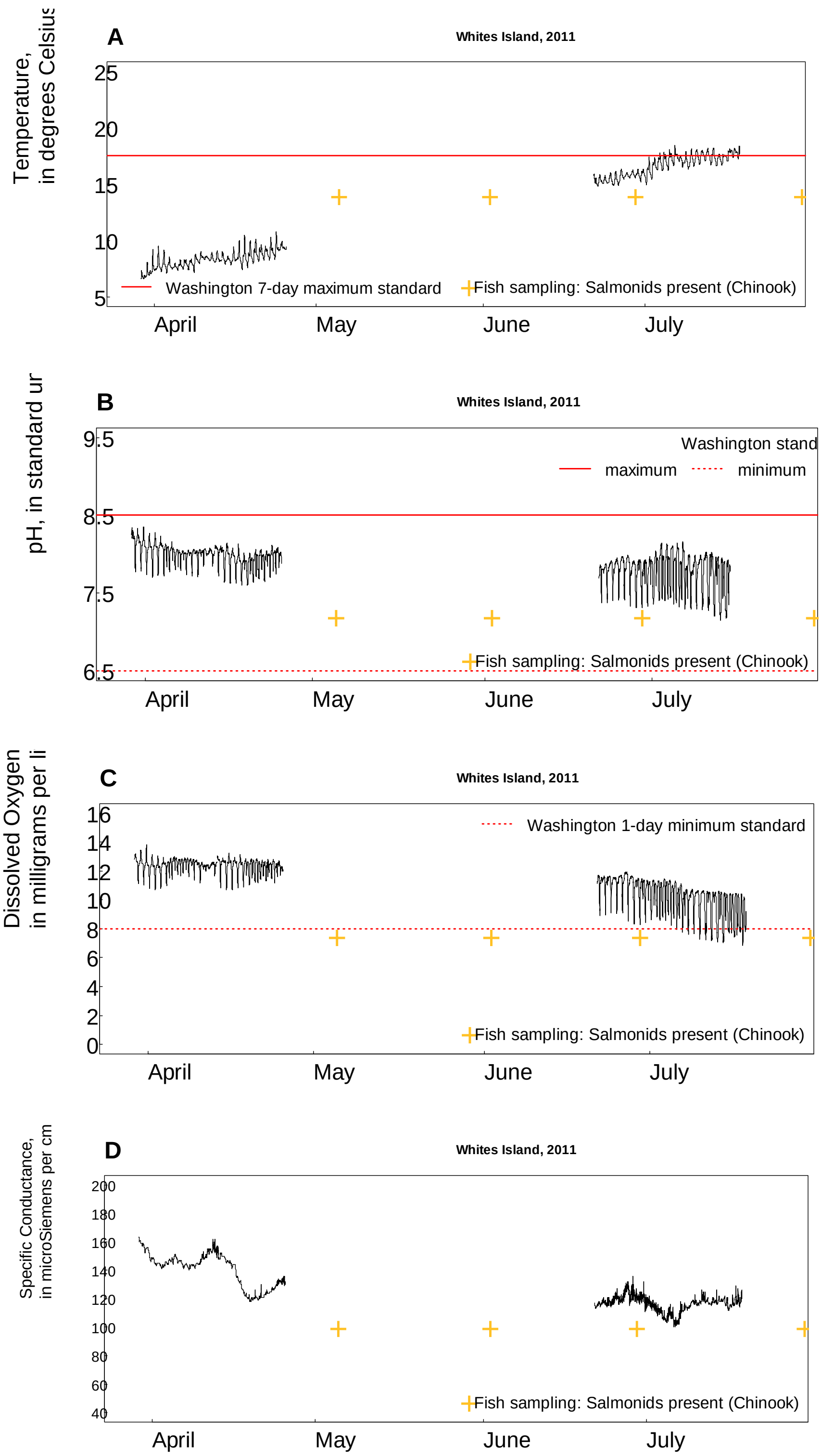


Figure 54. Continuous water quality monitor data: (A) water temperature, (B) dissolved oxygen, (C) pH, and (D) specific conductance measured at Whites Island, WA, March 29–April 25 and June 21–

July 19, 2011. Measurements were taken every 15 minutes while the monitor was submerged. The presence or absence of salmonids during NOAA fish sampling events is also shown.

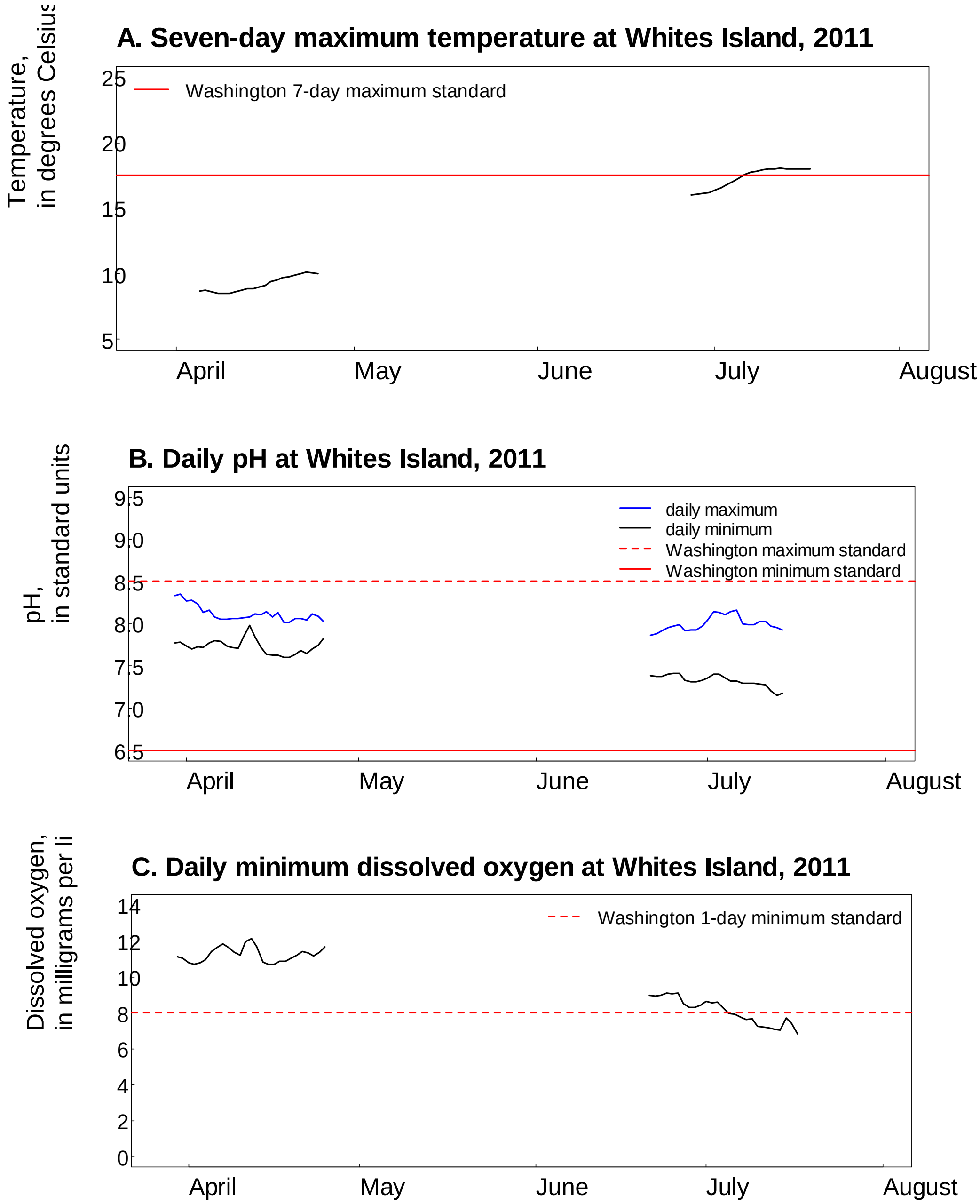


Figure 55. Calculated weekly maximum temperature (A), daily minimum and maximum pH (B), and daily minimum dissolved oxygen (C), at Whites Island, WA, March 29–April 25 and June 21–July 19, 2011, and comparable Washington State water quality standards.

Table 28: Average daily minimum, mean, median, and maximum water quality values by month, Whites Island, WA, March 29–April 25 and June 21–July 19, 2011. [°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter]

Whites Island		April	May	June	July
Temperature (° C)	daily min	7.9	no data	15.1	16.5
	daily mean	8.4	no data	15.6	17.2
	daily median	8.4	no data	15.5	17.2
	daily max	9.3	no data	16.1	17.9
pH (standard units)	daily min	7.7	no data	7.4	7.3
	daily mean	8.0	no data	7.8	7.8
	daily median	8.0	no data	7.9	7.9
	daily max	8.1	no data	7.9	8.0
Dissolved Oxygen (mg/L)	daily min	11.2	no data	8.8	7.7
	daily mean	12.3	no data	11.1	9.8
	daily median	12.5	no data	11.4	10.2
	daily max	12.8	no data	11.6	10.8
Specific Conductance (µS/cm)	daily min	136	no data	115	111
	daily mean	139	no data	120	115
	daily median	139	no data	120	115
	daily max	142	no data	126	120

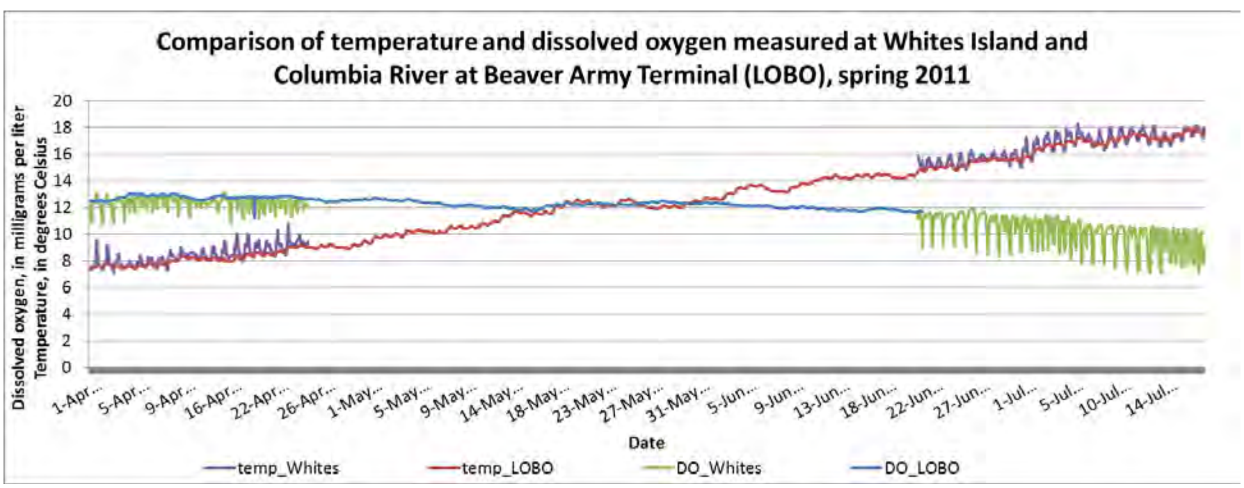


Figure 56. Comparison of temperature and dissolved oxygen data from Whites Island, WA (Whites) and an upstream site in the main stem of the Columbia River (LOBO), April 1–July 18, 2011. [temp, temperature; DO, dissolved oxygen]

Ilwaco. The water quality monitoring site at Ilwaco is a tidal channel that runs through a mudflat southwest of the entrance to Ilwaco marina in Baker Bay, WA (Figure 57). All water quality parameters showed strong daily fluctuations because of the tidal influence at the site. The 2011 monitoring period at this site was April 12–July 25, 2011.

Figure 57. Google Earth images showing the location of the monitored tidal channel at Ilwaco, WA relative to the main stem of the Columbia River (Baker Bay). The star indicates approximate monitoring location in 2011. (A) Imagery taken September 20, 2009, showing connectivity between the tidal channel and Baker Bay; (B) Imagery taken September 10, 2009, showing the exposed mudflat and poor connectivity between the monitored tidal channel and Baker Bay at low tide.

Water temperature at the Ilwaco monitoring site fluctuated daily, gradually increasing throughout the monitoring period (Figure 58). Temperature ranged from 6.2 to 27.4° C. Weekly maximum temperature cycled approximately every 10 days, with a gradual upward trend through the monitoring period (Figure 59). The Washington state weekly temperature standard of 17.5° C was exceeded in late April and then nearly continuously from mid-May through July.

pH ranged from 6.8 to 8.9 standard units during the monitoring period. pH cycled consistently each day, but the trend over the monitoring period was flat. Average daily minimum, median, and maximum pH decreased by 0.2 to 0.3 standard units between April and July (Table 29); this site had the most consistent pH of all the water quality monitoring sites in 2011. Maximum daily pH peaked above the Washington maximum pH standard of 8.5 on 8% of monitored days, only during April and July.

Dissolved oxygen concentrations ranged from 1.4 to 20.9 mg/L during the monitoring period. Daily variation was greatest in July, with an average difference of 10.2 mg/L between the daily minimum and maximum concentration. The lowest average variation was in May, with an average daily fluctuation of 7.0 mg/L. The daily minimum dissolved oxygen concentration was less than the Washington state standard of 8.0 mg/L on 94 percent of days, with only six daily minima (all during April) meeting the standard. However, dissolved oxygen concentrations were never less than 8.0 mg/L for a full day during the monitoring period.

Specific conductance was highest at this site, ranging from 937 to 15,500 µS/cm. The high specific conductance at this site shows the influence of marine water so low in the estuary. Specific conductance varied daily and during the season, with a dip in June likely reflecting the influence of high freshwater flows during the spring freshet.

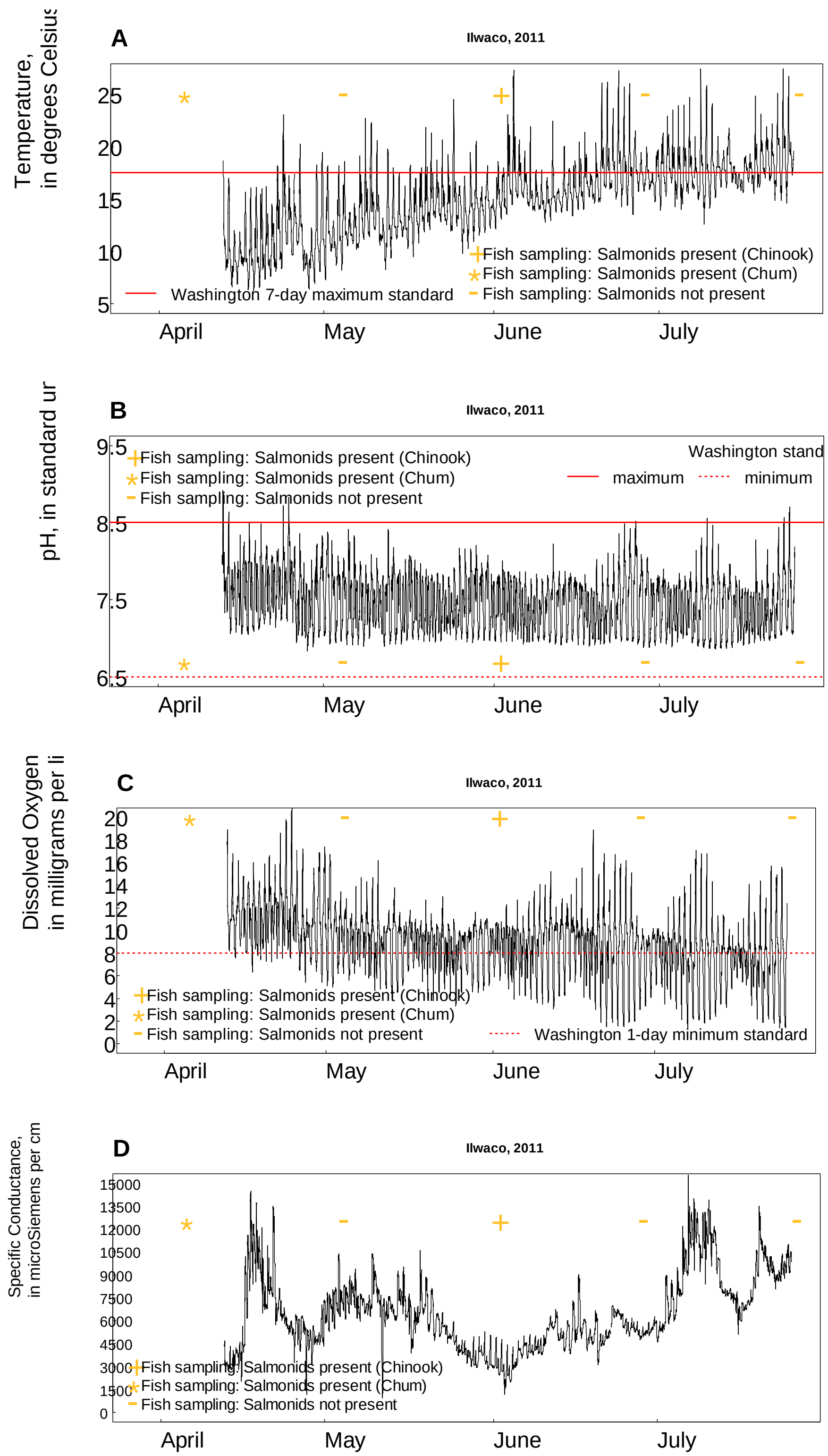


Figure 58. Continuous water quality monitor data: (A) water temperature, (B) dissolved oxygen, (C) pH, and (D) specific conductance measured at a tidal channel near Ilwaco , Baker Bay, WA, April 12–July 25, 2011. Measurements were taken every 15 minutes while the monitor was submerged. The presence or absence of salmonids during NOAA fish sampling events is also shown.

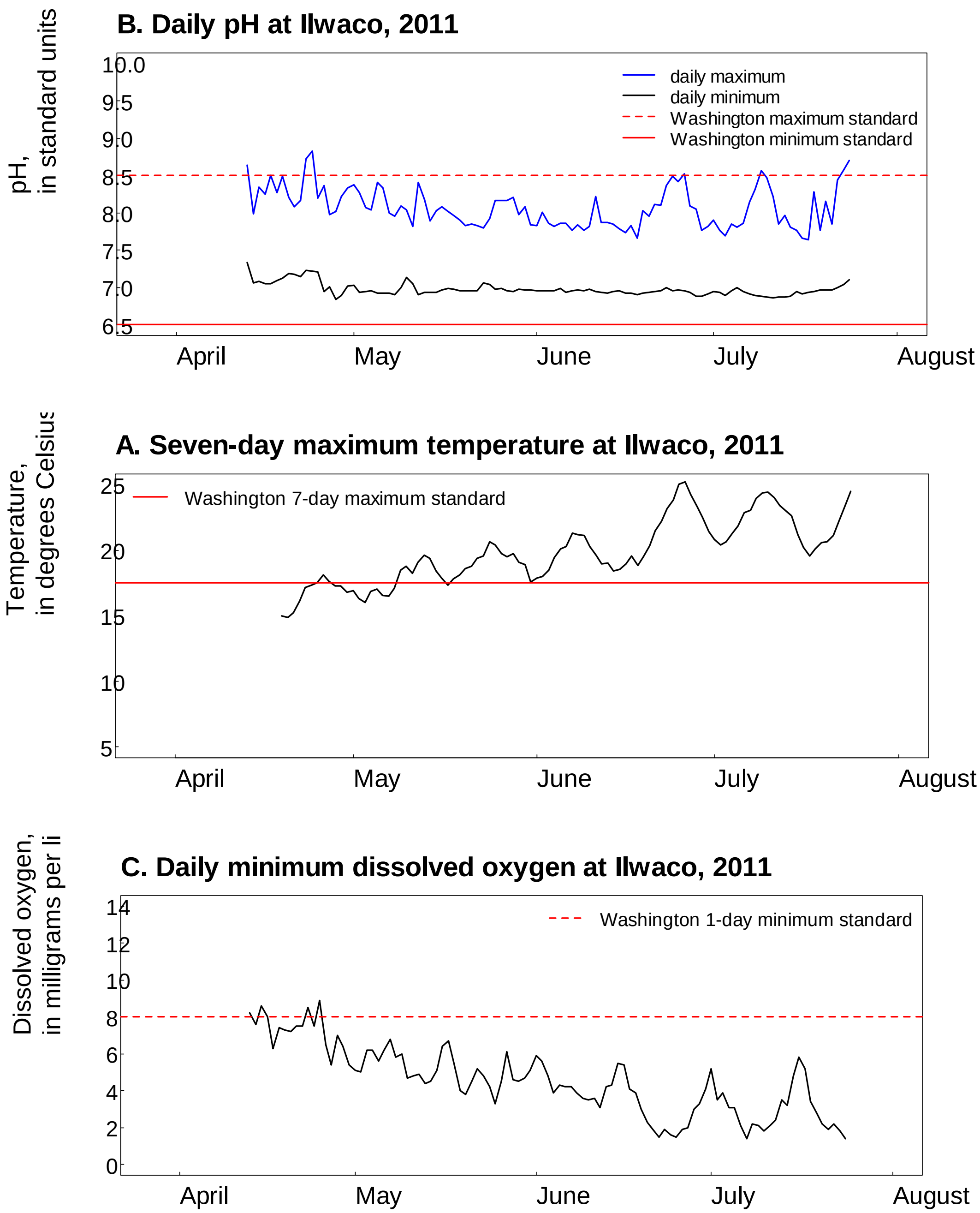


Figure 59: Calculated weekly maximum temperature (A), daily minimum and maximum pH (B), and daily minimum dissolved oxygen (C), at a tidal channel near Ilwaco , Baker Bay, WA, April 12–July 25, 2011, and comparable Washington State water quality standards.

Table 29: Average daily minimum, mean, median, and maximum water quality values by month, tidal channel near Ilwaco , Baker Bay, WA, April 12–July 25, 2011. [°C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter]

Ilwaco		April	May	June	July
Temperature (° C)	daily min	8.0	10.8	14.3	15.4
	daily mean	11.1	13.6	16.6	18.1
	daily median	10.6	13.3	16.4	18.0
	daily max	16.5	18.4	21.0	22.7
pH (standard units)	daily min	7.1	7.0	6.9	6.9
	daily mean	7.7	7.5	7.4	7.4
	daily median	7.7	7.5	7.5	7.4
	daily max	8.3	8.1	8.0	8.0
Dissolved Oxygen (mg/L)	daily min	7.4	5.1	3.5	2.9
	daily mean	11.3	9.0	8.5	7.5
	daily median	11.2	9.5	9.2	7.7
	daily max	16.6	12.1	13.3	13.1
Specific Conductance (µS/cm)	daily min	4,664	4,895	4,066	7,711
	daily mean	6,250	6,119	4,868	9,019
	daily median	6,180	6,094	4,830	8,860
	daily max	8,122	7,451	5,827	10,467

4.4.4 Food Web Resource Assessment

Nutrients

Nutrient data collected at Campbell Slough in 2010 were not available for the 2010 annual report and are presented here along with the 2011 data.

Total nitrogen concentrations in Campbell Slough followed no clear trend during either sampling period or between years (Figure 61). Total Kjeldahl nitrogen (TKN) accounted for most of the total nitrogen concentration; nitrate accounted for the remainder. TKN is the sum of organic nitrogen, ammonia (NH_3), and ammonium (NH_4^+). In 2010, the greatest concentration of nitrate, the main bioavailable form of inorganic nitrogen, was during the earliest sample, in mid-April (Figure 60, Figure 61). There was another small peak in nitrate concentration in late June 2010; otherwise, organic nitrogen accounted for nearly all the total nitrogen. Phosphorus also showed no distinct pattern during or between sampling seasons (Figure 61). However, the relationships in total nitrogen and total phosphorus were similar in 2010; there are too few data to detect a trend in 2011.

