Ecosystem Monitoring Project

Annual Report

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Lower Columbia River Ecosystem Monitoring Project
Annual Report for Year 3 (September 2005 to August 2006)

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Project Goals and Purpose

Our ability to understand the relationship of sensitive organisms such as salmonids to the Columbia River Estuary ecosystem is greatly hindered by major data gaps and poor access to existing data. The Lower Columbia River Estuary Partnership (Estuary Partnership) implements elements of its Aquatic Ecosystem Monitoring Strategy to address habitat and toxics monitoring needs and data management through the Ecosystem Monitoring Project. The Ecosystem Monitoring Project has two main components – habitat monitoring, which involves field surveys and the development of an ecosystem classification system, and water quality monitoring, comprised of water chemistry data collection, juvenile salmonid sampling and the creation of three models related to salmonid uptake, transport and ecological risk of toxics. This monitoring was originally intended to address Reasonable and Prudent Alternatives 161, 163, and 198 of the 2000 Biological Opinion for the Federal Columbia River Power System.

The Habitat Monitoring component focused on creating the tools necessary for planning and conducting comprehensive habitat monitoring for measuring the status and trends of habitat types in the Columbia River Estuary. The work elements listed under Habitat Monitoring for Year 3 (September 1, 2005 to August 31, 2006) of this contract were directed at creating a scientifically sound sampling plan and creating a hydrogeomorphic classification for the Columbia River Estuary. University of Washington and USGS Biological Resource Division (USGS BRD) were subcontracted to develop the Columbia River Estuary Ecosystem Classification System (Simenstad et al., 2006) and the Pacific Northwest National Laboratory (PNNL) was subcontracted to conduct on-the-ground field surveys in tidally influenced wetlands in the Columbia River Estuary.

The Toxics monitoring component continued to address issues such as the accumulation of toxics in sensitive habitat areas, contaminant trends over time, and contaminant impacts on salmonids. The work elements listed under Toxics Monitoring for Year 3 (September 1, 2005 to August 31, 2006) of this contract were directed at completing salmonid and water quality sampling and analyzing the information and updating the three models related to salmonid uptake, transport and ecological risk of toxics. National Oceanic and Atmospheric Administration (NOAA) Fisheries was subcontracted to sample juvenile salmonids and integrate the salmonid and water quality information into the three toxics models, and USGS Water Resources Discipline (USGS WRD) was subcontracted to monitor toxics in the water column and suspended sediments.

Project Background and Introduction

Bonneville Power Administration (BPA) originally awarded a three year contract in September 2003 to the Lower Columbia River Estuary Partnership (Estuary Partnership) for its Ecosystem Monitoring Project. Prior to this date, the Estuary Partnership's Science Work Group had been working on designing the elements of this project involving toxics monitoring and habitat monitoring. Once funding was secured, BPA project managers conferred with the Science Work Group to finalize the project. Plans were developed during fall 2003 to proceed with a toxics monitoring plan that took a multi-species approach, including salmon, eagles, and osprey, monitored conventional and toxic pollutants, including fecal coliform, and mercury, and investigated a data management strategy.

With plans to move forward with on the ground work in late 2003, BPA notified the Estuary Partnership of the need for a review by the Independent Scientific Review Panel (ISRP) after the project was further defined. Specifically, the toxics monitoring program focus should be on salmonids and the effects of toxic and conventional pollutants in the Columbia River Estuary on salmonid species. Further, it was requested that fecal coliform, mercury, and data management be removed from the proposal. It was also indicated that the habitat monitoring portion of the project was in relatively good condition; however, no work could proceed until the toxics monitoring portion of the project was resolved. USGS, NOAA Fisheries, and Estuary Partnership staff re-submitted the toxics portion of the project and both components, habitat and toxics monitoring, were reviewed by the ISRP in April. ISRP yielded a favorable review of the toxics monitoring portion of the project and given minor additions, the water quality monitoring could move forward. The habitat monitoring portion did not receive favorable reviews and the Columbia River Estuary Habitat Monitoring Plan (Lower Columbia River Estuary Partnership, 2004) was drafted to define clearly the goals and methods of the habitat monitoring program.

Once the Columbia River Estuary Habitat Monitoring Plan was reviewed by the ISRP, Estuary Partnership staff, Pacific Northwest National Laboratory, USGS, and the University of Washington focused on creating a scientifically sound sampling plan for the Columbia River Estuary during Year 2 (September 1, 2004 to August 31, 2005) of the Ecosystem Monitoring Project. The habitat monitoring program is utilizing the sampling plan to measure the status and trends of habitat types in the Columbia River Estuary. The sampling plan was informed by the creation and refinement of the Columbia River Estuary Ecosystem Classification System by University of Washington and USGS BRD (Simenstad et al., 2006). This classification is being developed from Landsat TM imagery and bathymetry data and was used to identify specific reaches of the Columbia River Estuary to sample during summer 2005. Field surveys were conducted in reaches D and F to collect biological and chemical data on habitat conditions, including salinity, depth, temperature and dissolved oxygen as well as vegetative cover and water elevation estimates (Figure 2). The results of this sampling are summarized in the Columbia River Estuary Habitat Monitoring Pilot Field Study and Remote Sensing Analysis (Sobocinski et al., 2006a) available on the Estuary Partnership's web site at: http://www.lcrep.org/eco_habitat_monitor.htm.

During Year 2 (September 1, 2004 to August 31, 2005), toxics monitoring was also implemented by NOAA Fisheries and USGS WRD to address issues such as the accumulation of toxics in sensitive habitat areas, contaminant trends over time, and contaminant impacts on salmonids. NOAA Fisheries organized a workshop to coordinate fish, habitat, and water quality monitoring projects being undertaken in the lower Columbia River (RM 0-146) as a means of creating a conceptual model to track toxic sources, pathways, and effects on salmonid populations. (Dietrich et al. 2005; see also Scholz et al. 2006). This conceptual model was used as a basis for developing quantitative models for the uptake and bioaccumulation of contaminants by juvenile salmon in the Columbia River Estuary. Moreover, NOAA developed ecological risk models to link contaminant body burdens in salmonids to health risks such as impaired immune systems, growth inhibition, and reduced survival rates. (Spromberg and Meador 2005, Loge et al. 2005) The ecological risk models also examine the impacts of these health risks on the survival and productivity of listed salmonids. Finally for Year 2, NOAA conducted fish sampling from April 2005 through September 2005 and USGS WRD conducted fixed station water quality monitoring and installed semipermeable membrane devices (SPMDs) to provide data on conventional pollutants and toxics near NOAA salmonid sampling sites.

During Year 3 (September 1, 2005 to August 31, 2006), the Estuary Partnership's Science Work Group selected Reach G to continue habitat monitoring surveys during summer 2006 (Figure 2). Field sampling was completed in July 2006 at four tidally influenced wetlands in Reach G: the Water Resources Center in Vancouver, Chatham Island, the old channel of the Sandy River Delta, and McGuire Island. Two sites from habitat monitoring efforts during Year 2 were sampled to determine interannual variability in vegetation species cover and composition: Campbell Slough at the Ridgefield National Wildlife Refuge and Cunningham Lake on Sauvie Island. Data Analysis commenced after the end of field sampling and a final report was submitted to the Estuary Partnership at the end of August 2006 (Sobocinski et al., 2006b).

Revisions to the Columbia River Estuary Ecosystem Classification System were completed by the University of Washington (UW); however, due to postponements in the release of the LiDAR data by the Department of Interior, major updates to the classification system have been rescheduled to Year 4

(September 1, 2006 to August 31, 2007) of this contract. For Year 3, UW developed a new level of the classification hierarchy (Geomorphic Catena); developed essential ancillary datasets to refine the Landsat TM 2000 classified imagery; finalized the first stage of the Landsat TM 2000b refinement, and presented the classification at several Columbia River Estuary science and management meetings. Additionally, USGS BRD collected field bathymetry data to fill in critical data gaps for secondary channels and shallows in priority reaches and incorporated this into the full GIS bathymetric dataset. USGS BRD also expended funds to further research the availability of additional bathymetry datasets, which were then incorporated into the comprehensive bathymetric database and developed and implemented computer programs to standardize the delineation of ecosystem complexes in the Columbia River Estuary Ecosystem Classification System based on bathymetry data. Finally, USGS BRD continued to work with the Estuary Partnership and UW to update our understanding of bathymetry data gaps and data needs, data sharing and coordination.

Additionally during Year 3, NOAA Fisheries completed juvenile salmonid sampling and analysis from samples collected during Year 2. Samples collected included whole bodies for analysis of chlorinated hydrocarbons, stomach contents for analysis of chlorinated and aromatic hydrocarbons, bile for analysis of metabolites of aromatic hydrocarbons, and fin samples for genetic stock determination. Juvenile salmon were screened for vitellogenin induction in the field using the Best-Checker™ Vitellogenin Detection Kit (Ito 2003). This is an indicator of exposure to environmental estrogens. All salmonid sampling information will be available on the Estuary Partnership's web site in Fall 2006.

Revisions to the conceptual model, the contaminant transport and uptake model and the ecological risk models were completed during Year 3. NOAA also worked on an expanded population model that incorporates population-specific effects on salmon stocks within the Lower Columbia River Evolutionary Significant Unit (ESU) (Spromberg and Johnson 2006). As data became available, the models were updated with fish exposure data in addition to water quality, sediment, and salmonid prey information generated from NOAA's and USGS's field sampling in 2005. Moreover, NOAA is continuing to incorporate new information on the biological effects of contaminants on salmonids into the ecological risks models and is exploring various existing options for modeling contaminant uptake by juvenile salmonids in the Columbia, including Trophic Trace, steady state uptake models developed by Battelle and Windward. NOAA is also developing their own non-equilibrium model which may more effectively capture contaminant uptake in salmonids that move quickly through some parts of the Columbia River Estuary.

Finally during Year 3, USGS WRD retrieved Semipermeable Membrane Devices (SPMDs) in September 2005 from the Willamette River at Portland site as well as from the Columbia River at Warrendale, Beaver Army Terminal, and Point Adams. The SPMDs were sent to Environmental Sampling Technologies (EST) for extraction. The extracts from the SPMDs were sent from EST to Severn Trent Labs in West Sacramento, CA, for the analysis of polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides (OCs), and polybrominated diphenyl ethers (PBDEs). The results of the water column and suspended sediment sampling will be outlined in the data report that will be available on the Estuary Partnership's web site in Fall 2006.

Project Area Description

The Ecosystem Monitoring Project's study area is the Columbia River Estuary, defined by the Clean Water Act as those waters that are tidally influenced. The Columbia River Estuary extends from the plume of the Columbia River to the Bonneville Dam (RM 0-146). The Ecosystem Monitoring Project is focused on habitats that support juvenile salmonids, including shallow emergent wetlands, undiked tidally influenced sloughs adjacent to the Columbia River, scrub/shrub forested wetlands, mud/sand flats, and others.The toxics monitoring program is collecting data in the main channel of the Columbia River and in the Willamette River near the Morrison Street Bridge in Portland, OR (Figure 1). At these sites various types of water quality and fish sampling occurred until September 2005 and the results will be available in Fall 2006 on the Estuary Partnership's web site.

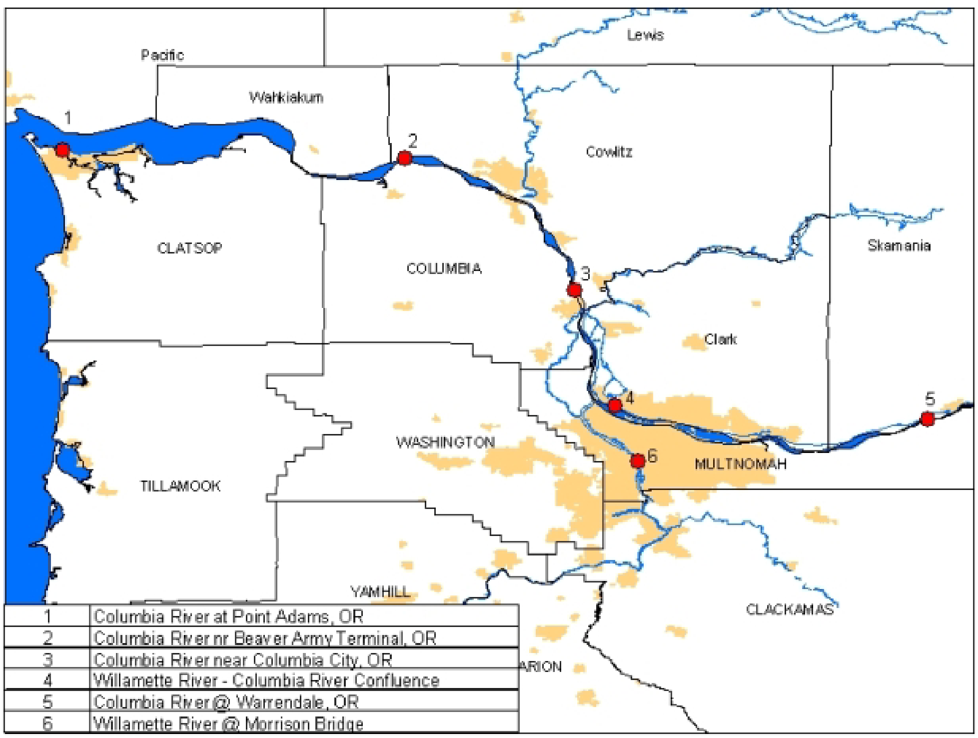

Figure 1: Water Quality and Fish Sampling Locations.

The habitat monitoring component of the Ecosystem Monitoring Project relied on a multi-scaled stratification of the Columbia River Estuary. As proposed in the Columbia River Estuary Habitat Monitoring Plan, the river was stratified based on major hydrogeomorphic transitions. Eight hydrogeomorphically distinct reaches were identified and each of these reaches has unique physical processes that shape its landscape. The reach boundaries are based on Environmental Protection Agencie's (EPA) Level IV Ecoregions and were modified to include important parameters such as salinity intrusion, maximum tide level, upstream extent of current reversal, geology, and major tributaries (Figure 2).

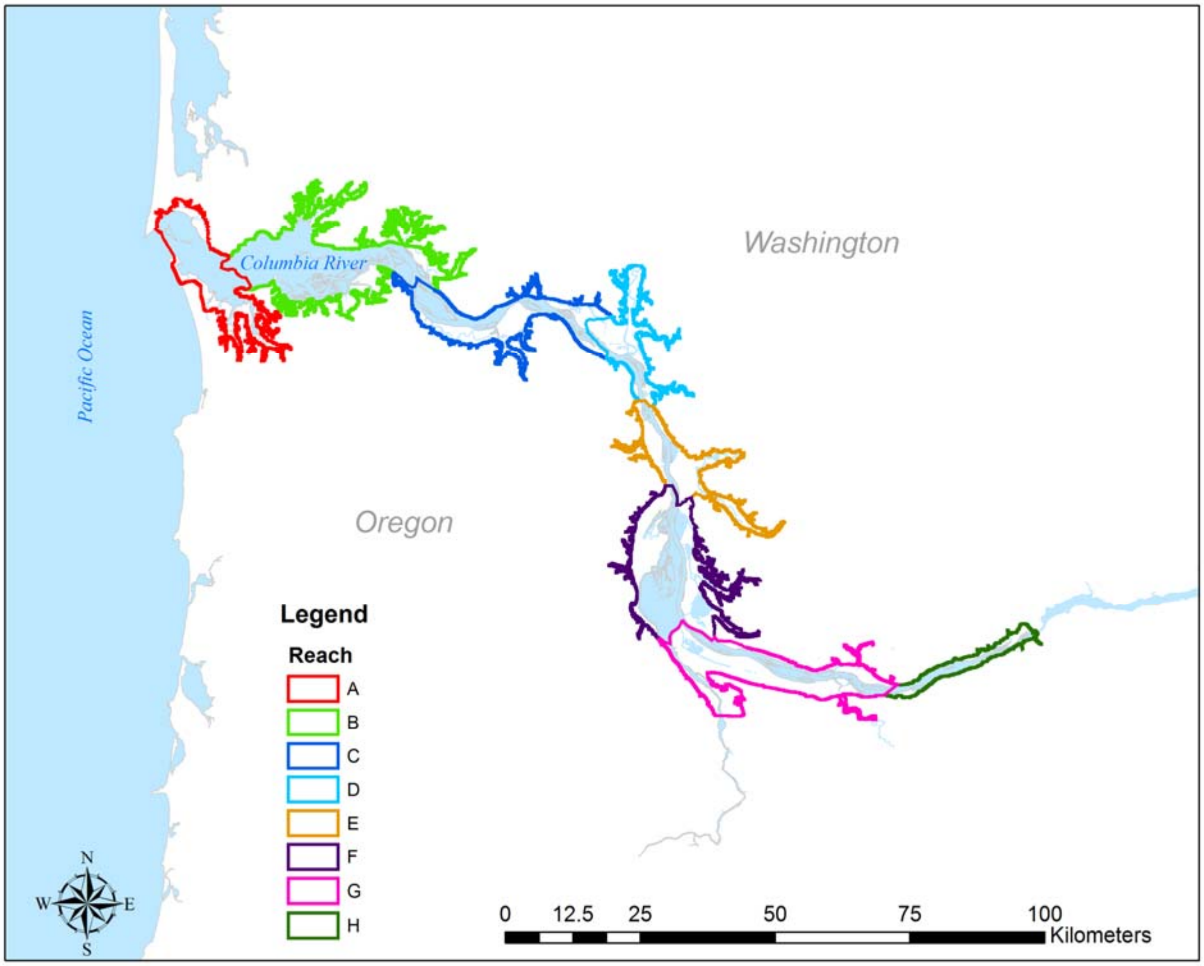

Figure 2: Columbia River estuary with hydrogeomorphic reaches outlined. The focus reaches for the Year 2 pilot field study were D and F and for Year 3 Reach G was sampled.

Summary of Toxics Monitoring Activities in Year 3

Water Quality Monitoring

USGS WRD Fixed Station, Expanded Flow Condition and Semipermeable Membrane Device Water Quality Monitoring Data Reporting

Introduction

During Year 2 (September 1, 2004 to August 31, 2005), USGS WRD conducted fixed station water quality monitoring and deployed semipermeable membrane devices (SPMDs) to provide water quality data on conventional and toxic pollutants near NOAA salmonid sampling sites (Figure 1). Monthly water-quality samples were collected at the Columbia River at Warrendale, the Willamette River at Portland, and the Columbia River at Beaver Army Terminal from May 2004 through April 2005. Expanded water-quality samplings involving water-column samples, suspended-sediment samples, and SPMDs were deployed to characterize low- and high-streamflow conditions. Water-column samples were collected to characterize low-flow conditions at the three monthly sites as well as the Columbia River at Columbia

City and near Point Adams in August 2004, while the suspended-sediment samples were collected and SPMDs were deployed at the three monthly sites and the Columbia River near Point Adams in August 2005. All of the high-flow sampling occurred in April 2005 at the three monthly sites as well as near Point Adams.

During Year 3 (September 1, 2005 to August 31, 2006), USGS WRD checked and verified the water-quality data collected during Year 2 and performed a thorough analysis of all of the associated quality-control data. The data are reported in a USGS Data Series report that will be available on the Estuary Partnership's web site in Fall 2006. These data will be interpreted in 2007, incorporated with the NOAA salmonid results, and published in a summary report prepared by the Estuary Partnership during Year 4 (September 1, 2006 to August 31, 2007). The significant findings that emerged from the data reported in the USGS Data Series report are as follows:

Significant Findings

- None of the aquatic-life or human-health benchmarks based on the USEPA water-quality standards were exceeded in either the Columbia or Willamette Rivers at locations measured in this study. It is important to note, however, that the majority of compounds measured in this study do not have standards established and even though a compound is not addressed by a standard, it does not mean that its presence or measured concentrations are not of concern.
- Although concentrations of arsenic, chromium, copper, and lead were not present at levels of concern with regards to aquatic-life toxicity, sublethal effects and signs of endocrine disruption have been linked to low levels of these compounds. While chromium was only detected in the Willamette River, arsenic was found at higher concentrations in the Columbia River than in the Willamette River. The median copper concentration from each of the three monthly sites was 1.0 µg/L, a level shown to have inhibitory effects on juvenile Coho salmon (*Oncorhynchus kisutch*).
- Concentrations of trace elements at Point Adams were elevated when compared to concentrations measured further upstream and in the Willamette River.
- Of the 177 pesticides and degradation products analyzed for, 29 were detected at least once, often times with two or more compounds occurring in a sample together. While 14 different compounds were detected in the Columbia River, 25 were found in the Willamette River.
- The triazine herbicides, atrazine and simazine, were the most frequently detected pesticides, most often in the Willamette River.
- Eight of the 54 wastewater compounds analyzed for were detected at least once, usually at trace levels. The known endocrine disruptor, bisphenol A, was detected in both the Columbia and Willamette Rivers, while the suspected endocrine disruptor, tri(2-chloroethyl)phosphate, was detected only in the Willamette River.
- Of the 24 pharmaceuticals analyzed for, acetaminophen, a common analgesic, and diphenhydramine, a widely used antihistamine, were detected in the Columbia River.
- Three of the 49 antibiotics analyzed for were detected. Anhydroerythromycin, a degradation product of the antibiotic erythromycin, and trimethoprim, an antibiotic used not only for people but also in aquaculture, were detected at most sites during low-flow conditions, but at only one site during high-flow conditions.
- Even though organochlorine compounds on suspended sediment were monitored monthly at the Beaver Army Terminal site from May 2004 to April 2005, p,p'-DDT was detected only once in October 2004 at 0.02 µg/g. No other organochlorine compounds were detected.

- During the seasonal samplings of suspended sediment at all four sites, no organochlorine compounds or PAHs were detected.
- Of the 11 PBDEs analyzed, all were detected on suspended sediment, usually in trace amounts. The only quantifiable concentrations were measured at Point Adams.
- Of the 209 PCB congeners analyzed, 102 were detected at some time on suspended sediment at the four sites, usually in trace amounts. A third of these detections were quantifiable at the Willamette River during the high-flow sampling. There were fewer PCB detections during the low-flow sampling than during the high-flow sampling.

NOAA Toxics Model Development and Salmonid Sampling

Introduction

Currently thirteen salmon stocks are listed as threatened or endangered under the Endangered Species Act that inhabit the Columbia River Basin. Numerous factors influence the recovery of these listed stocks, including ocean and climatic conditions, access to quality habitat, predators, hydropower operations, hatchery production, and harvest practices (NRC 1996; Waples 1991; Fresh et al. 2005). A number of studies have been conducted on the effects of physical habitat alteration on listed salmonids in the Columbia River and Estuary (Fresh et al. 2005; Bottom et al. 2005). However, less attention has been paid to the effects of chemical habitat quality on salmon productivity, in spite of the fact that contaminants are a recognized as a problem in the area, especially in the lower Columbia River (Fresh et al. 2005, Johnson et al. 2006).

With support from the Bonneville Power Administration for the Ecosystem Monitoring Project, NOAA Fisheries, USGS and the Estuary Partnership are examining the impacts of contaminants on the recovery of listed salmon in the Columbia River through a comprehensive study involving field assessment of exposure, and modeling of contaminant uptake and ecological risk. NOAA's objective was to document concentrations and examine temporal and spatial trends of persistent organic pollutants in outmigrant juvenile salmon in the lower Columbia River, and to evaluate the potential for adverse effects on salmon and the estuarine food web by comparing contaminant tissue concentrations with levels known to be associated with adverse effects in salmon and other fish species (Meador et al. 2002; Beckvar et al. 2005). Other concerns included the potential sources of contamination for juvenile salmon, such as contaminants in hatchery feed, sediments, water column, and prey; and the influence of stock of origin on contaminant accumulation and exposure risk. The study includes the following components:

1) A conceptual model of contaminant exposure and risk for juvenile salmon in the Columbia River Estuary (CRE) that describes qualitatively, the types and sources of contaminants present in the CRE, routes of exposure for different stocks of listed salmon, and potential impacts on salmon health. It also outlines our strategy for risk assessment of contaminant effects in threatened and endangered salmon.