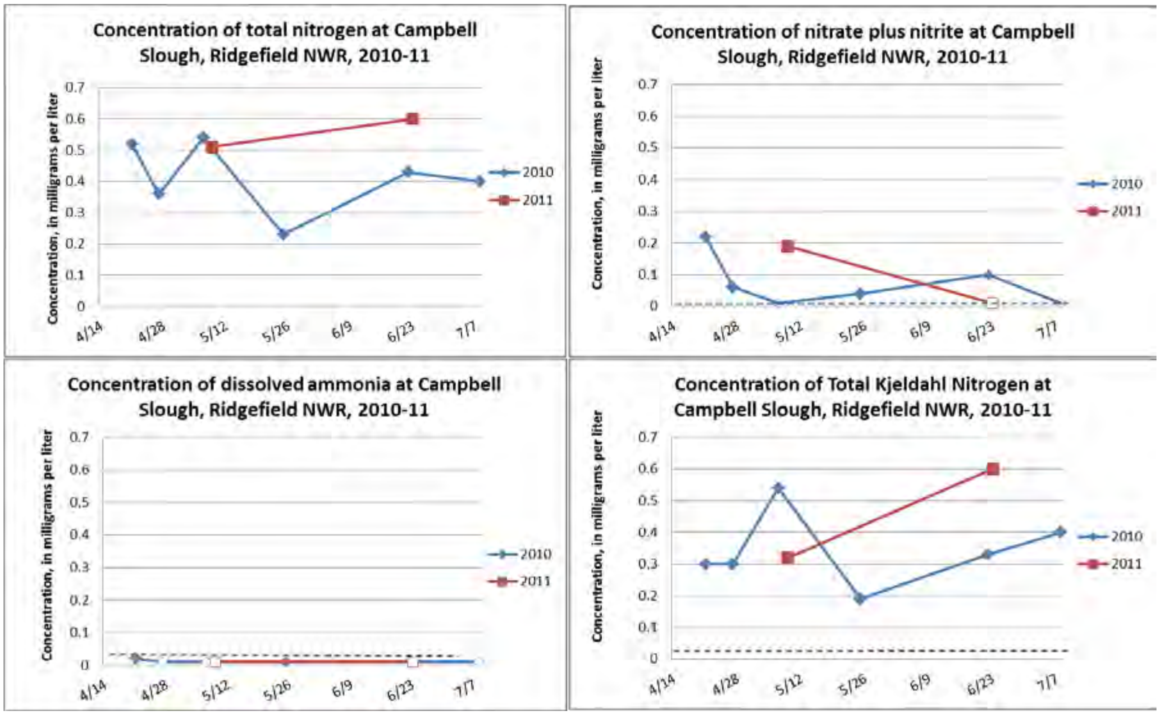


Figure 60. Concentrations of nitrogen species at Campbell Slough, Ridgefield NWR, April–July, 2010–2011. Concentrations that were not detected at the reporting limit are shown at the reporting limit (dashed line) and represented by outlined symbols.

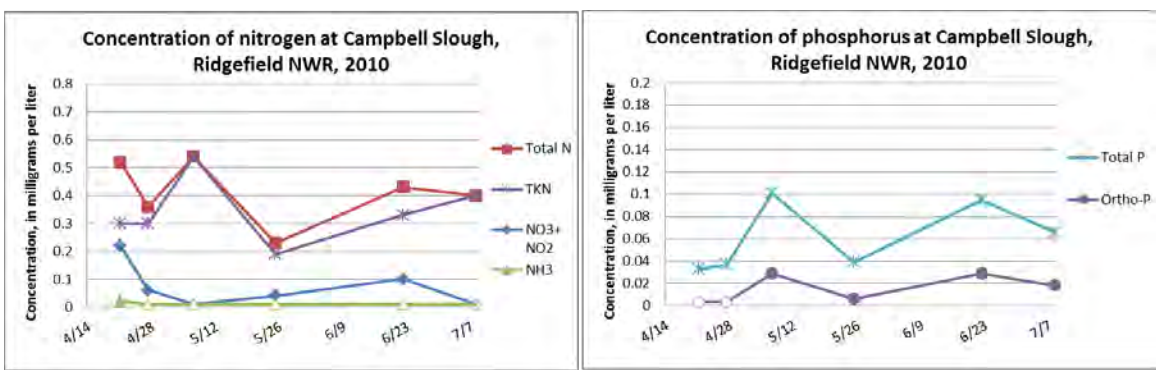


Figure 61. (A) Nitrogen and (B) phosphorus concentrations at Campbell Slough, Ridgefield NWR April–July 2010. Concentrations that were not detected at the reporting limit are shown at the reporting limit and represented by outlined symbols. [N, nitrogen; TKN, Total Kjeldahl Nitrogen; NO3, nitrate; NO2, nitrite; NH3, ammonia; P, phosphorus; Ortho-P, orthophosphate]

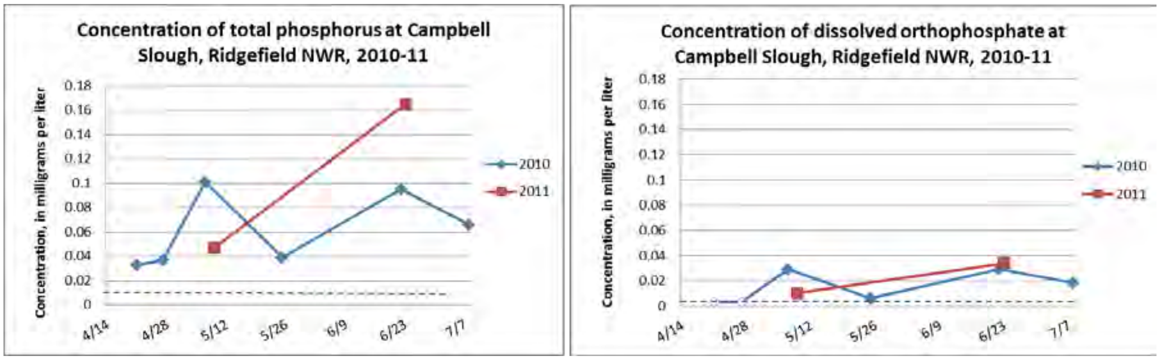


Figure 62. Concentrations of phosphorus species at Campbell Slough, Ridgefield NWR, April–July, 2010–2011. Concentrations that were not detected at the reporting limit are shown at the reporting limit (dashed line) and represented by outlined symbols.

2011

In 2011, total nitrogen and total phosphorus were highest in June at all sites, except Whites Island, where nutrient concentrations peaked in late May (Figure 63). Among sites, nitrogen concentrations were highest at Campbell Slough in early May and late June, and highest at Whites Island in late May. Phosphorus concentrations were similar among sites in early May and much higher in Campbell Slough than other sites by late June, although concentrations at all sites had increased by late June. As with nitrogen, phosphorus concentrations at Whites Island peaked in late May.

Organic nitrogen constituted most of the total nitrogen at all four sites. Nitrate was the dominant inorganic nitrogen species at all the sites, except at Ilwaco , where ammonia was increasingly present as the season progressed. At Franz Lake Slough, Campbell Slough and Ilwaco , nitrate available in May was taken up by organisms or flushed out of the system, drawing down the available nitrate to or below detectable concentrations by late June; at that time, all of the total nitrogen was organic nitrogen, except from a small concentration of ammonia at Ilwaco . Whites Island was the only site that had detectable concentrations of nitrate in the water column during all the sampling events.

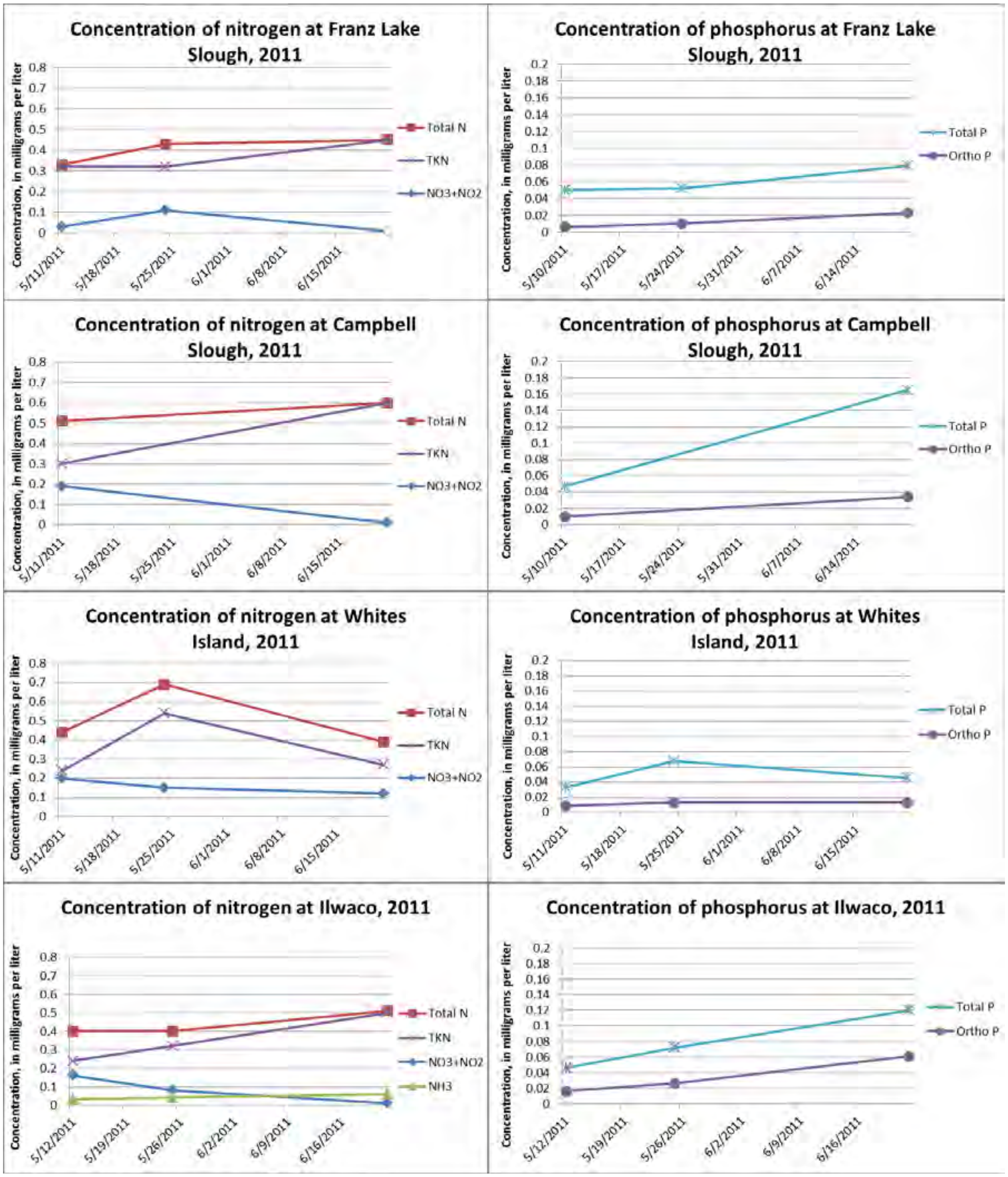


Figure 63. Nitrogen and phosphorus concentrations at (A) Franz Lake, (B) Campbell Slough, (C) Whites Island, and (D) Ilwaco, May–June 2011. Concentrations that were not detected at the reporting limit are shown at the reporting limit and represented by outlined symbols. [N, nitrogen; TKN, Total Kjeldahl Nitrogen; NO3, nitrate; NO2, nitrite; NH3, ammonia; P, phosphorus; Ortho-P, orthophosphate]

Photosynthetically Available Radiation (PAR)

Because of limitations of the light meter used in 2011, PAR data are available only above the water surface and at a depth of one-half to one foot below the water surface, rather than through the entire vertical profile of the water column. Full vertical profiles will be measured in 2012.

In addition to water-column conditions such as phytoplankton and suspended sediment concentrations, PAR depends on the angle of the sun to the water surface, cloud cover, precipitation, and disturbances to the water surface, such as wind. Therefore, PAR measurements are variable throughout a day. In 2011, PAR measurements taken just below the water surface (0.5–1 foot deep) show no distinct pattern across sites or over time. At most sites, PAR just below the water surface was approximately 40 percent of PAR above the water surface. The only exception was at Campbell Slough, where it was 30 percent, but only two paired measurements are available from the same day. Although these PAR data are of limited utility on their own, they will be useful in the analysis of algal productivity rates. However, those data are not available for this report.

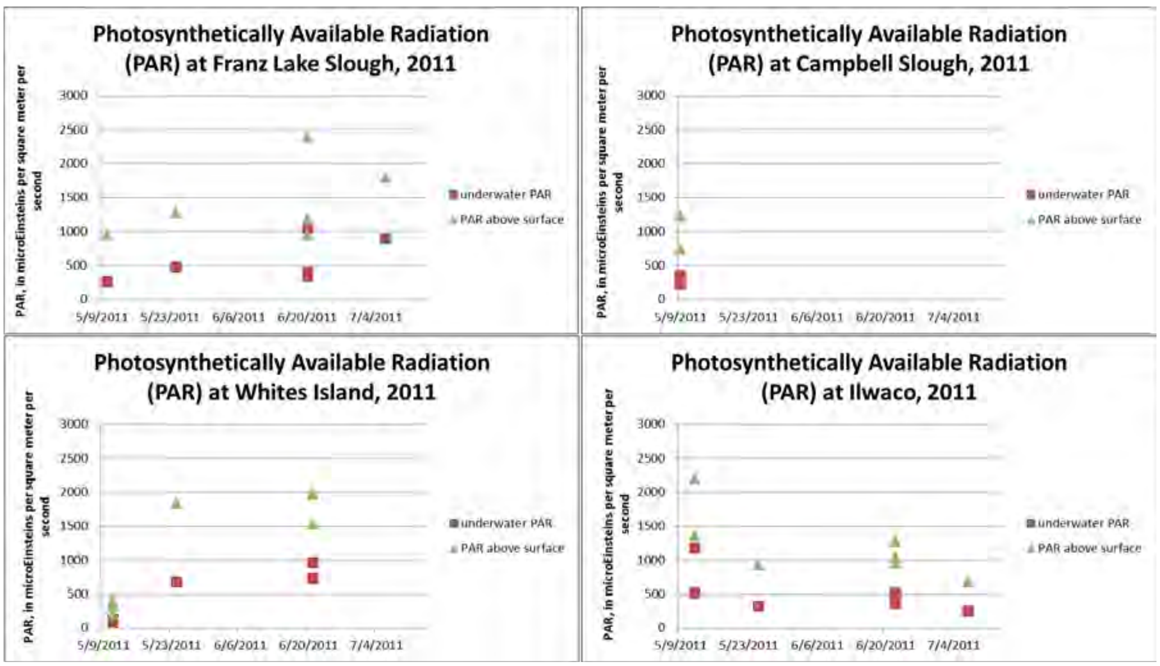


Figure 64. Photosynthetically available radiation (PAR) measured at one-half to one foot beneath the water surface and directly above the water surface.

Algal Biomass

2010–11: Campbell Slough

The concentration of chlorophyll *a* is a common estimator of algal biomass (Hambrook Berkman and Canova, 2007). Phytoplankton biomass measured as chlorophyll *a* concentration at Campbell Slough was similar in May 2010 and 2011 (Figure 65). In 2010, chlorophyll *a* was undetectable during the high water stage in late June, but increased in July to a concentration exceeding that measured in May. In 2011, phytoplankton biomass was greater in June than in May. Only one periphyton biomass value is available from each year because not much appropriate substrate was available at the site. However, the two points are consistent with the phytoplankton results in that the chlorophyll *a* concentration from the July sample (2010) is much greater than that of the May sample (2011).

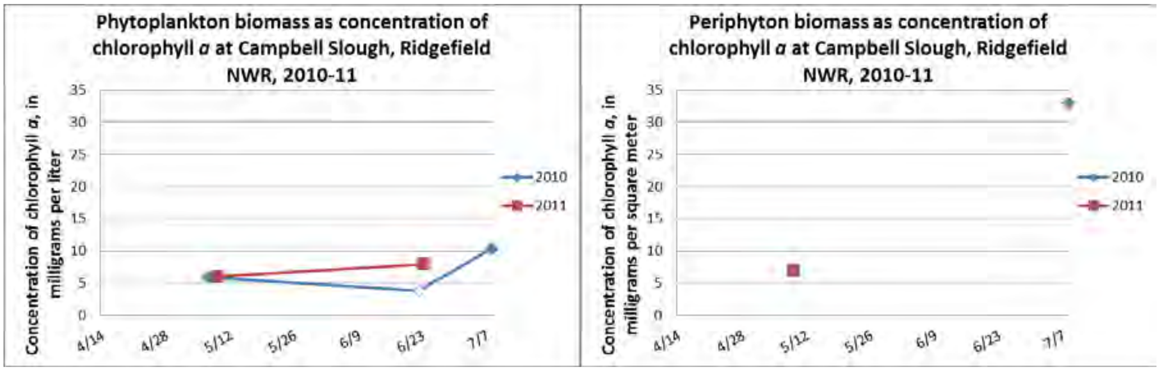


Figure 65: Algal biomass, measured as chlorophyll *a* concentration, at Campbell Slough, Ridgefield NWR, WA, 2010–11, (A) phytoplankton, and (B) periphyton. Concentrations that were not detected at the reporting limit are shown at the reporting limit and represented by outlined symbols.

2011

In 2011, algal biomass showed no distinct pattern over time or among sites (Figure 66). At Franz Lake Slough, phytoplankton and periphyton biomass decreased over the sampling season. Phytoplankton biomass increased from May to June at Campbell Slough; only one periphyton biomass datum is available. Periphyton concentrations were consistently high at Whites Island, and increased overall during the season. However, phytoplankton concentrations were never detectable at that site. In April, the tidal channel at Ilwaco had the highest phytoplankton concentration measured at any site, but the concentrations were undetectable later in the season. Similar to Whites Island, high periphyton concentrations were measured at Ilwaco during all three sampling events. Because of the strong tidal action at these two sites, phytoplankton could have been produced, but flushed out of the system between sampling events. Alternately, the strong tidal action and nutrient conditions at the two sites may favor the production of periphyton over phytoplankton.

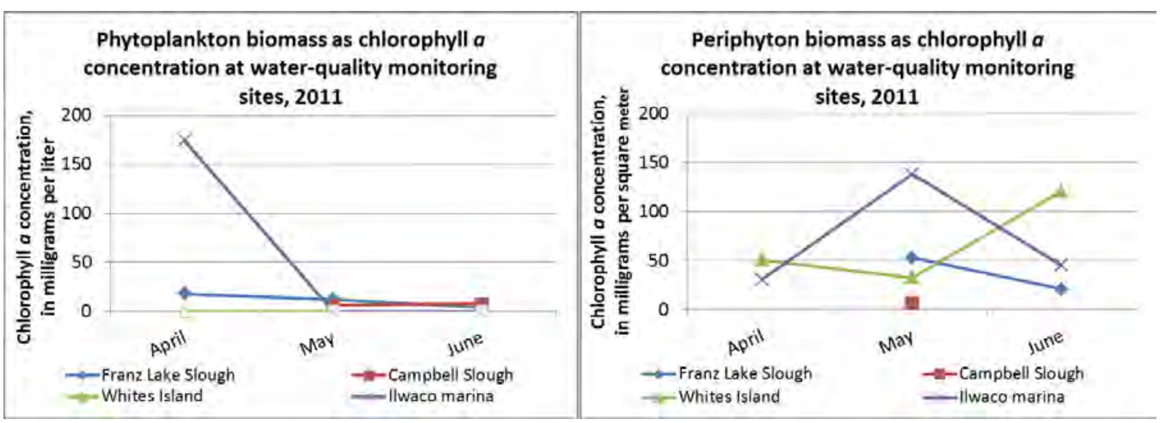


Figure 66. Algal biomass, measured as chlorophyll a concentration, from all four water quality monitoring sites in 2011: (A) phytoplankton, and (B) periphyton.

Algal Productivity Rates

Periphyton Productivity: Periphytometer Experiments

Data from the 2011 periphytometer experiments were not available when this report was written. Results from the 2010 periphytometer experiments in Campbell Slough were not available for the 2010 report, so they are presented here.

In 2010, periphytometers were deployed three times in Campbell Slough: once each in May, June, and July. However, the periphytometers deployed during June could not be analyzed because the site was not accessible for nearly a month and the glass-fiber filters were too degraded to analyze.

Periphytometers were placed directly on the substrate at the bottom of the water column in Campbell Slough at the intersection of the main channel and the ponded area. They were positioned so the filters were perpendicular to the substrate and parallel to the major axis of flow of the slough. Each periphytometer consisted of three nutrient-enrichment treatments (nitrogen [N], phosphorus [P], and N+P), and one ambient control. In 2010, screened and unscreened accrual rates were found not to be significantly different from one another, so these treatments were pooled for analysis.

Estimates of mean productivity for the May samples were 0.832, 1.31, 0.812, and 1.47 mg chlorophyll-*a*/m^2/day for C, N, P, and N+P, respectively (Figure 67) with standard deviations of approximately 0.50. Mean productivity estimates for July samples were 1.59, 3.08, 1.06, and 4.79 mg chlorophyll-*a* /m^2/day for C, N, P, and N+P, respectively. Variation in the N+P samples was, on average, 4.5 times greater than the other treatments.

The May samples had lower productivity compared to the July samples, reflecting seasonal variability. Although the difference in productivity among treatments collected in May seem small, results from the ANOVA indicated that the means are significantly different (p=0.01). The only significant difference among treatment pairs observed using the Tukey Honestly Significant Difference test was between the control and N+P treatments. This suggests that co-limitation was occurring. Single nutrient limitation was not occurring since the N and P treatments alone did not differ from the control. Results from the ANOVA of the July samples also indicated a significant difference among the means ($p=1.92 \times 10^{-6}$). There were many more differences among treatments from the July samples. Only two comparisons were not significantly different from each other: control versus P and N versus N+P. Therefore, periphyton growth remained co-limited by nitrogen and phosphorus in July, but nitrogen on its own also became limiting. Under these conditions, additional nitrogen in the water column would have increased periphyton growth rates, while additional nitrogen and phosphorus together would have had an even greater effect.

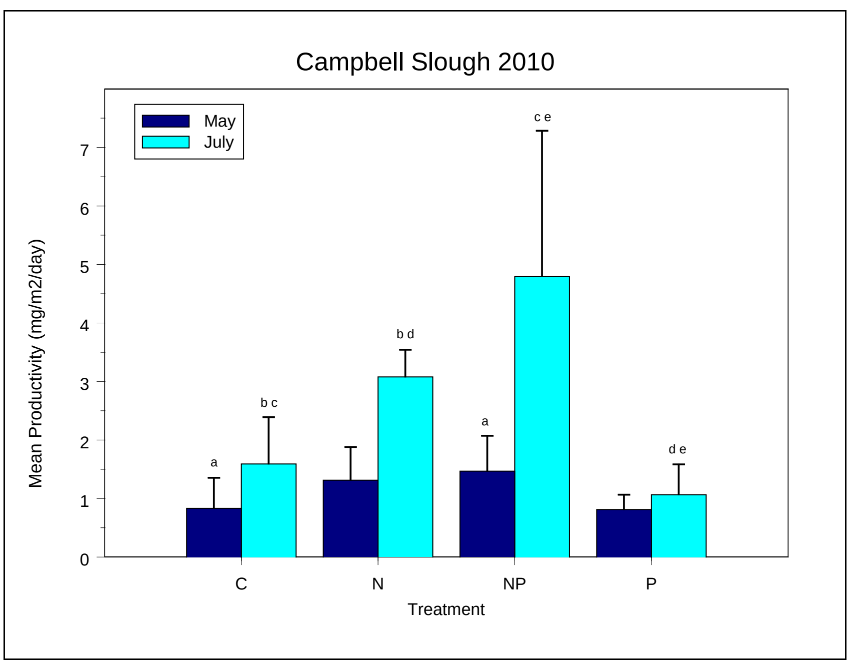


Figure 67. Mean periphyton production estimates for Campbell Slough in 2010 from the

periphytometer experiments. Estimates are based on 8 samples per treatment. Similar letters above error bars indicate a significant difference determined by Tukey's method on log transformed data (alpha = 0.05).

Phytoplankton Productivity: 14C Uptake Experiments

Results from the 2011 phytoplankton productivity experiments were not available for this report.

Stable Isotope Ratios of Algae, Plants, Insects, and Juvenile Salmonids

Stable isotope data were not available for this report.

4.4.5 Discussion

One of the key reasons for studying these sites is to learn more about their function as off-channel habitat for salmonids. In 2011, all four sites experienced periods of "poor" water quality with respect to conditions for salmonid health, although the duration of poor water quality periods varied among sites. Warm water (water temperatures greater than 17.5° C), low dissolved oxygen (less than 8 milligrams per liter [mg/L]), and high pH (higher than 8.5) create stressful conditions for salmon and are thresholds set by the State of Washington to protect salmonid spawning, rearing, and migration (Washington Department of Ecology, 2011).

In 2011, water quality parameters at Franz Lake Slough appeared to be influenced by inputs from Franz Lake and the Columbia River from April to the beginning of May, and then primarily influenced by the high waters of the Columbia River from mid-May through July. Conditions appeared to be hospitable for salmonids throughout much of the 2011 monitoring season, with cool water and high dissolved oxygen concentrations until July. At times, daily minima of dissolved-oxygen concentration were less than the standard starting in late May. Dissolved oxygen was acceptably high during at least half the day on most of those days, although the dips fell below the standard threshold for increasingly longer periods of the day as the season progressed. During the spring, peak daily pH reached levels that could have been stressful to salmonids. The high pH and its strong daily oscillations at this time probably reflect a period of high primary productivity at the site; this site had the highest phytoplankton concentration (as chlorophyll *a*) in April, slightly lower concentration in May, and lowest in June. Oppositely, nutrient concentrations trended upward during the three samplings (early May, late May, late June), except nitrate, which peaked in late May. During the early May algal sampling, this site had the highest phytoplankton (as chlorophyll *a*) concentration and the second-highest periphyton concentration (as chlorophyll *a*) among the four sites. Salmonids were not caught at this site in during the water quality monitoring period in 2011, although it was not sampled for fish until July 26. Coho and Chinook salmon were caught at this site in October and December 2011, after the water quality monitoring had ended for the year. In the spring and early summer of 2011, this site did not provide off-channel conditions to the extent that would be expected in lower-water years, since the channel banks were overtopped and the river connected laterally with the slough throughout the monitoring period (Figure 47). However, the stream velocity was observed to be slower in the slough area than in the main river channel during sampling trips, so the slough may have offered some refugia to juvenile salmonids, even if not to the same extent that it would during lower water levels.

Water quality conditions at Campbell Slough in 2011 were acceptable for salmonids during most of May, aside from a few daily minimum dissolved oxygen concentrations that were less than the Washington state standard of 8 mg/L. More than 30 juvenile Chinook were found in Campbell Slough on May 4. However, consistently low dissolved oxygen concentrations throughout June would have made the site inhospitable for salmonids. In July, as water levels dropped and stagnant water was flushed out of the slough, tidal flushing brought dissolved oxygen concentrations up to acceptable levels during parts of the day. However, lower water levels and seasonal warming brought water temperatures consistently above the Washington standard of 17.5° C for nearly all of July. No salmonids were caught at the site when it was fished on July 25. During the two nutrient sampling dates at this site (weeks of May 9 and June 20), Campbell Slough had the highest total nitrogen and total phosphorus concentrations among the sites. Concentrations were greater in June than in May for both nutrients. This was the only site that had detectable phytoplankton (chlorophyll *a*) concentrations every time it was sampled (early May and late June). During the July 6 visit, the density of visible phytoplankton in the water column was greater than was observed at any of the sampling sites during the monitoring period, although no quantitative sample was collected. Results of the periphytometer experiments in 2010 are consistent with measured periphyton and phytoplankton concentrations from Campbell Slough in 2010–11 in terms of seasonality; ambient periphyton productivity (measured from the control treatment of the periphytometer experiment) was approximately two times greater in July than in May, and measured algal biomass (as chlorophyll *a*) was greater during the early summer than during the spring. The 2010 periphytometer results indicated that periphyton were co-limited by nitrogen and phosphorus during May, and that nitrogen alone also became limiting during July. This is consistent with the ambient nutrient concentrations measured at the site; nitrate concentrations that were available earlier in the spring decreased by early summer. Even though by summer, concentrations of orthophosphate, the bioavailable form of inorganic phosphorus, had increased from being undetectable early in the spring, the increase appeared not to be sufficient to meet the demand of the greater periphyton biomass later in the season, as co-limitation of nitrogen and phosphorus remained in July.

Whites Island had the best water quality conditions for juvenile salmonids among the sites during the monitoring period. During most of the monitoring period for which there are data at Whites Island, the water was cool, well-oxygenated, and moderate in pH. Only in late July did any of the parameters at that site violate the Washington water quality standards; daily maximum temperature and minimum dissolved oxygen went beyond the standards. However, dissolved oxygen concentrations were acceptable during most of the day, even when the daily minimum was below the standard. Water temperature fluctuated typically in the range of 16.5 to 17.9° C during July. This is the only water quality monitoring site where salmonids were caught every time it was fished[8] and where the most salmonids were caught, perhaps because of the good water quality conditions and the proximity to the main stem of the river. Juvenile Chinook were found at the site on May 3, May 31, June 27, and July 28, every time during the monitoring period when fish sampling occurred. Phytoplankton concentrations (as chlorophyll *a*) were not detectable during any sampling (early May, late May, and late June), perhaps due to the frequent tidal flushing. However, periphyton was measureable during each sampling, with the highest chlorophyll *a* concentration in late June.

The tidal channel at Ilwaco is obviously the most tidally influenced site. Despite large daily variations, water quality parameters were relatively seasonally consistent. Water temperatures were generally cool from mid-April through mid-June, despite fairly regular brief peaks above 17.5° C; the standard was violated daily starting in early May. Dissolved-oxygen concentrations were high during April. By May, dissolved-oxygen concentrations were below the standard for approximately half of each day. Daily variation in dissolved oxygen and temperature increased in June and July, with daily minimum dissolved oxygen averaging 2.9 mg/L and maximum temperature averaging 22.7°C in July. During June and July, temperatures peaked above 25°C, creating conditions that are very stressful to salmonids. At low tide, this channel becomes very shallow (Figure 68), especially during the summer, so the high temperatures and low dissolved oxygen would be expected. When the tide is low, connectivity to the main river (in Ilwaco) is poor (Figure 57), and fish (species undetermined) were observed trapped in the channel and in small pools throughout the mudflat. Shaded refugia is practically non-existent during low tide. NOAA's fish sampling took place during high tide. One juvenile Chinook was caught at this site on May 31. Chums

[8] However, Franz Lake Slough could not be sampled for fish until late July, so the presence of salmonids earlier in the season at that site is unknown.

were caught at the site on April 4. The site was also fished on May 3, June 27, and July 25, but salmonids were not caught on those dates. The periphyton concentration (chlorophyll *a*) peaked in May, approximately 2.5 times greater than the concentration at the next-highest site. However, the phytoplankton concentration peaked in April, nearly nine times greater than at the next-highest site.

Figure 68. Photo of the Ilwaco water quality monitoring site, taken June 22, 2011 at low tide. At the deepest part of the channel, the water is less than one foot deep.

Bottom and others (2005) concluded that changes to habitats and the food web in the Columbia River estuary have changed its capacity to support juvenile salmonids. They note that restoration of estuarine habitats, especially diked emergent and forested wetlands, could significantly increase that capacity, but the lack of information on the habitat conditions and use by juvenile salmonids necessitates comprehensive, long-term monitoring in order to appropriately design restoration plans (Bottom and others, 2005). Monitoring at the four fixed EMP sites is designed to provide information about the trends in biological, physical, and chemical characteristics of tidally influenced emergent wetland habitats used by juvenile salmonids for rearing and refugia in the lower Columbia River and estuary in order to address those data gaps and to improve restoration planning. Since 2011 was the first year of water quality monitoring and primary productivity assessments at three of the sites, data in this report instead provide a one-year status assessment of conditions at those sites and begin forming the dataset from which trends can be assessed in time. Even at Campbell Slough, the fixed site that has been monitored for water quality for the longest period, too few years of data have been collected to determine any trends. The multi-year dataset from Campbell Slough shows annual variability in water quality parameters during years with different hydrologic and weather conditions and demonstrates the need for long-term data in order to determine water quality trends, just as several years of data will be required to draw any conclusions from the food web assessment.

4.5 Phytoplankton and Zooplankton

4.5.1 Introduction

The Columbia River is the second largest ‘big river’ system (by discharge) in the United States with a watershed size of 660,480 km^2 (Simenstad et al., 1992). It is the largest source of freshwater to the northeast Pacific Ocean (Simenstad et al., 1990) and provides critical habitat and passageway for many organisms, including federally endangered species such as Chinook salmon and steelhead trout. Within the Columbia River basin, 13 species of salmon and steelhead and native stocks (bull trout and sturgeon) are listed for protection under the Endangered Species Act. Because of its ecological and cultural significance, the Columbia River has been identified by the Environmental Protection Agency (EPA) as one of the nation's great water bodies, making its protection a national priority. As the fifth most densely populated watershed in the nation, the Columbia River basin has been strongly impacted by changes in land use, the construction of dams, and by inputs of legacy and emerging contaminants that accompany urbanization (Simenstad et al., 1992; Naiman and Bilby, 2001).

In addition to physical changes in habitat, major changes in the riverine food web are thought to have accompanied the installation of dams along the mainstem Columbia, significantly altering the productivity regime from one based on emergent vegetation to one dominated by pelagic, or fluvial phytoplankton (Sherwood et al., 1990; Small et al., 1990; Bottom et al., 2005). In particular, river flows have been altered in their timing and magnitude due to dam construction, channel diversion, irrigation, and dredging, resulting in a decreased overall river discharge and dampened seasonal flow variability (Sherwood et al., 1990). The peak flow of the Columbia River occurs in the late spring during the freshet and its lowest flow occurs in the late summer to early autumn. Due to the presence of dams, a high-turbidity, detritus-driven river ecosystem has given way to a much 'greener' river, where pelagic primary production (i.e., fluvial phytoplankton) has increased as a result of a reduced sediment load and longer water residence time behind the dams (Sullivan et al., 2001). Thus, the food web is dramatically different today than it has been historically, with a reduction in production associated with emergent marshes and an increase in the contribution by fluvial phytoplankton (Simenstad et al., 1990; Bottom et al., 2005). Bottom et al. (2005) concluded that loss of estuarine habitat has reduced rearing opportunities for subyearling Chinook salmon (*Oncorhynchus tshawytscha*). In particular, removal of wetland and shallow water habitats and flow regulation by dams are thought to have contributed to the loss of important habitats for Chinook salmon and potentially reduced the diversity of salmon life histories in the estuary. It is thought that a reduction in diversity of life histories in the estuary may undermine the resilience of populations to changing environmental conditions that may accompany climate change or changes in land use practices (Healy, 1991; Thorpe, 1994).

Phytoplankton and zooplankton are important components of the diet of salmon prey, including chironomids (dipteran insects of the family Chironomidae) and benthic amphipods [*Corophium* spp. (Lott, 2004), *Americorophium* spp. (Bottom et al., 2008)], which together comprise ~90% of the diet of juvenile Chinook salmon in the Columbia River estuary (Lott, 2004). Recently, multiple isotopic evidence showed that phytoplankton are an important component of the food web supporting salmon, with fluvial phytoplankton accounting for up to 60% of organic matter assimilated by chironomids and 40% of that assimilated by *Corophium* in March-April (Maier and Simenstad, 2009). A shift toward a greater contribution to vascular plant detritus and benthic diatoms as the dominant organic matter sources supporting chironomids was observed in June and July, respectively (Maier and Simenstad, 2009). Similar to the chironomids, the benthic amphipod *Corophium* consumed higher proportions of fluvial phytoplankton in March-April, while between June and August, the dominant organic matter source was vascular plant detritus.

Although they have important implications for the restoration of critical salmon habitats, the major factors that modulate primary productivity and species composition of phytoplankton are poorly known, both in the mainstem river and among the braided channels and sloughs. Quantifying the contemporary contribution of phytoplankton to the food web is thus essential for defining the status, function, and health of the Lower Columbia ecosystem. The EMP carried out through the Estuary Partnership seeks to fill this critical gap in our knowledge of food web structure and its spatio-temporal dynamics to more strongly link assessments of physical habitat opportunity with evaluations of habitat capacity to yield a holistic picture of environmental factors driving salmon condition and population dynamics.

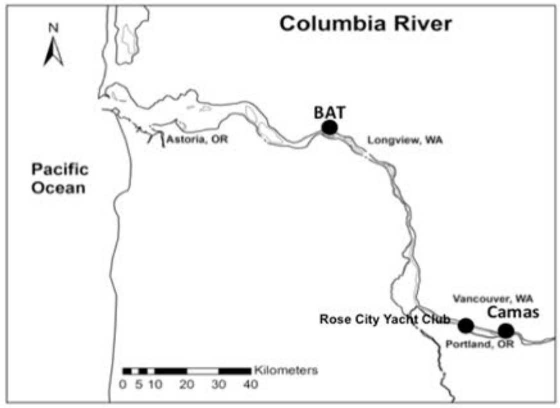


Figure 69. Map of the Lower Columbia River showing the location of moorings outfitted with suites of sensors that collect continuous high-resolution water quality data (BAT=Beaver Army Terminal; Rose City Yacht club, Portland, OR). The mooring at the yacht club will be installed in early 2012.

Bottom et al. (2008) recommended further investigations of tidal freshwater habitats in the Lower Columbia, which this program fulfills through the repeated sampling of sites between Franz Lake and Ilwaco. This report provides critical information about phytoplankton and zooplankton standing stocks and species composition, which, together with other components of the salmon diet including macroinvertebrates and submerged aquatic vegetation, will improve our ability to assess habitat quality for important fish species, primarily salmon.

4.5.2 Methods

Context

The characterization of lower food web components (phytoplankton and zooplankton) through the EMP is being conducted alongside continuous high-resolution measurements of water quality parameters that will yield contextual information and provide clues about the controls on primary production. One continuous, high-resolution water quality monitoring observation station was in place in 2011 at Beaver Army Terminal near Quincy, Oregon. A second station, established through the EMP will be installed in early 2012 at the Rose City Yacht Club (Portland, Oregon) (Figure 69) to yield essential corresponding data from a site that is upstream of the Willamette-Columbia confluence. The mooring systems used in this project are the Land Ocean Biogeochemical Observatory (LOBO) moorings (Jannasch et al., 2009) and include sensors for temperature, conductivity, dissolved oxygen, chlorophyll a, turbidity, and nitrate.

The main goal of the collective body of observations resulting from the EMP is to provide contemporary status assessments (how are estuary and tidal freshwater habitats doing now?) and trend analysis (how are estuary and tidal freshwater habitats doing in the big picture?).

Sites

Samples were collected from four sites in the lower Columbia River in order from most seaward to furthest upstream: Ilwaco (near Ilwaco Harbor in Baker Bay), Whites Island (Birnie Slough), Campbell Slough (in Ridgefield National Wildlife Refuge), and Franz Lake, upstream of the city of Portland on the Washington side of the Columbia River (Fig. 2; Table 30). The samples were collected by wading into the water at the Ilwaco, Campbell Slough, and Franz Lake sites, while a boat (Boston whaler) was used to sample the waters of Birnie Slough on Whites Island. Most of the samples for plankton identification and enumeration were collected by United States Geological Survey (USGS) personnel alongside those collected for their primary production work. It should be noted that high water levels encountered in spring 2011 precluded sampling at Campbell Slough (Ridgefield National Wildlife Refuge) until late

May, and thus data are not reported until later in the spring compared to the other sites.

The sites selected for the study were all shallow water habitats in the Lower Columbia River. Juvenile salmon have been shown to have fuller stomachs within peripheral bays and intertidal areas compared with deeper, pelagic habitats (McCabe et al., 1986; Bottom and Jones, 1990).

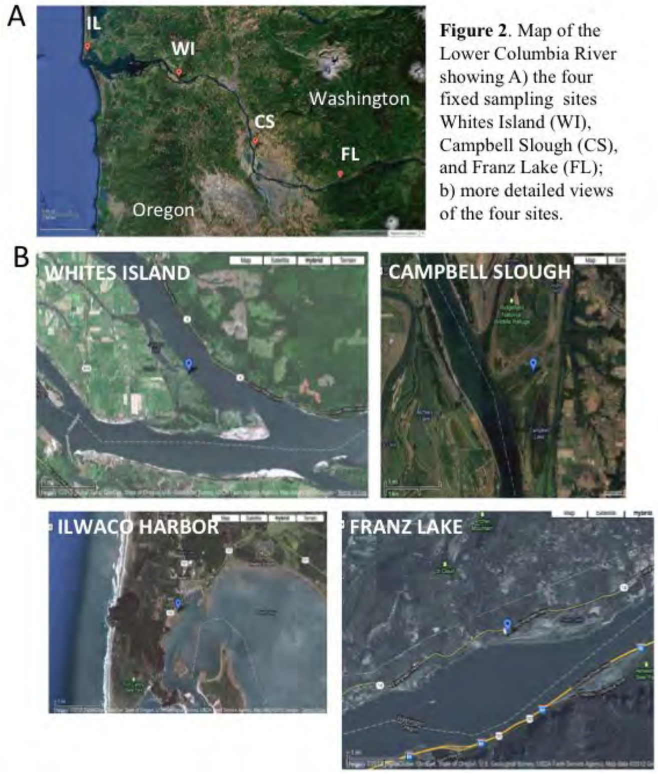


Figure 2. Map of the Lower Columbia River showing A) the four fixed sampling sites Whites Island (WI), Campbell Slough (CS), and Franz Lake (FL); b) more detailed views of the four sites.

Table 30. List of the fixed EMP sampling sites in 2011, their location, and type of access for lower food web sampling.

Site name	Location	Access type	Latitude	Longitude
Ilwaco	West of Ilwaco marina, Baker Bay, WA	By foot	46^{o}18’02	124^{o}02’44
Whites Island	Birnie Slough	By boat	46^{o}09’39	123^{o}20’16
Franz Lake	Franz Lake, WA	By foot	45^{o}36’05	122^{o}06’00
Campbell Slough entrance	Ridgefield National Wildlife Refuge, WA	By foot	45^{o}47’05	122^{o}45’15

Phytoplankton

Whole water samples were collected for identification and enumeration of phytoplankton from the sites identified above. For each sample, 100 ml was collected in duplicate and preserved immediately with Lugol’s iodine (final concentration ~1%). The samples were placed in a cooler with ice packs and transported back to the laboratory for processing and subsequently stored in the dark at room temperature.

For identification and enumeration, 10-25 ml sub-samples were concentrated using the Utermohl settling method (Utermohl, 1958). Briefly, each 100 ml whole water sample was gently inverted ~100 times and poured into a settling chamber and left for 24 h. After 24 h, the supernatant was discarded and the concentrated cells were enumerated using an inverted light microscope (Leica DMIL). At least 400 cells per sample were enumerated in at least five fields of view. Observations were made at 200 or 400x magnification, with an additional scan performed at 100x magnification to capture rare cells in a broader scan of the slide. An error estimate was derived by performing a sub-set of duplicate counts. The estimated error in abundance was < 5% at the class level, and ~10% for genus-level counts. The concentrated material was then transferred to small (7 ml) sampling vials for archiving and more detailed examination of acid-cleaned material. The archived samples were not examined during this part of the study; it is recommended that a detailed survey of the diatom populations be undertaken on a sub-set of samples for 2011 and in future years to provide a snapshot of phytoplankton biodiversity at the time of peak phytoplankton biomass.

Zooplankton

Due to the lower abundance of zooplankton compared to the smaller phytoplankton, zooplankton samples were first concentrated through the use of an 80 μm nylon mesh net with a mouth diameter of 0.5 m and a length of 2 m. When possible, the net was fully submerged under the water and was dragged back and forth (by hand) through the water for ~5 min. A flow meter (General Oceanics Inc., Model 2030R) was mounted to the net's bridle to provide an estimate of the volume flowing through the net. Unfortunately, the flow meter was not available until the late-May sampling dates; therefore, abundances of zooplankton can only be estimated for the dates sampled in April and early May 2011. Estimates of volume were made based on an approximation of the distance covered during the tow (where the person sampling walked back and forth, towing the net through the water), multiplied by the volume of a cylinder, according to: total volume = ($\pi r^2 h$)*distance or total volume = ($\pi D^2 h$)*distance, where r = radius and D = diameter of the net opening.

When the flow meter was used, the volume examined (Table 31) was calculated by determining the volume of water passing through the net by knowledge of the distance of water passing through the net, the velocity of the water passing through the net, and the volume of water passing through the net, as calculated from both the distance traveled and the net diameter, as described in the flow meter manual. The distance covered (in meters) was determined from:

$$Distance = \frac{Difference\ in\ counts \times Rotor\ Constant}{999999} \quad (1)$$

where the difference in counts refers to the difference between the initial and final counts on the six-digit counter, which registers each revolution of the instrument rotor. The speed is calculated from:

$$Speed = \frac{Distance\ in\ meters \times 100}{Time\ in\ seconds} \quad (2)$$

The volume is determined as:

$$Volume\ in\ m^3 = \frac{3.14 \times net\ diameter^2 \times Distance}{4} \quad (3)$$

For each net tow, the volume of material collected in the cod end of the net was recorded. From this, a concentration factor was calculated, and a final estimate of the volume examined (shown in Table 30) was determined by multiplying the concentration factor by the final volume of concentrated sample examined under the microscope.

Table 31. List of samples examined between April and July 2011. The volume examined is indicated for both phytoplankton and zooplankton. Details describing the respective concentration procedures are found in the Methods section. N/A indicates that actual volumes were not measured prior to acquiring a mechanical flow meter. Estimated volumes were computed (Appendix D), but likely have poor accuracy and are thus not reported here. Samples noted with an asterisk will be analyzed following the submission of this report.

Date	Site	Phytoplankton		Zooplankton	
		Analyzed	Vol examined (l)	Analyzed	Vol examined (l)
4/4/11	Ilwaco			X	N/A
4/12/11	Ilwaco	X	25	X	N/A
4/13/11	Whites Island	X	10	X	N/A
4/14/11	Franz Lake	X	10	X	N/A
4/25/11	Ilwaco	X	25		
4/25/11	Whites Island	X	10	*	
4/26/11	Franz Lake	X	10	*	
5/9/11	Campbell Slough	X	25	X	N/A
5/10/11	Franz Lake	X	10	X	N/A
5/11/11	Whites Island	X	10	X	N/A
5/12/11	Ilwaco	X	25	X	N/A
5/24/11	Franz Lake	X	25	X	106.0
5/24/11	Whites Island	X	10	X	37.4
5/25/11	Ilwaco	X	10	X	81.8
6/20/11	Franz Lake	*		X	20.6
6/21/11	Whites Island	*		X	56.7
6/22/11	Ilwaco			X	N/A
6/23/11	Campbell Slough	*		X	1.5
7/6/11	Franz Lake	*		X	38.5
7/6/11	Campbell Slough	*		X	15.0
7/7/11	Whites Island	*		X	15.3
7/7/11	Ilwaco	*		Sample lost	N/A

4.5.3 Results

2011 Hydrography

Daily river discharge volumes recorded at Beaver Army Terminal (provided by a U.S. Geological Survey's flow gauge) for 2011 are shown in Figure 70. The daily discharge volume (in kft^3 s^{-1} or kcfs) was maximal in early-mid June, indicative of the glacier-fed freshet, and also in the winter months (January-February), where rainfall typically drives localized high flows. Corresponding values of chlorophyll *a* (chl *a*) as estimated by an in situ fluorometer mounted as part of the sensor suite of the Land-Ocean Biogeochemical Observatory (LOBO) at this site show a corresponding decline of pelagic, or fluvial, phytoplankton when discharge volumes are high. An inverse relationship between chl *a* and discharge is consistent with observations in other years using the same methodology (Maier et al., in preparation) and in other programs (Sullivan et al., 2001) where less frequent (monhtly) observations were made. The inverse relationship likely results from dilution, where the fast-moving water does not allow enough time for the phytoplankton to grow before being carried downstream, in addition to effects of reduced light availability that accompany the high turbidity characteristic of high discharge volumes. The 2011 freshet was larger than the climatological mean (1999-2008), with a maximum value of approximately 580 kft^3 s^{-1} observed in early June. The timing of the freshet, however, was similar to other years (Figure 71). Notably, the pre-freshet phytoplankton peak was much larger than the peaks observed after the freshet in June and July.

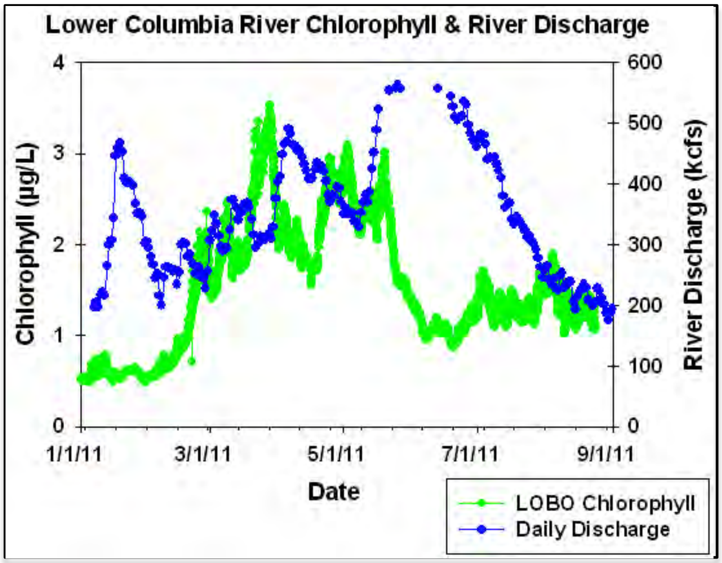


Figure 70. Daily discharge volumes (kft^{3}s^{-1}) in 2011 (January – October) and corresponding chlorophyll *a* fluorescence values (indicative of phytoplankton biomass) determined by hourly measurements made from an in situ chlorophyll fluorometer (WetLABS Inc.).