2) Field Assessment of contaminant exposure in juvenile salmon from the Columbia River Estuary and associated hatcheries. For this component of the study, NOAA monitored exposure to several persistent organic pollutants [polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), dichloro-diphenyl-trichloroethanes (DDTs) and other organochlorine pesticides] in outmigrant juvenile fall Chinook salmon (*Oncorhynchus tschawytscha*) at six sites in the Columbia River (Warrendale, the Morrison Street Bridge in the Willamette River at Portland, the Willamette-Columbia confluence, Columbia City, Beaver Army Terminal, and Point Adams), at locations ranging from Bonneville to the mouth of the estuary, and in pre-release juvenile fall Chinook salmon from six hatcheries along the Columbia River (Spring Creek, Big Creek, Elochoman, Cowlitz, Washougal, Little White Salmon, Klickitat, and Priest Rapids).

3) Quantitative modeling of contaminant exposure pathways and bioaccumulation in juvenile salmon from the Columbia River Estuary. This exercise was designed to partition exposure from different sources (e.g., water, prey, hatchery feed), and to compare modeled uptake to actual concentrations in field-collected fish to test our assumptions abut exposure pathways.

4) Quantitative modeling of the impacts of contaminants on salmon populations in the Columbia River Estuary. In this part of the project data on contaminant exposure in Lower Columbia River salmon, and data on effects of contaminants on individual fish, are used to model potential effects on population growth rates, through the application of individually-based and life-history matrix models population models. NOAA's findings are summarized in the subsequent pages.

Conceptual Model of Contaminant and Endangered Salmonid Species Interactions within the Columbia River Estuary

In this part of the Ecosystem Monitoring Project, NOAA reviewed the potential sources, pathways of uptake, and effects of chemical contaminants on listed salmon in the Columbia River and Estuary, and presented a conceptual model for evaluating contaminant exposure and ecological risk in these fish stocks. The general strategy for assessing risks of contaminants to salmon productivity is shown in Figure 3.

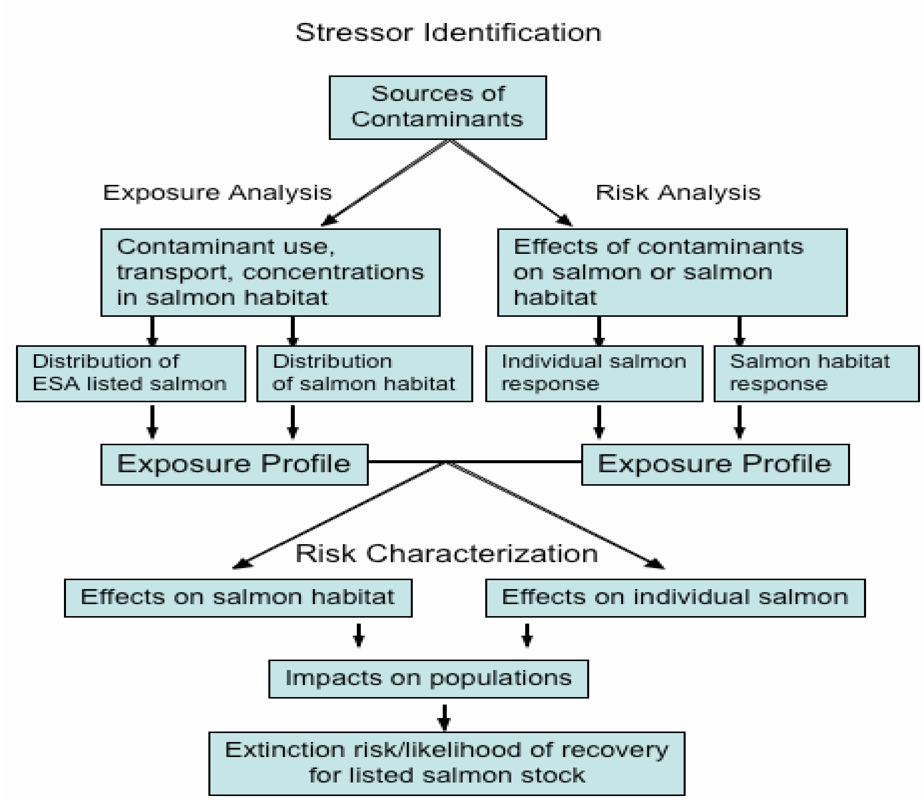

Figure 3: Framework for evaluating the risk of contaminant exposure to survival and productivity of listed salmon.

Basically, NOAA examines patterns of contaminant distribution in the Columbia River Estuary and patterns of habitat use by salmon to develop exposure profiles for listed salmon stocks, and then uses existing data on effects of those contaminants to evaluate potential risks to stock survival and productivity. Specific sources of contaminants, routes of exposure, and impacts are summarized in Figure 4, and are discussed briefly in the following paragraphs.

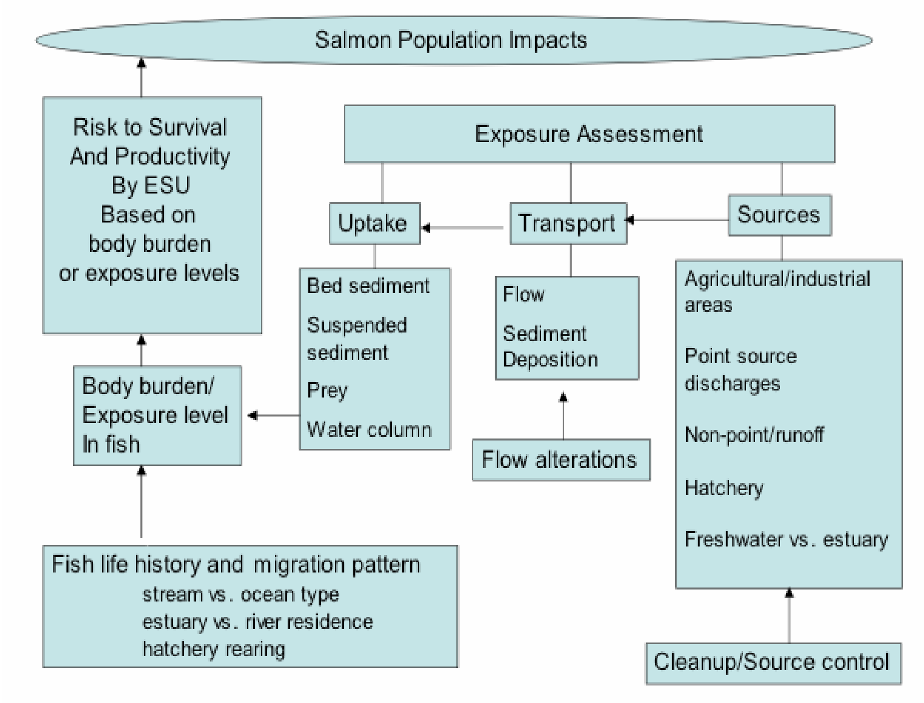

Figure 4: Simplified conceptual model of pathways of contaminant exposure and uptake for juvenile salmon in the Lower Columbia River and Estuary.

Exposure Analysis—Contaminants in the Columbia River Estuary.

Within the Columbia River Estuary drainage, land use can be categorized as 74% forest, 17% agriculture, and 5% industrial or municipal (Tetra Tech 1996; see also usgs.eros.gov; Figure 5). Urban development is concentrated in the areas around Portland and Vancouver, and the Willamette Basin is used heavily for agriculture. Much of the rest of the basin is comprised of forested land. While the urban areas of Clark and Multnomah counties constitute a small percentage of overall acreage, they have a major impact on water quality. Population density is greatest in this region, and it is the primary source of contaminants associated with vehicular traffic and wastewater, as well as point source pollutants from industry (USEPA 2006). Major classes of contaminants present in the region include PAHs, PCBs, dioxins, and various semi-volatile industrial organic compounds, and metals (e.g., see Tetra Tech 1996; Buck 2004; McCarthy and Gale 2001; Johnson and Norton 2005; Fuhrer et al. 1996; Weston 1998; Sethajintanin et al. 2004; Hinck et al. 2006); and there is concern that other emerging contaminants, including polybrominated diphenyl ethers (PBDEs), pharmaceuticals, personal care products, and surfactants present in wastewater may be entering the river as well. A survey by USGS indicated that several current use pesticides commonly used on lawns and in horticulture (carbaryl, diazinon, dichlobenil, prometon, and tebuthiuron) were present in urban streams in the Willamette basin (Anderson et al. 1996).

In the agricultural areas of the Willamette Basin, the USGS (Anderson et al. 1996; Wentz et al. 1998) identified a number of dissolved current use pesticides in the Willamette River Basin (e.g., atrazine, desethylatrazine, simazine, metolachlor, and diuron), at concentrations as high as 90 ppb. In forested lands, on the other hand, concentrations of agricultural pesticides were low (Anderson et al. 1996). Studies with SPMDs by the Washington State Department Ecology (WDOE) also indicate that concentrations of organochlorine pesticides and PAHs are low in the Kalama and Cowlitz Rivers where forested land predominates (Johnson and Norton 2005). Forested lands may contribute other types of herbicides and pesticides, such as fungicides such as Dazomet and Borax, and herbicides such as glyphosate, oxyfluorfen and Triclopyr, but their toxicity to fish is not well-studied (Cota 2004).

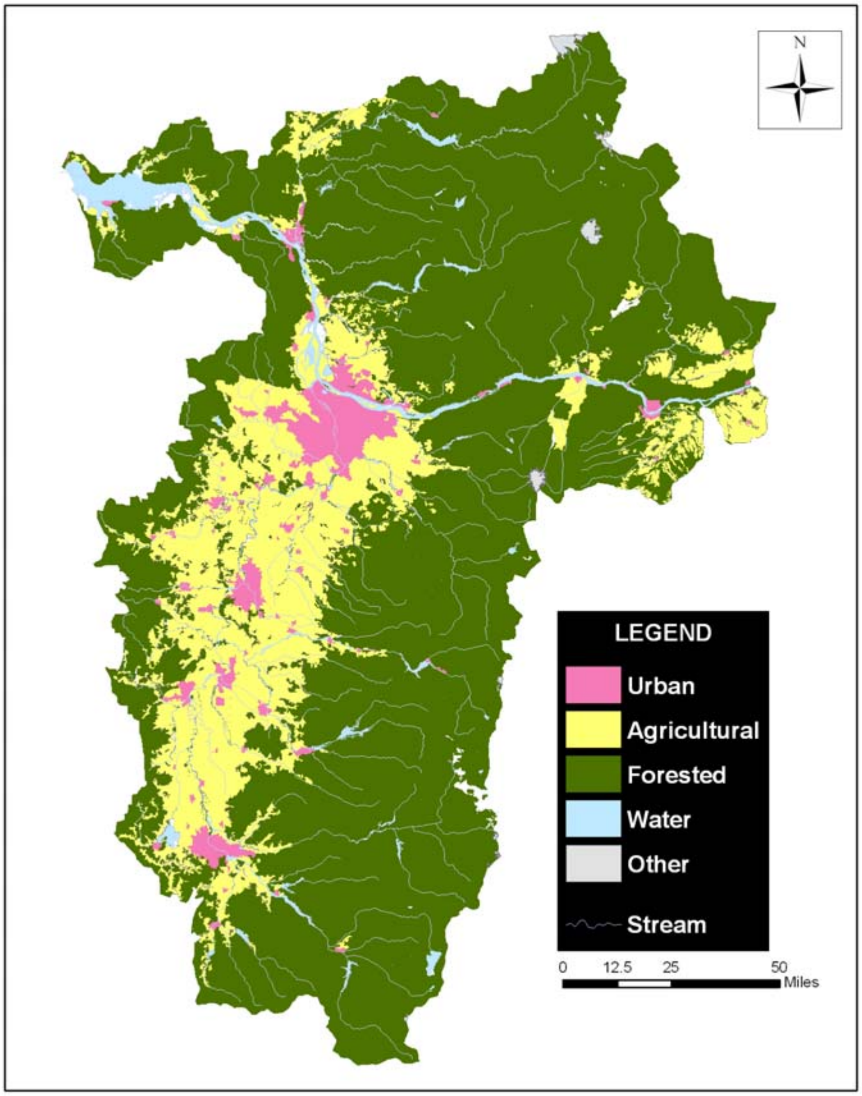

Figure 5: Land use patterns in the Columbia River Estuary and Willamette Basin.

Contaminants in the middle and upper Columbia and in freshwater tributaries of the Columbia River Basin outside of the Columbia River Estuary may also contribute to exposure in salmon stocks originating in these watersheds. USGS has surveyed contaminants in the water column, sediments, and fish tissue in several basins in Washington and Oregon that drain into the Columbia River, including the Upper Snake River Basin, and the Columbia Plateau (Clark et al. 1998; Williamson et al. 1998; Hinck 2006). Major contaminants identified in all of these areas include DDTs and other organochlorine pesticides and current use pesticides and herbicides associated with agricultural activities. In fact, studies by USGS and WDOE (Norton and Johnson 2005; McCarthy and Gale 2001) indicate that the middle and upper Columbia, as well as tributaries such as the Yakima River, are important sources for DDTs and other organochlorine pesticides in the Columbia River Estuary.

Salmon Exposure Profiles

Salmon in the Columbia River Estuary take up contaminants from the water column through gill uptake and dermal sorption, and, especially for lipid soluble contaminants, through their diet and through maternal transfer, as larvae and eggs. The extent to which salmon are exposed to contaminants in the Columbia River will be influenced by behaviors such as migration patterns and habitat preferences, which are associated with their life-history strategy (stream type vs. ocean type; Fresh et al. 2005), as well as the geographical location of their stock of origin (Figure 6). Stream-type fish rear and overwinter in freshwater and migrate as yearlings, spending minimal time in the estuary.

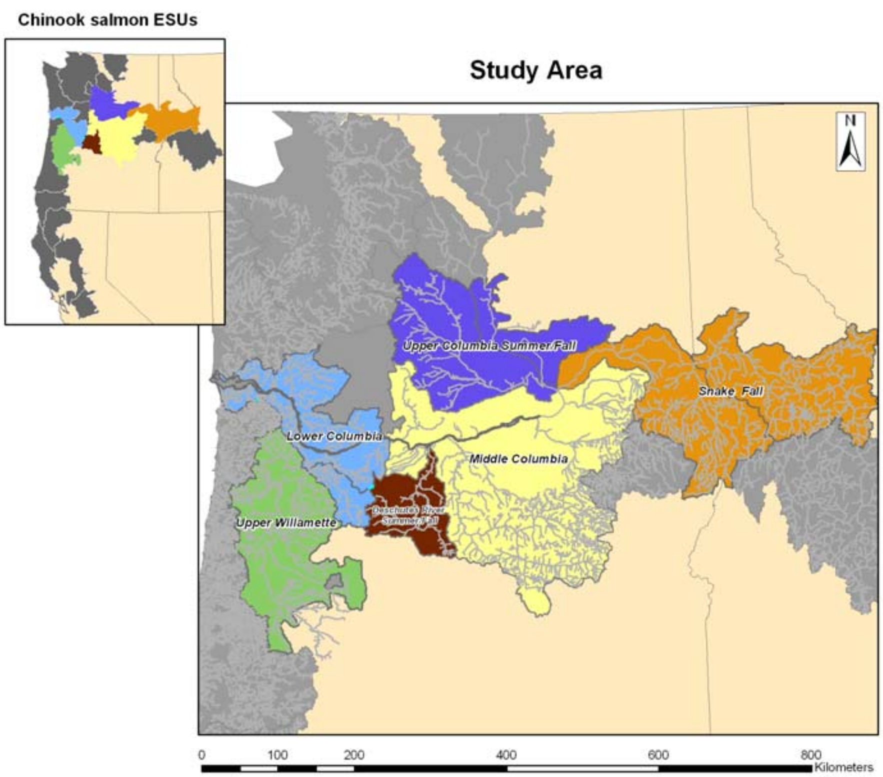

Figure 6: Geographic ranges of Columbia River salmon stocks (Evolutionarily significant units or ESUs).

Ocean-type fish begin their seaward migration in the subyearling fry or fingerling stages, and may spend up to several months rearing in the estuary before entering the ocean, or in some cases even overwinter in the estuary (Fresh et al. 2005; Bottom et al. 2005). In general, contaminant exposure profiles in stream-type salmonids, which include the Upper Columbia, Snake River, and Mid-Columbia Spring Chinook; (Fresh et al. 2005, Myers et al 2006), will likely reflect their freshwater habitat, and their exposure to contaminants in the Columbia River Estuary would be relatively short-term, and primarily due to contaminants in the water column and in deeper channel habitats. In contrast, contaminant exposure profiles in ocean-type salmonids (e.g., Lower Columbia fall, Snake River fall, and Deschutes River fall, and some Upper Willamette Chinook; Fresh et al. 2005; Myers et al. 2006) will be more reflective of the Columbia River Estuary habitat and of contaminant concentrations in prey species typically associated with the estuary. Geographical origin is also important; for example, populations from the areas around Portland, Vancouver, and the Multnomah channel are likely exposed to industrial contaminants, whereas populations that enter the estuary from other rivers (e.g., Youngs, Clatskanie, Elochoman, Cowlitz and Kalama Rivers) may show less contaminant uptake. Snake River and Upper Columbia ESUs, originating in heavily agricultural watersheds, such as the Yakima and Snake River Basin and parts of the Upper Columbia Plateau, may be especially at risk for exposure to current use herbicides and pesticides, as well as legacy pesticides such as DDT. For ESUs that include hatchery fish (e.g., the Lower Columbia River and Upper Columbia River ESUs) uptake of contaminants during hatchery rearing could contribute to exposure profiles.

Response analysis: Effects of Contaminants on Salmon

Exposure of salmonids to anthropogenic contaminants can reduce the survival and productivity of salmon populations by interfering with growth, reproductive function, smoltification, immune function, endocrine function, migration/homing, and behavior. The contaminants in the Columbia River Estuary that have been shown or suspected to affect these functions include PAHs and PCBs, which weaken the immune system in juvenile salmon and increase the likelihood of delayed disease-induced mortality (Arkoosh and Collier 2002), and may suppress growth or alter energy balance in juvenile salmon (Meador et al. 2006). Current use pesticides that inhibit acetylcholinesterase activity (e.g., diazanon, and carbaryl), as well as some water-soluble metals such as copper, can impair salmon olfactory responses and interfere with their ability to find food, avoid predators, and in adult stages, with homing and reproductive behavior (Scholz et al. 2000, 2006; Baldwin et al. 2003; Sandahl et al. 2005). Industrial contaminants and pesticides may also affect salmon indirectly through toxics effects on the salmon prey base, reducing food availability and suppressing growth and development.

Based on a review of available data on distribution of contaminants in the Columbia River, the distributions and habitat use patterns of salmon stocks occupying these areas, and the impacts of the classes of contaminants present in the region, NOAA has generated hypotheses about how toxic contaminant might impact listed salmon:

- Exposure profiles are likely to differ among various salmon stocks based on their geographic origin and life history type. Contaminant profiles in stream-type fish will more closely reflect contaminant types and concentrations present in freshwater rearing habitats in the Upper Columbia and in the tributaries. Contaminant profiles in ocean-type fish will more closely reflect contaminant concentrations and types present in the Columbia River Estuary.
- For ESUs that originate in the Snake River, Upper Columbia, and Mid-Columbia, major contaminants of concern are metals and agricultural pesticides, including DDTs
- Those stocks that feed and rear in the lower Willamette and lower Columbia Rivers between Portland and Longview will tend to have high body burdens of industrial contaminants, such as PCBs and greater exposure to PAHs; exposure will be lower in stocks that originate from lower Columbia river tributaries such as the Kalama and Cowlitz where contaminant levels are lower.
- Short term exposure to waterborne metals and current use pesticides may be a threat to the health of both ocean and stream-type stocks because of their acute effects on olfactory function and behavior
- Growth and disease resistance of outmigrant juvenile salmon migrating through the Columbia River Estuary may be compromised by exposure to environmental contaminants, especially ocean-type stocks that rear in these areas

These hypotheses can be examined in the context of the results from our field surveys of contaminant uptake in wild and hatchery juvenile salmon from the Columbia River Estuary, and accompanying bioaccumulation and population modeling.

Assessment of contaminant exposure in juvenile salmon from sites in the Columbia River Estuary and from associated hatcheries.

For the juvenile salmonid sampling conducted from April 2005 through September 2005, NOAA Fisheries has completed analyses of concentrations of PCBs, DDTs, PBDEs, and PAHs in salmon stomach contents, concentrations of metabolites of PAHs in salmon bile, and concentrations of PCBs, DDTs, and PBDEs in a subset of salmon whole bodies from the Columbia River at Warrendale, Willamette-Columbia Confluence, Columbia River at Columbia City, Beaver Army Terminal, and Point Adams(Figure 7). Genetic stock of origin was also determined for the sampled fish, and their lipid content was measured.

Genetic analyses showed that although most of the fish sampled were from the Lower Columbia River ESU, fish from a range of other Columbia River ESUs were also represented. At the Willamette-Columbia Confluence and Morison Street Bridge sites, most of the fish were from the Willamette ESU. At the Columbia River at Warrendale, a number of fish were from the Snake River, Upper Columbia, and Middle Columbia ESU. So far, NOAA has analyzed whole body samples only from fish assigned to the Lower Columbia River ESU, but analyses of bodies of fish from the other groups are currently in progress and will be completed during Year (September 1, 2006 to August 31, 2007) of the Ecosystem Monitoring Project.

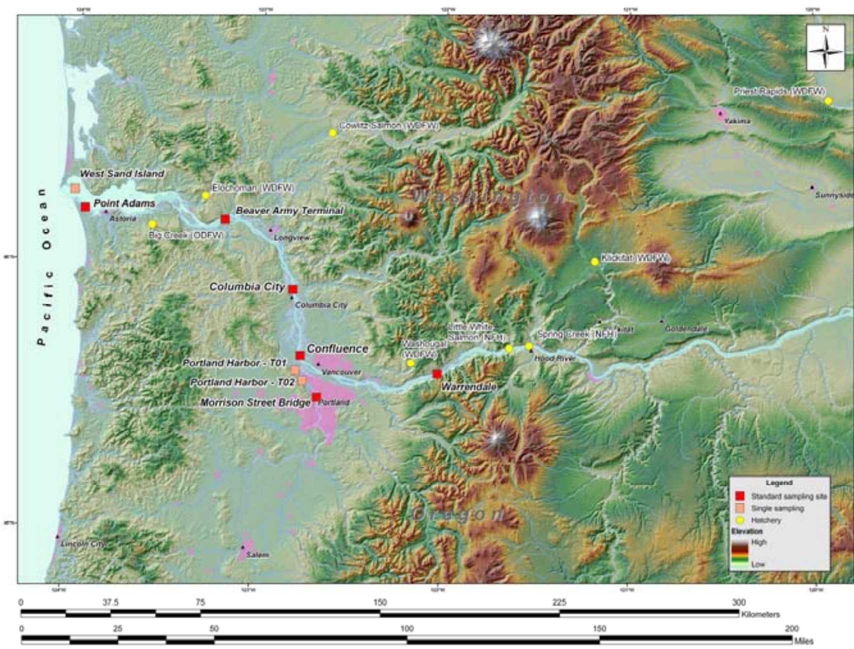

Figure 7: Locations of sampling sites and hatcheries where juvenile salmon were collected for the fish contamination study.

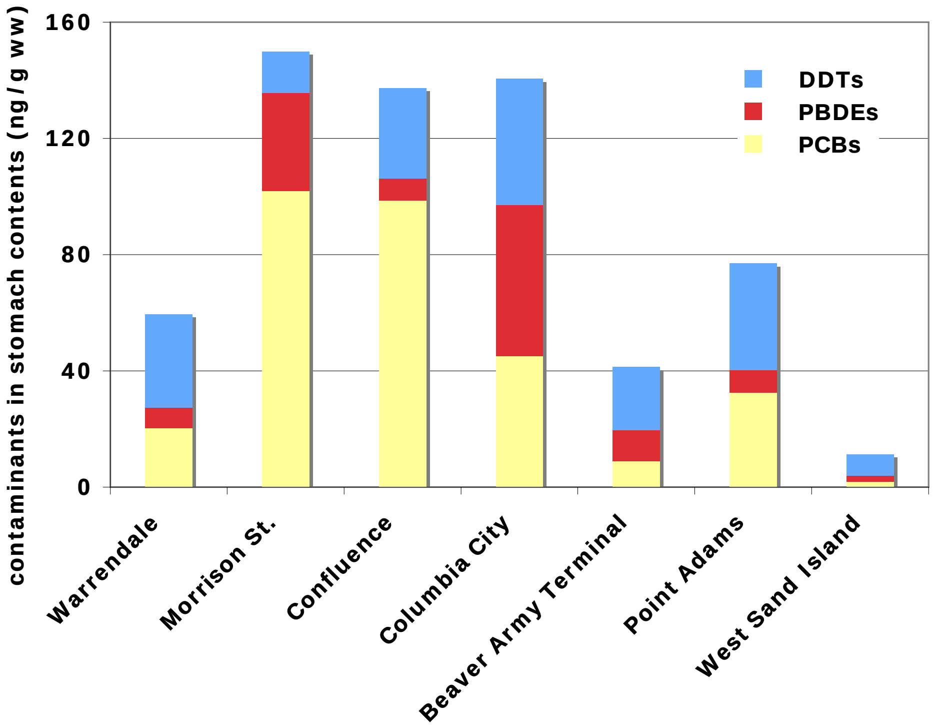

Figure 8: Concentrations of bioaccumulative contaminants in stomach contents of juvenile salmon from sites in the Lower Columbia River and Estuary.

NOAA found PCBs, DDTs, PBDEs, and PAHs in stomach contents of salmon from all sites, indicating that prey are a source of exposure to these compounds (Figure 8). Levels of PCBs, PAHs, and PBDEs were especially high in stomach contents of salmon from the Morrison Street Bridge in Portland and the Willamette-Columbia Confluence site, Columbia River at Columbia City, and Beaver Army Terminal sites. DDTs, on the other hand, were present at similar concentrations in the stomach contents of salmon collected throughout the Columbia River Estuary. In comparison with concentrations of DDTs, PCBs, and PAHs in stomach contents of juvenile salmon collected from other estuaries around the Pacific Northwest (Johnson et al. 2006), levels of DDTs were relatively high at all of the Columbia River Estuary sites, while PCBs and PAHs were elevated at the sites from Morrison Street Bridge to Beaver Army Terminal.

The predominant contaminants in salmon whole bodies were PCBs, PBDEs, and DDTs, while metabolites of PAHs were found in salmon bile (Figure 9). Concentrations of PCBs, PBDEs, and DDTs were highest in salmon from the Beaver Army Terminal site, even though contaminant concentrations in stomach contents of fish from this area were not especially high. Concentrations of PCBs in several composite samples from Beaver Army Terminal and the Confluence were above NOAA Fisheries' estimated threshold for adverse health effects of 2400 ng/g lipid, with concentrations as high as 30,000 ng/g lipid. A few samples from these sites also had DDT concentrations approaching estimated thresholds for effects on fish (~5,000-6,000 ng/g lipid). Concentrations of PBDEs in fish bodies ranged from < 1 to 46 ng/g ww, similar to levels found in resident fish from various streams in Washington by the Washington State Department of Ecology (Johnson and Olson 2001). Interestingly, the salmon from Beaver Army Terminal had the lowest average lipid content of any of the fish sampled, and had lipid profiles most closely resembling those of starving fish. This site also had the lowest proportion of marked (hatchery) fish. Metabolites of PAHs in salmon bile were highest in fish from the Morrison Street Bridge in Portland, Columbia River at Columbia City, Willamette-Columbia Confluence site, and Beaver

Army Terminal sites. NOAA also found vitellogenin in blood samples of juvenile salmon from the sites near Portland, indicating that fish in this area are exposed to compounds that mimic the female hormone, estrogen. Previous studies have shown that juvenile salmon from the Columbia are exposed to PCBs, DDTs, and PAHs, but to our knowledge these are the first reports of xenoestrogen exposure or exposure to PBDEs in Columbia River Estuary juvenile salmon.

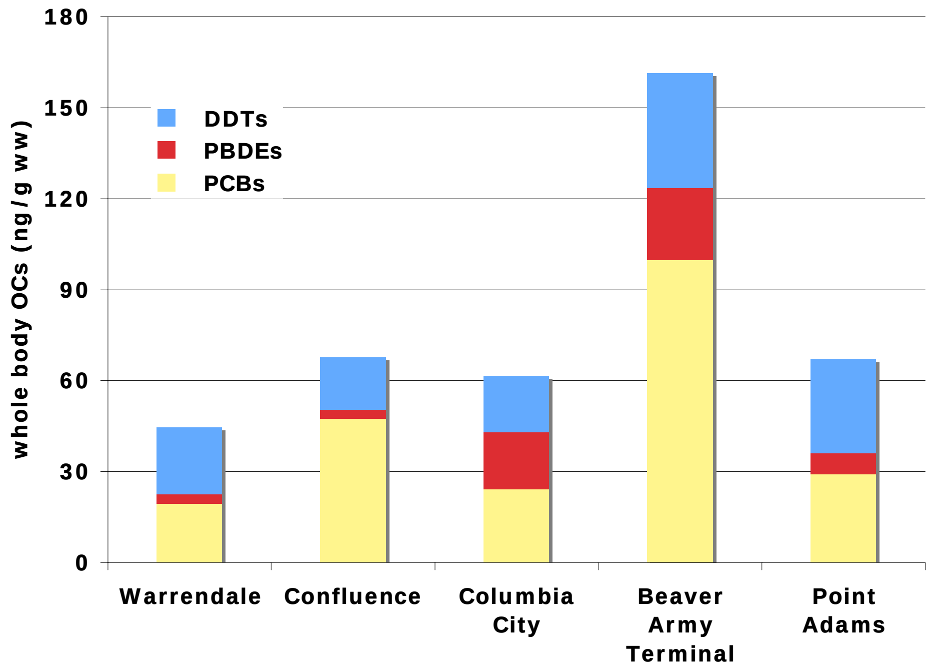

Figure 9: Concentrations of bioaccumulative contaminants in whole bodies of juvenile salmon collected from sampling sites in the Columbia River Estuary.

NOAA also completed analyses of contaminant concentrations in juvenile salmon and feed from several Columbia River hatcheries (Spring Creek, Big Creek, Elochoman, Cowlitz, Washougal, Little White Salmon, Klickitat, and Priest Rapids; Figure 7). Results indicate that some contaminants are present in hatchery feed (PCBs, DDTs, and lower molecular weight PAHs) that could be derived from petroleum products such as gasoline or diesel fuel (Figure 10). PCBs and DDTs were also present in salmon bodies, and metabolites of PAHs were found in bile (Figure 11). Concentrations were fairly low, generally similar to those in fish and prey collected from rural estuaries. Concentrations of PBDEs were near or below detection levels, suggesting that the environment is the major source for these chemicals, not hatchery feed. To provide a rough estimate of how hatchery exposure is contributing to the body burdens of fish collected in the field, NOAA compared contaminant concentrations in the fish collected at the hatcheries to those in fish collected from our field sites in the Columbia River Estuary. The analysis suggested that when salmon growth was taken into account, the hatchery was an important source of PCBs at sites with limited industry, but the estuary was more important at sites where industrial activity was high. Moreover, results from the stomach contents chemistry analysis show that salmon were taking up DDTs at the six juvenile salmonid sampling sites, and based on DDT body burdens in the hatchery fish, the estuary, rather than the hatchery, appeared to be the major source of DDTs in salmon from all sites.

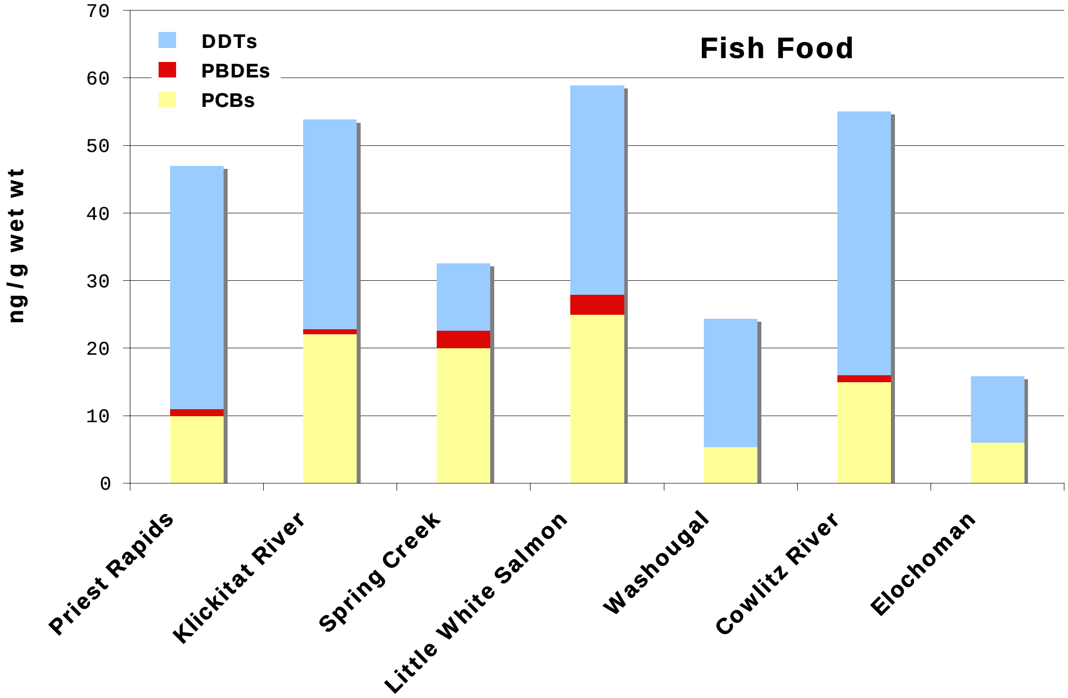

Figure 10: Concentrations of bioaccumulative contaminants in feed from Columbia River hatcheries.

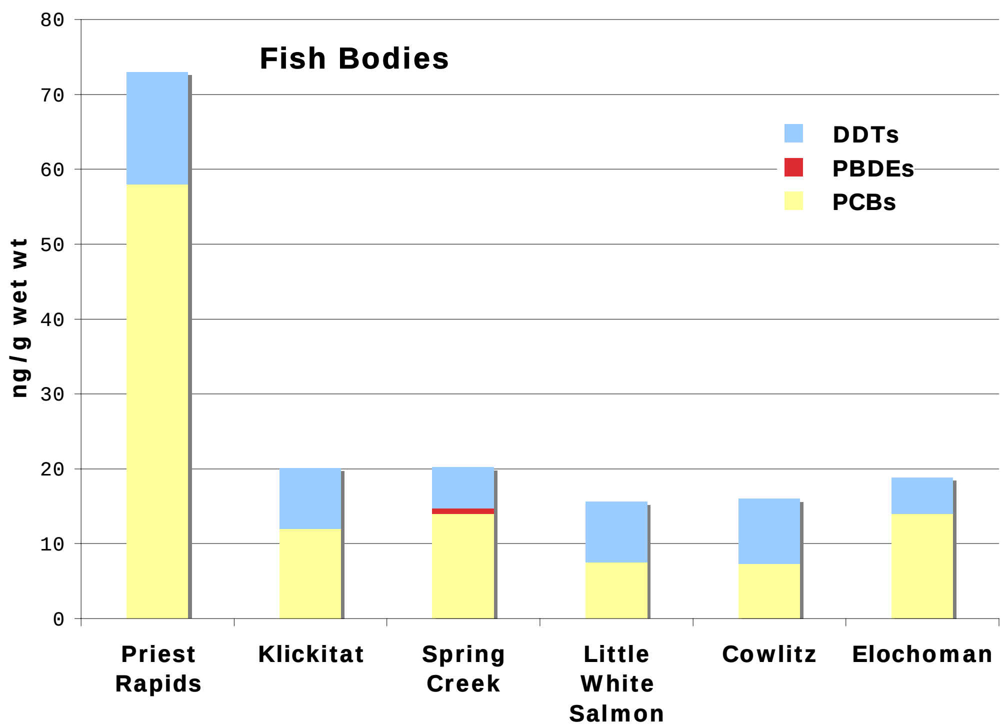

Figure 11: Concentrations of bioaccumulative contaminants in whole bodies of juvenile salmon collected from Columbia River hatcheries.

Models of Contaminant Uptake and Bioaccumulation in Juvenile Salmon from the Columbia River Estuary—PCB Case Study.

In this component of the Ecosystem Monitoring Project, trophic transport models were developed and applied to field data on contaminants to assist in determining potential sources of contaminant uptake in juvenile Chinook salmon in the Columbia River Estuary. Polychlorinated Biphenyls (PCBs) were chosen as the case study for developing and testing of the models, which can then be applied to other classes of contaminants.

Chemical contamination in the Columbia River Estuary is evident in its sediments and resident benthic invertebrates, as well as in the water column and the salmon that rear, migrate, and spawn there (Fuhrer et al., 1996; Johnson and Norton, 2005; McCarthy and Gale, 1999; Tetra Tech, 1996). The PCB concentrations in whole bodies of subyearling Chinook salmon, sampled during the 2005 NOAA Fisheries field monitoring effort in the Columbia River Estuary, were greater than those found in hatchery fish, prior to release. This provides some evidence that juvenile salmon that migrate through the estuary have accumulated chemical contaminants.

Exposure to chemical contaminants can occur at all life stages, with the primary routes of exposure likely being: (i) ingestion of contaminated prey; (ii) absorption of contaminants dissolved in the water column through the gills and dermis, and (iii) maternal transfer of contaminants to eggs (Figure 12).

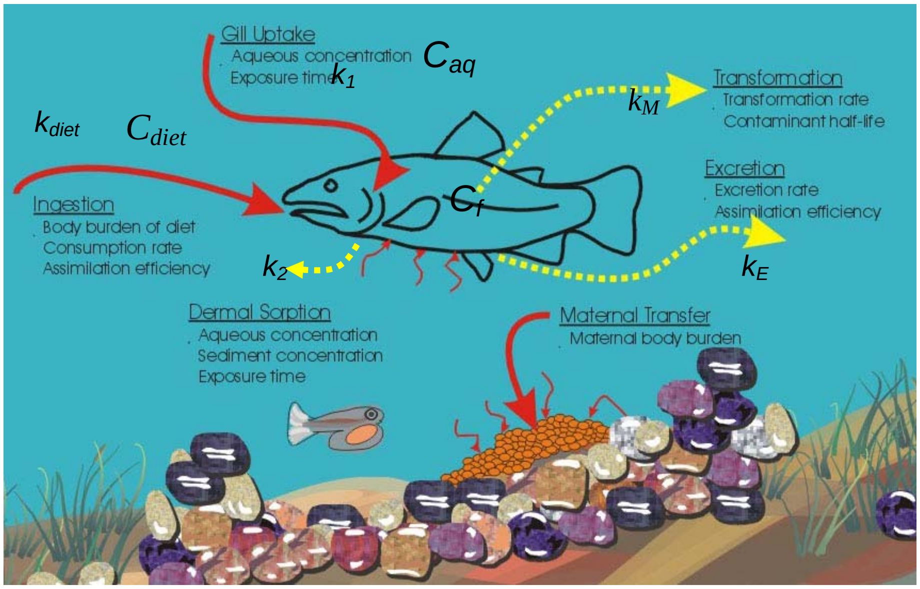

Figure 12: Sources of contaminants, routes of exposure, and mechanisms of uptake and loss in fish.

Modeling chemical uptake within fish or organisms can take several forms, including: (i) physiologically-based models of accumulation, (ii) bioaccumulation and biomagnification within food-webs, and (iii) bioenergetic models. A commonality among modeling methods is the description of contaminant uptake with differential equations that represent the time-varying nature of the process. Despite this time dependence, bioaccumulation models often use steady-state assumptions to explore the body burden in fish. These assumptions may be warranted for adult and resident fish populations. However, this assumption may be unreasonable when modeling the chemical uptake within anadromous populations during their juvenile migration through a heterogeneous environment, like the Columbia River Estuary.

As one approach to this question, NOAA applied a standard steady-state equilibrium model, Trophic Trace, to predict PCB body burdens in juvenile salmon, as a test of whether these transient species persist in the system a sufficient time for equilibrium partitioning to predict uptake and body burdens adequately. PCB concentrations in juvenile salmon stomach contents and the water column, from the Ecosystem Monitoring Project and related studies (e.g., Johnson and Norton 2005; McCarthy and Gale 1999, 2001) were used to parameterize the model. The model generally overestimated salmon body burdens, implying that the sampled subyearling Chinook have not spent sufficient time at the sampling sites to come to equilibrium with the PCB concentrations in the water, sediment and biota around them. For this reason, it seems that a steady state exposure model is not the most appropriate for estimating body burdens for these highly transient individuals. Possible reasons for the differences also include the amount and quality of available habitat near the contaminated sites. If there are not sufficient resources present, the fish sampled there may have just been passing through, and not rearing.

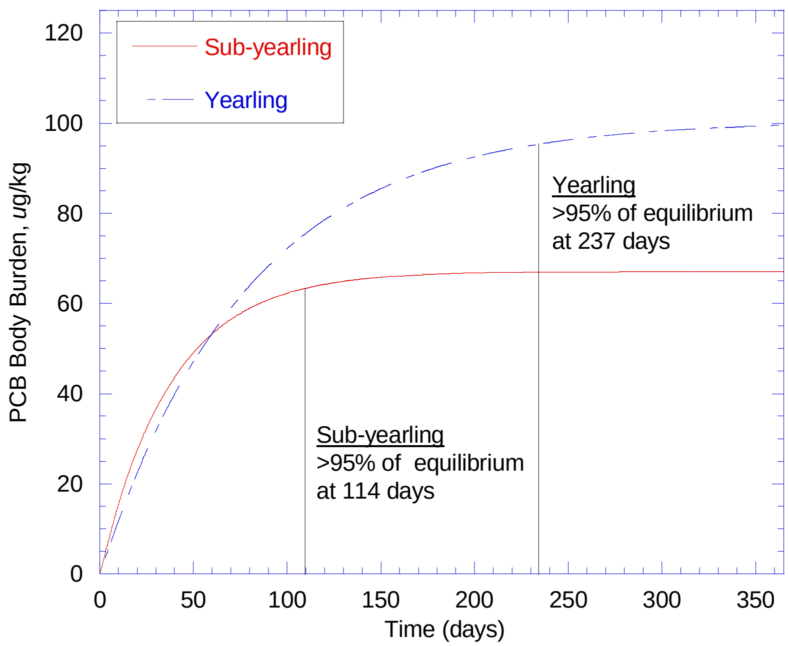

Figure 13: Temporal accumulation of PCBs in Subyearling, and Yearling model fish; calculated steady-state body burdens were: 67.0, and 100.5 µg/kg for Subyearling, and Yearling fish, respectively

In a subsequent modeling effort, simulations of contaminant uptake and elimination were constructed by solving a differential equation describing the fluxes of PCBs in Chinook salmon (Eq. 1):

$$\frac{dC_f}{dt} = k_1 \cdot C_{aq} + k_D \cdot C_{Diet} - (k_2 + k_E + k_M + k_G) \cdot C_f \quad \textit{adapted from Gobas (1993)} \qquad (1)$$

Where, C_f is the contaminant concentration within the fish (µg/kg), C_{aq} is the bioavailable aqueous concentration of the contaminant in the water column (µg/l), C_{Diet} is the concentration of the contaminant in the salmon prey base (µg/kg), and the k_i parameters represent rate constants associated with uptake (gill and dietary) and loss (respiration, excretion, transformation and growth). Again, PCB concentrations in the stomach contents and water column, as well as other field-derived data, were used to parameterize the model. The non-steady state (dynamic) simulations were then compared to the steady state (equilibrium) simulations with model fish representing yearling and subyearling Chinook salmon from up-river wild and hatchery origins, as well as from lower Columbia River wild and hatchery origins. Hence, the model runs simulated potential PCB accumulation amongst different ESUs utilizing the Columbia River Estuary under different migration hypotheses.

The modeling effort demonstrated that:

1. Over 100 days are required for PCBs to reach equilibrium in yearling and subyearling fish (Figure 13).
2. Because of their larger mass and slower growth rate, the modeled yearling Chinook fish took longer to reach equilibrium concentrations than subyearling fish. Assuming they reared in an environment with equivalent PCB concentrations, and final PCB body burdens were greater in modeled yearling than in modeled subyearling fish (Figure 13).
3. The significance of an initial PCB body burden (either from hatchery or other up-river sources) in Chinook salmon at the time of ocean entry is greater for Chinook that migrate rapidly (< 2 weeks) through the Columbia River Estuary, and/or temporarily reside in the least contaminated reaches (Figure 14).
4. Depending on the migration hypothesis and time, the PCB body burden is reduced in reaches with low levels of PCB contamination in the prey base.
5. Due to the heterogeneous distribution of PCB contamination in the Columbia River Estuary and the variation in residence times, as well as the variation in locations at which fish from different populations enter the mainstem of the Columbia, Chinook salmon would be expected to have a distribution of PCB body burdens at ocean entry that would not be explained by equilibrium modeling.

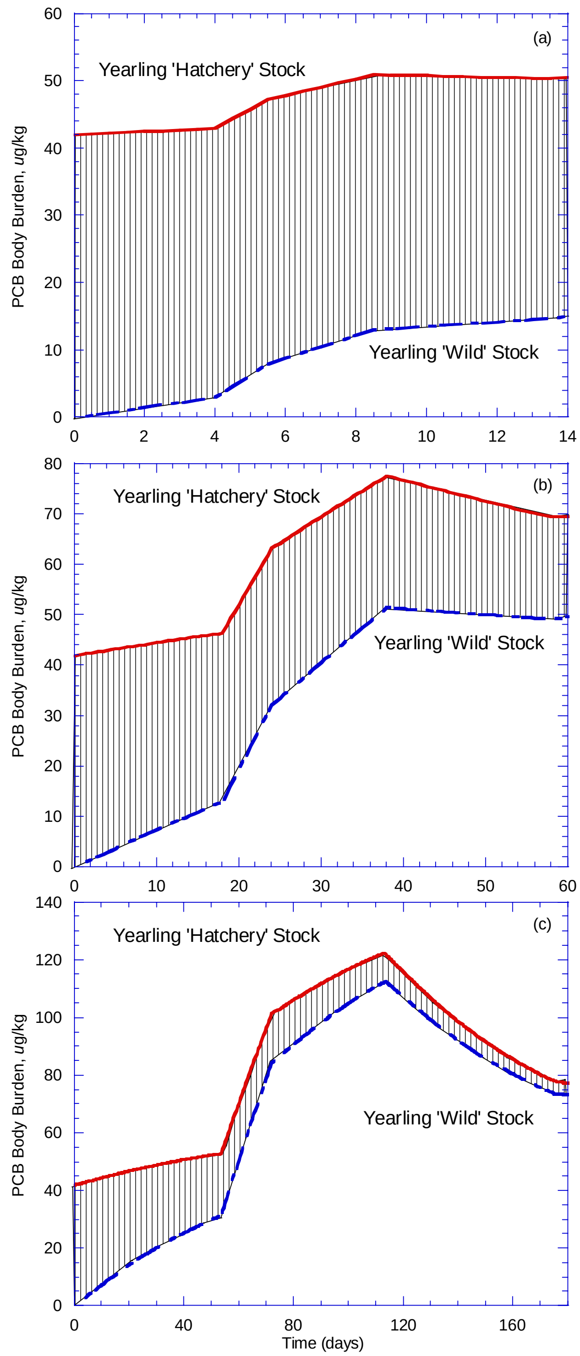

Figure 14: Temporal accumulation of PCB in Yearling model fish during 14 days (a), 60 days (b), and 180 days (c) of continuous migration with Initial body burdens of: 0.0 and 42.0 µg/kg, representing wild (pristine) and hatchery-reared fish, respectively.