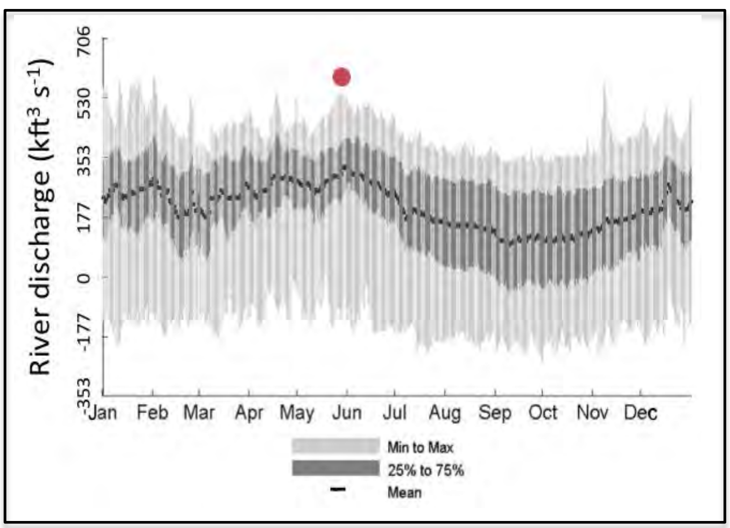


Figure 71. Climatology of daily discharge volumes (kft^{3}s^{-1}) from Jan 1999-Dec 2008 from Beaver Army Terminal (data from U.S. Geological Survey, reprocessed for climatology by Center for Coastal Margin Observation and Prediction). Red dot indicates the maximum river discharge volume observed at Beaver during the April – July sampling period (early June 2011).

Phytoplankton species composition and abundance

Similar to findings reported in other studies (e.g. Sullivan et al., 2001), the phytoplankton assemblage was dominated by diatoms (Class Bacillariophyceae) throughout the study period (Figure 72). The abundances (cell L^{-1}) of diatoms are listed in Table 3. One exception where diatoms did not dominate the assemblage was at Campbell Slough (Ridgefield National Wildlife Refuge) in June-July when numerous colonial cyanobacterial species in June and July were observed, many of which are known toxin producers. These samples have not yet been enumerated or analyzed in full since the number of phytoplankton samples was initially determined to be fewer than zooplankton. However, given the potential importance of the late spring/early summer assemblage, as well as the potential threat from toxigenic cyanobacterial species entering the food web, these samples will be analyzed following the submission of this report. The summer data will be included in the overall data analysis and synthesis in future. Interestingly, cyanobacterial blooms are a known problem in Vancouver Lake (Boyer et al., 2011), which is connected to the Columbia through Lake River and Campbell Lake/Campbell Slough. Therefore, it is likely that the origin of the high cyanobacteria abundances came from Vancouver Lake.

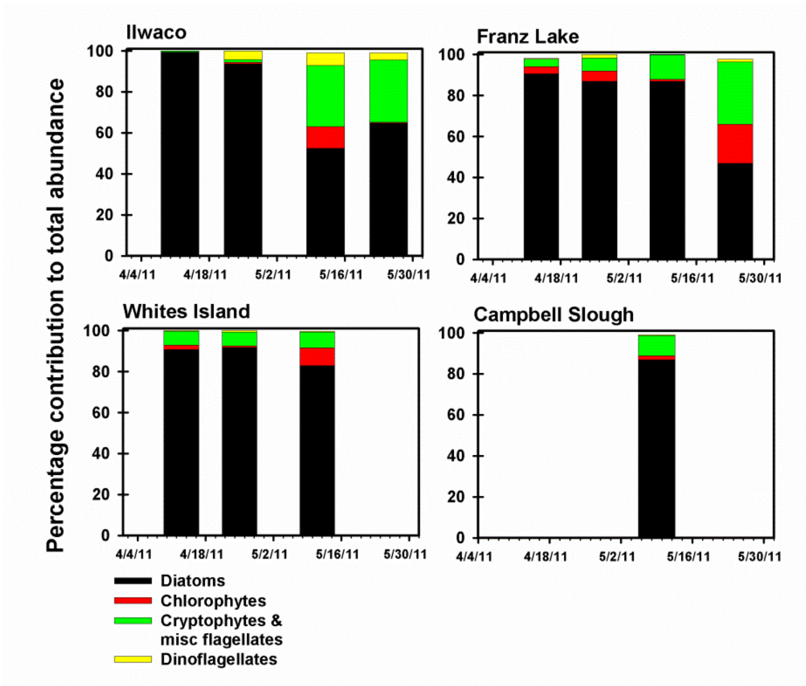


Figure 72. Percent contribution by dominant taxa to total phytoplankton abundance.

Ilwaco differed from the other sites in the presence of marine or estuarine species, including *Pseudo-nitzschia* spp. and *Myrionecta rubra*, and a variety of poorly pigmented pennate diatoms (mainly *Acnanthes* spp., *Navicula* spp., and *Nitzschia* spp.), likely associated with the benthos. Empty diatom frustules were particularly abundant in late May as river discharge volumes began to increase. In general, abundances of phytoplankton were lower at Ilwaco than at the freshwater sites (Figure 73) with empty diatom frustules (silica shells) present in high numbers. Greater abundances of ciliates, annelid worms and foraminifera (Rhizaria) were also observed at this site relative to the other freshwater sites.

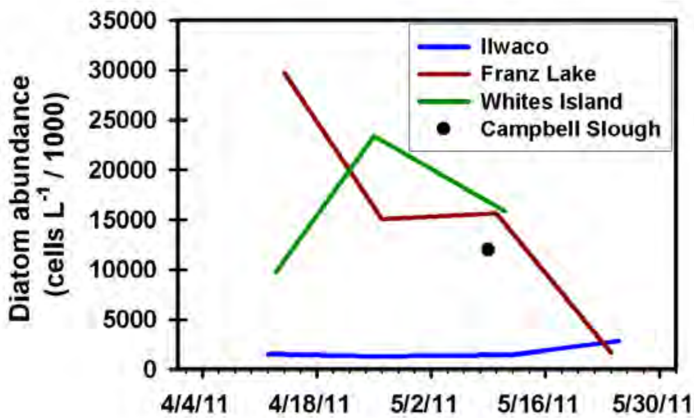


Figure 73. Abundances (in cells L^{-1}) of total diatoms at each of the four sites where data are available.

A comparison of the dominant diatom abundances determined at Beaver Army Terminal in a concurrent study (Maier et al., in prep.) with those at nearby Whites Island (Birnie Slough) suggests that abundances can be ~10 times higher in the shallow water environments compared to the mainstem (data not shown) when the river discharge volumes are relatively low (i.e., not during the freshet). It is hypothesized that when discharge increases, the shallow water environments may be flushed, and fluvial phytoplankton can be exported into the mainstem river. This is based on the observation that differences between diatom abundances in shallow water habitats and the mainstem river at BAT were larger when river flows were of smaller magnitude relative to the rest of the time series.

The highest abundance of diatoms was observed at Franz Lake in mid-April where the assemblage was dominated by *Stephanodiscus* spp. At Franz Lake an apparent decline in the number of diatoms was observed between early and late spring, which may have been occurring at Whites Island (Birnie Slough) as well, but sufficient data points were not obtained to confirm this.

Although not recorded explicitly, parasitism of the dominant diatoms *Asterionella formosa*, *Aulacoseira granulata*, and *Fragilaria crotonensis* by zoosporic (chytrid) fungal parasites was commonly observed in the samples from Whites Island and Franz Lake. Parasitism of diatoms by chytrid parasites is routinely observed in samples collected from Beaver Army Terminal (Maier et al., in preparation), with unknown consequences for partitioning of organic carbon into detrital versus fluvial phytoplankton components of the food web. Figure 7 shows images of infected cells, which are readily apparent when examined at 200 or 400x magnification.

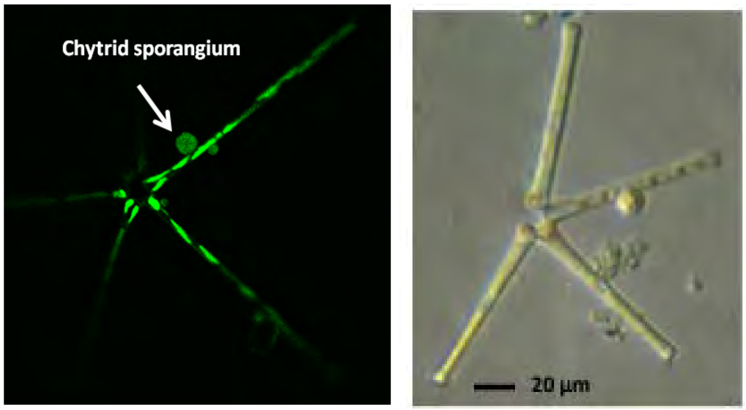


Figure 74. Images showing evidence for zoosporic chytrid infections of the dominant fluvial primary producers in freshwaters of the Lower Columbia River. Shown are two images of Asterionella formosa with attached chytrid sporangia. A) fluorescence microscope image (Laser Scanning Confocal Microscope) showing sporangium stained with a f fluorophore specific for fungi; b) light microscope image showing loss of cell contents presumably due to infection (photo credit for B: M. Maier, OHSU)

Zooplankton

Zooplankton species composition and abundances showed distinct differences between the marine-influenced Ilwaco and the tidal freshwater sites (Whites Island, Campbell Slough, and Franz Lake). In particular, the relative abundances of rotifers were much lower in the marine-influenced reach (<10% of total zooplankton abundance) compared to the freshwater environments (Figure 75). Instead, copepods dominated the zooplankton biomass in Ilwaco at all times. Two other groups – the Rhizaria (mainly represented by foraminiferans) and the ciliates – were far more abundant at Ilwaco compared to the freshwater sites.

At Whites Island (Birnie Slough) and Franz Lake, rotifers dominated the zooplankton biomass in the early spring (April-May), where they accounted for >50% of total zooplankton abundances. Later on copepods and cladocerans contributed more to total zooplankton abundances at these sites, accounting for 40-70% (combined) of zooplankton biomass. Zooplankton biomass peaked in June at Franz Lake, but in May at Whites Island (Figure 76).

Between April and July, changes in the relative abundance of the dominant groups was observed at Whites Island and at Franz Lake. Smaller changes in the zooplankton composition were observed at Ilwaco. At the two tidal freshwater sites, a dominance of rotifers early in the season (April-May) gave way to a dominance of copepods and cladocerans in the summer (Figure 77). At Ilwaco, in contrast, copepods were always dominant, with a slight decline in proportional abundance observed in May-June when ciliates became more abundant. It is worth noting that ciliates are much smaller than copepods, and therefore their contribution to organic matter resources would not be as large as for the copepods, even if their abundances reached relatively high levels. Tables 4-7 give the relative abundance categories for each of the zooplankton taxonomic divisions. The categories were chosen in accordance with an earlier study of the Columbia River Estuary by Haertel (1967).

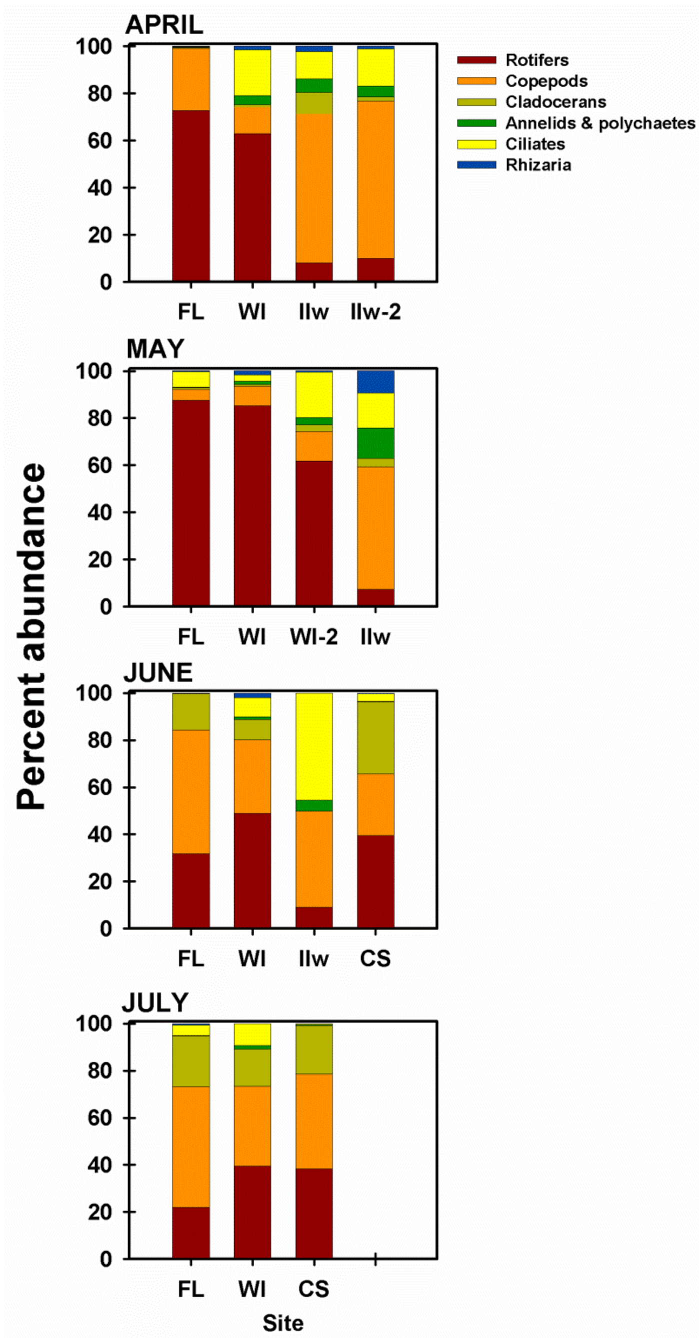


Figure 75. Percent abundance of six taxa of zooplankton in the Lower Columbia River: rotifers, copepods, cladocerans, annelids & polychaetes, ciliates, and Rhizaria. FL = Franz Lake, WI = Whites Island (Birnie Slough), Ilw = Ilwaco, CS = Campbell Slough (Ridgefield National Wildlife Refuge).

Table 32**.** Abundances of diatom taxa observed between early April and late May 2011 at fixed sites in the lower Columbia River. IL = Ilwaco, FL = Franz Lake, WI = Whites Island, CS = Campbell Slough.

Taxa	**IL 4/12**	**IL 4/25**	**IL 5/12**	**IL5/25**	**FL 4/14**	**FL 4/26**	**FL 5/10**	**FL 5/24**	**WI 4/13**	**WI 4/25**	**WI 5/11**	**WI 5/24**	**CS 5/09**
Acnanthes lanceolata	0	0	0	103,878	0	0	0	0	0	0	0	0	0
Acnanthes longipes	0	0	0	51,939	0	0	0	0	0	45,455	0	0	0
Acnanthes minutissima	0	0	0	0	3,380	0	0	0	0	0	0	0	0
Acnanthes (small)	0	0	0	934,903	0	0	0	0	0	0	0	0	0
Acnanthes spp.	23,214	0	0	17,313	0	0	0	0	9,286	90,909	166,667	27,778	40,000
Actinocyclus	0	0	0	0	0	0	0	0	0	0	0	0	0
Actinoptychus (small)	0	0	0	0	0	0	0	0	41,667	0	0	0	0
Amphora	0	14,444	0	0	0	50,000	0	13,000	0	0	0	0	0
cf. *Amphora*	0	0	0	0	0	0	0	0	0	0	0	0	0
Asterionella formosa	**97,500**	**57,778**	**138,889**	**398,199**	**1,100,000**	**277,160**	**5,863,000**	**0**	**2,321,429**	**19,208,333**	**11,958,333**	**8,125,000**	**8,000,000**
Asterionellopsis glacialis	0	0	0	1,000	0	0	0	0	0	0	0	0	0
Asteroplanus	0	0	166,667	0	0	50,000	0	0	0	0	0	27,778	0
Aulacoseira granulata	**32,500**	**0**	**0**	**69,252**	**67,600**	**0**	**770,714**	**0**	**120,714**	**590,909**	**1,708,333**	**2,277,778**	**2,580,000**
Aulacoseira sp.	0	0	0	0	100,000	0	0	0	0	0	3,600	0	0
Cocconeis	4,643	0	0	0	0	0	0	0	0	0	41,667	0	0
Cyclotella choctawhacheeana	0	0	0	0	0	0	0	0	125,000	0	0	0	0
*Cyclotella meneghenian*a	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Cyclotella spp.	13,929	3,611	111,111	225,069		0	8,300,000	923,000	195,000	1,159,091	416,667	777,778	240,000
Cyclotella/Thalassiosira	0	0	0	34,626	0	0	0	0	0	0	0	0	0
Cymatopleura	4,643	0	0	0	0	0	0	0	0	0	0	0	0
Cymbella	0	0	0	34,626	50,000	0	50,000	13,000	0	0	41,667	0	531
Cymbella affinis	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Cymbella proxima	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Cymbella turgidula	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Diatoma	0	0	0	0	0	0	0	0	0	0	1,000	0	0
Diatomella	0	0	0	0	0	0	0	0	0	0	41,667	0	0
Entomoneis	0	3,611	0	0	0	0	0	0	0	0		0	0
Epithemia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Eunotia sp.	0	0	0	0	3,380	0	0	0	0	0	0	0	0
Fragilaria crotonensis	**0**	**14,444**	**83,333**	**0**	**450,000**	**0**	**190,357**	**442,000**	**37,143**	**363,636**	**708,333**	**222,222**	**346,667**
Fragilaria intermedia/Navicula	0	0	0	0	200,000	0	0	0	0	0	0	0	0
Fragilaria sp.	18,571	0	0	17,313	253,500	100,000	150,000	0	0	45,455	0	0	0
Frustulia cf. *rhomboides*	0	0	0	605,956	100,000	0	0	0	0	0	0	0	0
Gomphonema lingulataeforme	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Gomphonema sp.	0	3,611	0	51,939	0	0	0	0	9,286	22,727	0	0	0
Gyrosigma/Pleurosigma	4,643	18,056	0	0	0	0	0	0	0	0	0	0	531
Hannaea arcus	0	0	0	0	0	0	0	0	9,286	0	0	0	0
Myrionecta rubra	27,857	0	0	0	0	0	0	0	0	0	0	0	0
Meloseira sp.	18,571	7,222	0	0	50,000	0	0	0	0	0	0	55,556	440,000

Meridion circulare	9,286	0	0	0	0	0	0	0	0	181,818	0	0	0
Meridion sp.	0	0	0	0	0	0	0	0	0	0	2,000	0	0
misc centric	4,643	0	0	0	50,000	0	0	0	208,333	68,182	125,000	0	0
misc pennate	9,286	43,333	111,111	69,252	0	50,000	50,000	0	41,667	181,818	400	27,778	40,000
Navicula capitata	**23,214**	**75,833**	**111,111**	**86,565**	**150,000**	**50,000**	**0**	**0**	**27,857**	**454,545**	**375,000**	**83,333**	**0**
Navicula capitoradiata	**598,929**	**0**	**0**	**0**	**0**	**200,000**	**0**	**0**	**74,286**	**113,636**	**400**	**27,778**	**20,000**
Navicula cincta	13,929	0	0	0	0	0	0	0	458,333	0	0	0	0
***Navicula* large spp.**	**306,429**	**0**	**0**	**0**	**50,000**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**266**
Navicula small spp.	0	169,722	0	0	0	0	0	0	83,333	0	0	27,778	0
Navicula sp.	88,214	0	0	17,313	250,000	0	0	0	269,286	45,455	0	0	40,000
Naviculoid	0	675,278	0	640,582	0	150,000	0	0	0	22,727	83,333	0	0
small Naviculoid	0	108,333	0	0	0	0	0	0	0	0	0	0	0
Neodelphinium	0	0	27,778	0	0	0	0	0	0	0	0	0	0
Nitzschia	27,857	97,500	0	259,695	200,000	100,000	0	0	27,857	0	0	83,333	0
Nitzschia acicularis	0	0	0	0	0	0	0	0	18,571	0	0	0	0
Nitzschia bicapitata	9,286	0	0	0	6,760	0	50,000	208,000	0	250,000	0	0	220,000
Nitzschia longissima				800	0	0	0	0	0		0	0	0
Nitzschia sm.	9,286	7,222		0	0	0	200,000	0	18,571	0	0	0	0
Nitzschia sicula	0	0	0	0	50,000	0	0	0	0	0	0	0	0
Nitzschioid	13,929	21,667	55,556	17,313	0	14,050,000	0	0	0	45,455	200	0	0
Paralia sp.	0	0	0	800	0	0	0	0	176,429	409,091	1,200	0	0
Pleuro/Gyrosigma	18,571	0	0	600	0	0	0	0	0	0	200	0	0
Pleurosigma delicatula	9,286	0	0	0	0	0	0	0	0	0	0	0	0
Pleurosigma elongatum	0	0	0	0	0	0	0	0	41,667	0	0	0	0
Pseudo-nitzschia spp.	69,643	0	0	17,313	0	0	0	0	0	0	0	0	0
Rhoicosphenia spp.	4,643	0	0	0	3,380	0	0	0	9,286	0	0	0	0
smaller diatom stack	0	0	0	0	200,000	0	0	0	0	0	0	0	0
square centric	0	0	0	0	0	0	0	0	0	0	0	0	0
Staurosirella	0	0	0	17,313	0	0	0	0	0	0	0	0	0
***Stephanodiscus* spp.**	**0**	**0**	**0**	**0**	**10,950,000**	**0**	**0**	**0**	**0**	**22,727**	**27,400**	**55,556**	**531**
Stephanopyxis	0	0	0	0	0	0	0	26,000	0		3,000	0	0
Surirella linearis	4,643	0	0	17,313	0	0	0	0	0	0	600	0	0
Surirella	0	0	27,778	0	0	0	0	0	0	0	0	0	0
Synedra acus	9,286	0	0	0	0	0	0	0	0	0	0	0	0
Synedra binodis	0	0	0	0	0	0	0	0	27,857	0	0	0	0
Synedra sp.	4,643	0	27,778	34,626	50,000	0	60,357	0	9,286	68,182	125,000	55,556	40,000
Synedra sp. A	0	0	0	0	0	0	0	0	41,667	0	0	0	0
Synedra ulna	0	0	0	0	0	0	0	0	0	0	0	0	0
Synedra/Frustula	0	0	0	0	0	0	0	0	0	0	0	0	0
Tabellaria	0	0	0	0	0	0	0	0	0	0	1,400	0	0
Thalassiosira resting spore	0	0	0	34,626	0	0	0	0	0	0	0	0	0
Thalassiosira sp.	0	0	0	17,313	0	0	0	0	0	0	0	0	0
unknown pennate, cf. *F. crotonensis*	0	0	0	0	520,520	0	0	0	0	0	0	0	0
diatom resting spore	0	0	0	0	0	50,000	0	0	0	0	0	0	0

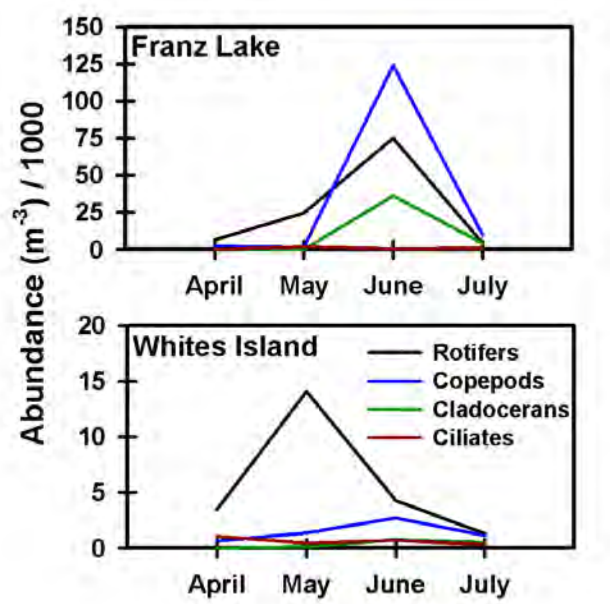


Figure 76. Abundances of the four dominant groups of zooplankton at Campbell Slough (Franz Lake), Birnie Slough (White's Island), and at Ilwaco. Data from Ridgefield National Wildlife Refuge are not shown because sampling did not begin until late May.

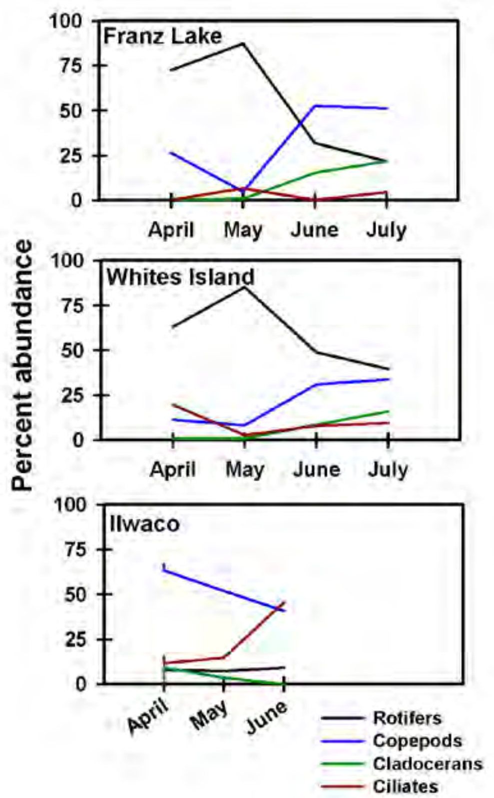


Figure 77. Percent abundance of the four major groups of zooplankton over time (April-July 2011) at Franz Lake, Whites Island (Birnie Slough), and Ilwaco (Baker Bay, WA).