Modeling Impacts of Chemical Contaminants on Salmon Populations in the Columbia River Estuary

In this study (see Spromberg and Johnson 2006) NOAA examined the potential effects of sublethal contaminant exposure during freshwater and estuarine residence on the population growth rates and productivity of 22 populations of fall Chinook within the Lower Columbia River Chinook evolutionarily significant unit (ESU), using matrix and metapopulation modeling techniques. Exposure was modeled by changing demographic rates through: 1) reduced first year survival; 2) delayed mortality; and 3) reproductive inhibition to simulate toxicant effects documented in field and laboratory studies. Projected reductions in survival and reproductive rates ranged from 10-20%. NOAA assessed the impacts of heterogeneous contaminant distribution by applying differential exposure scenarios to the metapopulation; e.g., in one scenario, there were uniform impacts on all populations; in another, all populations downstream of the Portland area, where inputs for most contaminants are highest, were affected, and in a third scenario, only those populations within the Portland area were affected. The output suggests that for the Lower Columbia River fall Chinook populations connected by low-level straying, metapopulation dynamics, may be protecting some populations and depleting others, while simultaneously masking the direct effects. The exposure scenarios predicted that the perturbations experienced by Chinook salmon populations at contaminant hot spots may influence the abundance and dynamics of unexposed populations elsewhere in the ESU. While contaminants may not be directly impacting the majority of populations within the ESU, it is apparent that their direct and indirect effects as well as the metapopulation dynamics should be considered in ESU-wide restoration and management decisions.

Summary of Year 3 Habitat Monitoring Activities

Habitat Monitoring

In August 2004, USGS and UW prepared a draft Lower Columbia River and Estuary Ecosystem Classification (Classification System) that was designed to provide guidance to the Estuary Partnership in developing and refining their Columbia River Estuary Habitat Monitoring Plan. The Classification System provided a first order landscape hierarchy for implementation of the initial Columbia River Estuary Habitat Monitoring Plan design and subsequent pilot sampling during summer 2005.

In October 2004, a habitat monitoring planning meeting was convened by Estuary Partnership staff, Pacific Northwest National Laboratories (PNNL), USGS, and the University of Washington. During that meeting, preliminary and intermediary steps for classifying reaches of the Columbia River estuary were suggested (Figure 1). It was agreed that landscape scale analysis using Landsat TM imagery would be completed by the University of Washington and USGS prior to undertaking field sampling. This step was deemed necessary in order for PNNL to select the most appropriate reaches for the pilot field study in summer 2005 as well as to put the selected field sites in geomorphologic and ecological context. The results of the landscape scale analysis were presented as part of a March 2005 habitat monitoring workshop and guided the selection of sites for the field study.

Habitat Monitoring Workshop

In March 2005, the habitat monitoring team convened a workshop to present the classification system, bathymetry data assessment, and preliminary field plan to a wider audience for peer review. Battelle received suggestions regarding the field plan ranged from emphasizing the nature of the work as a pilot study (and thus a chance to refine and test protocols) to specific suggestions for field collected data, such as collecting water quality data from tidal wetlands to tie in with the mainstem river water quality monitoring project. Emphasis was placed on using the field study as an opportunity to focus on ecosystem function. USGS and UW also presented the initial draft of the classification system for review at the workshop. USGS and UW obtained important feedback on the objectives, design and information sources to revise the Classification. This feedback is reflected in an updated draft of the Classification for Year 2.

University of Washington (UW) and USGS Revised DRAFT Columbia River Estuary Ecosystem Classification System

Columbia River Estuary Ecosystem Classification System Objective

The Columbia River Estuary Habitat Monitoring Plan calls for the development of a hierarchical framework that will allow delineation across different scales of diverse ecosystems and component habitats in the Columbia River Estuary. The primary purpose of the Columbia River Estuary Ecosystem Classification System (Classification) is to enable systematic monitoring of diverse, scale-dependent and scale-independent ecosystem attributes. It is, however, designed to provide a more utilitarian framework for understanding the underlying ecosystem processes that create the dynamic structure of the Columbia River Estuary. As such, it is intended to assist the broader community of scientists and managers who seek a larger scale of understanding required to study, manage and restore the estuary's ecosystems.

Columbia River Estuary Ecosystem Classification System Methods

Based on the structure of other classification schemes developed for estuarine ecosystems described in the literature, and common concepts of ecosystem geography (Bailey 1996), UW and USGS defined a classification scheme for the Columbia River Estuary that is structured in six hierarchical levels:

1. **Ecosystem Province**
2. **Ecoregion**
3. **Hydrogeomorphic Reach**
4. **Ecosystem Complex**
5. **Geomorphic Catena**
6. **Primary Cover Class**

The Classification is designed to aggregate conceptualized land and aquatic cover classes according to the ecosystem processes that structure landscape attributes, including biotic habitats, at different spatial scales. The classification methodology is entirely GIS-based using automated processes with minimal manual classification to generate an objective, repeatable, hydrogeomorphic class system. An explicit goal is to not involve any subjective delineation of classes at any level, but to either utilize scientifically-based classification schemes that already exist for the area or to develop rational rules adaptable to GIS-based analyses. Many data sources are all readily available and inexpensive GIS map layers that, if updated or improved in the future, can be incorporated into the classification methodology. All GIS data in the classification methodology are readily available and offered free of charge from state and federal government agencies (Table 1). The classification relies primarily on contemporary data sources; however, UW and USGS will incorporate historical data sources to cross-validate the methods. UW and USGS are requesting additional data, e.g. higher resolution bathymetric data from the U.S. Army Corps of Engineers, to improve the spatial extent and resolution of the classes in the next phase. Therefore, updated and improved data may replace existing data listed in Table 1 in subsequent phases of this project. After further development and refinement of the datasets to either improve the delineation of existing Classification levels or to develop analytical techniques for a new level, a final version of the Classification system will be published during Year 4 (September 1, 2006 to August 31, 2007).

Table 1: Sources and attributes of spatial data used to develop present version of the Columbia River Estuary Ecosystem Classification; (RKm 75 = RM 46, Rkm 214 = RM 133, RKm 230 = RM 145).

Data Type	Year	Spatial Extent	Resolution	Data Sources
Ecoregions	1984 to 2003	RKm 0 to 230	Varies	U.S. Environmental Protection Agency (EPA)
Bathymetry	2001 -2002 survey	RKm 0 to 75	To be determined	U.S. Army Corps of Engineers
	1938 to 1958	RKm 75 to RKm 230	30m	NOAA National Ocean Service
Hydrology	varies	RKm 0 to 230	1:24,000	USGS topographic surveys as digital raster graphics (DRG)
	varies	RKm 0 to 230	30m	Floodplain extent from Earth Design Consultants, Inc.
Land cover	2000	RKm 0 to 230	30m	Landsat 7 TM imagery from Estuary Partnership and Earth Design Consultants, Inc.
	1974	RKm 0 to 230	1:24,000	National Wetland Inventory (NWI
Elevation	varies	RKm 0 to 230	10m	USGS Digital Elevation Models (DEMs)
	2004 (avail. 2006)	RKm 0 to 230	unknown	USGS LIDAR Survey
Aerial Imagery	2001	RKm 0 to 230	1m	Digital Ortho Quads from Oregon Spatial Data Clearinghouse
Historical Bathymetry (H-sheets)	1866 to 1901	RKm 0 to 214	1:10,000 to 1:20,000	U.S. Coast and Geodetic Surveys, provided by NOAA Coastal Services Center
Historical Topography and Land Cover (T-sheets)			1:10,000	

Classification Hierarchy

Each level of the ecosystem classification encompasses different scales of influence on ecosystem structure, where the highest levels in the scheme describe regional-scale structure and the lowest levels composing the finer scale components of the strata in the levels higher in the hierarchy. For example, each of the Geomorphic Catena in level 5 is composed of sets of the Primary Cover Classes in Level 6. These sets or aggregations of cover classes are not necessarily unique, other than their association with larger scale features (described below). Similarly, each Hydrogeomorphic Reach in Level 3 is composed of various compositions and arrangements of Ecosystem Complexes in Level 4, which are somewhat unique within each reach.

Level 1: Ecosystem Province

Level 1 of the Columbia River Estuary Ecosystem Classification is defined as the Ecosystem Province encompassing the Marine West Coast Forest of EPA's Ecoregion Level II that occupies the coastal terminus of the Columbia River watershed (Figure 15). This is immediately adjacent to the Western Cordillera Province that occupies much of the remainder of the Columbia River basin.

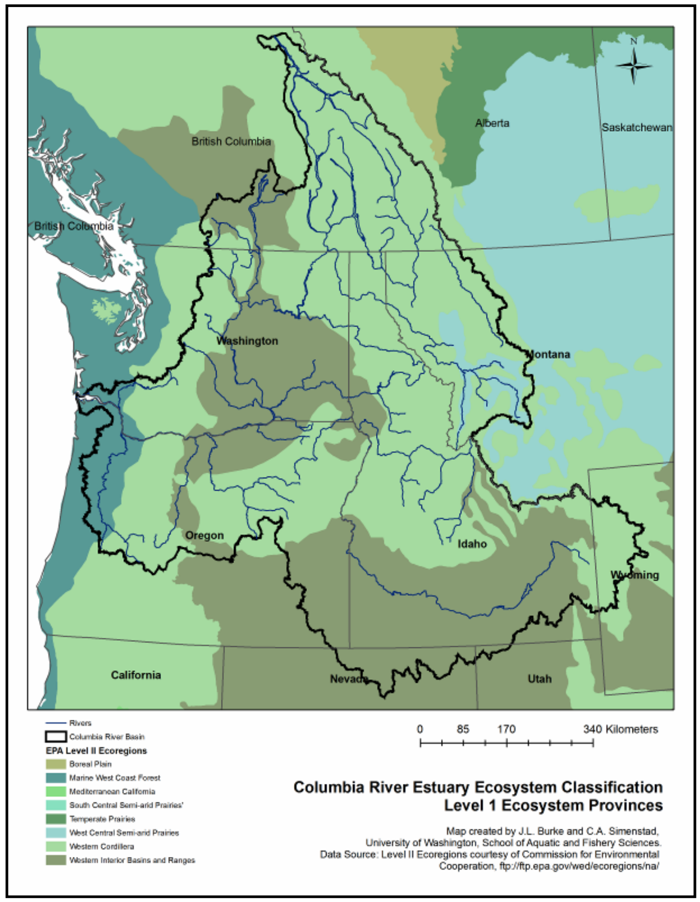

Figure 15: Level 1 Ecosystem Provinces of the Columbia River Estuary Ecosystem Classification based on EPA Level II Ecoregions.

Level 2: The Ecoregion

The Ecoregion level of the Columbia River Estuary Ecosystem Classification System adopts in principle and basic delineation the EPA Ecoregion Level III structure (Figure 16). Four Ecoregion strata are delineated within the Estuary Partnership's study area.

Level 3: Hydrogeomorphic Reach

The structure of the Hydrogeomorphic Reach level of the Columbia River Estuary Ecosystem Classification is based initially upon the EPA Level III and IV Ecoregions (Figure 16). These strata were then modified, either by further division or by adjusting their upstream or downstream boundaries using spatial data that demarked transitions in strong, large-scale hydrogeomorphic and tidal fluvial forcing, including: (a) maximum (historic) salinity intrusion, based on Sherwood et al. (1990); (b) transitions in maximum flood (pre-regulation) tide level (USACE 1968; Kukulka and Jay 2003); (c) the upstream extent of current reversal (estimated from predicted currents using Tides & Currents Ver. 2.5, Nautical Software, Inc.); and (d) convergences with major tributaries and slough systems. These extensions or modifications of the Level IV Ecoregions resulted in eight Hydrogeomorphic Reaches (Table 2, Figure 17).

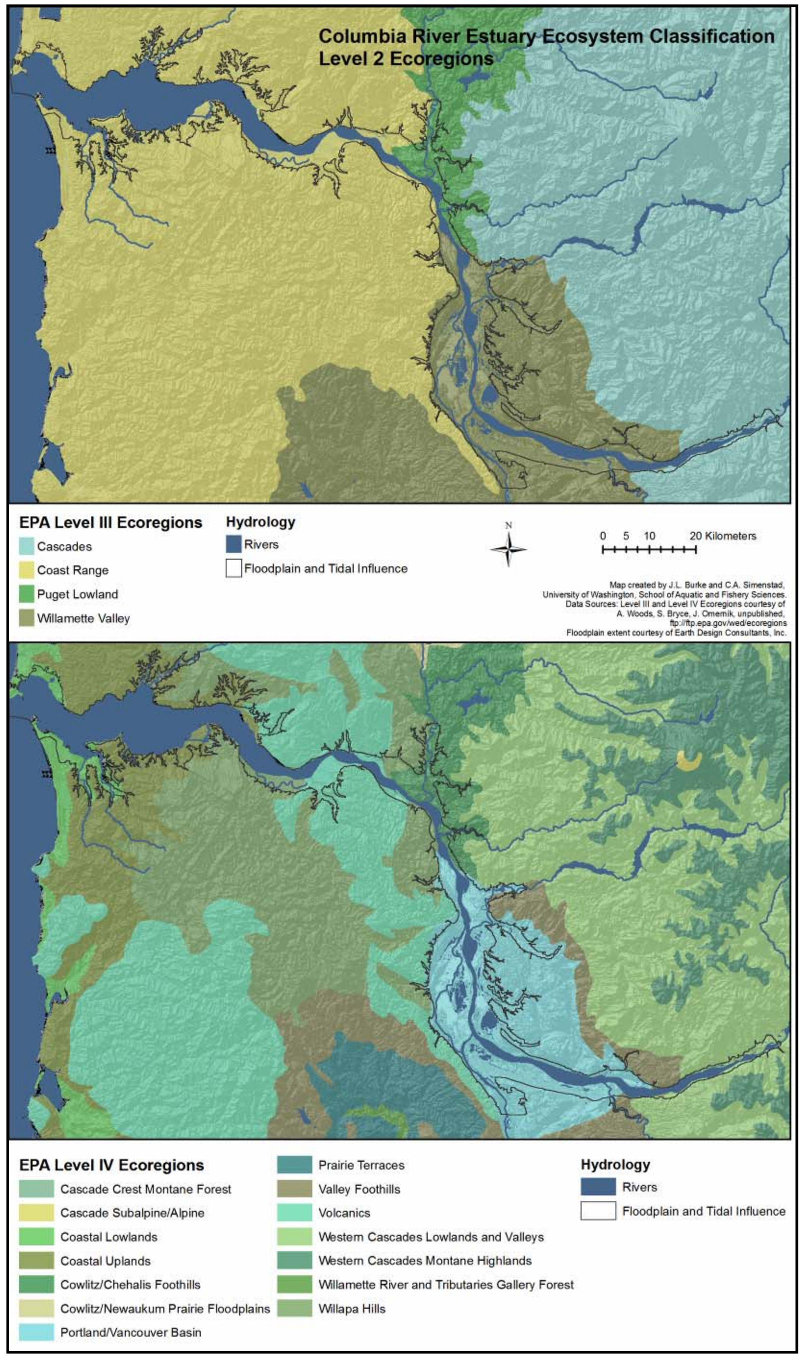

Figure 16: Level 2 of the Columbia River Estuary Ecosystem Classification based on EPA's Level III and IV.

Table 2: Name and abbreviated reach code for Level 3 Classification of the Eight Hydrogeomorphic Reaches.

Hydrogeomorphic Reach	Reach Name
A	Coastal Lowlands Entrance-Mixing
B	Coastal Uplands Salinity Gradient
C	Volcanics Current Reversal
D	Western Cascades Tributary Confluences
E	Tidal Flood Plain Basin Constriction
F	Middle Tidal Flood Plain Basin
G	Upper Tidal Flood Plain Basin
H	Western Gorge

Level 4: Ecosystem Complex

The fourth level in the Columbia River Estuary Ecosystem Classification System is intended to capture similar abiotic and biotic (Primary Cover Class, Level 5) characteristics in distinct geomorphic settings within each hydrogeomorphic regime (Level 3). These complexes are also distinguished by their landscape setting. These complexes are likely the most appropriate level of the classification to use for designing and implementing monitoring and assessment of biotic habitats. Until all datasets are available, UW and USGS can only provide a focal area example (e.g., Cathlamet Bay region of lower estuary), where polygon classification, georeferencing, bathymetry, etc. are available and complete (Figure 18). After initial testing, UW and USGS found that complexes in this pilot area could be delineated by selective bathymetric divisions that could distinguish the deeper mainstem (principally navigation) channel and the distributary channels (defined as channels greater than 1 m in depth). In some cases, there were apparent mismatches between these boundaries and the Level 5, Primary Cover Class dataset, primarily due to the tidal elevation at which the 2000 Landsat ETM+ dataset was collected. However, these were relatively minor occurrences and easily identified.

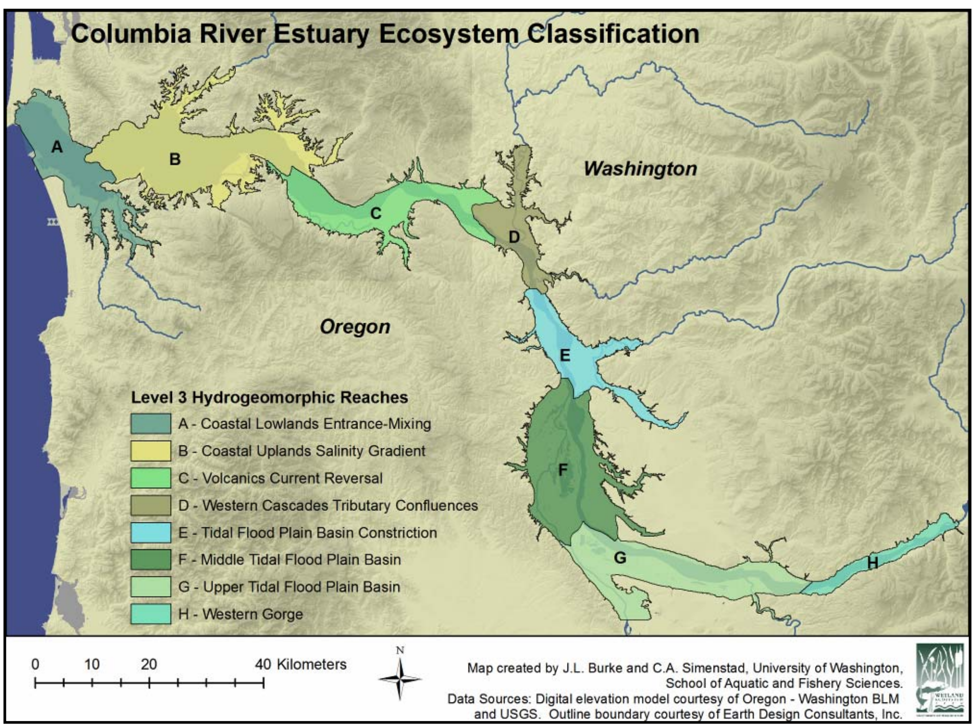

Figure 17: Level 3 Hydrogeomorphic reaches of the Columbia River Estuary Ecosystem Classification.

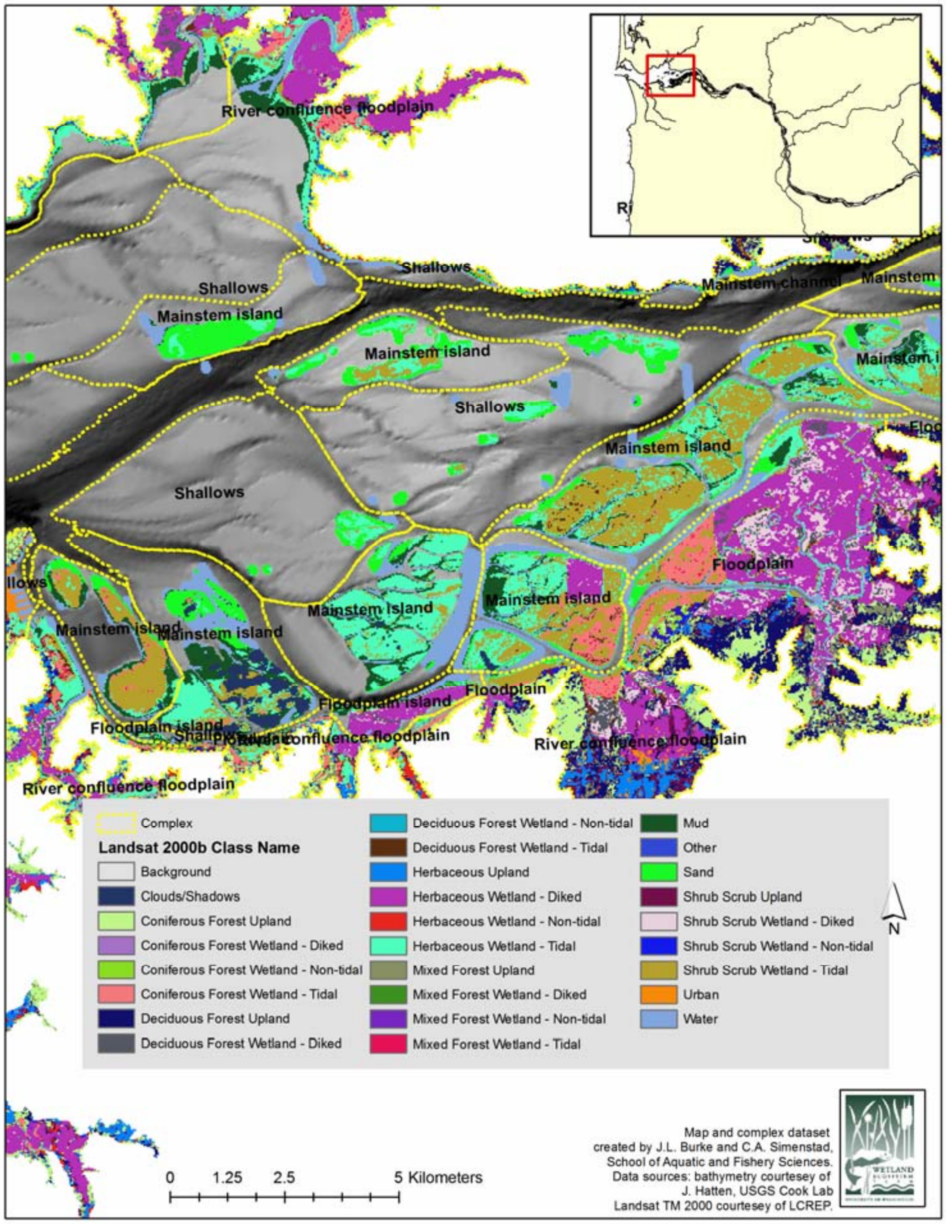

Figure 18: Level 4 Complexes of the Columbia River Estuary Ecosystem Classification.

Complexes are classified by their geomorphic and bathymetric characteristics and the composition and arrangement of the cover classes composing them. In the pilot example, UW and USGS identified six Ecosystem Complexes: Deep Channel; Shallow Subtidal Slope; Mud/Sand Flat, Unvegetated Sand; Emergent Marsh, and Scrub-Shrub Forested. Where anthropogenic factors are known to or can be reliably interpreted to modify the Primary Cover Class elements or structure, it is additionally distinguished by a Modifier (M in parentheses), which might for example distinguish the dredged channel or disposed dredged (sand) material. Although the Ecosystem Complexes delineated and classified in this example were derived primarily from expert knowledge, in the operational Columbia River Estuary Ecosystem Classification, UW and USGS will develop systematic rules (e.g., GIS queries) that will be used to delineate and classify the Complexes analytically.

Level 5: Geomorphic Catena

While Level 4 encompasses discrete organizations of landscape elements into units delineated primarily by distributary channel bathymetry, these units are composed of elements described by structure that represents a suite of geomorphic processes UW and USGS theorize to correlate with the different complexes. UW and USGS have adopted the concept of geomorphic catena as Level 5, described by Stanford et al. (in press) for floodplain rivers. Since they describe connectivity along the river-estuary corridor and characterize floodplain mosaics, they capture metrics of both ecologically important landscapes and their dynamic nature. They also are based principally on geomorphic surface and form. USGS and UW anticipate that a combination of bathymetry, topography and remote sensing classification of surface substrates can be applied with a set of spatial analysis rules to map discrete catena (e.g., Poole et al. 2002). The preliminary list of geomorphic catena are listed in Table 3 and illustrated as an example for Hydrogeomorphic Reach B in Figure 19.

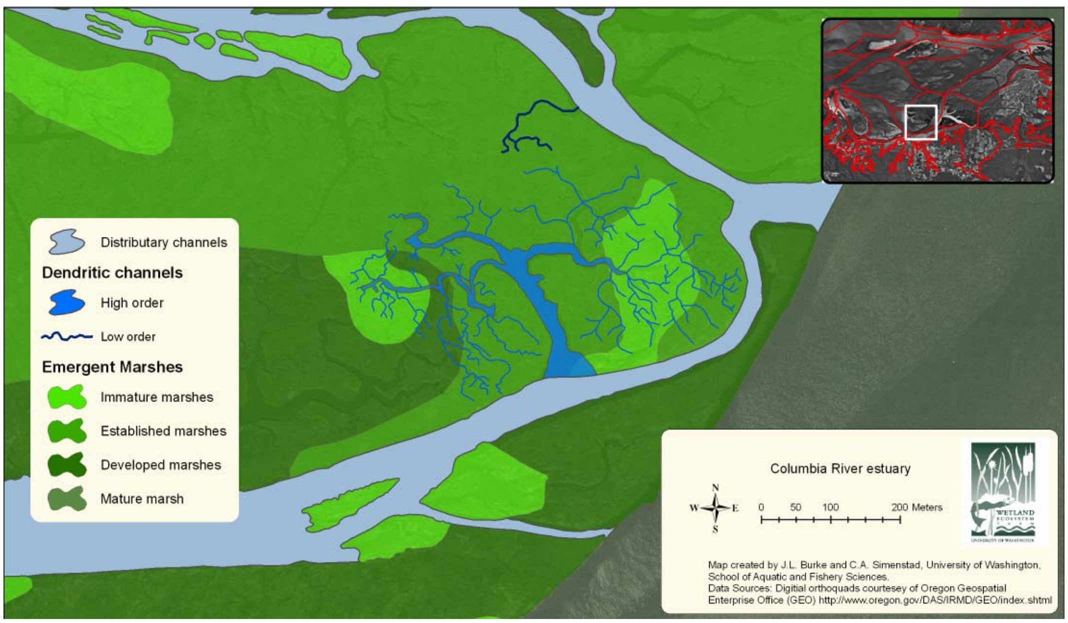

Figure 19: Level 5 of the Columbia River Estuary Ecosystem Classification, Geomorphic catena example for a portion of Russian Island in Reach B. Three catena are illustrated, distributary channels, dendritic channels, and emergent marsh development stages.

Table 3: Preliminary list of geomorphic catena that constitute Level 5 in the Columbia River Estuary Ecosystem Classification.

- Active mainstem channel(s)
- Secondary (distributary) channels
- Shallow subtidal slopes (adjacent to channels)
- Floodplain-terrace transition zone
- Floodplain ponds and relict channels
    - Connected
    - Unconnected
- Floodplain distributary channel
    - Paratidal (inundated during high water events)
    - Orthotidal (inundated only during rare and extreme floods)
- Natural levees; stable vegetation
- Forested tidal floodplain
- Scrub-shrub tidal floodplain
- Emergent tidal marsh
    - Mature (stable, high)
    - Mid-successional (low)
    - Immature (low)
- Dendritic tidal channel and sloughs
    - Low order (always drains except during extreme tides)
    - High order (always retains water at lower extremes)
- Flats (mud and/ or sand)
    - Fringe(transition between marsh and channel)
    - Mid-channel
    - Bay (e.g. Youngs Bay or Grays Bay)

Level 6: Primary Cover Class

The Primary Cover class is the fundamental level of the hierarchical scheme (Figure 18). Its components are represented in the Ecosystem Complexes in Level 4. From a number of available classified cover class data sources UW and USGS are presently using the Estuary Partnership's 2000 Landsat 7 TM data because it provides the most recent and comprehensive information and is supported by extensive training data in some regions of the system. However, further validation, groundtruthing, and structuring of the Landsat TM dataset occurred in Year 3 and will be completed in Year 4 of this project. Any artificial or otherwise modified Primary Cover Class is additionally distinguished by a Modifier. In the pilot example, Primary Cover Classes are presented (Figure 18).

USGS BRD's Columbia River Research Laboratory Bathymetry Assessment, Collection and Database Creation

During Year 3 of the Ecosystem Monitoring Project, USGS BRD's Columbia River Research Laboratory converted the 2006 US Army Corps of Engineers' bathymetric survey data for the lower Columbia River into a North American Vertical Datum (NAVD-88). Then USGS BRD inspected the dataset for holes to determine its utility for improving the existing master bathymetric dataset for the lower Columbia River and had the US Army Corps of Engineers' Hydrographic Survey review the datum conversion scripts. Next, USGS BRD needed to incorporate the Scappoose Bay Light Detection and Ranging (LiDAR) data into the Ecosystem Monitoring Project's master bathymetry layer. This was accomplished by converting the LiDAR data into a Triangulated Irregular Network (TIN) and using linear interpolation to convert the data into a 4-meter resolution Digital Elevation Model (DEM). Moreover, to incorporate multibeam sonar data for the lower Willamette River (mouth to Willamette Falls) into the master bathymetric dataset, USGS BRD converted the information into a Universal Transverse Mercator coordinate system with a NAVD-88 vertical datum. Finally, USGS BRD incorporated echo-sounder data that Columbia River Research Laboratory staff collected near the mouth of the Cowlitz River, and side-channels in the lower Columbia River, into the master bathymetric dataset. Bathymetric data collected by CRRL staff was registered directly to the NAVD-88 datum, so no additional conversion was necessary.

UW and USGS BRD YEAR 3 (2006): Refined Draft Classification and Landsat TM

Refining the Columbia River Ecosystem Classification and developing the Level 5 Geomorphic Catena for Year 3 were delayed until Year 4 when a critical dataset, LiDAR, for the entire estuary will be available. LiDAR was scheduled for release in early 2006 but was postponed until September 2006. The LiDAR will provide a critical base dataset for GIS analyses and will potentially fill data gaps where the Classification is lacking shallow water bathymetry needed for Level 4 Complex delineation. Therefore, for Year 3, UW continued refining and testing the classified Landsat ETM+ imagery to improve inaccuracies and issues for the Level 6 Cover Class in the Columbia River Estuary Ecosystem Classification. The refinement of the classified imagery will continue in Year 4 for reasons discussed in the following paragraphs.

Refining YR2000 Landsat ETM+ classified feature data

Groundtruthing

UW tested and refined the classified polygon feature data containing the Primary Cover Classes generated from YR2000 Landsat 7 ETM+ satellite imagery. While a considerable number of training data points were used in the processing of the satellite imagery to classify land cover classes, due to the size and complexity of the Columbia River Estuary, there still was a need to improve some regions and cover classes that lacked sufficient training data. UW developed two datasets for the groundtruthing process, a blind point feature dataset and a validation polygon feature dataset. The blind dataset consisted of 209 randomly generated points throughout the estuary that excluded water features but were unknown as to their cover classification. The purpose of the blind dataset was to identify systematic errors in the Landsat cover class and to establish a groundtruthing error rate. The validation dataset was composed of potentially erroneous cover classes collected from comments during a 2005 Estuary Partnership Science Workgroup Meeting, and personal observations of UW and Ecosystem Monitoring Project members. The purpose of the validation dataset was to verify potentially erroneous vegetation classifications. In May of 2005, UW flew an aerial survey to groundtruth 200 unknown points and to validate 150 polygons of questionable classification.

Processing the Landsat TM 2000b data for improved landcover classification

Key objectives:

1. **Groundtruth to determine attribute accuracy and validate errors**
2. **Analyses to define refinement process**
3. **Refinement will not 'reclassify' data**
4. **Refine classified Landsat TM**
5. **Establish reasonable accuracy in cover classes**

During Year 2 of the Ecosystem Monitoring Project (September 1, 2005 to August 31, 2006), UW initiated the refinement of YR2000 classified Landsat 7 ETM+ imagery for the Columbia River Estuary. The classified Landsat imagery developed under an Estuary Partnership and BPA-funded habitat mapping project (Project # 2002-012-00) was the first attempt to map cover classes in the Columbia River Estuary comprehensively since the NOAA C-CAP effort of 1992. The YR2000 land cover dataset serves as the data source for the Columbia River Estuary Ecosystem Classification's Level 6 Primary Cover Class. While a considerable amount of effort was undertaken in developing and processing the YR2000 Landsat imagery, there was a need to evaluate and address some regions and cover classes for error and classification accuracy. UW's objective was to determine sources of systematic error and refine the classified dataset without returning to the initial analyses used to spectrally classify the imagery. Therefore, UW refined the existing product produced by Estuary Partnership and BPA and limited repeated geoprocessing. Key items that needed to be addressed in the evaluation and final product included: determining the extent of spectral classification error, establishing if the ancillary datasets applied post-production were beneficial, assessing how the classified imagery could be improved post-production, and refining the post-production classified imagery.

Approach and methods

Evaluating and refining the classified YR2000 Landsat 7 ETM+ imagery required collecting field data for groundtruthing, analyzing the groundtruthing data and the classified imagery using an accuracy assessment matrix to quantify error in the cover class, and an evaluation of the potential sources of error and methods to address the error. UW's methodology involved three important iterations in the process: groundtruthing and analyses, updating ancillary datasets or modifiers, and refining the classified imagery. Because the analyses provided beneficial comparative information, the refinement of the classified imagery was initiated after preliminary assessment of the accuracy assessment and analyses. Therefore, the analyses include a third comparison to the initial version of the refined classified imagery that will progress as the analyses and ancillary datasets develop further in Year 4 of the Ecosystem Monitoring Project.

Groundtruthing

UW conducted a two-day field component to groundtruth data points to quantify error in the imagery classification. Two independent datasets were developed for the aerial groundtruthing effort which involved a flyover of the entire estuary. The first dataset, a blind dataset, consisted of 209 randomly generated points throughout the estuary, excluding water features, using ERDAS Imagine 8.7. The cover class associated with the blind points was unknown during the groundtruthing effort to prevent biasing during field classification. The purpose of the blind dataset was to identify systematic errors in the Landsat cover class through an accuracy assessment matrix and additional analyses. The second dataset, validation polygons, comprised of 204 area polygons potentially misclassified in the Landsat TM 2000b as identified by the Estuary Partnership's Science Workgroup members and from observations of UW and Ecosystem Monitoring Project members. The validation polygons were extracted from the classified imagery to maintain consistent boundaries during the comparison, and the polygons often included more than one cover classes. Hardcopy paper maps were produced from the blind and validation datasets, and were groundtruthed in-flight independently during the two-day effort in May 2005. UW successfully classified 118 blind points, and 151 validation polygons of the original dataset points were not classified because they may have been difficult to locate from air, located on water despite objective efforts in GIS to remove those points, or there was insufficient timing to acquire all sites (Table 4).

Table 4: Description of datasets developed to groundtruth classified Landsat TM imagery for the Level 6 Primary Cover class.

Dataset	Sampling unit	Number of sites	Source	Cover class	Purpose	Field classified
Blind	Points	209	Random	Unknown	Accuracy Assessment	118
Validation	Polygons	204	Selected	Known	Verify known errors	151

Classified imagery

To refine the YR2000 Landsat 7 ETM+ classified imagery, referred to as Landsat TM 2000b, UW obtained an early draft version of the classified imagery from Earth Design Consultants, Inc., that preceded modification of the classification through ancillary masking datasets or modifiers. The early draft classified imagery, referred to as the Landsat TM premask dataset, was analyzed for error in comparison to the Landsat TM 2000b imagery which was released in October 2003. A third generation classified imagery was later produced from the TM premask imagery, and was analyzed with the Landsat TM and premask to track the progress of the refinement. The decision to refine the classified imagery based on the TM premask imagery developed from preliminary groundtruthing analyses of both the Landsat TM 2000b and TM premask datasets.

Consistent cover classes

Inconsistent classification schemes and vegetation cover classes that did not appear in all schemes required a classification crosswalk table to analyze properly the datasets. The most notable difference was the lack of an agriculture cover class in the Landsat classified imagery. The blind and validation datasets included an agriculture cover class for lack of anything more appropriate or consistent as identified from the aerial survey. In addition, there were cases when the vegetation cover type such as deciduous or coniferous was not discerned beyond forested. The absence or disparity in the cover class names resulted in either aggregating similar classes, such as assuming all diked wetlands matched the field observed agriculture cover class, or as in the later case, all three forested wetland classes in the classified imagery were grouped for comparison to the field-observed forested wetland cover class. The Landsat TM 2000b has a classification scheme developed from a tidal modifier and a dike modifier, which were not present in the Landsat TM premask. In this case, depending on the comparison, tidal and non-tidal may be grouped, and diked wetlands were either grouped with the tidal and non-tidal wetlands, or considered equivalent to agriculture. An excel spreadsheet with cross-walking tables for each classification scheme was developed, exported to GIS, and appended to the blind and validation datasets to run the accuracy assessment.

Accuracy assessment matrix

An accuracy assessment matrix comparing the results of two datasets provided a means to quantify accuracy or error. UW chose to generate producer accuracy or the probability that a field classified pixel or area will be classified as the same cover class in the classified Landsat TM imagery (Stehman and Czaplewski 1998). UW generated an accuracy matrix using ArcGIS 9.1 Spatial Analyst extension, Tabulate Area function in the Zone toolset, for the blind and validation cover classes against the Landsat TM 2000b, Landsat TM premask, and the first version of the refined Landsat TM.

Modifiers

Two ancillary datasets are being developed concurrently with the analyses and first stages of the refinement. An updated dike and floodplain feature dataset will be developed as polylines and polygon datasets. The dike layer will be intersected with the refined classified imagery to provide a dike category, potentially an integer field attributed as 1 for diked and 0 for non-diked.

Floodplain modifier

The Columbia River Estuary currently lacks a historical floodplain dataset which would be useful for analyses as well as identifying cover classes and the area of historical flood influence. The FEMA 500 and 100 year flood plain are not comprehensive for the entire estuary and do not include diked areas. Two approaches were attempted to update the historical floodplain extent of the Columbia River Estuary, without investing time and effort associated with hydrologic and geomorphic modeling. The resulting floodplain extent will be estimated objectively in GIS and developed further by professional feedback. Completion of either approach is currently on-hold until the LiDAR becomes available due to the limitations and errors associated with the USGSU 10 meter digital elevation models (DEM) for the Columbia River Estuary.

One method to develop a historical flood plain is to combine historical land cover maps with historical flood profile graphs. Historical land cover maps are complete but not publicly available for the entire Columbia River estuary, however, a preliminary version was incorporated.

The US Army Corps of Engineers 1968 flood profile graph was converted to digital point format in GIS for the 1876 maximum elevation values at 33 river height gages (USACE 1968). Elevations were interpolated for every river mile from the mouth to Bonneville Dam (RM 146) using ERSI ArcGIS 9.1 Spatial Analyst extension Kriging function in the Interpolation toolbox. The kriged values per river mile point are joined with a polygon dataset to extract from a DEM of the estuary all pixels less than the flood elevation for each river mile (Figure 20). The Estuary Partnership reviewed and provided feedback for problem areas identifying the limitation of using a constant elevation for a complex system with river and tributary inflows.

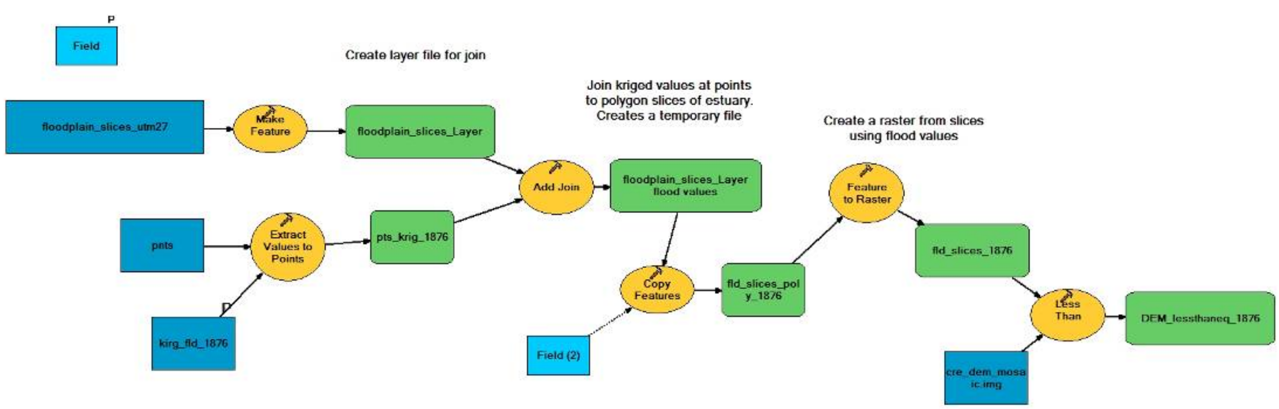

Figure 20: Geoprocessing model of a method to determine the extent of the flood plain.

A potential second method is to use slope and the cost distance function with a DEM for the entire estuary. The theory of this approach is that as distance from the river increases, cost calculated from the slope generated from the DEM increases. A sharp increase in cost should indicate the edge of the flood plain assuming a sharp or noticeable rise in elevation exists and is the appropriate extent of historical floods. This method was tested with USGS 10 meter digital elevation models using ArcGIS 9.1 Spatial

Analyst Tools extension, Slope function in the Surface toolset and Cost Distance function in the Distance toolset. The methodology will be further tested when the LiDAR becomes available during Year 4.

Dikes modifier

Limited mapping exists identifying the presence and the spatial extent of influence of active and inactive dikes for the Columbia River Estuary. Inquiries to the US Army Corps of Engineers revealed a need to update their existing GIS data layer which is incomplete and contains spatially inaccuracies. An early attempt by Earth Design Consultants, Inc to generate a dike map for the Landsat TM 2000b imagery led to the gathering of maps and best professional judgments from regional resource managers and planners. Both sources are incomplete and must be updated. The US Army Corps of Engineers conducted ground surveys of all dikes in 1989, producing a document with hard copy maps of dikes for the entire estuary. Unfortunately, the hard copy maps are coarse and spatially inaccurate for GIS, but the maps can be used to locate the dikes in GIS using heads-up digitizing onto a higher resolution data source. UW initiated the updating of the dikes layer by combining all available GIS data. In addition, UW provided printed maps of high resolution digital orthoquads to regional resource managers to annotate active and inactive dikes. Furthermore, UW will add in additional dikes from the LiDAR bare earth dataset, from which dikes are visible. The final dataset will be sent out for review to multiple regional personnel for comment and feedback before it is applied as a modifier to the classified Landsat imagery.

Refining the classified imagery

All processing of the classified Landsat TM premask imagery occurred in ERSI ArcGIS 9.1 using the Spatial Analyst Tools extension and its toolsets.

Results

Several issues were identified by UW and the Estuary Partnership as a priority for the assessment and the refinement of the Classification. First, classification errors appeared to be unusually high despite the high user and producer accuracy assessment rates as reported by Earth Design Consultants, Inc. (Garono et al., 2003). Second, pixelation of the imagery increased the level of detail rendering the data difficult to interpret and use with complementary land cover and other datasets (Alpin et al. 1999), and to further confound this issue, the pixelation often included misclassified cover classes. Through the course of analyzing the results, these and several other issues manifested and resolutions were identified.

Interpreting the Accuracy Assessment Matrix

Classification error rate with the validation dataset was expected to be lower than the blind dataset because the validation dataset specifically addressed known issues with the classified Landsat TM 2000b imagery. However, the validation dataset matched the Landsat TM 2000b by 54% compared to the blind dataset corresponding to the Landsat TM 2000b at only 51% (Tables 5 through 8). The most useful aspect of the accuracy assessment matrix is viewing how the imagery cover was classified in comparison to our observations. In addition, the TM premask experienced a drop in producer accuracy to 43% with the validation dataset, 50% for the blind dataset.

Upland and wetland misclassification

One source of error in the Landsat TM 2000b was spectral misclassification of uplands and wetlands within each of the vegetation classes. For instance, known forested wetlands on Welch Island included the presence of misclassified pixels of deciduous forest upland. The differences observed between the Landsat TM 2000b and TM premask with the blind and validation datasets indicate that the tidal and dike modifiers may have adjusted upland cover classes to wetland cover classes. One method to refine this error is to aggregate the upland and wetland class within each vegetation class and apply an improved elevation and or dike dataset to identify upland vegetation, wetlands, and diked or reclaimed wetlands. While this methodology may reduce some of the spectral classification error, the refined classified imagery will continue to reflect the quality of the elevation and dike datasets and the decisions incorporated.

Forested cover class

Three forested cover classes were present in the Landsat TM 2000b and TM premask imagery: coniferous, deciduous, and mixed. The comparison of the blind and validation datasets with both TM imagery revealed that classification could be improve by aggregating the three forested cover classes to one cover class (Tables 5 though 7).

Tidal and dike modifiers

Ancillary datasets for tidal influence and dikes, represented as polygon areas shielded from high river events, were applied by Earth Design Consultants, Inc. in the post-processing stages of the classified Landsat TM imagery. Since these modifier datasets were in need of improvements and updating, some areas were excluded from proper classification. In addition, there were some areas modified in error. One such misclassification was non-tidal wetlands adjacent to the tidal river in Young's Bay near Astoria, OR. Based on the results from analyzing the accuracy of the cover classes using the blind and validation datasets, UW was confident in the choice to base the refinement on the TM premask, which lacked the modifiers. However, UW continued to use the Landsat TM 2000b to quantify errors and track the refinement progress.

Table 5: Accuracy assessment matrix of Blind dataset and Landsat TM 2000b cover classes, units are number of pixels.

Landsat TM 2000b cover classes		Herbaceous Wetland	Herbaceous Upland	Shrub-scrub Wetland	Shrub-scrub Upland	Mud	Sand	Deciduous Wetland	Deciduous Upland	Coniferous Wetland	Coniferous Upland	Mixed forested Upland	Water	Urban	Wetland	Agriculture	Forested Wetland	Forested Upland	Sum
Herbaceous	Wetland - Tidal	3	1	0	0	2	0	1	0	0	0	0	1	0	0	3	1	0	12
	Wetland - Diked	1	1	1	0	0	0	0	0	0	0	0	0	0	0	6	0	0	9
	Wetland - Non-tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upland	0	0	0	0	0	0	0	2	0	0	0	0	3	0	0	0	1	6
Shrub-scrub	Wetland - Tidal	3	0	3	0	0	0	1	0	0	0	0	0	0	1	0	0	0	8
	Wetland - Diked	0	1	0	1	0	0	1	0	0	0	0	0	0	1	4	0	0	8
	Wetland - Non-tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upland	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	3
	Mud	1	0	0	0	6	0	0	0	1	0	0	2	0	0	0	0	0	10
	Sand	1	0	0	0	1	6	0	0	0	0	0	3	0	0	1	0	0	12
Deciduous forest	Wetland - Tidal	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2
	Wetland - Diked	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	3
	Wetland - Non-tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upland	0	0	0	0	0	0	1	2	0	2	0	0	1	0	0	0	0	6
Coniferous forest	Wetland - Tidal	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3
	Wetland - Diked	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
	Wetland - Non-tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Upland	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2
Mixed forest	Wetland - Tidal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Wetland - Diked	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
	Wetland - Non-tidal	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
	Upland	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	3
	Water	0	0	0	0	0	0	1	0	0	0	0	7	0	0	1	0	0	9
	Urban	0	0	0	0	1	0	0	0	0	0	0	0	12	0	0	0	0	13
	Clouds, Shadows	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
	Other	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	5
	Sum	9	3	4	3	11	6	8	9	6	4	2	13	16	2	20	1	1	**118**
	Number correct	4	0	3	1	6	6	0	2	3	1	2	7	12	2	11	0	0	**60**
	Producer's accuracy	0.44	0.00	0.75	0.33	0.55	1.00	0.00	0.22	0.50	0.25	1.00	0.54	0.75	1.00	0.55	0.00	0.00	**0.51**

Blind cover classes

Table 6: Accuracy assessment matrix for blind dataset and Landsat TM premask cover classes, units are number of pixels.