Table 33. List of zooplankton taxa and their relative abundances at Whites Island (Birnie Slough) over the 4-month period. The abundance categories are as follows: I = 0.1-0.9/m^3; II = .0-9.9/m^3; III = 10.0-99.9/m^3; IV = 100.0-999.9/m^3; V = 1,000-9,999.9/m^3; VI = 10,000.0-99,999.9/m^3; VII = >99,999.9/m^3.

Category		**April**	**mid-May**	**Late-May**	**June**	**July**
Rotifera	Misc rotifers				III	
	Anuraeopsis sp.					IV
	Asplanchna spp.	III	III	IV	IV	IV
	Brachionus + *Keratella* spp.	IV	V	V	V	IV
	Diacranophoris forcipatus					
	Kellicottia spp.		III			
	Brachionus eggs	IV	IV	IV	IV	IV
Cladocera	*Bosmina* spp.		III	IV	IV	
	Daphnia/misc cladocerans	III		IV	IV	IV
	Cladoceran eggs					III
	Orange cladoceran eggs					IV
	Penilia spp.					
Copepoda	Nauplii	IV	IV	IV	V	IV
	Calanoid/cyclopoid copepod	III	III	IV	IV	IV
	Harpacticioid copepod			III	III	III
	Copepod eggs					IV
Annelida	*Chaetogaster diaphanus*		II	IV	III	III
	nematode	III	III	III	III	
Arthropoda	Misc arthropod			III	III	
Ostracoda	Spiny-legged crustacean	IV		IV		
Ciliophora	*Strombidium* spp.				III	IV
	Tintinnopsis spp.	IV	III	IV	IV	IV
	Long tintinnid				III	
	Misc ciliates	IV	III	IV	IV	
Rhizaria/Amoeobozoa	*Cyphoderia* sp.	III	III	III	IV	
	Foraminifera					
Unknown/misc	unknown	III	III	IV		
	Cysts	IV	III	V	IV	III
	Eggs			III		IV
	Cyst/egg					IV
	Misc siliceous				III	
	Pollen	IV	IV	IV	IV	IV

Table 34. List of zooplankton taxa and their relative abundance at Franz Lake over the 4-month period. The abundance categories are as follows: I = 0.1-0.9/m^3; II = .0-9.9/m^3; III = 10.0-99.9/m^3; IV = 100.0-999.9/m^3; V = 1,000-9,999.9/m^3; VI = 10,000.0-99,999.9/m^3; VII = >99,999.9/m^3.

Category		**April**	**mid-May**	**Late-May**	**June**	**July**
Rotifera	Misc rotifers					
	Anuraeopsis sp.	IV				IV
	Asplanchna spp.	V		IV	VI	IV
	Brachionus + *Keratella* spp.	II		VI	VI	V
	Diacranophoris forcipatus					
	Kellicottia spp.				V	IV
	Brachionus eggs	V		V	V	IV
Cladocera	*Bosmina* spp.	II		IV		
	Daphnia/misc cladocerans	II		II		V
	Cladoceran eggs				IV	IV
	Orange cladoceran eggs					
	Penilia spp.					IV
Copepoda	Nauplii	V		IV	VI	V
	Calanoid/cyclopoid copepod	III		IV	VI	V
	Harpacticioid copepod	III			IV	III
	Copepod eggs			IV		
Annelida	*Chaetogaster diaphanus*	III		III		
	nematode			III		
	Misc annelid			II		
Arthropoda	Misc arthropod			III		
Ostracoda	Spiny-legged crustacean					
Ciliophora	*Strombidium* spp.			II		IV
	Tintinnopsis spp.	II		V	IV	IV
	Long tintinnid			II		
	Larger tintinnid			III		
	Misc ciliates	II		IV	IV	IV
Rhizaria/Amoebozoa	*Cyphoderia* sp.			III	III	IV
	Foraminifera					
	amoeba	II				
Unknown/misc	unknown			IV		
	Cysts			IV	IV	III
	Eggs	II		V	IV	IV
	Resting egg					III
	Cyst/egg	II		IV	IV	IV
	Misc siliceous					
	Pollen	II			III	IV

Table 35. List of zooplankton taxa and their relative abundance at Ilwaco over the 4-month period in 2011. The abundance categories are as follows: I = 0.1-0.9/m^3; II = .0-9.9/m^3; III = 10.0-99.9/m^3; IV = 100.0-999.9/m^3; V = 1,000-9,999.9/m^3; VI = 10,000.0-99,999.9/m^3; VII = >99,999.9/m^3.

Category		**April**	**mid-April**	**Late-May**	**June**	**July**
Rotifera	Misc rotifers					
	Anuraeopsis sp.					
	Asplanchna spp.	III				
	Brachionus + *Keratella* spp.	III	III	III	III	
	Diacranophoris forcipatus	II				
	Kellicottia spp.				III	
	Brachionus eggs	III				
Cladocera	*Bosmina* spp.	III		III		
	Daphnia/misc cladocerans	II	III			
	Cladoceran eggs					
	Orange cladoceran eggs		III			
	Penilia spp.					
Copepoda	Nauplii	IV	III	IV	III	
	Calanoid/cyclopoid copepod	IV	IV	IV	IV	
	Harpacticioid copepod	III	III			
	Copepod eggs					
Annelida	*Chaetogaster diaphanus*	III	III			
	nematode	III	III	III	III	
	Misc annelid					
Arthropoda	Misc arthropod	II				
Ostracoda	Misc ostracod	III				
Ciliophora	*Strombidium* spp.		III			
	Tintinnopsis spp.	II	III		III	
	Long tintinnid	III		III		
	Larger tintinnid					
	cf. *Codonellopsis* sp.	II				
	Misc ciliates	IV	III	III	IV	
	cf. *Myrionecta rubra*	III				
	Misc. tintinnids	II				
Rhizaria/Amoebozoa	*Cyphoderia* sp.	III	III	III		
	Foraminifera	III		III	III	
	amoebae	II				
Unknown/misc	unknown	III				
	Cysts	IV	III			
	Eggs	IV			III	
	Resting egg					
	Cyst/egg	III	IV		III	
	Misc siliceous	III				
	Pollen	III	III	III	III	

Table 36. List of zooplankton taxa and their relative abundance at Ridgefield National Wildlife Refuge over the 4-month period. The abundance categories are as follows: I = 0.1-0.9/m^3; II = .0-9.9/m^3; III = 10.0-99.9/m^3; IV = 100.0-999.9/m^3; V = 1,000-9,999.9/m^3; VI = 10,000.0-99,999.9/m^3; VII = >99,999.9/m^3.

Category		**April**	**mid-May**	**Late-May**	**June**	**July**
Rotifera						
	Misc rotifers					
	Anuraeopsis sp.				VI	IV
	Asplanchna spp.				VI	V
	Brachionus + *Keratella* spp.				VII	V
	Diacranophoris forcipatus				V	VI
	Kellicottia spp.				VI	IV
	Brachionus eggs				VI	V
Cladocera						
	Bosmina spp.					
	Daphnia/misc cladocerans				VII	VI
	Cladoceran eggs				VI	V
	Orange cladoceran eggs				VI	IV
	Penilia spp.				VI	V
Copepoda						
	Nauplii				VII	VI
	Calanoid/cyclopoid copepod				VI	VI
	Harpacticioid copepod				V	
	Copepod eggs					IV
Annelida						
	Chaetogaster diaphanus				IV	IV
Ciliophora						
	Strombidium spp.					IV
	Tintinnopsis spp.				VI	IV
	Misc ciliates					
Rhizaria & Amoebozoa						
	Cyphoderia sp.				V	
	Foraminifera					
	amoebae					
Unknown/misc						
	Cysts					IV
	Eggs				VI	IV
	Cyst/egg				IV	
	Resting egg					
	Pollen				IV	III
	unknown				V	V

4.5.4 Discussion

The work carried out through the EMP seeks to evaluate the status of Lower Columbia River habitats in relation to salmon performance and to analyze trends that emerge over time that can be used to direct recovery efforts. An emerging understanding of the importance of estuarine habitats over the last decade and their role in supporting diverse life histories of salmon has placed a renewed emphasis on identifying the complex interactions between habitat structure and capacity to support healthy salmon populations in tidal environments of the lower river and estuary (Bottom et al., 2005; Bottom et al., 2008). Importantly, recommendations for restoration call for an evaluation of the impact of physical habitat loss on salmon performance. In this context, it is important to also take into account the effect of habitat capacity (for example, food resources) as a determinant of salmon performance, considering in particular how the latter relies on habitat structure. It is the aim of this component of the EMP to document the spatial and temporal distributions of primary producers and primary consumers in an effort to identify controls on these food web components that impact salmon prey availability and thus habitat capacity. One ultimate goal is to identify a series of indicators or metrics that provide a litmus test for salmon performance or health of populations. In order to identify useful indicators, a thorough understanding of food web linkages and their dependence on physical habitat structure must be achieved.

Spatiotemporal patterns in phytoplankton species composition and abundance in the Lower Columbia River - The Columbia River has undergone major changes in hydrography, largely due to the installation of dams (Sherwood et al., 1990). As a result, the river exhibits much more dramatic increases in phytoplankton biomass, termed the "greening" of the river (Sullivan et al., 2001). For example, an analogous system, the undammed Fraser River, British Columbia, is a sediment-laden river with comparatively low primary production (Harrison et al., 1991). Interestingly, in situ sensors installed in June 2009 at Beaver Army Terminal at river mile 53 (maintained as a collaboration between USGS, OHSU, and WetLABS Inc., Philomath, OR) have revealed a number of phytoplankton peaks or "blooms" over the course of the spring-summer period (Maier et al., in preparation). Based on traditional sampling done at relatively coarse resolution (~monthly during the one published study that examined the seasonality of phytoplankton biomass), multiple blooms were not apparent, and it was believed that a single spring bloom characterized the lower river (Sullivan et al., 2001). Sensors on the mooring at Beaver Army Terminal (BAT), a USGS historical water quality monitoring site in the lower Columbia River, continuously measure chlorophyll (chl), nitrate, turbidity, oxygen saturation, colored dissolved organic matter (CDOM), temperature and conductivity on an hourly basis (June 2009-present). Low chl corresponded to elevated river discharge in 2011 (relative to a 10-year mean) compared to 2010.

Over the 2-year time series, the dominant phytoplankton species identified at BAT were the diatoms *A. formosa*, *Aulacoseira granulata* (4500-8500 cells/ml), and *Stephanodiscus* spp. The time series at BAT showed that the major spring bloom in the Columbia River is composed of recurring species, similar to lake ecosystems and coincident with a peak in chl concentrations, which were comprised of similar species in 2010 and 2011, despite very different river discharge patterns. The species most commonly observed in the samples were similar to those observed in a year-long monthly survey of phytoplankton carried out by the U.S. Geological Survey in 2004-2005 (J. Morace, pers. comm.). In both studies, a similar species dominated the early spring diatom biomass (*Asterionella formosa*); this species was replaced by chain-forming centric species, including *Stephanodiscus* spp. and *Aulacoseira granulata*, which dominated the remainder of the spring and into early summer. Thus, it seems that a regular and repeatable pattern of phytoplankton species is observed in the Lower Columbia River.

The installation of dams along the river has created a system where reservoirs behind the dams have longer residence times, and as a result, diatoms are able to flourish. This process has produced a 'greening' of the river (Sullivan et al., 2001), with higher algal standing stocks resulting from longer residence times and higher light penetration as suspended sediment loads are reduced behind the dams when particles sink out. An interesting potential additional result from this phenomenon is an increase in opportunities for phytoplankton parasites such as zoosporic (chytrid) fungi to infect hosts. Elsewhere (mainly in lakes), parasites of phytoplankton can dramatically alter food webs by shunting organic matter from phytoplankton to detritus and zoospores. The latter are readily consumed by zooplankton, especially cladocerans and copepods. This has been termed the "mycoloop" (Kagami et al., 2007), and it is thought to make the organic matter stored in large colonial diatoms (often considered inedible to copepods and cladocerans due to their large size) more available to zooplankton grazers. The implications of an active mycoloop in the Columbia River are entirely unknown, but the transfer of organic matter from primary producers to primary consumers could have important consequences for salmon and their prey.

Spatio-temporal trends in zooplankton species composition and abundance – A clear shift from rotifer-dominated to copepod/cladoceran-dominated zooplankton assemblages was observed between April-May and June-July. Prior to the spring freshet, rotifers dominated the zooplankton assemblage in the tidal freshwater sites, whereas after the freshet, the crustaceans dominated. At Ilwaco, where waters tend to be brackish for most of the year, copepods dominated the zooplankton assemblages at all times. Zooplankton maximum abundances were observed in late May (Whites Island) and in June (Franz Lake), with much higher abundances observed at the latter. In contrast, the maximum concentrations of phytoplankton (composed mainly of diatoms) were higher in April, or even earlier. Interestingly, in addition to higher zooplankton abundances, Franz Lake had higher abundances of diatoms compared to the other sites. Franz Lake is located upstream of the confluence of the Willamette River and the Columbia; it is possible that the dilution of standing stocks of primary and secondary producers by the Willamette impacted the overall abundances of plankton downstream.

Potential implications of phytoplankton and zooplankton assemblage composition – The phytoplankton assemblage of the Lower Columbia is dominated by large colony-forming diatoms that are thought to be inaccessible to zooplankton grazers, particularly the rotifers. Counts of small phytoplankton species suitable for grazing by rotifers (small flagellates, including cryptophytes, chrysophytes, and small green motile species) were relatively low, either indicating low growth of these small forms, or else heavy grazing. The high abundance of rotifers at Whites Island and Franz Lake (including observations of numerous eggs) presumably meant that small phytoplankton and flagellates were being heavily grazed in the early spring. The switch to dominance by copepod and cladoceran (together, crustaceans) zooplankters later in the spring/summer may have coincided with a reduction in food supply of the small flagellates typically consumed by rotifers, although the phytoplankton samples that would support or refute this hypothesis have not yet been examined. In laboratory studies, it has been shown that rotifers exhibit high growth rates and a rapid response to the presence of food (Hansen et al., 1997). Therefore, to sustain significant populations of this grazer, a large standing stock of prey is required. Interestingly, observations of nanoflagellate dynamics in the Columba River estuary using molecular methods of detection (using molecular markers) revealed high concentrations of the nanoflagellate *Katablepharis* (a genus common in lakes) at salinities > 10 PSU (Kahn et al., in preparation). Since the populations of rotifers observed in the present study suggest that they are less abundant in brackish waters relative to freshwaters, it is quite possible that the high numbers of *Katablepharis* in waters 10-15 PSU resulted from a release of grazing pressure in the estuarine environment.

The prevalence of zoosporic fungi (chytrid) parasites on colonial diatoms could have significant implications for salmonid food webs. For example, copepods and cladocerans are easily able to feed on zoosporic fungi, which are small (<10 µm), whereas some of the diatom colonies (e.g. *Asterionella formosa*) are more difficult to consume due to their large size. Thus, the existence of a 'mycoloop', where organic matter from large, indigestible diatoms is converted to smaller, more accessible microzooplankton (Kagami et al., 2011), may support larger populations of crustaceans, which are directly fed upon by juvenile salmon.

Potential indicators of habitat capacity related to primary and secondary producers – Recently, natural abundance stable isotope signatures of carbon, nitrogen, and sulfur were determined for a variety of organic matter sources, including fluvial (pelagic) phytoplankton, zooplankton, vascular plants, and benthic diatoms in the Lower Columbia River (Maier and Simenstad, 2009). These data were used to build a mixing model to infer the dominant sources of organic matter ultimately supporting salmon. The results from analysis of salmon tissue suggested that salmon prey preferentially use vascular plant detritus as a source of organic matter. The conclusion drawn from this work is that changes to wetland habitats in the Columbia River estuary (including tidal freshwater habitats) has resulted in a shift from a vascular plant-based food web to a fluvial phytoplankton based food web, which is ultimately detrimental to salmon performance and life history diversity, threatening their resilience to environmental change.

The reliance of salmon prey on vascular plant organic matter is curious and worthy of attention. Studies elsewhere have shown that salmon prey, including chironomid insects which are highly valued sources of nutrition (Bottom et al., 2008), will consume vascular plant detritus, but only after it has been 'pre-conditioned' by microbial activity (Barlocher and Kendrick, 1975; Moran et al., 1988). Therefore, an increased reliance on this source of organic matter from spring to summer is often seen (Campeau et al., 1994). Yet, phytoplankton tend to be a more readily available and therefore more nutritious source of organic matter, since they do not possess lignin or indigestible celluloses. It is therefore unclear why an increase in fluvial phytoplankton should result in poor food quality for salmon prey and ultimately for salmon. It is possible that the high production occurring within the fluvial phytoplankton pool is exported via the river plume and is therefore lost to the system. This is consistent with previous studies that showed the estuary to be a strong exporter of fluvial phytoplankton (Lara-Lara et al., 1990).

Management implications - Higher abundances of phytoplankton in shallow water habitats relative to the mainstem river, particularly in waters upstream of the Willamette-Columbia confluence, suggest that the availability of pelagic phytoplankton may be greater within protected areas. Therefore, in addition to the importance of wetlands and emergent vegetation for providing a source of vascular plant macrodetritus to fuel salmon food webs, these environments might also potentially provide additional organic matter through fluvial sources that could be important to salmon prey. Providing enough protected habitat to increase residence time of fluvial phytoplankton may decrease the export losses of organic matter from the system and provide additional resources to salmon prey.

Recommendations for sampling of primary producers and primary consumers – In order to provide a detailed characterization of diatom assemblages, it is recommended that a sub-set of specimens be cleaned of organic material to examine the fine details of the silica frustule (cell wall) required for taxonomic assignation. Although rather labor intensive, this would provide an added level of detail that could be valuable in choosing potential indicator species to look for changes in water chemistry, for example, since diatoms are often used as indicator species (Pan et al., 1996). The potential threat of cyanobacterial toxins present at Ridgefield National Wildlife Refuge should be given further attention. It is recommended that phytoplankton characterization (identification and enumeration) be carried out into the summer months to capture cyanobacterial bloom events and to detect potentially harmful species throughout the Lower Columbia. Ideally, it would be prudent to test water samples for a suite of cyanotoxins that could be present if known toxin-producers are present.

It is recommended that a comparison between phytoplankton and zooplankton assemblages in the mainstem river versus shallow water habitats be carried out at least once during the pre-freshet and once during the post-freshet to put the fixed site data into context. Comparisons of the 2011 data suggest that there can be large differences in the abundances of primary (and likely secondary) producers, which could be important for assessing the habitat capacity of shallow water habitats as part of the system as a whole.

4.6 Benthic sampling

4.6.1 Introduction

Columbia River Estuary Study Taskforce (CREST) was contracted to aid in the analysis of the juvenile salmonid food web for the Estuary Partnership's EMP. Specifically, in 2011 CREST was contracted to process and analyze benthic cores for up to 40 macroinvertebrate prey samples from the four "fixed" EMP sites (Campbell Slough, Whites Island, Franz Lake and Ilwaco). Benthic core prey samples were collected by USGS monthly from April to July.

The goal for the EMP was to assess biomass, taxonomic composition and contribution of benthic macroinvetertebrates to the juvenile salmon food web. An additional benefit of this work is that macroinvertebrates are valuable indicators of the condition or health of waterbodies. Many invertebrates have very specific requirements in terms of water quality and consequently react to several forms of pollution, including chemical pollution and physical disturbance to the landscape around the site, wetland structure and hydrology (Helgen 2002). There are several advantages of using macroinvertebrates:

- Invertebrates are commonly found in wetlands, rivers, streams, lakes, ponds, reservoirs, estuaries and near coastal areas.
- Aquatic invertebrates are significant in wetland food webs for wildlife.
- Invertebrates respond with a range of sensitivities to many kinds of pollution.
- Many aquatic invertebrates complete their life cycles in wetlands, so they are exposed directly to the physical, chemical and biological conditions within the wetland.

The term macroinvertebrates encompasses all insects (6 legs, adults with 2 pair of wings and antennae) along with other invertebrates (animals without backbones) and arthropods (jointed legged animals). Macroinvertebrates are large enough to be seen without the aid of a hand lens or dissecting scope (however these tools are necessary for classification). Macroinvertebrates occupy a variety of niches throughout a system and provide a substantial contribution to the food web. Collectively macroinvertebrates represent the majority of animal life on earth, playing a fundamental role in the transfer of energy through the food chain by providing a mechanism for recycling the organic debris that settles to the bottom of any water body.

The sediment core samples collected by USGS monthly from April through June at the Ilwaco, Whites Island, Franz Lake and Campbell Slough sites contain a variety of macroinvertebrates. Analyzing these samples and identifying the macroinvertebrates to order, family or species when possible can help determine the benthic component of prey availability at each of these sites. When this information is combined with other prey availability research, it can provide a means of identifying which sites have adequate species composition and abundance to support a healthy food web for species such as salmonids. Results provide a means to demonstrate what each site potentially offer salmonids to eat.

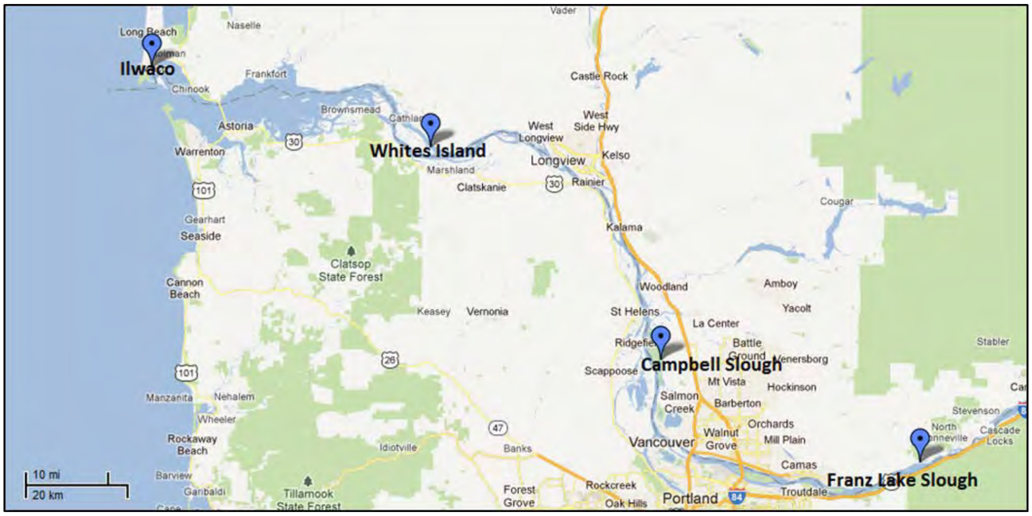


Figure 78. Map of locations in which benthic core samples were taken by USGS staff during the spring of 2011 (no samples were collected at Franz Lake due to high water).

Table 37. Sample location, month of collection and total number of samples collected by USGS in the spring of 2011.

Site	When samples were taken in 2011	Number of samples taken
Campbell Slough	April	**0**
Campbell Slough	May	3
Campbell Slough	June	**0**
Whites Island	April	3
Whites Island	May	3
Whites Island	June	3
Ilwaco	April	3
Ilwaco	May	3
Ilwaco	June	3

4.6.2 Methods

The sampling protocol used by USGS was to press the PVC corer into exposed sediment of the channel down to the 10 cm marking on the corer. Then, the sample was held in the corer while the bottom end was closed off and the collected core sample was placed in a sieve. The sample was rinsed with water to remove as much of the sediment as possible, then the sample was poured from the sieve into a storage jar and topped with 95% ethyl alcohol. CREST then processed the samples identifying taxonomy to at least Order, if possible, to family or species. In this analysis, CREST quantitatively described each of the identified taxa and characterized each site by composition and abundance. The methods implemented during the sample processing are as follows:

- Each sample was individually rinsed through a 500-micrometer sieve to filter out any debris smaller than 500 micrometers.
- The next step was to put the rinsed sample into a sample jar and introduce a combination of 90 % ethanol (preservative) and Rose Bengal Salt diluted in distilled water (several milliliters) into each sample. Rose Bengal is a stain that is used in the preparation for microscopic analysis, allowing the distinction between forms of flora and fauna that were alive or dead at the time of collection.