			Blind cover classes																
			Herbaceous		Shrub-scrub				Deciduous		Coniferous		Mixed Forested					Forested		
			Wetland	Upland	Wetland	Upland	Mud	Sand	Wetland	Upland	Wetland	Upland	Upland	Water	Urban	Wetland	Agriculture	Wetland	Upland	Total
Landsat TM premask cover classes	Herbaceous	Wetland	3	0	1	0	2	0	1	0	0	0	1	0	0	0	3	1	0	12
		Upland	1	2	0	0	0	0	0	2	0	0	0	0	3	0	6	0	1	15
	Shrub-scrub	Wetland	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
		Upland	0	1	0	2	0	0	3	1	0	0	0	0	0	2	4	0	0	13
		Mud	1	0	0	0	6	0	0	0	1	0	2	0	0	0	0	0	0	10
		Sand	1	0	0	0	1	6	0	0	0	0	3	0	0	0	1	0	0	12
	Deciduous forest	Wetland	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3
		Upland	0	0	0	0	0	0	1	3	0	2	0	0	1	0	1	0	0	8
	Coniferous forest	Wetland	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	3
		Upland	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	3
	Mixed forest	Wetland	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
		Upland	0	0	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	4
		Water	0	0	0	0	0	0	1	0	0	0	7	0	0	0	1	0	0	9
		Urban	0	0	0	0	1	0	0	0	0	0	0	0	12	0	0	0	0	13
		Clouds, shadows	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
		Other	0	0	0	0	0	0	1	0	0	0	0	0	0	0	4	0	0	5
		Total	9	3	4	3	11	6	8	9	6	4	13	2	16	2	20	1	1	**118**
		Producer accuracy	0.33	0.67	0.75	0.67	0.55	1.00	0.00	0.33	0.33	0.25	0.54	1.00	0.75	0.00	0.50	0.00	0.00	**0.50**

Table 7: Accuracy assessment matrix of Validation dataset and Landsat TM 2000b cover classes, units are in meters.

Landsat TM 2000b cover classes		Validation cover classes: Herbaceous Wetland	Herbaceous Upland	Shrub-scrub Wetland	Shrub-scrub Upland	Mud	Sand	Deciduous Forest Wetland	Coniferous forest Wetland	Coniferous forest Upland	Mixed forest wetland	Water	Urban	Wetland	Agriculture	Forested wetland	Upland	Sum
Herbaceous	Wetland - Tidal	1860300	0	532800	0	18900	5400	0	13500	0	32400	32400	0	522000	1343700	347400	267300	4976100
	Wetland - Diked	1791900	262800	62100	21600	0	0	1800	26100	0	0	630900	377100	1925100	714600	0	40500	5854500
	Wetland - Non-tidal	496800	0	59400	0	0	0	56700	0	0	900	0	0	19800	900	10800	13500	658800
	Upland	466200	0	39600	1800	0	26100	13500	900	0	0	0	0	18000	1058400	70200	948600	2643300
Shrub-scrub	Wetland - Tidal	371700	0	618300	0	0	0	7200	2700	0	41400	0	0	166500	68400	143100	0	1419300
	Wetland - Diked	1131300	44100	7200	0	0	0	5400	900	0	0	144900	105300	660600	492300	0	0	2592000
	Wetland - Non-tidal	46800	0	117000	0	0	0	4500	0	0	0	0	0	0	0	37800	24300	230400
	Upland	174600	0	51300	0	0	0	47700	0	2700	6300	0	0	5400	6300	37800	5400	337500
	Mud	85500	0	10800	0	40500	900	900	2700	0	0	3600	900	1800	0	7200	0	154800
	Sand	207000	0	27000	0	5400	57600	1800	1800	0	8100	6300	0	12600	3600	4500	0	335700
Deciduous forest	Wetland - Tidal	13500	0	278100	0	0	0	15300	54900	0	766800	3600	0	371700	9000	254700	0	1767600
	Wetland - Diked	306000	0	2700	0	0	0	156600	4500	0	0	11700	182700	264600	3839400	0	0	4768200
	Wetland - Non-tidal	35100	0	2700	0	0	0	9900	900	0	1800	0	0	1800	1800	900	0	54900
	Upland	63000	0	59400	900	0	0	581400	8100	3600	184500	0	0	32400	1800	168300	27000	1130400
Coniferous forest	Wetland - Tidal	19800	0	81000	0	0	0	2700	20700	0	52200	2700	0	70200	0	417600	0	666900
	Wetland - Diked	8100	0	900	900	0	0	109800	8100	0	0	0	900	44100	33300	0	0	206100
	Wetland - Non-tidal	1800	0	9000	0	0	0	0	0	6300	0	0	0	900	0	156600	0	174600
	Upland	16200	0	8100	900	0	0	271800	11700	39600	1800	0	0	25200	0	359100	153000	887400
Mixed forest	Wetland - Tidal	1800	0	2700	0	0	0	900	0	0	62100	900	0	4500	0	11700	0	84600
	Wetland - Diked	5400	0	0	0	0	0	0	0	0	0	0	0	1800	2700	0	0	9900
	Wetland - Non-tidal	900	0	0	0	0	0	0	0	0	0	0	0	0	0	14400	0	15300
	Upland	5400	0	900	0	0	0	0	0	900	0	0	0	0	0	13500	53100	73800
	Water	133200	0	12600	0	29700	0	7200	4500	0	0	328500	7200	319500	44100	30600	900	918000
	Urban	19800	12600	9900	0	0	0	0	0	0	0	18900	2700	13500	59400	0	3600	140400
	Clouds, Shadows	10800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10800
	Other	57600	0	0	0	0	0	0	0	0	0	2700	42300	157500	501300	900	0	762300
	Sum	7330500	319500	1993500	26100	94500	90000	1295100	162000	53100	1158300	1E+06	719100	4639500	8181000	2087100	1537200	**30873600**
	Correct	4149000	0	742500	0	40500	57600	181800	28800	39600	62100	328500	2700	4053600	5046300	855900	1187100	**16776000**
	Producer accuracy	0.57	0.00	0.37	0.00	0.43	0.64	0.14	0.18	0.75	0.05	0.28	0.00	0.87	0.62	0.41	0.77	**0.54**

Table 8: Accuracy assessment matrix of Validation dataset and Landsat TM premask cover classes, units are in meters.

			Validation cover classes																
			Herbaceous		Shrub-srub					Coniferous forest									
			Wetland	Upland	Wetland	Upland	Mud	Sand	Deciduous forest wetland	Wetland	Upland	Mixed forest wetland	Water	Urban	Wetland	Agriculture	Forested wetland	Upland	Sum
Landsat TM premask	Herbacous	Wetland	1918800	900	548100	0	18900	4500	56700	23400	0	25200	216000	6300	706500	69300	90000	13500	3698100
		Upland	2688300	269100	145800	23400	0	27000	15300	17100	0	8100	447300	370800	1778400	3048300	338400	1256400	10433700
	Shrub-scrub	Wetland	168300	0	453600	0	0	0	11700	900	0	900	8100	1800	68400	14400	101700	24300	854100
		Upland	1551600	46800	340200	0	0	0	53100	2700	2700	46800	136800	103500	764100	552600	117000	5400	3723300
		Mud	85500	0	10800	0	40500	900	900	2700	0	0	3600	900	1800	0	7200	0	154800
		Sand	207000	0	27000	0	5400	57600	1800	1800	0	8100	6300	0	12600	3600	4500	0	335700
	Deciduous	Wetland	56700	0	30600	0	0	0	11700	2700	0	10800	7200	3600	68400	27000	25200	0	243900
		Upland	361800	1800	312300	900	0	0	751500	65700	3600	942300	8100	179100	602100	3825000	398700	27000	7479900
	Coniferous	Wetland	24300	0	72900	0	0	0	0	2700	6300	4500	900	0	7200	900	444600	0	564300
		Upland	20700	0	26100	1800	0	0	384300	37800	39600	49500	1800	900	133200	32400	488700	153000	1369800
	Mixed forested	Wetland	3600	0	1800	0	0	0	900	0	0	7200	900	0	6300	2700	26100	0	49500
		Upland	10800	0	1800	0	0	0	0	0	900	54900	0	0	0	0	13500	53100	135000
		Water	133200	0	12600	0	29700	0	7200	4500	0	0	328500	7200	319500	44100	30600	900	918000
		Urban	19800	12600	9900	0	0	0	0	0	0	0	18900	2700	13500	59400	0	3600	140400
		Clouds, shadows	10800	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10800
		Other	57600	0	0	0	0	0	0	0	0	0	2700	42300	157500	501300	900	0	762300
		Sum	7318800	331200	1993500	26100	94500	90000	1295100	162000	53100	1158300	1187100	719100	4639500	8181000	2087100	1537200	**30873600**
		Number correct	1918800	269100	453600	0	40500	57600	11700	2700	39600	7200	328500	2700	856800	7425900	495900	1494900	**13405500**
		Producer accuracy	0.26	0.81	0.23	0.00	0.43	0.64	0.01	0.02	0.75	0.01	0.28	0.00	0.18	0.91	0.24	0.97	**0.43**

Evaluating source of disparity in cover classes

To identify the sources of error between the Landsat TM 2000b and the validation cover classes, UW reduced the area of the validation polygons by generating a centroid or point within each polygon for a more manageable dataset. The individual points (n=129) were evaluated with the overlapping Landsat TM 2000b pixels to determine if discrepancies were due to the resolution of the Landsat, tidal stage, or spectral misclassification (Figure 21). Tidal stage and dike modifiers were ignored and considered equivalent to a wetland. Agriculture was not included as a cover class in the validation dataset due to the absence of the cover class in the Landsat TM 2000b. Total discrepancies between the validation points and the Landsat TM 2000b classification amounted to 54% of the 129 points. To evaluate the effect of resolution, UW compared the 8 pixels surrounding the target pixel to determine if at least one of the pixels matched the validation cover class. While the evaluation does not eliminate the fact that the target pixel was misclassified spectrally, it does assess the complexity of the region and error often encountered where land cover boundaries contribute to mixed pixel error. Resolution accounted for 22% of the errors indicating that the per-pixel cover classes were complicated by the diversity of the Columbia River estuarine land cover. Tidal stage resulted in one, or 1%, error in which the cover class disparity was between mud and water. Throughout the extent of the dataset, 32% of the 129 pixels tested were spectrally misclassified, while 46% of the 129 points were correct cover classes

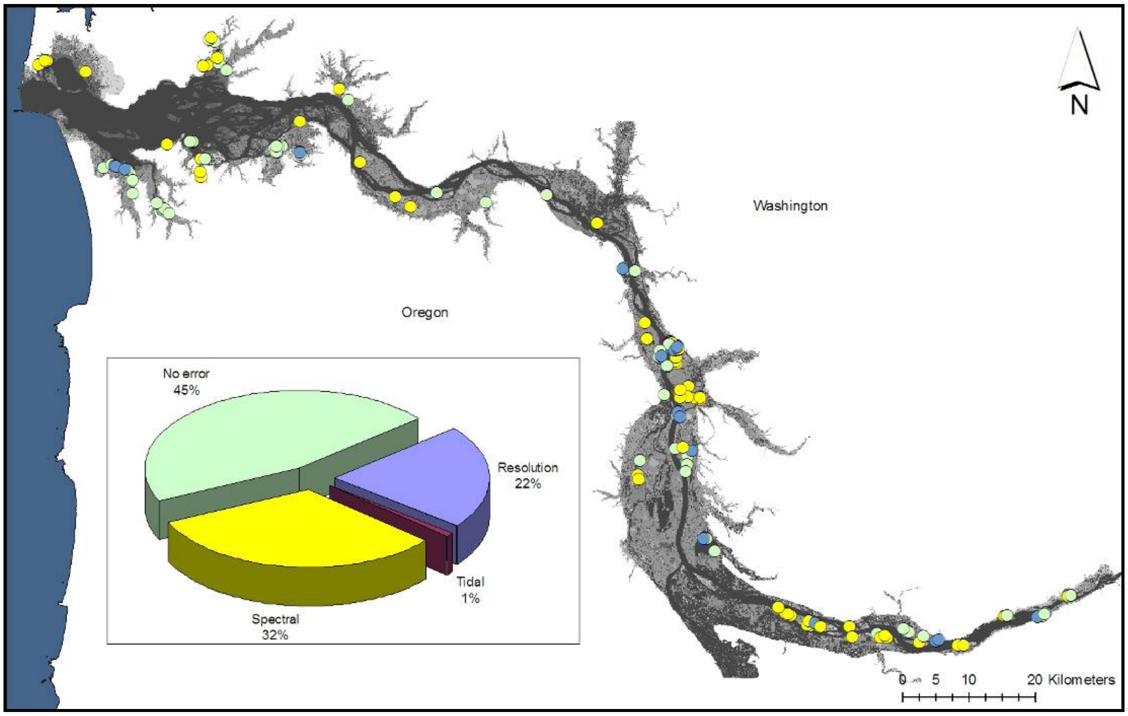

Figure 21: Review of the source of producer error in the validation dataset excluding the agriculture cover class and dike/tidal modifiers.

Additional observations during the course of the analyses include:

1. Herbaceous and shrub-scrub wetlands were often intermixed and would have been difficult to identify spectrally
2. Non-tidal pixels occurred adjacent to the Columbia River
3. Discerning between conifer, deciduous, and mixed forested wetlands spectrally had variable success
4. Floodplain wetlands were lacking in the upper estuary cover class creating discrepancies in the evaluation
5. Estuarine land cover and boundaries in the Columbia River are highly complex
6. Ancillary datasets should be used to identify wetlands due to the difficulty of spectrally discerning wetlands from uplands

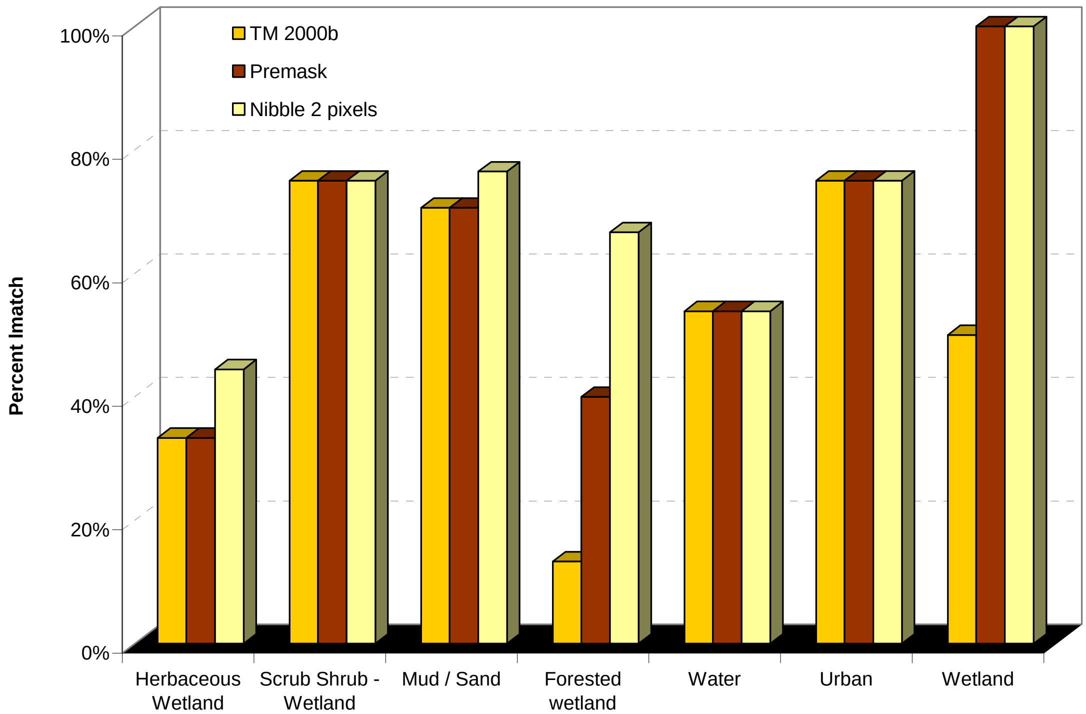

Figure 22: Cover class accuracy of the blind dataset with three versions of the classified Landsat 7 ETM+ imagery.

Pixelation

Confounding the analyses and the use of the classified Landsat TM 2000b is the extensive pixelation or high rate of heterogeneity in the cover classes, which is also present in the TM premask. Per-pixel land cover has inherent properties and should be used with caution (Townsend et al. 2000, Alpin at el. 1999). However, Earth Design Consultants, Inc. decided not to remove any pixelation due to the apparent complexity of the estuarine cover classes and the potential to obscure legitimate cover classes such as roads, which often appear as single pixel width and might be removed if the imagery was processed to remove pixelation.

To generate a more evenly distributed classification of cover types, various systematic procedures exist in ESRI ArcGIS 9.1 and ERDAS Imagine 8.7 to reduce pixelation by reclassifying isolated pixels using adjacent classified pixels. UW chose to geoprocess the TM premask imagery with the Nibble function in ESRI's Spatial Analyst Extension, Interpolation toolset. Nibble is a generalization function that reclassifies specific pixels, as identified by the user using criteria and spatial analyses, using adjacent land cover classification.

Refining the imagery

The initial results of the Landsat TM 2000b and TM premask analyses contributed to the decision to collapse similar vegetation classes, remove modifiers, and process the Landsat TM premask imagery to remove pixelation and generate a first version of the refined classified imagery, referred to as the Landsat TM nibble. As the ancillary datasets are fully developed, a second version of the refined imagery will be developed and will include stand-alone modifiers independent of the cover classes.

Testing aggregation of cover classes and geoprocessing of imagery

The analysis of the 76 blind points (excluding uplands, agriculture, etc.) with three versions of the classified Landsat 7 ETM + imagery revealed an improved match in several of the classes when the classes are aggregated. The validation polygons were not included in this analysis since those were recognized as misclassified cover classes. The most significant improvement occurred in the forested wetlands cover class (Figure 22).

Two Nibble processes were tested, a four pixel and three pixel minimum for contiguous cover classes. The three pixel minimum removed two or less pixels and produced the best visible results because it maintained boundaries and cover classes at 2700 m^2 that were of interest.

The nibble process achieved several desirable effects in the landcover data. Pixelation of the landcover classes was reduced and errant pixels were removed. Furthermore, boundaries between landcover types were retained. However, while the nibble process may have reclassified single and double contiguous pixels, the possibility remains that the surrounding pixels could be misclassified.

Conclusions

Many of the issues identified in the evaluation of the Landsat TM 2000b dataset were often confounding. Complicating spectral classification errors were two potential issues. First, there may have not been adequate training data through the extent of the estuary for the number of classes attained in the final dataset. Second, the original classification scheme may have been too detailed with too many classes. Some of the classes may have been discerned through analyses with other datasets. For instance, elevation could have been used to identify wetlands.

The user and producer accuracy rates as reported by Earth Design Consultants, Inc., (Garono et al., 2003) may have been overestimated since the data used to generate the error matrix were a subsample of the training data. Since training data sites are often homogenous and ideal for classification purposes, the rate of accuracy is likely to be higher than a randomly collected dataset (Hammond and Verbyla 1996 as cited in Stehman and Czaplewski 1998).

Our initial approach to the Landsat refinement was to reclassify erroneous pixels after identifying any patterns of error. It appears there is no pattern in the misclassification of the landcover; thus, UW was unable to reclassify systematically the landcover classes. However, the blind point's dataset provided a method to evaluate the error and to inform methods for improvement and the will aid in generating a refined classified Landsat TM. Finally, because a majority of the polygons in the validation dataset were derived from areas of suspected misclassification, the validation polygons may be applied to the final refined Landsat TM imagery to reclassify those polygons identified as being in error.

Battelle-Pacific Northwest National Laboratory (PNNL) Field Sampling Summer 2006

Introduction

The goals for PNNL's habitat monitoring efforts in summer 2006 were to select four study sites in the focal area, Reach G, and to conduct field measurements at the selected sites in Reach G, as well as at two sites in Reach F, which were previously surveyed in summer 2005 (Figure 23).

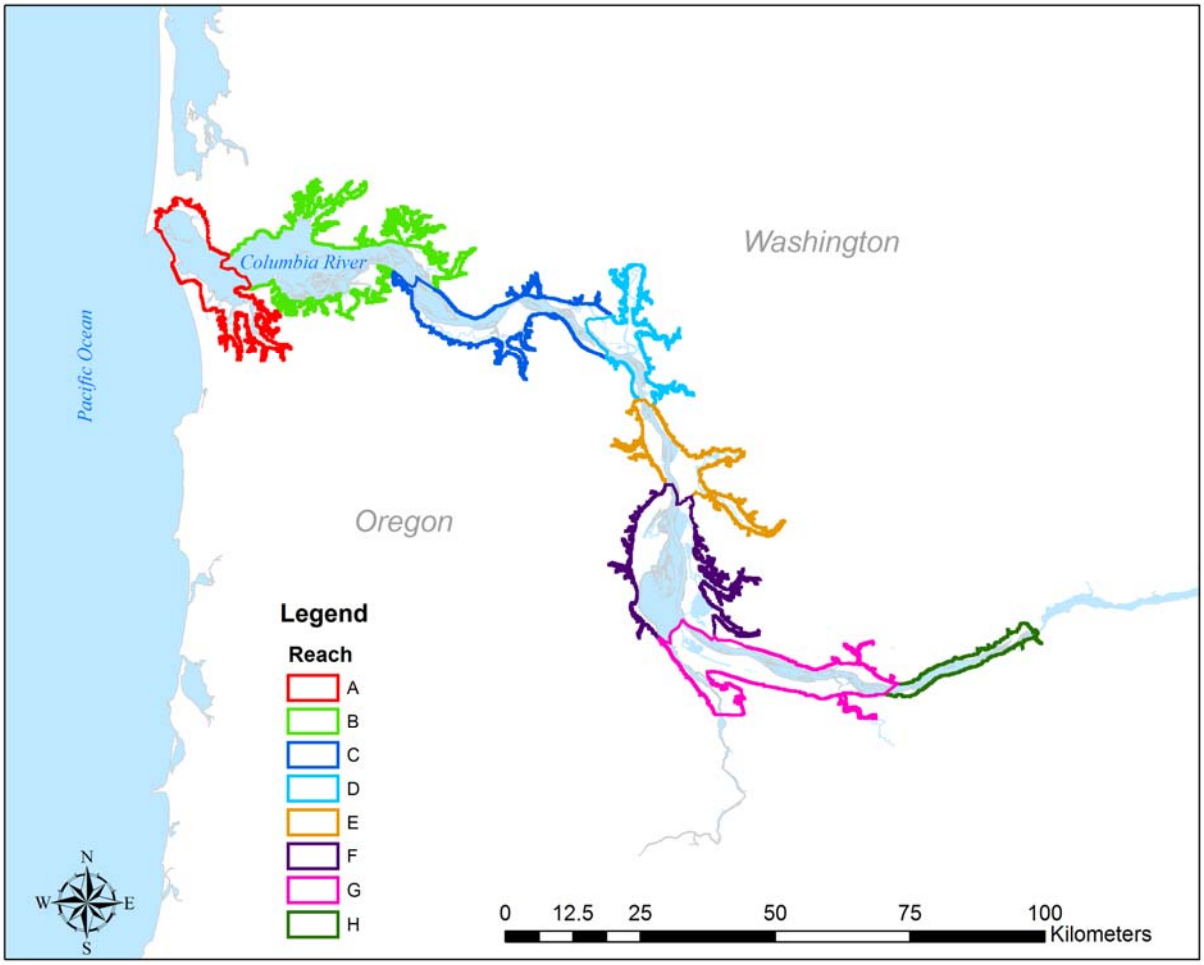

Figure 23: Columbia River Estuary with hydrogeomorphic reaches outlined. The focus reach for 2006 was Reach G (outlined in pink).