- After the stain has set for 24 hours, each sample is individually dispersed in equal proportion within several Petri dishes to promote optimal visibility of macroinvertebrates.
- Each Petri dish from the sample is then carefully analyzed under a microscope, slowly sweeping across the entire dish and removing any invertebrates encountered for further classification.
- After a sample has been thoroughly checked and all invertebrates have been removed into a separate Petri-dish, each of the invertebrates is identified to at least order, if possible, to the family or species.
- Once their taxonomy is identified, each individual is hand recorded onto a datasheet, labeled with the sample site location, collection date, sample processing date, sample number, taxa, life history stage, and any other additional comments about the sample (i.e. high quantities of vegetation, sediment or woody debris that may conceal other inverts).

For Taxonomic Identification these references were used:

- Triplehorn, Charles A. and Johnson, Norman F. (2005). *Borror and Delong's introduction to the study of insect 7th edition*. Thomson Brooks/Cole. 10 Davis Drive Belmont, CA 94002 USA.
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4.6.3 Results and Discussion

USGS was not able to collect benthic core samples at Franz Lake Slough because water levels were too high during the sampling season. At Campbell Slough, high water levels prevented sample collection in April and June.

Looking at all sites collectively, temporal and spatial patterns revealed adult invertebrates to be more prevalent than other life history stages throughout the sampling period. 98% of the invertebrates sampled were adults, 2% were larva, and less than 1% was a nymph or pupa life history stage. At individual sites, the Ilwaco samples consisted entirely of adult invertebrates while Whites Island and Campbell Slough samples were less uniform. Whites Island samples consisted of 87% adults, 9% larva, 3% nymphs and 1% pupa. Campbell Slough samples consisted of 96% adult, 2% larva and 2% nymph. Species of the Annelida phyla (Oligochaetes, Nematodes and Polychaetes) are the most abundant prey taxa throughout all of sample sets. Amphipoda and Dipteran orders represented the next highest proportion of invertebrates present within the sample set.

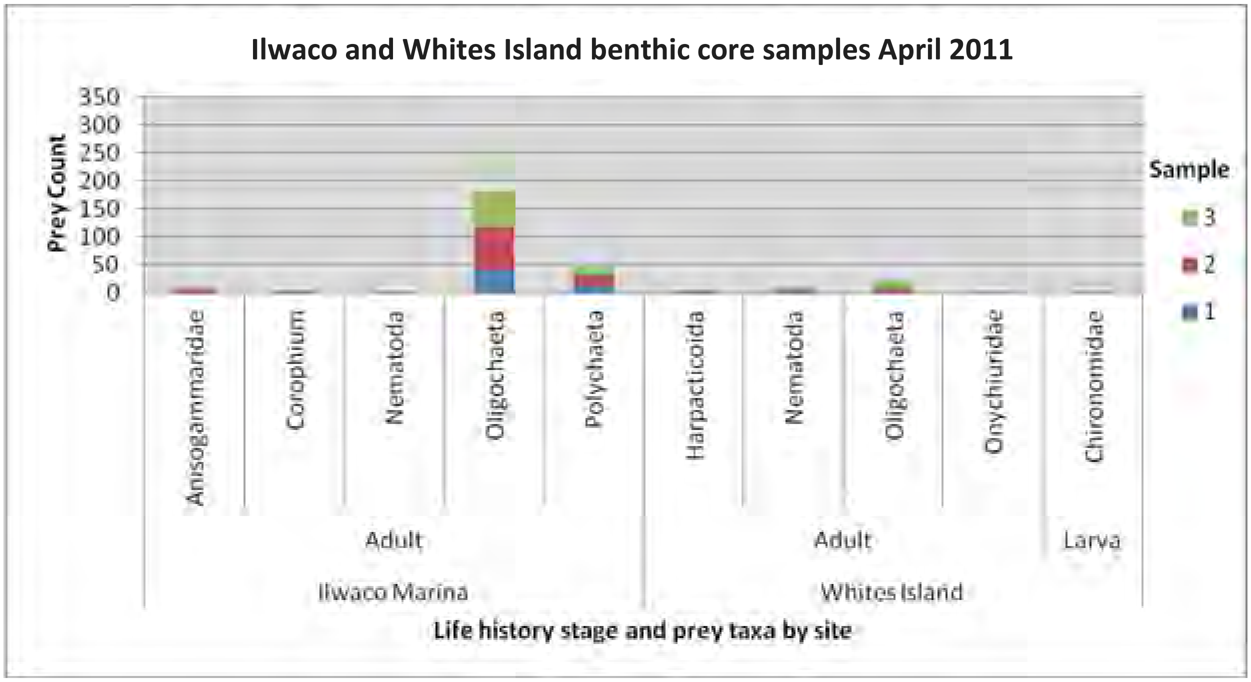

Figure 79. Salmonid prey availability, Ilwaco and Whites Island sediment cores, April 2011.

Table 38. Total number and species composition observed in Ilwaco and Whites Island sediment cores, April 2011.

Sum of Count			Sample			
Site	Stage	Taxa	1	2	3	Grand Total
Ilwaco	Adult	Anisogammaridae	1	5	4	10
		Corophium		3	1	4
		Nematoda		1	2	3
		Oligochaeta	41	74	67	182
		Polychaeta	11	20	14	45
	Adult Total		53	103	88	244
Ilwaco Total			53	103	88	244
Whites Island	Adult	Harpacticoida		2	1	3
		Nematoda	4	3	1	8
		Oligochaeta	1	7	13	21
		Onychiuridae	1		2	3
	Adult Total		6	12	17	35
	Larva	Chironomidae			1	1
	Larva Total				1	1
Whites Island Total			6	12	18	36
Grand Total			59	115	106	280

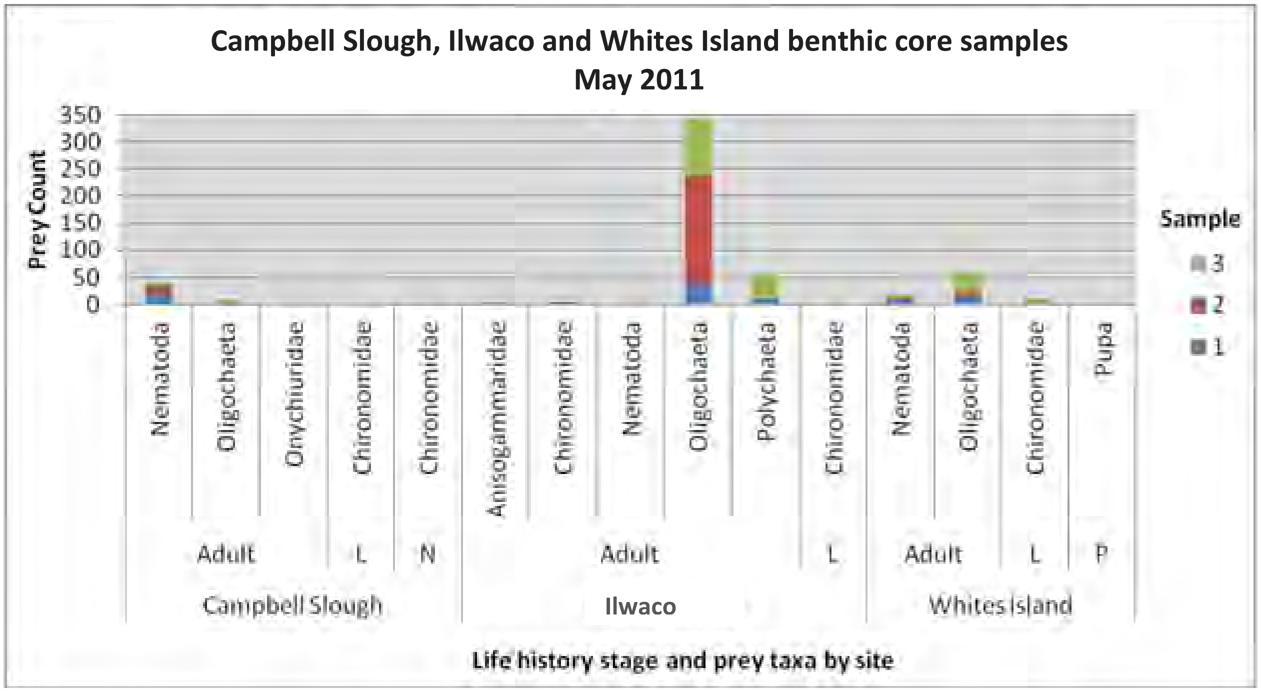

Figure 80. Benthic prey availability across all sites, May 2011. Life history stages Larva, Nymph and Pupa are illustrated as L, N and P respectively.

Table 39. Total number and species composition observed in sediment core samples across all three monitoring sites, May 2011. Life history stages Larva, Nymph and Pupa are illustrated as L, N and P respectively.

Sum of Count			Sample			
Site	Stage	Taxa	1	2	3	Grand Total
Campbell Slough	Adult	Nematoda	16	18	7	41
		Oligochaeta			9	9
		Onychiuridae		2		2
	Adult Total		16	20	16	52
	L	Chironomidae	1			1
	L Total		1			1
	N	Chironomidae		1		1
	N Total			1		1
Campbell Slough Total			17	21	16	54
Ilwaco	Adult	Anisogammaridae			4	4
		Chironomidae		3		3
		Nematoda			4	4
		Oligochaeta	36	201	105	342
		Polychaeta	11		44	55

	Adult Total		47	204	157	408
	L	Chironomidae	2			2
	L Total		2			2
Ilwaco Total			49	204	157	410
Whites Island	Adult	Nematoda	8	4	7	19
		Oligochaeta	16	7	38	61
	Adult Total		24	11	45	80
	L	Chironomidae		2	9	11
	L Total			2	9	11
	P	Pupa		1		1
	P Total			1		1
Whites Island Total			24	14	54	92
Grand Total			90	239	227	556

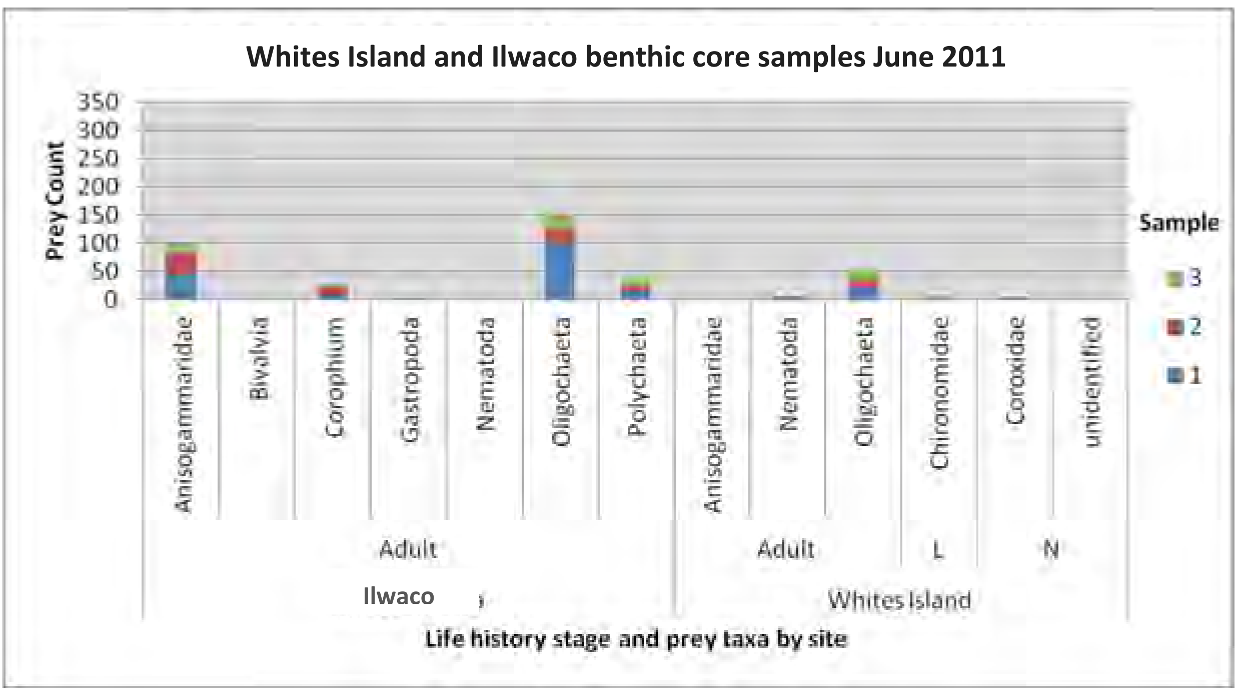

Figure 81. Salmonid Prey Availability, Whites Island and Ilwaco Sediment Cores, June 2011. Life history stages Larva and Nymph are illustrated as L and N respectively.

Table 40. Total number and species composition observed at Whites Island and Ilwaco sediment cores, April-June 2011. Life history stages Larva and Nymph are illustrated as L and N respectively.

Sum of Count			Sample			
Site	Stage	Taxa	1	2	3	Grand Total
Ilwaco	Adult	Anisogammaridae	45	38	15	98
		Bivalvia	1			1
		Corophium	5	16	6	27
		Gastropoda	2		1	3
		Nematoda	2			2
		Oligochaeta	102	21	29	152
		Polychaeta	16	9	12	37
	Adult Total		173	84	63	320
Ilwaco Total			173	84	63	320
Whites Island	Adult	Anisogammaridae			1	1
		Nematoda	3	2		5
		Oligochaeta	21	12	21	54
	Adult Total		24	14	22	60
	L	Chironomidae	2		3	5
	L Total		2		3	5
	N	Coroxidae	4			4
		unidentified	1			1
	N Total		5			5
Whites Island Total			31	14	25	70
Grand Total			204	98	88	390

Ilwaco samples suggested it to be the most productive site in terms of abundance and species richness. Whites Island took a close second, followed by Campbell Slough which demonstrated only a slight decrease in species richness but a significant decline in overall abundance. The Ilwaco samples are the only samples containing Polychaetes and a large quantity of Amphipods. Polychaetes are almost exclusively marine annelids (Smith 2001), with a variety of species and high numbers of individuals found in many types of marine habitats. The Ilwaco samples lacked any vegetative debris; instead they were heavily comprised of silt. This sites location and relative salinity give details to the composition of substrate within the sample; it could also be a contributing factor to the increase in species richness and overall abundance of taxa. Within an estuary the mixing of waters with such different salt concentrations creates a very fascinating and unique ecosystem. The other invertebrate distinctive to the Ilwaco site is Anisogammaridae. Anisogammaridae are a species of amphipods from the family Coriphiidae. The Ilwaco was one of two sites containing this species (the other site was Whites Island). It is important to note that the Whites Island samples had only one Anisogammaridae, whereas, the Ilwaco samples had 112.

Among all sample sites, Oligochaetes, Polychaetes and Nematodes demonstrated the greatest diversity of life history stages. Each site had a higher prevalence of Oligochaetes proportional to other taxa with the exception of Campbell Slough. Nematodes proved to be the dominant taxa at the Campbell Slough site, with a higher composition of Nematodes than any other site within the sample set. Nematodes are abundant in sand and mud, and in the sediment that accumulates on sessile invertebrates, algal growths, and other substrata (Kozloff 1996).

The family Chironomidae had one or more stages of life history present at each of the four sites. Whites Island samples had the greatest abundance (16 Chironomidae larvae) but the least amount of diversity in terms of life history stages present: Campbell Slough and Ilwaco each had at least two life history stages of Chironomids present within samples. The Chironomidae family is commonly referred to as midges. This group of insects is large, with about 1,090 North American species. The larvae of most midges are aquatic, and live in all sorts of aquatic habitats. Some live in decaying matter, soil, under bark, and similar habitats that are wet and rich in organic matter (Triplehorn and Johnson 2005). The Whites Island samples were comprised of a relatively large amount of vegetative debris in relation to the other sites. This may be a contributing factor to the noticeable increase in Chironomidae larvae present at this site in comparison to the others (Table 38, Table 39, Table 40).

The Whites Island sample set was the only site containing taxa from the Order Hemiptera. Corixidae or water boatmen as they are commonly referred to are one of the largest families in the infraorder, with about 120 North American species. Corixidae are unique among the aquatic Hemiptera in that they are mostly non-predatory, feeding on aquatic plants, detritus and algae instead of insects and other aquatic organisms. Members of the Corixidae family are commonly found in freshwater ponds and lakes, occasionally occurring in streams and brackish pools just above the high-tide mark along the seashore (Smith 2001). Whites Island was also the only site with Harpacticoida, an order of copepods, in the Subphylum Crustacea. This order comprises 463 genera and about 3,000 species. Most families of Harpacticoida are benthic copepods found throughout the world in the marine environment, with relatively few found in fresh water. A small number of them are planktonic or live in association with other organisms. Harpacticoida represents the second-largest meiofaunal group in marine sediment milieu, after nematodes (Barnes 1982). In the estuarine mud, copepods are, numerically, the next most important group after the nematodes. Unlike the pelagic swimming forms, they are reduced in size and have lost their swimming appendages. The harpacticoids are the most common of the bottom-dwelling (benthic) copepods and form the basic food resource for small and juvenile fish in estuaries (Gee, 1989).

It is important to take into consideration the disparity in the number of samples taken at each sampling site (Table 37). Nine sediment core samples were taken at the Ilwaco and Whites Island sites, while only three were taken from the Campbell Slough site. Increased sampling events often yield greater, more accurate results of species composition in particular. If it had been possible to take a greater number of replicate samples from each location the analysis may have revealed a more definitive relationship between habitats and basins. It is also significant to consider the reality that it is the nature of the life within an estuary to change with the seasons driven by alterations of freshwater inflows and the changes in light and temperature. The findings resultant from the data collected in this instance is only representative of the late spring dry season.

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4.2 Habitat

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6.0 Appendix

Appendix A. Ecosystem Monitoring Reconnaissance Trip Report

Ecosystem Monitoring Reconnaissance Trip
November 17-18, 2010

Objectives:

1. Conduct site visits in Reaches D, E, and F to determine feasibility of sampling fish and adequacy of sites to meeting project criteria (i.e., relatively undisturbed, emergent marsh , of adequate size and connectivity to the Col. River, with sloughs or channels present and potential for fish access) with intent to choose 3 rotating sites for 2011.
2. Conduct site visits in Reach A to determine feasibility and potential for meeting site criteria with intent to choose one fixed site for long term monitoring.

Original Site List:

Rotating Sites

Reach D

- Dibblee Slough; sampled for vegetation in 2005 (technically now in Reach C due to changes in Classification)
- 2 sites on Cottonwood Is; sampled for vegetation in 2005; sampled for fish under Salmon Benefits and NMFS in 2010, 2011
- North of Prescott-across from Cottonwood Island; might have road access

Reach E

- Lewis River confluence (dredge material islands); sampled for vegetation in 2007
- Martin Island (cattle impacts?); sampled for vegetation in 2007
- Sandy Island; sampled for vegetation and fish/fish prey in 2007
- Goat Island (dredge material placement)
- Deer Island on upstream side of Goat Island

Reach F

- Inside Willow Bar
- Cunningham Lake (might be inaccessible for seining)
- West side of Sauvie Island
- Backside of Scappoose Landings
- West Hayden Island
-

Fixed site in Reach A

- Inside of Clatsop Spit
- Inside lee side of West Sand Island
- Just west of Ilwaco Marina
- Wallacut Creek confluence
- Chinook River confluence

Day One – November 17 – Rotating Site Selection

Amy Borde, PNNL
Sean Sol and Paul Olson, NOAA
Keith Marco, LCREP
0800 Reach D. Launched at Rainier to visit Reach D sites. We prioritized the site visit to include Cottonwood Is. and Prescott slough, but not Dibblee slough due to time constraints and the fact that it is in Reach C.

Cottonwood Island

Observations: Both sites were deemed acceptable by all parties, with the larger slough site being preferable for fish sampling due to the size. Both sites would have to be accessed at high water for fish sampling.

Other information: Vegetation has been previously sampled by PNNL as part of this study in 2005 and for the Reference Site Study (RSS) in 2010. Fish sampling (monthly beach seining) has occurred at both sites in 2010 as part of the Salmon Benefits project. Water properties sampling (TSS, nutrients, chlorophyll) has also occurred at or near the sites as part of the SB project. The NOAA Fish Ecology (FE) group has also been conducting fish sampling at the downstream end of Cottonwood Island near the confluence of the Cowlitz and Columbia. To our knowledge no prey, diet, or contaminant research has been conducted in any of these studies, but this should be checked. A PNNL depth sensor is located in the big slough (since March 2009).

Prescott Slough

Observations: The site was accessed by foot due to low water. The site has a narrow channel at the entrance leading back to an open, shallow wetland that grades up to *P. arundinacea* (reed canary grass, willows, and cottonwoods). The channel continues up past the site, under the railroad trestle to a tide gated diked area where the old Trojan nuclear reactor was built but never activated. The site was seen as feasible for fish sampling at high water.

Other Information: No previous sampling is known to have occurred at this site. Ownership is unknown at this time. Access is possible from the Prescott Beach County Park located near the site either by walking along the shoreline at low water or by walking through the trees. PNNL installed a water level sensor and sediment accretion stakes at the site (on 11/19/10) in the event the site is selected as a monitoring site.

1100 Reach E. Launched at St. Helens to visit Reach E sites. We prioritized the site visit to focus on Deer Is., Goat Island, and Burke Island (a late addition based on a recommendation from a PNNL colleague). We did not visit the site near the confluence of the Lewis River due to small size of the site and the lack of any real off channel habitat. We boated past Martin Island to confirm that the site also had only a small fringing wetland with no channel habitat and cows were present at the site. Sandy Island had been sampled by all parties in 2007 and therefore a site visit was not necessary.

Deer Island/Goat Island

Observations: The sloughs at the upstream end of Deer Island were accessed by boat to the pile structure running along the upstream end of Goat/Deer Island. We walked over to the slough on Deer island. The water levels were up to the higher marsh, so lower vegetation areas could not be observed, but based on the aerial imagery and the shape of the slough, it is assumed that an area of low marsh also exists at the site. The site was deemed fish-able. We could see a portion of the wetland slough on Goat Island from our location on Deer Island and based on the imagery and previous site visits by PNNL the site was also deemed acceptable by all. Fish sampling would need to be conducted at high water.

Other information: Ownership of Goat Island in known to be private. Ownership of Deer Island needs to be determined. PNNL has sampled vegetation in 2009 as part of the Cumulative Effects (CE) project and RSS. Limited fish sampling was conducted in this year by NOAA-FE (Curtis Roegner).

<u>Burke Island</u>

Observations: We accessed the site by boat at high water. There is a small channel outlet at the mouth of the slough bordered by shrubs and trees. Just past this border, the site opens up into a shallow slough bordered by low and high marsh grading up to pasture on one side and trees on the other side. The pasture was separated from the wetland by a barbed wire fence. No cows were seen in the area and no sign of grazing was observed in the wetland area. Due to the high water the lower elevations of the site could not be observed, however similar to Deer Island the site likely meets the criteria for vegetation sampling. The site was seen as feasible for fish sampling at high water.

Other information: Ownership of the site needs to be determined; it appeared to be private property due to presence of a duck blind and no trespassing signs. The site can only be accessed by boat.

<u>Reach F</u> – Due to time constraints and weather, we decided not to visit the Reach F sites.

Day Two – November 18 – Fixed Site Selection in Reach A

Amy Borde, PNNL
Sean Sol and Paul Olson, NOAA
Keith Marco, LCREP
Whitney Temple and Dave Piatt, USGS
Due to time and access constraints we decided not to visit the Wallacut Creek site, a low priority due to the apparent lack of tidal channels from the imagery.

<u>0900 High Tide</u>. We observed the Chinook River mouth site from across the Chinook River to get an idea of the extent of inundation relative to the vegetation and the channels. We then launched the boat from the Ilwaco marina and visited the site just west of the marina and on west Sand Island. The Sand Island site was rejected due to the lack of channel habitat. The marina site and the Chinook site were deemed worthy of a second visit at lower water later in the day.

<u>1300 Mid Tide</u>. We drove to the Clatsop Spit/Trestle Bay site and walked out to the marshes located just outside the old trestle/dike. The marshes were well vegetated, however the tidal channels were very small and did not meet the site criteria.

<u>1500 Low Tide</u>. We returned to the two sites that seemed most viable: Chinook and the Marina site for evaluation at low tide.

<u>Chinook River Mouth</u>

Observations: We walked into this site at low water via an old road off Hwy 4. This site has a diverse mix of vegetation from low elevation marsh gradually sloping up to high marsh with driftwood along the upper margin. The channel was deep (approx. 4 ft) and 10 to 15 ft wide with vegetation on the banks and submerged vegetation in the channel. Wood was observed in the banks and on the bottom of the channel, indicating 1) the area is and/or has been a repository for large wood and 2) the marsh has been around long enough to accrete considerable amounts of sediment over the wood noted in the banks of the channel. The channel appeared to have some deep pools that might allow for deployment of USGS sensors; evaluation at a lower water level would be needed. It was determined that the site would be difficult to sample logistically due to the location and the wood in the channel, however it seemed to be the least disturbed of all the sites we looked at and to have the most developed marsh and tidal channel making it worth the effort to figure out the sampling challenges.

Other information: The site is in private ownership and long-term access to the site would need to be determined. PNNL sampled the vegetation, elevation, and water level at this site in 2009. CREST has sampled for fish sometime prior to that. The site was present on the historic maps of the late 1800's unlike any of the other marshes on our site selection list or possibly in all of Reach A. This site is a unique example of a diverse, mature, and stable marsh that was likely common in the historic floodplain of the estuary. This site would be the first choice of the EM team if access/ownership is resolved.

<u>Ilwaco Marsh</u>

Observations: We were able to walk into the site via the western jetty of the marina (Sean Sol gained permission from the business located on the jetty). The channel was shallower and wider than the Chinook site with no observable wood in the channel or on the marsh. The site would be accessible for fish sampling and the channel could possibly be deep enough for the USGS sensor at low tide. The vegetation was a mix of low marsh species (as much as could be discerned from the remnant fall vegetation). There did not appear to be a higher marsh, as the low marsh abuted the steep bank/bluff at the margin of the site.

Other information: Ownership of the site appears to be the State and the Port based on the Pacific County Assessors website. The marsh was not present on the historic maps and seems likely to have formed in the years since due to sedimentation from changes in circulation in Baker Bay and possibly from the jetty/marina located nearby. This would explain the shallow channel and the presence of only low marsh.

While at the site, PNNL installed a water level sensor and sediment accretion stakes. This was done because ownership was not a concern and to gain preliminary information in the event the site is chosen for monitoring.

Summary

Priorities based on site feasibility (not ownership or other research):

Potential Reach D sites

- Cottonwood Island big slough and Prescott slough
- Cottonwood Island small slough

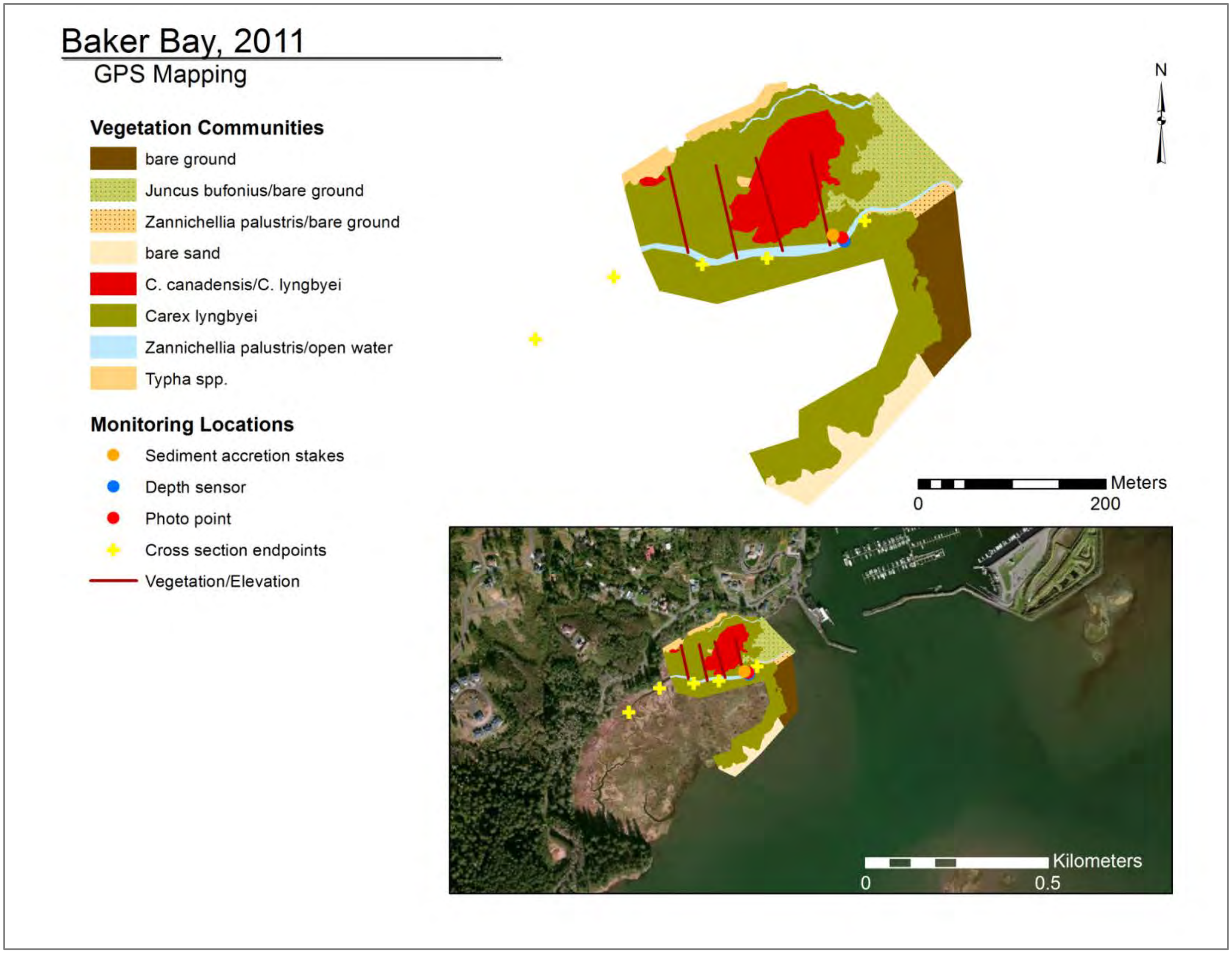
Potential Reach E sites

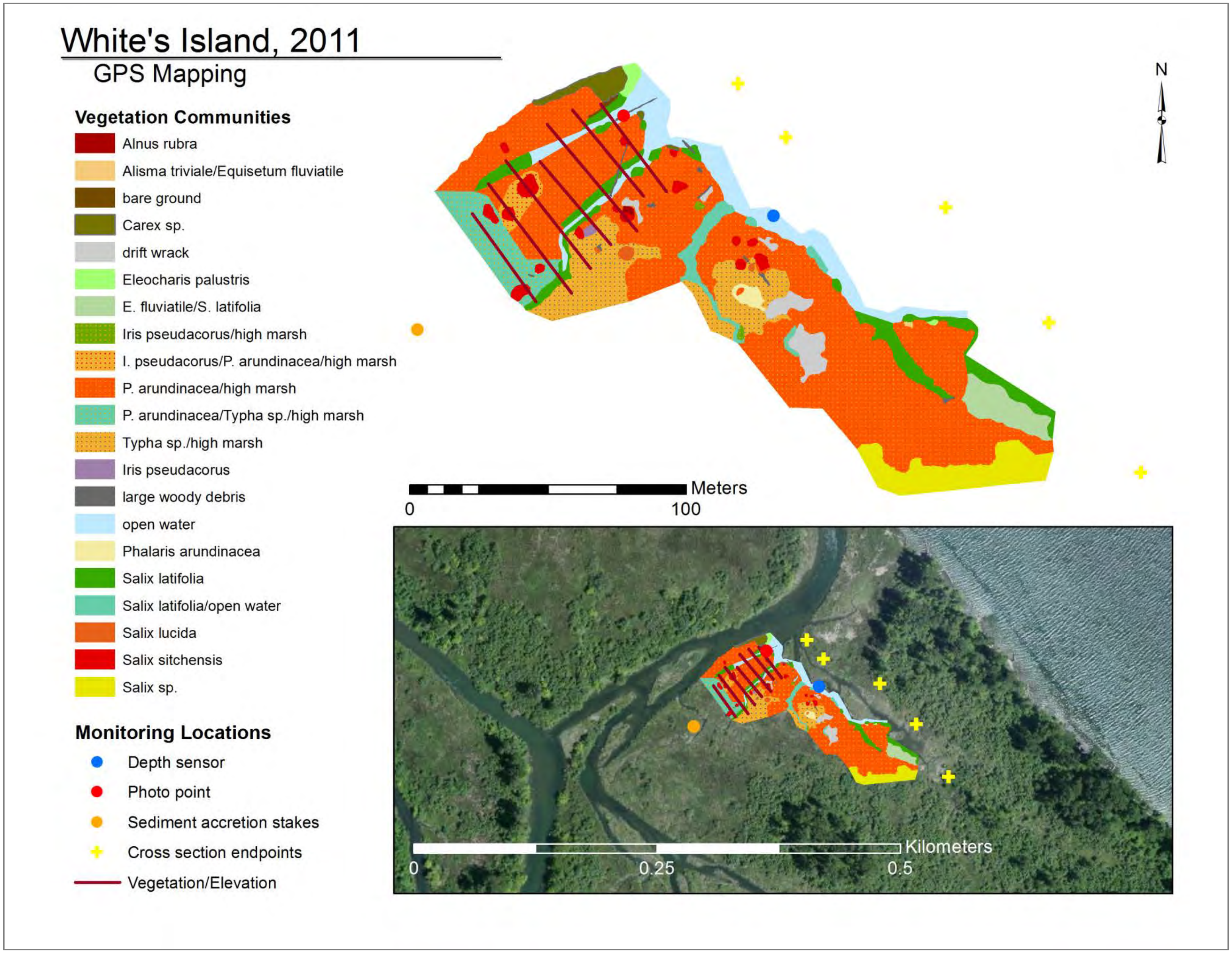
- All sites equal: Deer Island, Goat Island, Burke Island, Sandy Island

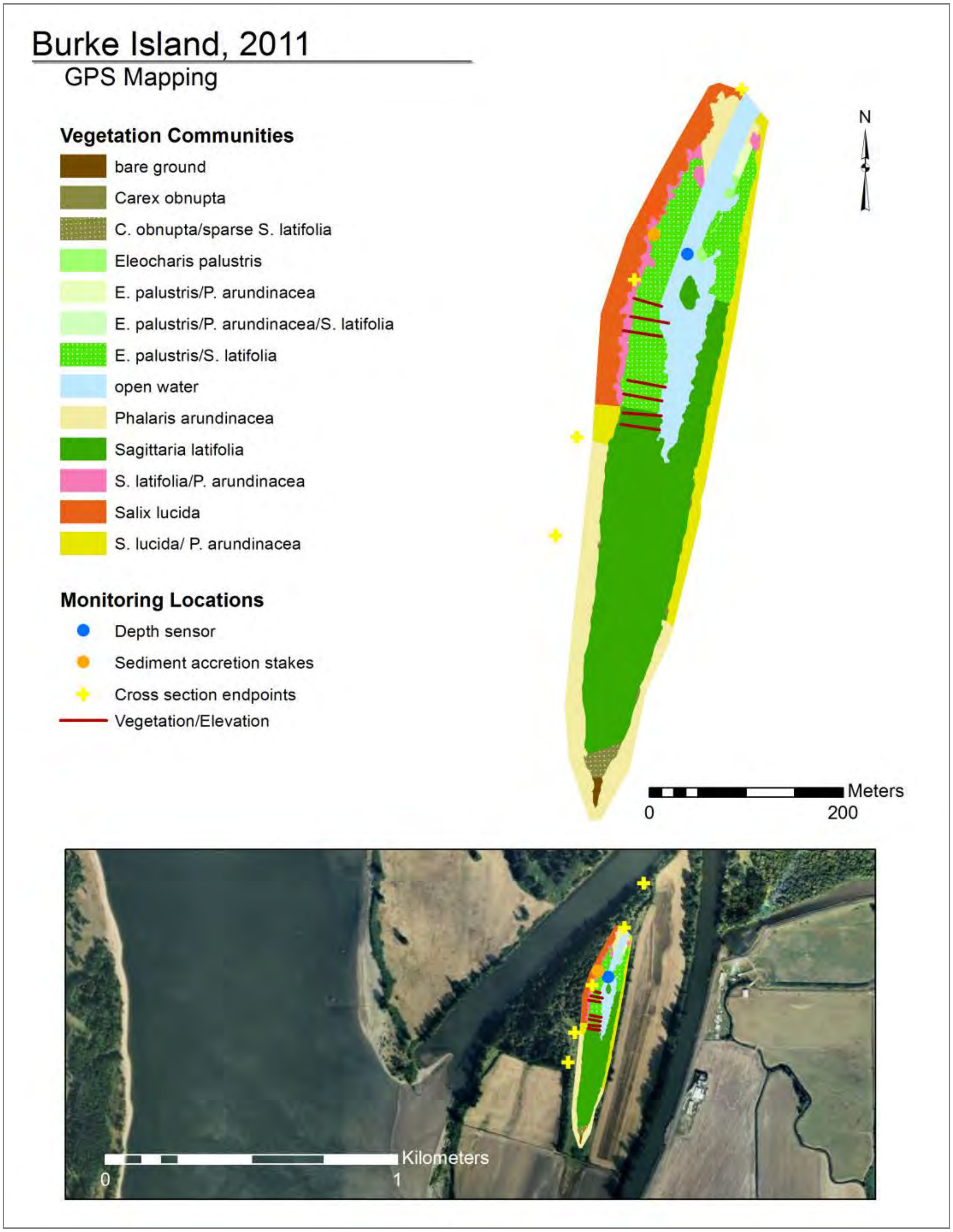
Potential Reach A fixed site

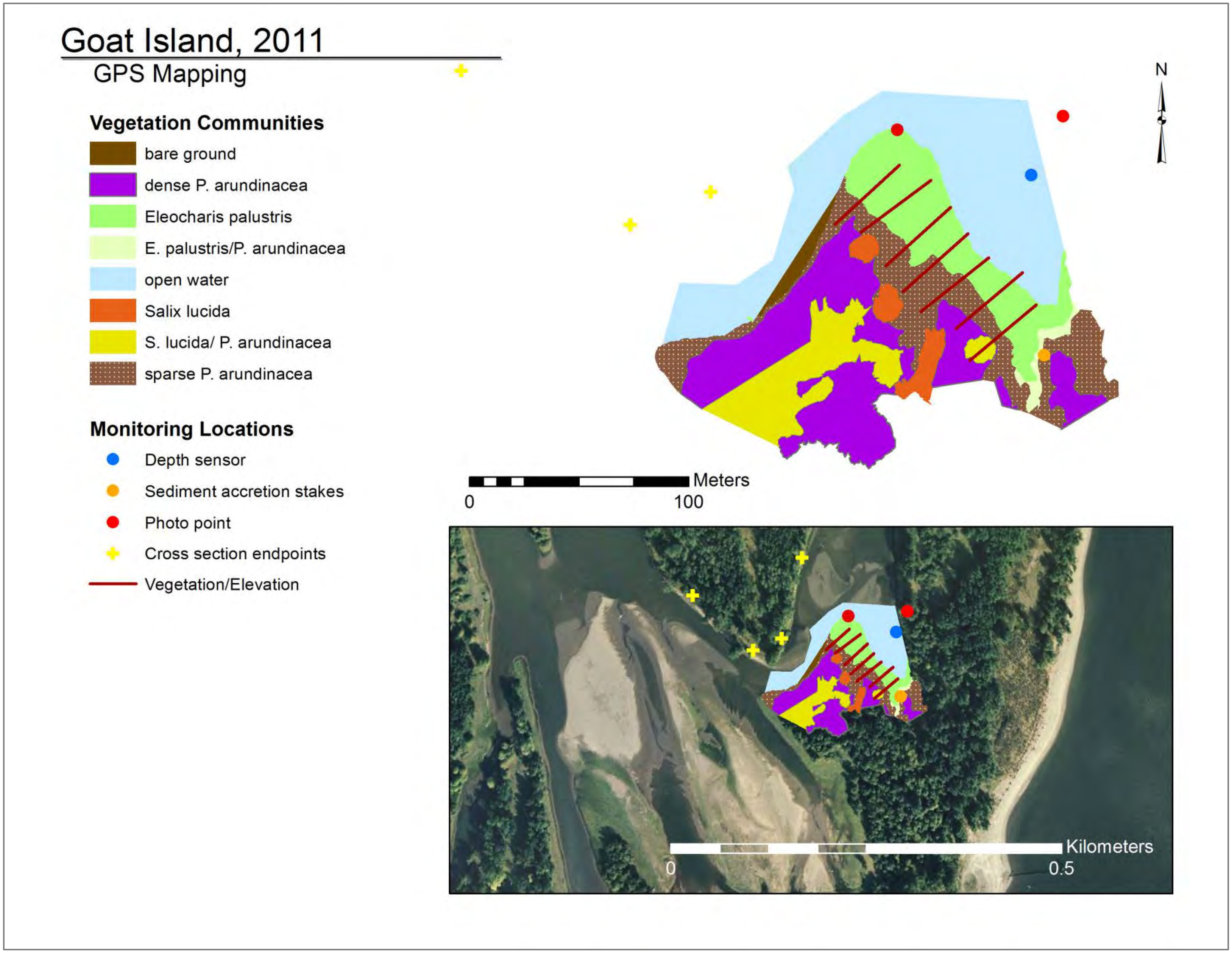
- Chinook
- Ilwaco

Appendix B. Vegetation Site Maps

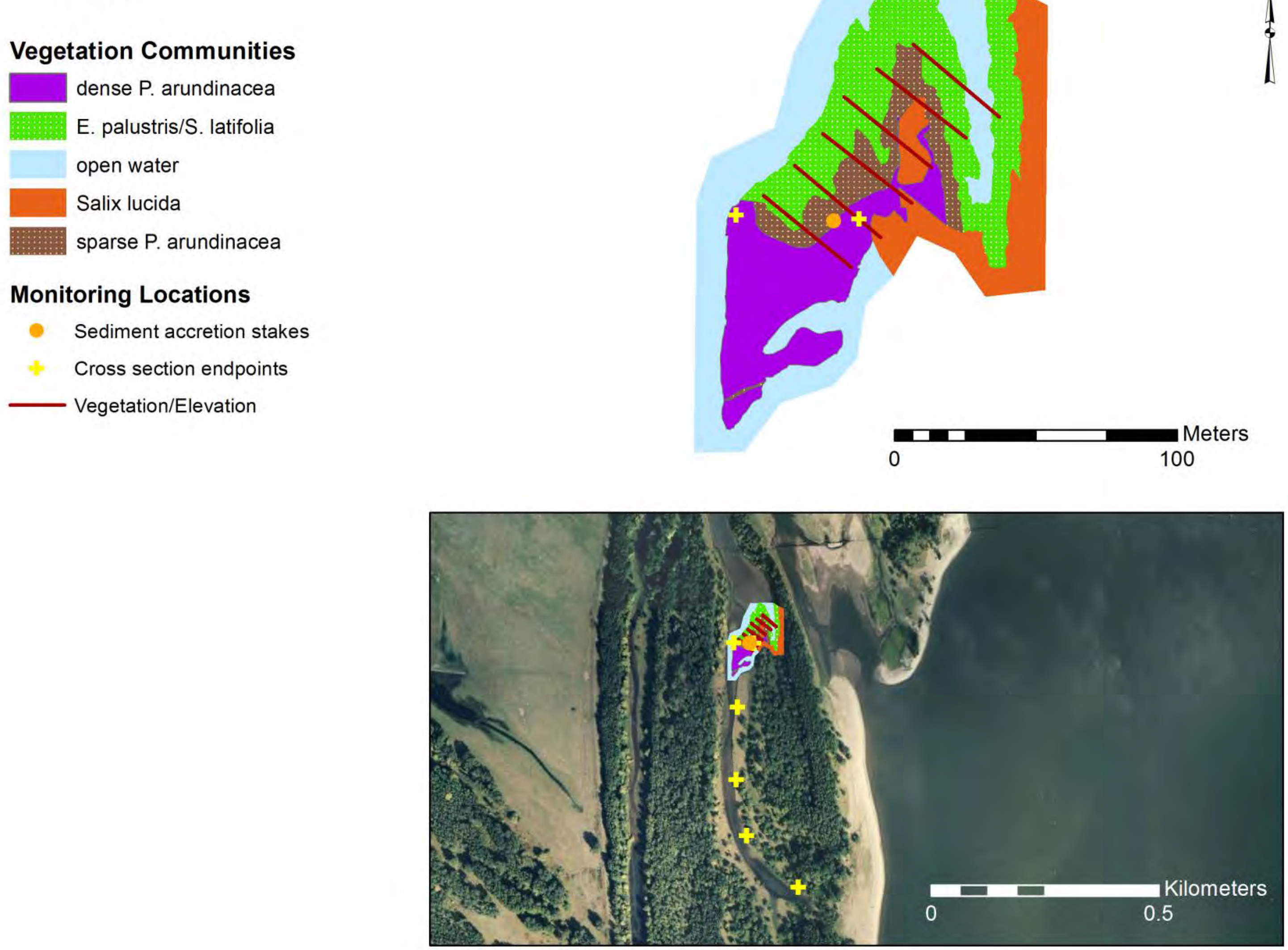


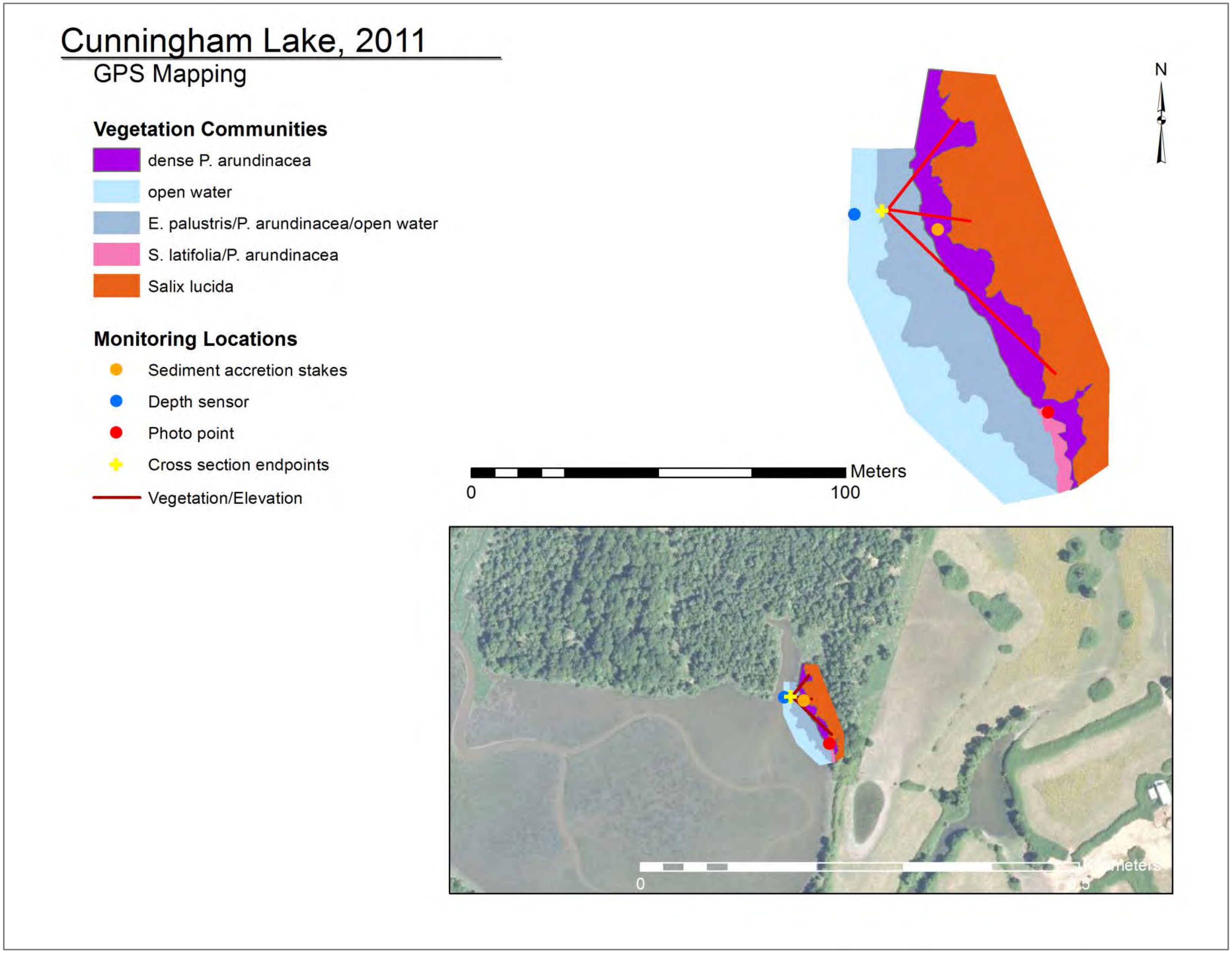

White's Island, 2011
GPS Mapping
Vegetation Communities
Alnus rubra
Alisma triviale/Equisetum fluviatile
bare ground
Carex sp.
drift wrack
Eleocharis palustris
E. fluviatile/S. latifolia
Iris pseudacorus/high marsh
I. pseudacorus/P. arundinacea/high marsh
P. arundinacea/high marsh
P. arundinacea/Typha sp./high marsh
Typha sp./high marsh
Iris pseudacorus
large woody debris
open water
Phalaris arundinacea
Salix latifolia
Salix latifolia/open water
Salix lucida
Salix sitchensis
Salix sp.
Monitoring Locations
Depth sensor
Photo point
Sediment accretion stakes
Cross section endpoints
Vegetation/Elevation
N
Meters
0
100
Kilometers
0
0.25
0.5