Reach G was selected as the focal reach because of its upstream, tidal freshwater character and the fact that little research has been conducted in this part of the estuary. It extends just upstream of the confluence of the Willamette and Columbia Rivers to upstream of Reed Island. There are several large islands within Reach G including Government and Hayden Islands, as well as smaller islands such as Gary, Lady, and Flag Islands. The Sandy River and the Washougal River are the major riverine inputs to the Columbia River Estuary in this reach, with the Sandy being the larger of the two. River flow in this reach is dominated by outflow from Bonneville Dam, including fluctuations caused by daily power peaking (Kukulka and Jay 2003). Tidal effect is negligible, with a mean tidal range of less than one foot during low flows.

In April 2006, a site selection field trip was made to evaluate potential work sites in Reach G. In selecting the sites, the research team sought out areas similar in type to those surveyed in Reaches D and F in 2005: shallow water wetlands, mainstem fringing or off-channel, with characteristic emergent marsh vegetation and typically fine sediments. While the team was able to arrive at a list of potential sites, high water precluded selection of study sites at that time. It is important to note that 2006 was an abnormally high water year during April-July (Figure 24), with sustained outflow over 350,000 cfs in June. Additionally, during the site selection trip it was determined that the numerous islands in Reach G would likely have candidate sites and a boat-based evaluation of those areas was necessary.

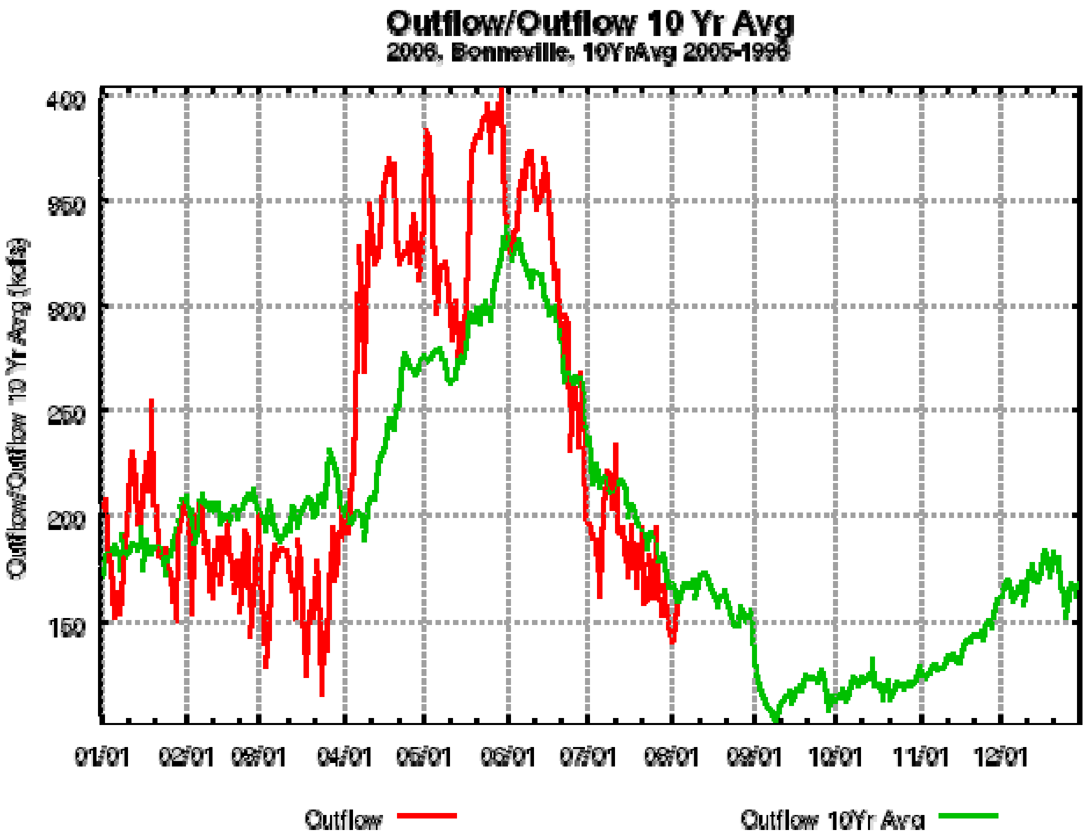

Figure 24: Outflow at Bonneville Dam, comparing outflow in 2006 (red) to 10-year average (green). Data from Columbia River DART web site: http://www.cqs.washington.edu/cgibin/dart/makegraph/dart/makegraph/html-src/river.config.

Sites

On-the-ground habitat monitoring field surveys were undertaken from July 14th-21st, 2006. A total of six sites were visited, four in Reach G and two in Reach F. The sites in Reach G were: the east end of McGuire Island, Chatham Island, the old channel of the Sandy River delta, and the Water Resources Center in Vancouver, WA (Figure 25). The Chatham and McGuire Island sites are located in inlets along the island shoreline and are areas of low energy, with direct connection to the Columbia River (Figure 26a and b). The Sandy River site is located in the old channel of the Sandy River Delta, which is still connected to the mainstem of the Columbia River, but is disconnected for the mainstem Sandy River by a dike. This habitat monitoring site is near the head of the now-blind channel (Figure 26c). The Water Resources Center site (Figure 26d) is the only site not directly connected to the river—it is separated by a sand bar at the river's edge. It is still influenced by riverine conditions, as the water in the wetland rises and falls according to the water level in the mainstem of the river.

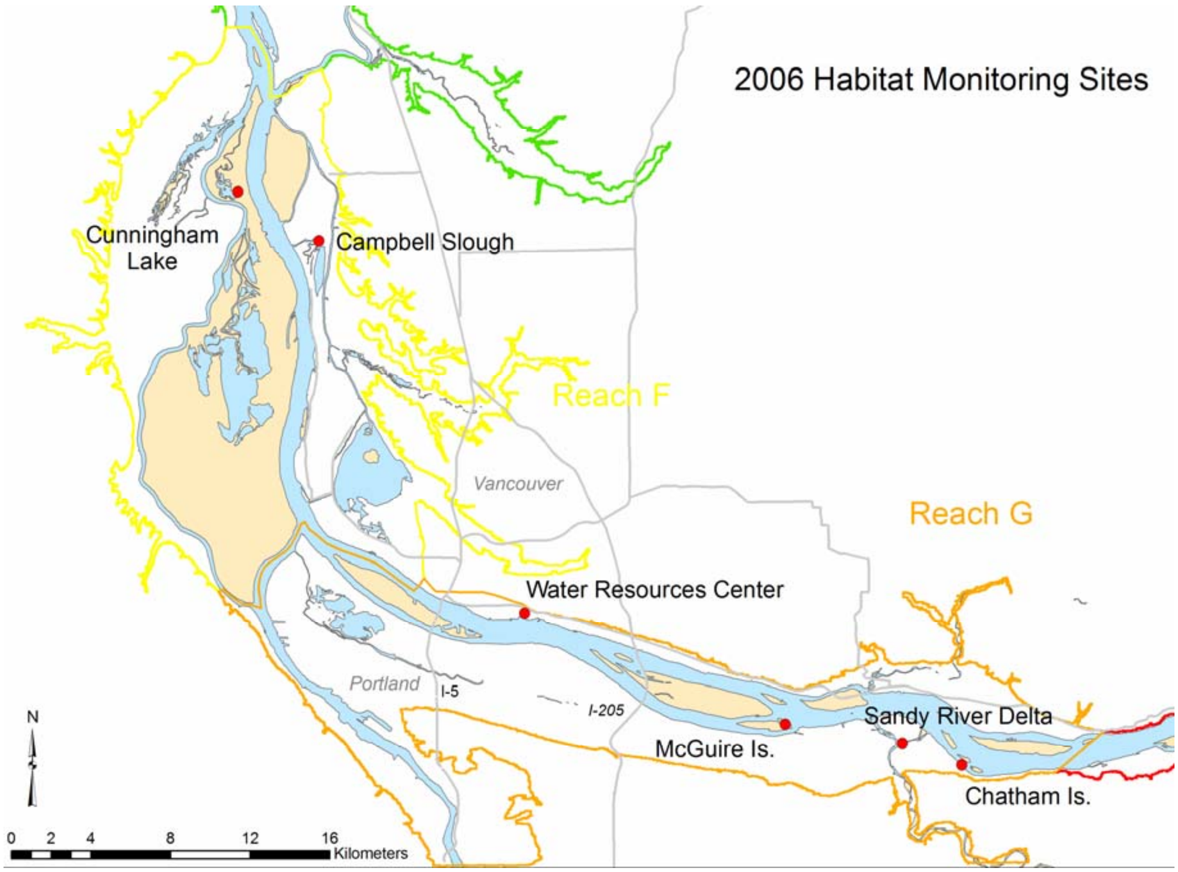

Figure 25: Map of Reaches F (outlined in yellow) and G (outlined in orange), showing 2006 habitat monitoring sites.

The sites sampled in Reach F were Campbell Slough and Cunningham Lake, both of which were originally surveyed during the summer 2005 field effort. The Campbell Slough site is located approximately 1.4 kilometers from the mainstem of the Columbia along the slough (Figure 26e).Cunningham Lake is located at the end of Cunningham slough approximately 6.4 kilometers from the mainstem of the river (Figure 26f). These sites were included in 2006 to assess inter-annual variability at these shallow water wetlands.

Figure 26: Reach G sites: a) McGuire Island, b) Chatham Island, c) Sandy River old channel, d) Water Resources Center wetland; Reach F sites: e) Campbell Slough, f) Cunningham Lake.

Methods

Transect Surveys

As in the habitat monitoring efforts during summer 2005, the sites were surveyed for elevation and percent cover of vegetation along transects, and prominent vegetation types at the sites were mapped. Upon arrival at a site, PNNL determined the optimum location of transects such that all major plant communities from the water's edge to the upland area would be included in the survey. Typically three transects were established at each site, radiating from a single hub. A station was also designated for each site from which photographs were taken to document a 360-degree view.

Above the influence of tides, PNNL installed a length of rebar as a benchmark from which all local elevation measurements were made. This benchmark was surveyed in using a Trimble real time kinematic (RTK) global positioning system (GPS), with survey-grade accuracy. All surveying was referenced to the North American Vertical Datum (NAVD-88); horizontal position was referenced to North American Datum (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.

Trimble Geomatics Office (TGO) was used to process the data. Each survey was imported and overviewed. Benchmark information was entered into TGO and rover antenna heights were corrected for disc sink (measured at each survey point to the nearest half inch) at each point. Then the survey was recomputed within TGO and exported in a GIS shapefile format. The surveys were visually checked within TGO and GIS software for validity.

Along each transect, PNNL made percent cover estimates every two meters (every five meters if the transect was over 100m long and/or the vegetation was considered relatively homogeneous). At each station on the transect tape, a 1-m^2 quadrat was placed on the substrate and percent cover was estimated by two observers. An average of the two observations was entered for each station to minimize observer bias. In addition to vegetative cover, features such as bare ground, open water, and wrack were also recorded. When plants could not be identified a sample was collected for later identification using keys or manuals; if the identification was unclear, it was considered unidentified. Where visibility through the water column was possible, cover estimates were also estimated for submerged aquatic vegetation. Sediment character was qualitatively noted (fines, mixed coarse, sand, etc.).

All data were entered directly into a Hewlett Packard Pocket PC with Microsoft Excel. Data sheets were standardized and error checked once downloaded to a desktop PC, which occurred daily. Elevations from the RTK survey were then entered into the data sheet to correspond to the appropriate transect and quadrat location. Additionally, a field notebook with written observations was also kept.

Mapping

Using a Trimble GeoXT handheld GPS unit, PNNL mapped the extent of the site (using reasonable natural boundaries) and delineated major vegetation bands and patches within the site. Additionally, features of importance to the field survey (including benchmarks, transect start/end points, and photopoints) were also identified and catalogued. All data were input to a GIS and maps of each site showing major communities and features were created.

Grids

In addition to the elevation surveys conducted along the transects, at two sites PNNL conducted an intensive elevation survey to better understand topographic changes within the field sites. These surveys, performed with a RTK GPS with base-station and rover, were comprised of a 100m by 100m grid, with survey points located at 10-meter intervals (Figure 27). Grid surveys were done at Chatham Island (Reach G) and Campbell Slough (Reach F). These surveys will eventually be used to look at the sensitivity of LiDAR imagery, which will be used to refine the Columbia River Estuary Ecosystem Classification, to the changes in topography, as measured in the field with survey-grade equipment. In developing a classification system for shallow-water areas, the ability to discern between subtle changes in elevation could prove significant. This effort was undertaken to aid in accurately assigning classes to these areas.

Figure 27: Grid survey showing RTK base station and rover (in the distance).

Water Quality and Hydrography

Due to high water in late spring, PNNL was unable to deploy the water quality sensors at the designated locations until the habitat monitoring field surveys in July. YSI autonomous water quality sensors (model 600XLM) were placed at two sites: the sensor that was previously installed at Campbell Slough (Reach F) remains in that location and the sensor previously installed at Dibblee Slough, in Reach D, has been moved to the old channel at the Sandy River delta (Reach G). These multi-probe sensors are equipped with temperature, salinity, and dissolved oxygen probes, as well as a pressure transducer for measuring water depth and take measurements every 15 minutes. They are downloaded monthly, and calibrated in the lab every other month. Additionally, HOBO temperature and pressure sensors were installed at two sites: the Water Resources Center in Vancouver, WA and McGuire Island (both in Reach G). These instruments record temperature and depth measurements at 30 minute intervals and will record for a full year at these sites before being retrieved and downloaded.

Findings

Transect Surveys and Mapping

Vegetation patterns in Reach G were similar to those in Reaches D and F despite the more upstream location of Reach G. Common spikerush (*Eleocharis palustris)* dominated at lower elevations, reed canary grass (*Phalaris arundinacea*) at mid-elevations, and the upland border was mostly comprised of willows (*Salix* spp.); however, Oregon ash (*Fraxinus latifolia*) was observed less along the upland border than at some of the sites further downstream. Additionally, some of the Reach G sites had very mixed communities dominated by young willows interspersed with a variety of other plants (sedges, herbs, and grasses). This generally occurred in sandy, depressional areas, which likely remain inundated through the spring season and do not retain moisture during the late summer and early fall. Mapping these communities presented a challenge in that the edges were not obvious and the dominant species changed within a given community.

While sediment grain size was not measured, it was noted that sites in Reach G tended to have a higher percentage of sand than similar sites downstream, which were comprised of mixed fines. This may be due to the 2006 sites' closer proximity to the mainstem of the Columbia River, where seasonally swift currents deliver larger particles to peripheral areas. Additionally, none of the sites in Reach G were off-channel wetlands connected by tidal channels, as were several sites studied in the downstream reaches (e.g. Hogan Ranch, Cunningham Lake, and Campbell Slough from 2005).

The re-survey this year of the two sites in Reach F, Campbell Slough and Cunningham Lake, allows for the comparison of data from 2005 and 2006 at the same transects. Overall, the vegetation patterns were similar between years at both sites. The variation in cover between years for the three most abundant species (reed canary grass [*P. arundinacea*], wapato [*S. latifolia*], and common spikerush [*E. palustris*]) is not great (Tables 9 and 10). It is important to note though that percent cover estimates in 2005 were done every five meters and in 2006 were done every 2 meters to gain more sample points within a transect.

Table 9: Species with greater than 15% occurrence at Campbell Slough in 2005 and 2006.

Species	*2005*	*2006*
Phalaris arundinacea	60%	48%
Sagittaria latifolia	52%	58%
Eleocharis palustris	48%	52%
Veronica americana	24%	*0%*
Lysimachia nummularia	16%	*<1%*
Callitriche heterophylla	*0%*	20%
Salix spp.	*4%*	30%*

*This value represents canopy vegetation near the upland end-points of the transects and could be disproportionately greater in 2006 due to the increased sampling frequency.

Table 10: Species with greater than 15% occurrence at Cunningham Lake in 2005 and 2006.

Species	*2005*	*2006*
Phalaris arundinacea	63%	61%
Eleocharis palustris	60%	67%
Sagittaria latifolia	50%	59%
Veronica americana	40%	19%
Eleocharis parvula	17%	*0%*
Equisetum fluviatile	17%	20%
Polygonum hydropiperoides	17%	*9%*
Sparganium emersum	*7%*	16%

Percent occurrence along a transect does not fully represent species occurrence at a site, particularly because the vegetation in these shallow-water areas tends to be banded rather than heterogeneously distributed. The following figures show a comparison of percent cover of a given species (e.g., wapato [*S. latifolia*],) between years at one permanent transect at Campbell Slough (Figure 28) and one transect at Cunningham Lake (Figure 29). While the overall trend is similar for both years (decreasing wapato with increasing elevation), at both sites wapato at lower elevations appears less abundant in 2006; this is especially noticeable at Cunningham Lake, where the change in elevation across the transect is more gradual. Additionally, wapato had higher values for percent cover at the mid-elevations at both sites in 2006. Figures 30 and 31 show the same plots with a different species, reed canary grass (*Phalaris arundinacea*). At both sites, reed canary grass at the higher elevation quadrats is less abundant in 2006 than in 2005. This is likely due to high water during 2006 (see full discussion below).

In addition to the transect comparisons, mapping from each year shows slightly different boundaries between the major vegetation types (Figure 32). Mapping was performed by the same observer in both years to minimize observer error. It is likely the difference in hydrologic variability between the years had some influence on vegetation community composition and it is expected that the boundaries between the major communities will shift annually.

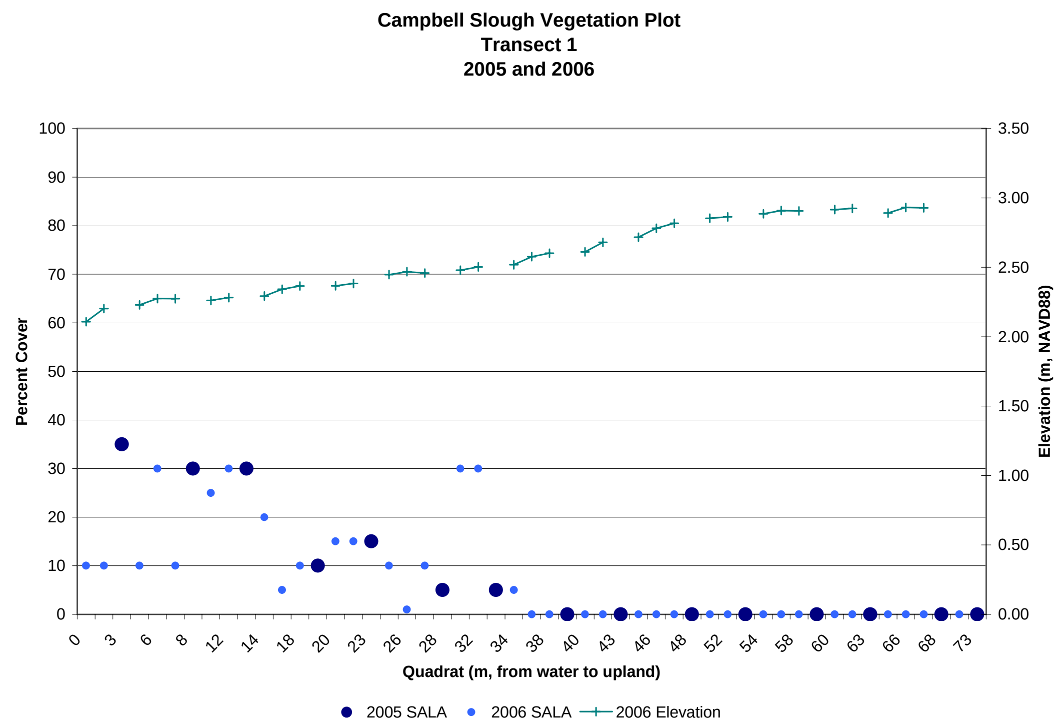

Figure 28: Comparison of percent cover of *Sagittaria latifolia* (SALA) from 2005 and 2006 at Campbell Slough, Transect 1.

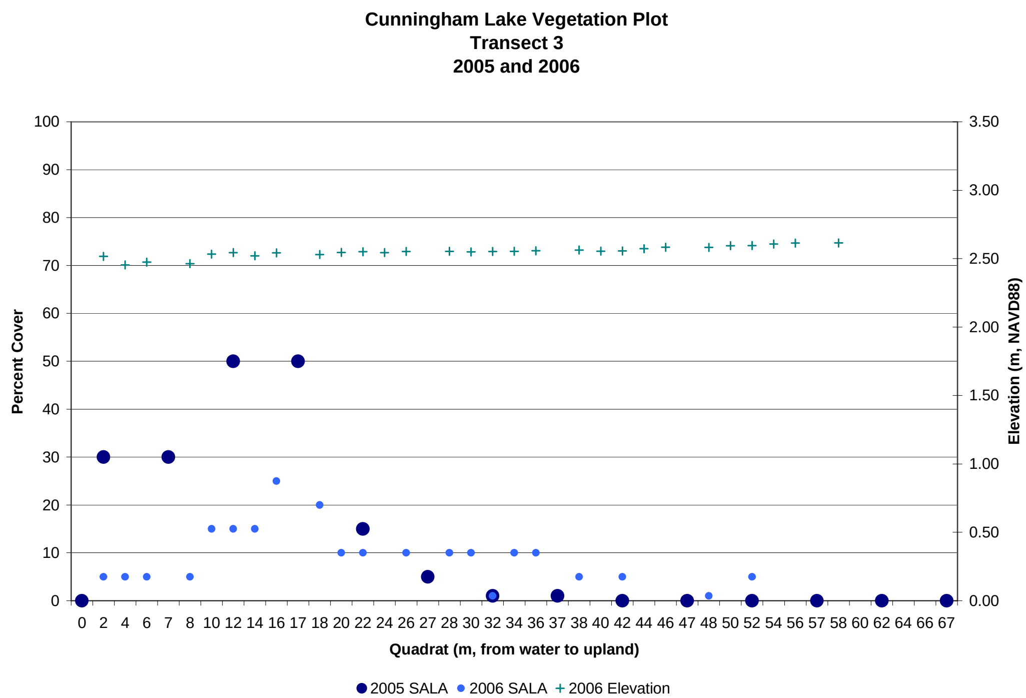

Figure 29: Comparison of percent cover of *Sagittaria latifolia* (SALA) from 2005 and 2006 at Cunningham Lake, Transect 3.

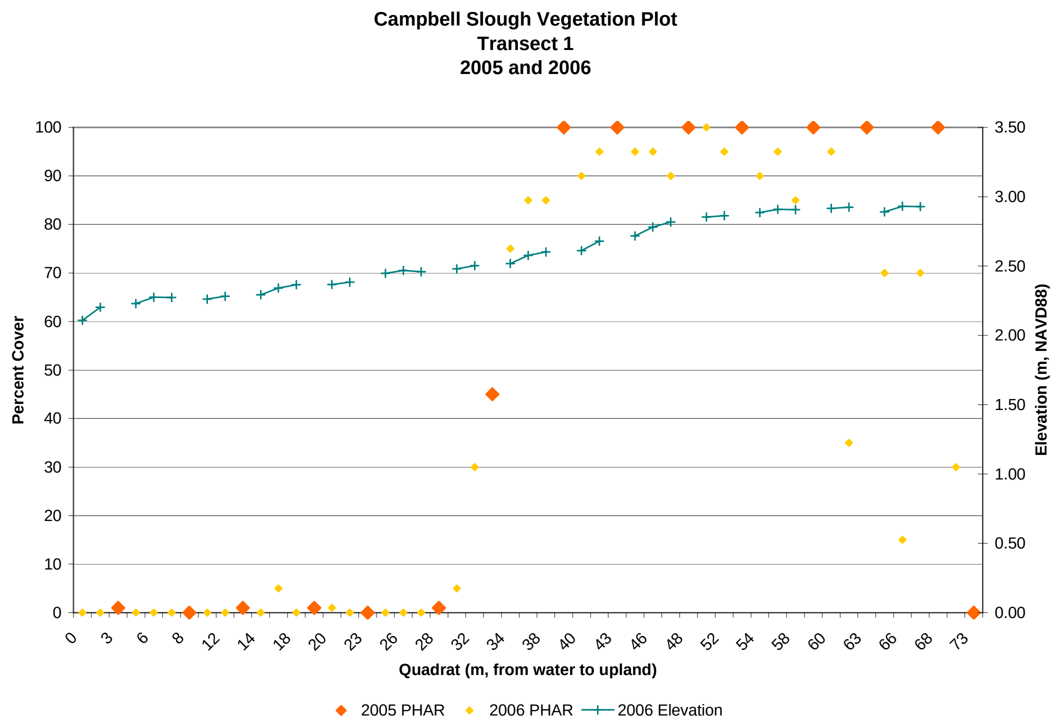

Figure 30: Comparison of percent cover of *Phalaris arundinacea* (PHAR) from 2005 and 2006 at Campbell Slough, Transect 1.