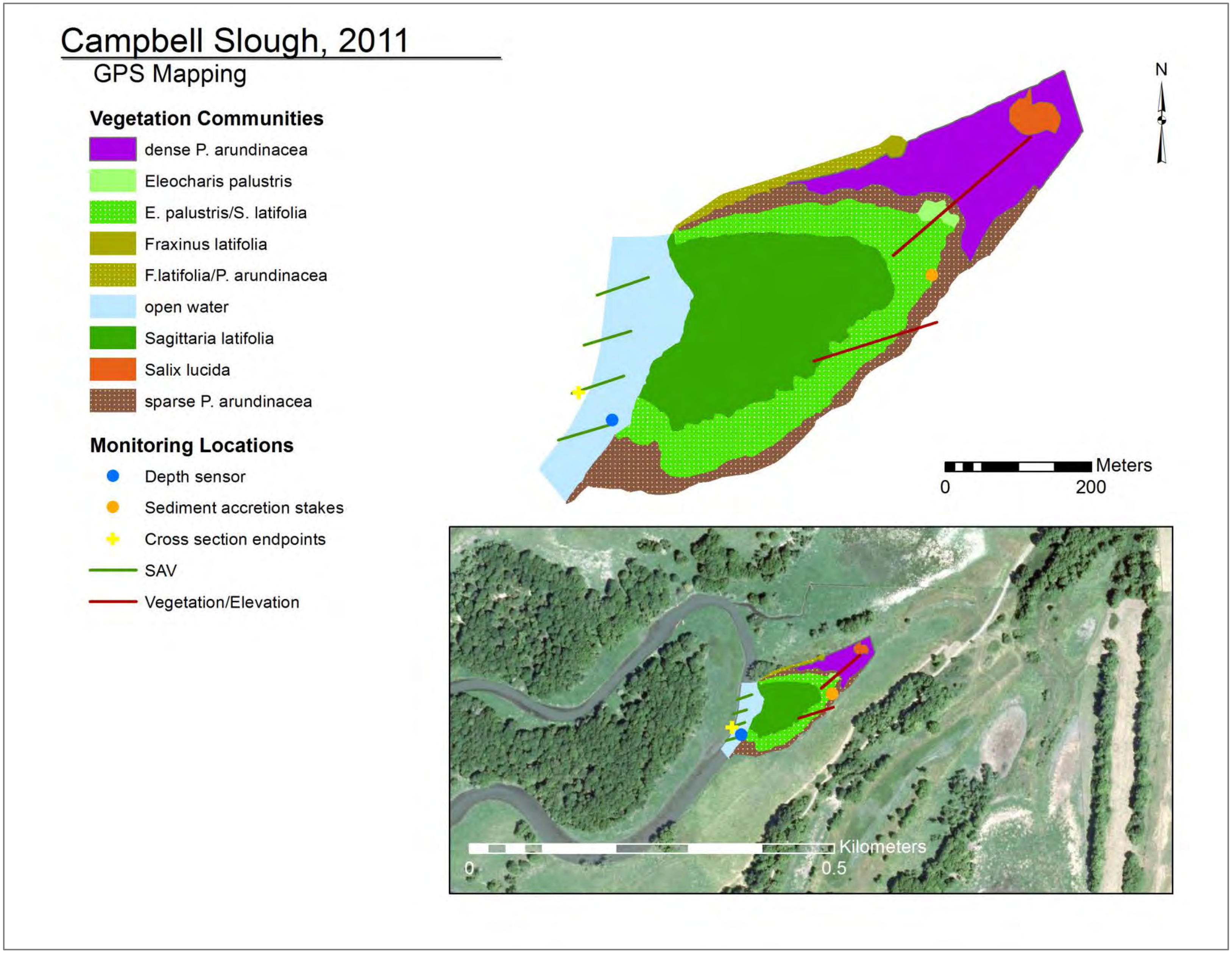

Burke Island, 2011
GPS Mapping
Vegetation Communities
bare ground
Carex obnupta
C. obnupta/sparse S. latifolia
Eleocharis palustris
E. palustris/P. arundinacea
E. palustris/P. arundinacea/S. latifolia
E. palustris/S. latifolia
open water
Phalaris arundinacea
Sagittaria latifolia
S. latifolia/P. arundinacea
Salix lucida
S. lucida/ P. arundinacea
Monitoring Locations
Depth sensor
Sediment accretion stakes
Cross section endpoints
Vegetation/Elevation
N
Meters
0
200
Kilometers
0
1


Goat Island, 2011
GPS Mapping
Vegetation Communities
bare ground
dense P. arundinacea
Eleocharis palustris
E. palustris/P. arundinacea
open water
Salix lucida
S. lucida/ P. arundinacea
sparse P. arundinacea
Monitoring Locations
Depth sensor
Sediment accretion stakes
Photo point
Cross section endpoints
Vegetation/Elevation
N
Meters
0
100
Kilometers
0
0.5

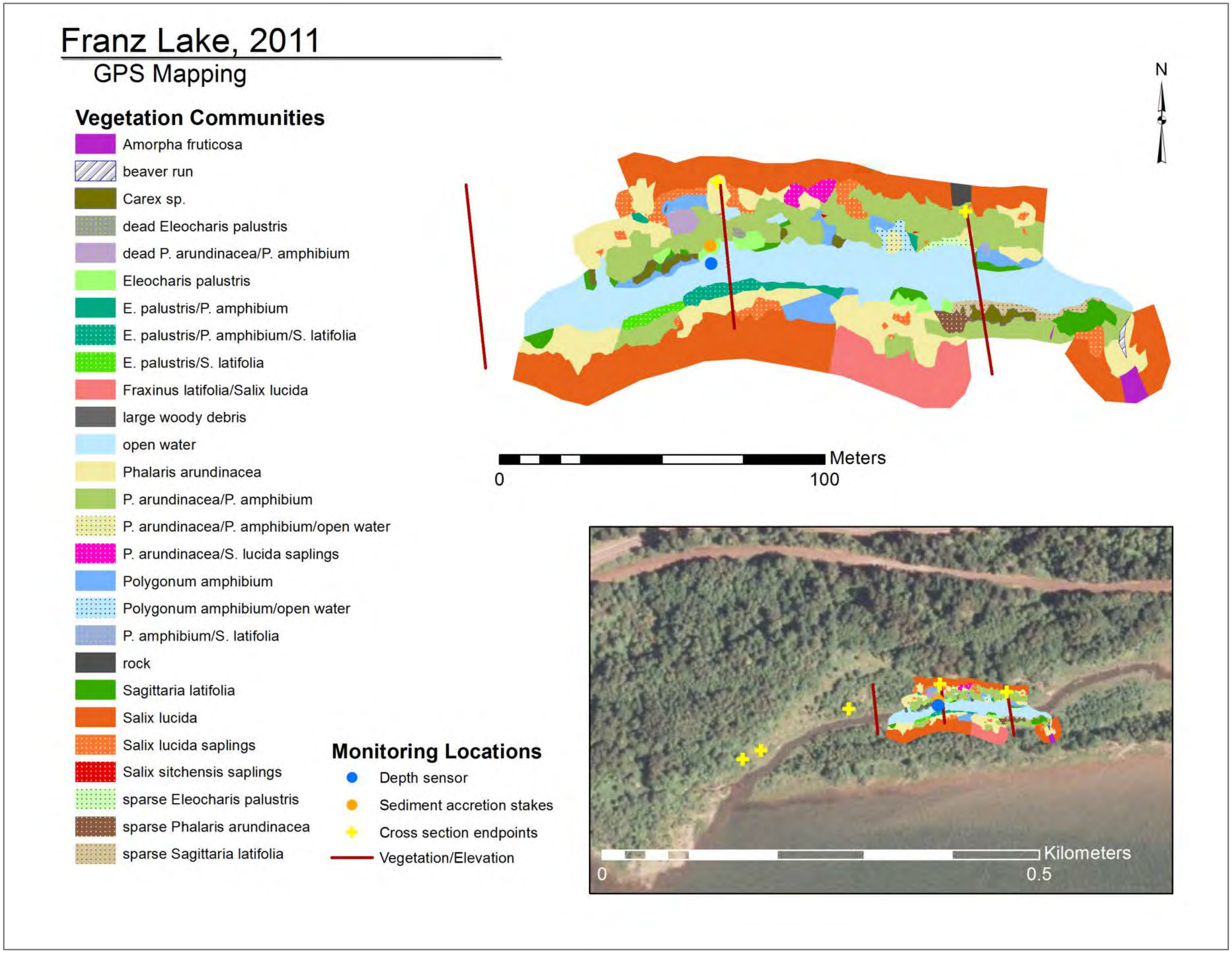
Deer Island, 2011
GPS Mapping




Cunningham Lake, 2011
GPS Mapping
Vegetation Communities
dense P. arundinacea
open water
E. palustris/P. arundinacea/open water
S. latifolia/P. arundinacea
Salix lucida
Monitoring Locations
Sediment accretion stakes
Depth sensor
Photo point
Cross section endpoints
Vegetation/Elevation
N
0
100
Meters
0



Campbell Slough, 2011
GPS Mapping
Vegetation Communities
dense P. arundinacea
Eleocharis palustris
E. palustris/S. latifolia
Fraxinus latifolia
F.latifolia/P. arundinacea
open water
Sagittaria latifolia
Salix lucida
sparse P. arundinacea
Monitoring Locations
Depth sensor
Sediment accretion stakes
Cross section endpoints
SAV
Vegetation/Elevation
N
Meters
0
200
Kilometers
0
0.5


Franz Lake, 2011
GPS Mapping
Vegetation Communities
Amorpha fruticosa
beaver run
Carex sp.
dead Eleocharis palustris
dead P. arundinacea/P. amphibium
Eleocharis palustris
E. palustris/P. amphibium
E. palustris/P. amphibium/S. latifolia
E. palustris/S. latifolia
Fraxinus latifolia/Salix lucida
large woody debris
open water
Phalaris arundinacea
P. arundinacea/P. amphibium
P. arundinacea/P. amphibium/open water
P. arundinacea/S. lucida saplings
Polygonum amphibium
Polygonum amphibium/open water
P. amphibium/S. latifolia
rock
Sagittaria latifolia
Salix lucida
Salix lucida saplings
Salix sitchensis saplings
sparse Eleocharis palustris
sparse Phalaris arundinacea
sparse Sagittaria latifolia
Monitoring Locations
Depth sensor
Sediment accretion stakes
Cross section endpoints
Vegetation/Elevation
N
Meters
0
100
Kilometers
0
0.5

Appendix C. Vegetation Species Cover

Site elevation (in meters, relative to the Columbia River vertical datum CRD) and vegetation species average percent cover. The three dominant cover classes are bolded in red for each site and the invasive species are shaded in yellow (not necessarily non-native species). Species are sorted by their four letter code (1st two letters of genus and 1st two letters of species).

Code	Scientific Name	Common Name	Wetland Status	Native	BBM	BIM	CLM	CS1	DIC	FLM	GIC	WHC
					Elevation (m, CRD)							
				Min	0.97	0.97	1.02	1.16	0.85	0.968	1.09	1.66
				Avg	2.00	1.18	1.37	1.66	1.51	1.851	1.57	1.95
				Max	2.39	1.56	1.68	2.69	2.60	2.333	2.13	2.24
Code	**Scientific Name**	**Common Name**	**Wetland Status**	**Native**	**Average Percent Cover**							
AGST	Agrostis stolonifera L.	creeping bentgrass	FAC	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62
ALTR	Alisma triviale	northern water plaintain	OBL	yes	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.62
CAAM	Castilleja ambigua	paint-brush owl-clover; johnny-nip	FACW+	yes	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CACA	Calamagrostis canadensis	bluejoint	FACW+	yes	**9.78**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAHE	Callitriche heterophylla	Water starwort	OBL	yes	0.00	0.03	0.00	0.00	0.00	3.51	0.00	0.79
CALY	Carex lyngbyei	Lyngby sedge	OBL	yes	**60.38**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CAOB	Carex obnupta	Slough sedge	OBL	yes	0.00	0.00	0.00	0.00	0.00	3.02	0.00	**4.93**
CAPA	Caltha palustris	Yellow marsh marigold	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
CASE	Calystegia sepium	Hedge bindweed	FAC	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
CASP	Carex sp.	Carex	mixed	yes	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
CEDE	Ceratophyllum demersum	Coontail	OBL	yes	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00
COMA	Conium maculatum	Poison hemlock	FAC+	no	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00

Code	Scientific Name	Common Name	Wetland Status	Native	BBM	BIM	CLM	CS1	DIC	FLM	GIC	WHC
DECE	Deschampsia cespitosa	Tufted hairgrass	FACW	yes	2.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DISP2	Distichlis spicata	saltgrass	FACW	yes	**7.03**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ELAC	Eleocharis acicularis	Needle spikerush	OBL	yes	3.50	0.03	1.27	0.05	0.27	0.26	0.03	0.00
ELCA	Elodea canadensis	Canada waterweed	OBL	yes	0.00	**4.21**	0.08	0.05	0.87	0.00	0.09	0.52
ELPA	Eleocharis palustris	Common spikerush	OBL	yes	0.00	2.35	2.80	**12.63**	**5.90**	4.28	**8.83**	1.36
ELPAR	Eleocharis parvula	Dwarf spikerush	OBL	yes	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EPCI	Epilobium ciliatum	Willow herb	FACW-	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
EQFL	Equisetum fluviatile	Water horsetail	OBL	yes	0.00	1.12	0.00	0.00	0.00	0.00	0.00	3.52
EQPA	Equisetum palustre	marsh horsetail	FACW	yes	0.00	0.00	0.22	0.00	1.00	1.02	0.83	0.00
FRLA*	Fraxinus latifolia	Oregon ash	FACW	yes	0.00	0.00	0.00	0.73	0.00	1.62	0.00	0.00
FUDI	Fucus distichus	Rockweed	OBL	yes	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GASP	Galium spp	Pacific bedstraw; cleavers; small bedstraw	mixed	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
GLGR	Glyceria grandis	American mannagrass	OBL	yes	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.62
HEAU	Helenium autumnale	common sneezeweed	FACW	yes	0.00	0.00	0.00	0.00	0.37	0.08	0.14	0.00
IRPS	Iris pseudacorus	Yellow iris	OBL	no	0.00	0.03	0.02	0.00	0.00	0.00	0.00	3.33
JUAR	Juncus arcticus Wild. ssp. littoralis	mountain rush	No	yes	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
JUEN	Juncus ensifolius	Daggerleaf rush	FACW	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00
JUOX	Juncus oxymeris	Pointed rush	FACW+	yes	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.12
LEMI	Lemna minor	Duckweed	OBL	yes	0.00	0.12	0.00	0.02	0.00	0.00	0.00	0.00
LEOR	Leersia oryzoides	Rice cutgrass	OBL	yes	0.00	0.12	0.00	0.00	0.00	1.08	0.00	0.62
LIAQ	Limosella aquatica	Water mudwort	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
LIOC	Lilaeopsis occidentalis	Western lilaeopsis	OBL	yes	6.55	0.06	0.00	0.00	0.03	0.00	0.00	0.00

Code	Scientific Name	Common Name	Wetland Status	Native	BBM	BIM	CLM	CS1	DIC	FLM	GIC	WHC
LOCO	Lotus corniculatus	Birdsfoot trefoil	FAC	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60
LUPA	Ludwigia palustris	False loosestrife	OBL	yes	0.00	0.00	0.17	1.21	0.00	0.51	0.00	0.00
LYAM	Lysichiton americanus	Skunk cabbage	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29
LYNU	Lysimachia nummularia L.	Moneywort, Creeping Jenny	FACW	no	0.00	0.00	0.00	1.21	1.20	0.00	0.00	0.00
LYSA	Lythrum salicaria	Purple loosestrife	FACW+	no	0.00	0.00	0.00	0.00	0.20	0.00	0.14	0.55
MIGU	Mimulus guttatus	Yellow monkeyflower	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
MYSC	Myosotis scorpioides	Common forget-me-not	FACW	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
MYSI	Myriophyllum sibiricum	northern milfoil, short spike milfoil	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
MYSP3	Myriophyllum spicatum	Eurasian water milfoil	OBL	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OESA	Oenanthe sarmentosa	Water parsley	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.38
PHAR	Phalaris arundinacea	Reed canary grass	FACW	no	0.00	**6.21**	**15.59**	**33.55**	**17.47**	**23.69**	**15.37**	**56.79**
PHAR-d	dead Phalaris arundinacea	Reed canary grass	FACW	no	0.00	0.00	**24.83**	**6.37**	0.00	**8.40**	0.00	0.00
POAM	Polygonum amphibium	water ladysthumb, water smartweed	OBL	yes	0.00	0.00	0.00	0.02	0.00	**9.89**	0.00	0.00
POAN	Potentilla anserina ssp. Pacifica/Argentina egedii ssp. Egedii	Pacific silverweed	OBL	yes	2.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00
POCR	Potamogeton crispus	Curly leaf pondweed	OBL	no	0.00	0.47	0.00	0.18	0.03	0.00	0.00	0.12
POHY	Polygonum hydropiper, P. hydropiperoides	Waterpepper, mild waterpepper, swamp smartweed	OBL	mixed	0.00	0.15	0.00	0.00	0.00	0.08	0.03	0.69

Code	Scientific Name	Common Name	Wetland Status	Native	BBM	BIM	CLM	CS1	DIC	FLM	GIC	WHC
PONA	Potamogeton natans	Floating-leaved pondweed	OBL	yes	0.00	0.44	0.00	0.00	0.33	0.00	0.06	0.00
PONO	Potamogeton nodosus	longleaf pondweed	OBL	yes	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00
POPE	Polygonum persicaria	Spotted ladysthumb	FACW	no	0.00	1.24	0.15	0.00	0.20	0.00	0.00	0.05
POPU	Potamogeton pusillus	Small pondweed	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
PORI	Potamogeton richardsonii	Richardson's pondweed	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36
POZO	Potamogeton zosteriformis	Eelgrass pondweed	OBL	yes	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
RUCR	Rumex crispus	Curly dock	FAC+	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24
RUMA	Rumex maritimus	Golden dock, seaside dock	FACW+	yes	0.00	0.00	0.00	0.08	0.03	0.00	0.00	0.05
SALA	Sagittaria latifolia	Wapato	OBL	yes	0.00	**14.65**	2.32	5.81	**1.93**	2.09	0.80	**4.07**
SALU	Salix lucida	Pacific willow	FACW+	yes	0.00	0.00	0.00	0.00	0.20	3.31	0.00	0.00
SALU*	Salix lucida	Pacific willow	FACW+	yes	0.00	1.91	**5.51**	0.97	0.20	3.31	**5.00**	0.00
SASI	Salix sitchensis	Sitka willow	FACW	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.79
SCAM	Schoenoplectus americanus	American bulrush, threesquare bulrush	OBL	yes	2.90	0.00	0.00	0.00	0.00	0.00	0.00	0.14
SCMA	Schoenoplectus maritimus	Seacoast bulrush	OBL	yes	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCTA	Schoenoplectus tabernaemontani	Softstem bulrush, tule	OBL	Yes	0.00	0.74	0.00	0.02	0.00	0.15	0.00	0.00
SISU	Sium suave	Hemlock waterparsnip	OBL	yes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.38
SODU	Solanum dulcamara	Bittersweet nightshade	FAC+	no	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
SPAN	Sparganium angustifolium	Narrowleaf burreed	OBL	yes	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.02
SYSU	Symphyotrichum subspicatum	Douglas aster	FACW	yes	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Code	Scientific Name	Common Name	Wetland Status	Native	BBM	BIM	CLM	CS1	DIC	FLM	GIC	WHC
TRMA	Triglochin maritima	Seaside arrowgrass	OBL	yes	4.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TYAN	Typha angustifolia	Narrowleaf cattail	OBL	no	1.15	0.00	0.00	0.00	0.00	0.00	0.00	3.17
VEAM	Veronica americana	American speedwell	OBL	yes	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00
ZAPA	Zannichellia palustris	horned pondweed	OBL	yes	2.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix D. Abundances (in cells L^{-1}) of non-diatom phytoplankton and microzooplankton (shaded in grey) taxa.

Taxa		**FL 4/14/11**	**FL 4/26/11**	**FL 5/10/11**	**FL 5/24/11**	**WI 4/13/11**	**WI 4/25/11**	**WI 5/11/11**	**CS 5/9/11**	**IL 4/12/11**	**IL 4/25/11**	**IL 5/12/11**	**IL 5/25/11**
Cryptophyta	*Cryptomonas erosa*	40625	150000	150000	520000	46429	227273	42267	440000	0	3611	27778	17313
	Cryptomonas sp.	24375	0	0	0	0	0	0	0	0	0	138,889	0
	misc crypto	265000	700000	2000000	546000	393,571	454545	1458333	160000	0	14444	444444	1298476
	Rhodomonas sp.	1080000	250000	0	0	277857	1045455	0	740000	9,286	0	194,444	34,626
Dinoflagellates	athecate dino	0	0	0	13000	0	0	0	0	0	0	0	400
	dino cyst	0	0	0	0	0	22727	0	200	0	28,889	0	0
	Dinophysis ovum	0				0	0	0	0	0	0	0	200
	Glenodinium	8125	0	0	0	10140	22,727	0	0	0	0	0	0
	Gymnodinium/ Gyrodinium	0	300000	50000	26000	0	0	0	0	0	0	0	86765
	Katodinium	0	0	0	13000	0	22727	44067	0	0	25278	83333	69652
	misc dinos	0	0	0	0	27857	0	0	60000	0	3611	83333	0
	misc heterotrophic dinos	0		0	0	0	0	0	0	0	3611	0	0
	Peridiniopsis	50000	0	0	0	0	113636	2600	0	0	0	0	0
	thecate dino	0	0	0	0	0	0	41,667	0	0	0	0	0
Chlorophyta	*Ankistrodesmus*	32500	100000	150000	26000	3380	68182	125000	160000	0	7222	94556	17313
	Apiocystis	50000	0	0	0	0	0	0	0	0	0	0	0
	Asterococcus	8125	0	0	0	0	0	0	0	0	0	0	0
	Chlamydomonas	8125	350000	0	0	0	68,182	400	0	0	0	0	0
	Chlorella	1105000	0	0	0	0	0	0	0	0	0	0	0
	Crucigenia lauterbornii	0	0	0	0	0	0	9000	0	0	0	0	0
	Desmodesmus	0	0	0	0	0	0	1500000	80000	0	0	111111	0
	Excentrosphaera viridis	0	0	0	0	0	0	1000	0	0	0	0	0
	Gloeocystis	8125	250000	0	428307	0	0	0	0	0	0	0	0
	green flagellate	8125	0	0	13000	0	0	800	0	0	0	0	0
	misc round green	8125	0	0	0	0	0	200	20000	0	3611	83333	0
	Pandorina	8125	0	0	0	0	0	0	0	0	0	0	0
	Pediastrum boryanum	0	0	0	0	74,286	0	0	0	0	0	0	0
	Pediastrum sp.	0	0	0	0	0	0	2800	6800	0	0	0	0
	Scenedesmus acutus	0	0	0	195000	0	0	0	0	0	0	0	0
	Scenedesmus sp.	0	0	0	0	0	90,909	0	0	0	0	0	0
Taxa		**FL**	**FL**	**FL**	**FL**	**WI**	**WI**	**WI**	**CS**	**IL**	**IL**	**IL**	**IL**

		4/14/11	4/26/11	5/10/11	5/24/11	4/13/11	4/25/11	5/11/11	5/9/11	4/12/11	4/25/11	5/12/11	5/25/11
Chrysophyta	*Mallomonas*	8125	100000	0	376	0	0	1200	0	0	0	0	0
	Dinobryon	0	0	0	52000	0	0	1600	0	0	0	0	0
	misc chrysophyte	8125	50000	0	13000	0	41,667	800	140000	0	0	27778	0
	Ochromonas	400000	0	0	0	0	0	0	0	0	0	0	0
Ciliophora	*Strombidium*	168265	3380	0	13000	125000	0	41,667	40400	0	0	27778	34626
	Myrionecta rubra	0	0	0	0	0	0	0	0	0	0	0	34626
	misc ciliate	0	100000	0	0	0	45455	12000	1000	0	3611	109333	0
	small tintinnid	0	0	0	0	0	0	0	20800	0	0	0	17313
	misc tintinnids	0	0	0	1878	0	0	0	0	0	0	0	0
	Tintinnopsis	0	0	0	0	0	0	4200	0	0	0	0	0
	Tiorina	0	0	0	0	0	0	0	0	0	0	0	400
Euglenophyta	*Euglena*	0	0	0	0	0	0	0	400	0	0	0	0
	Eutreptiella	0	0	0	0	0	0	0	800	0	0	0	34626