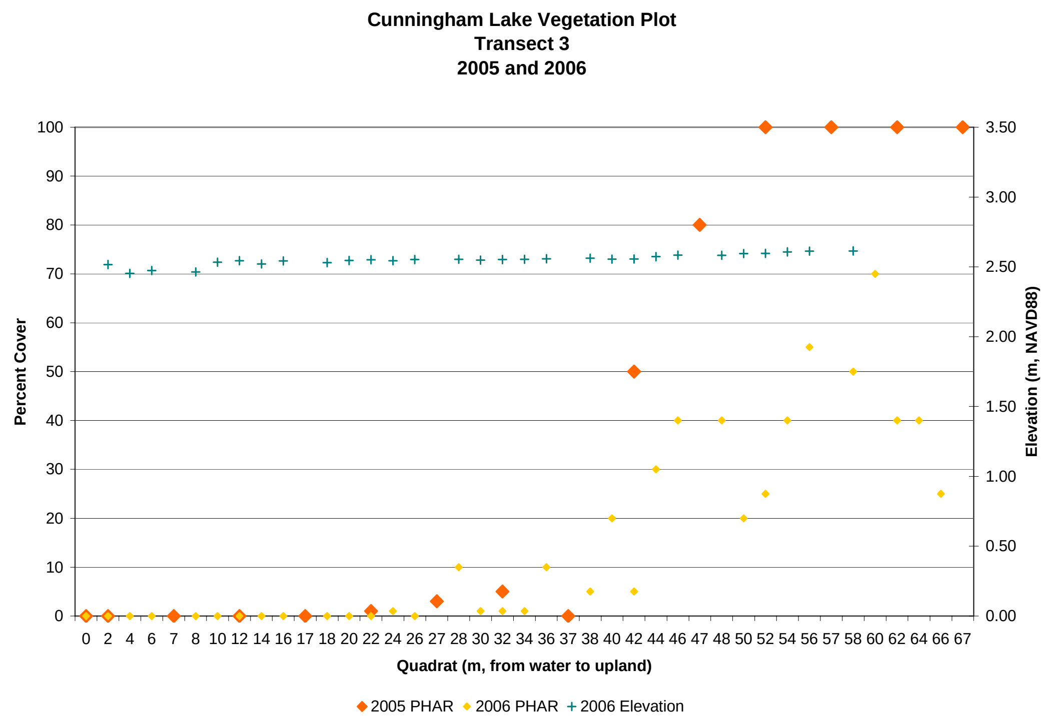

Figure 31: Comparison of percent cover of *Phalaris arundinacea* (PHAR) from 2005 and 2006 at Cunningham Lake, Transect 3.

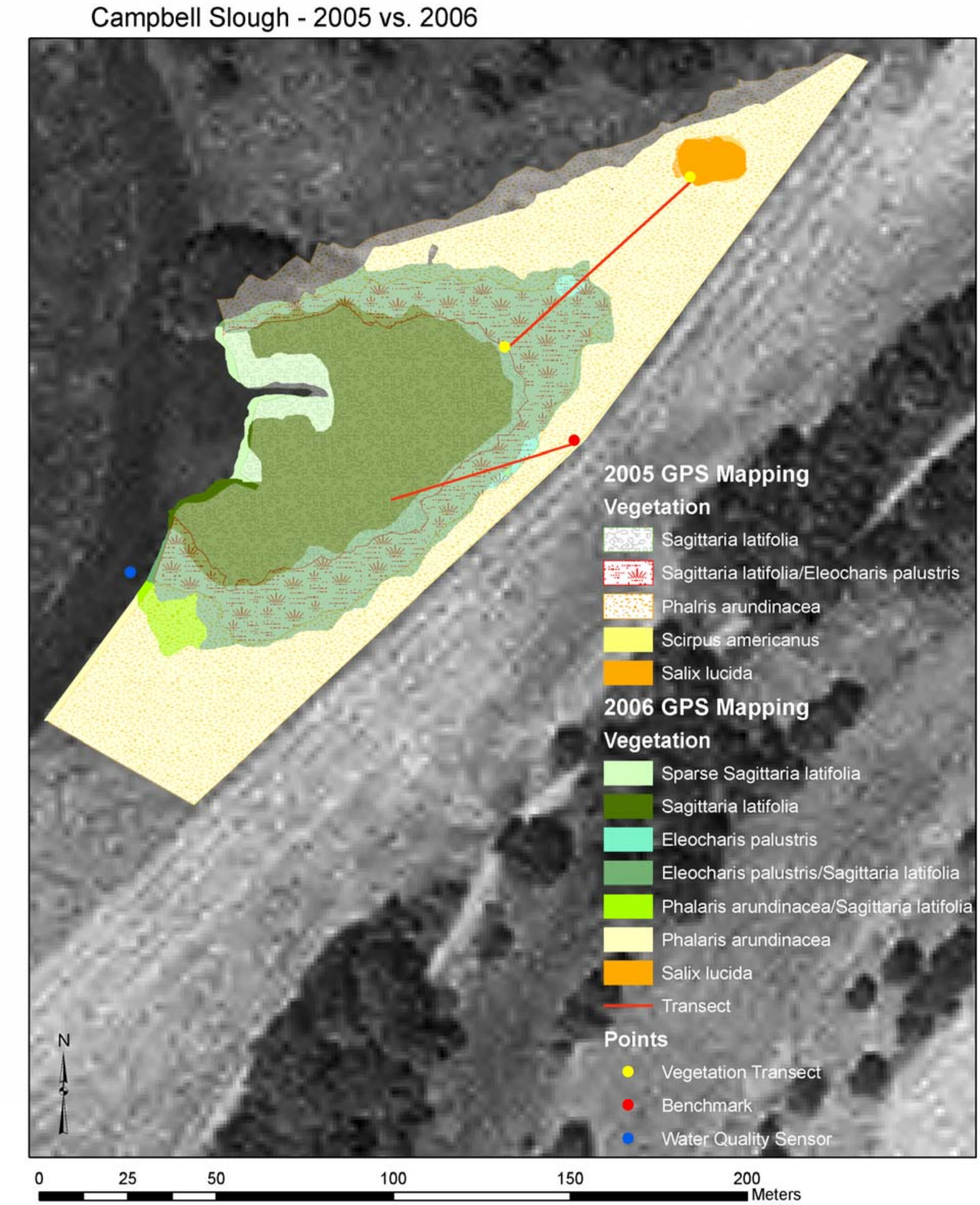

Figure 32: Comparison of vegetation mapped at Campbell Slough in 2005 and 2006.

At Campbell Slough in 2005, there were a total of 10 species found in 25 quadrats. In 2006 there were 15 species in 62 quadrats surveyed with the average number of species per quadrat being 2.7; this is in large part due to the relative predominance of a few species in the marsh. As an example, a species-area curve was developed for Campbell Slough from the 2006 survey data (Figure 33). The lack of a clear flexion point suggests that increasing the number of samples will continue to add new species. However, it is important to note that the majority of the species observed had 1-5% cover in less than 10% of the quadrats sampled. For example, water horsetail (*Equisetum fluviatile*) was commonly found at all sites, but was never dominant in percent cover or occurrence, occurring in less than 10% of the quadrats at most sites. Increasing the sampling frequency during a given sampling period will likely yield fewer new species than sampling at multiple times during the year; the latter option would be PNNL's recommendation for future years.

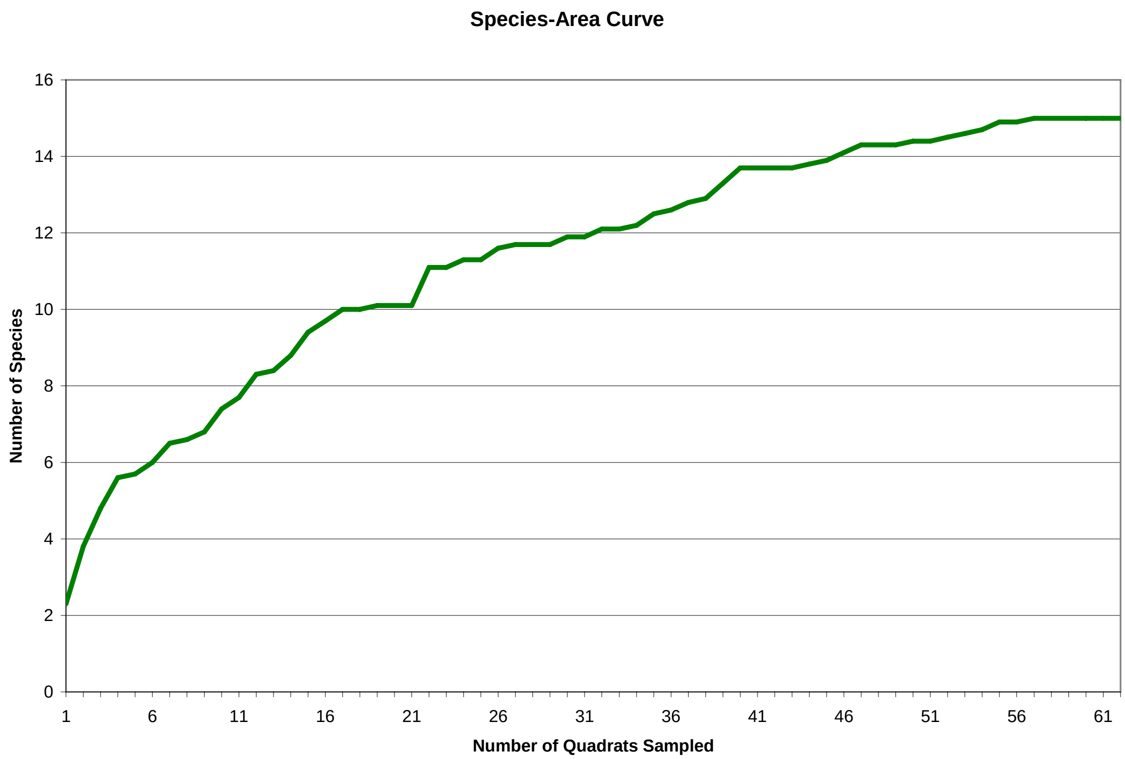

Figure 33: Species-Area Curve showing the number of species observed at Campbell Slough in 2006.

Water Quality

Since the water quality instruments were deployed in July 2006, no data are available at this time. The sensors are currently logging data and will be downloaded throughout the fall and winter months, with hopes of catching spring 2007 depth changes in association with salmonid outmigration and seasonal changes in river conditions. To account for the magnitude of flux in the river conditions, PNNL proposes adding additional infrastructure to the sites with water quality sensors; the sensors would be moved to a post at the appropriate water depth (seasonally) to prevent missed sampling opportunities in the future.

Outflow

River levels in 2006 were abnormally high through June. This meant that in addition to having difficulty choosing sites early in the season, many of the plant species which were in bloom in 2005 were not yet to that stage during the 2006 sampling period due to the high water levels. Positive identification of plant species (particularly grasses and sedges, but also some forbs) is difficult when flowers and fruits are not present. For this reason, sampling during multiple periods is preferable.

PNNL observed much of the reed-canary grass in low lying areas to be stunted and pollinating. Additionally, the plants at higher elevations (thus, inundated for less time) were more robust and had gone to seed by the July site visit. Likewise, wapato plants were observed to be less robust than in 2005, probably owing to the delay in high water recession for the summer months. When the outflow from 2005 and 2006 are compared against the 10 year average (Figure 34), it is clear that 2005 was a low water year and 2006 was a high water year; thus, we would expect some difference in plant growth and development based upon hydrologic variability.

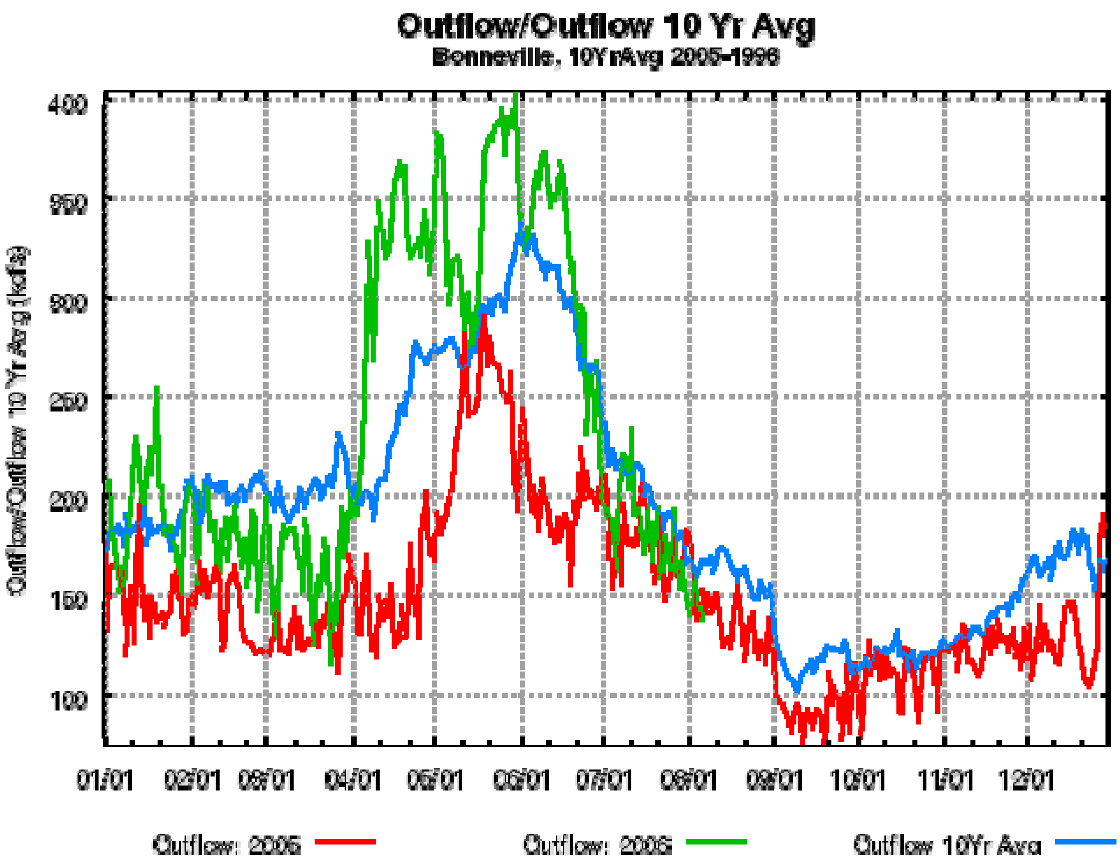

Figure 34: Outflow at Bonneville Dam, comparing outflow in 2005 (red) and 2006 (green) to 10-year average (blue). Data from Columbia River DART website: http://www.cqs.washington.edu/cgibin/dart/makegraph/dart/makegraph/html-src/river.config.

While some of the variation in plant development can be attributed to the earlier sampling dates in 2006 (July 14-21) as opposed to 2005 (July 24-August 6), it is more likely a result of delayed growth and development due to the protracted period of high water. This observation is important in determining ideal future sampling periods and in designing a long-term study that takes into account inter-seasonal and inter-annual variability.

2006 Site Maps

At each site, major vegetation bands and transition areas were mapped. Figures 35 through 40 illustrate vegetation patterns and the geographic locations of each of the major bands, especially related to tidal channels for the four habitat monitoring sites in Reach G and the two sites in Reach F. Although these maps are not intended to represent every species observed, they can be used to detect change in space during future surveys. Additionally, the positions of water-quality instruments, benchmarks, and transects were collected and mapped for ease in resurveying the sites.

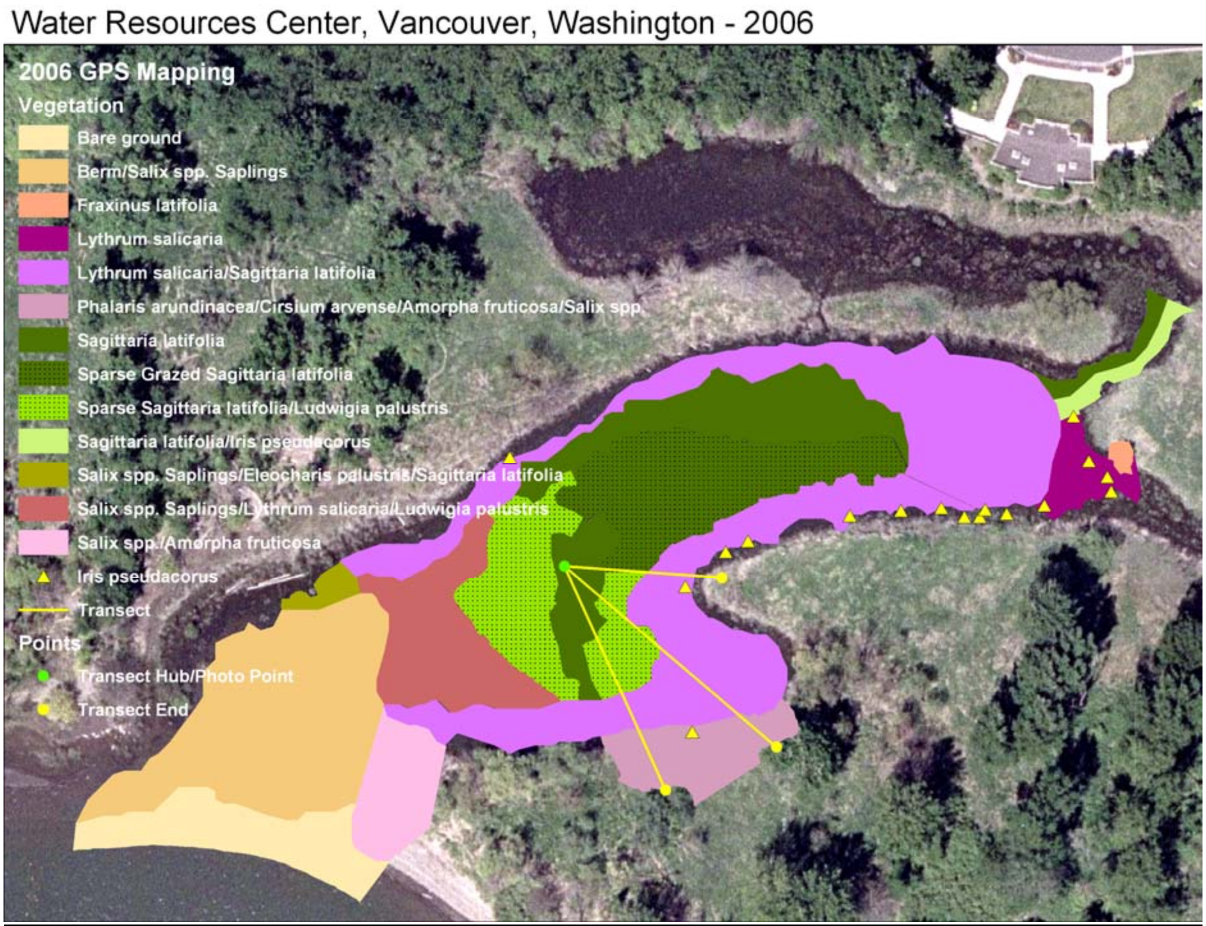

Figure 35: Site map, Water Resources Center, Vancouver, Washington in Reach G.

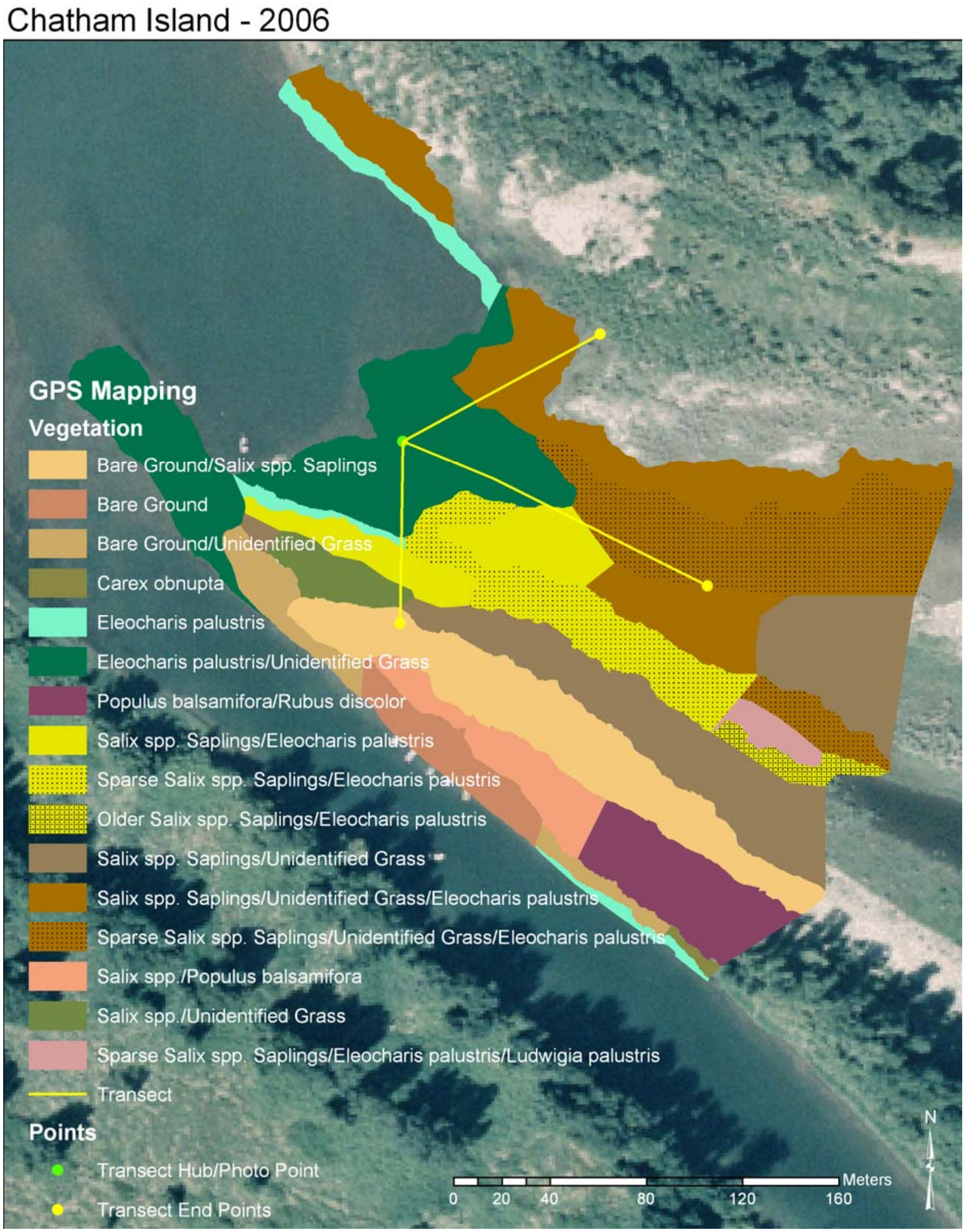

Figure 36: Site Map, Chatham Island in Reach G.

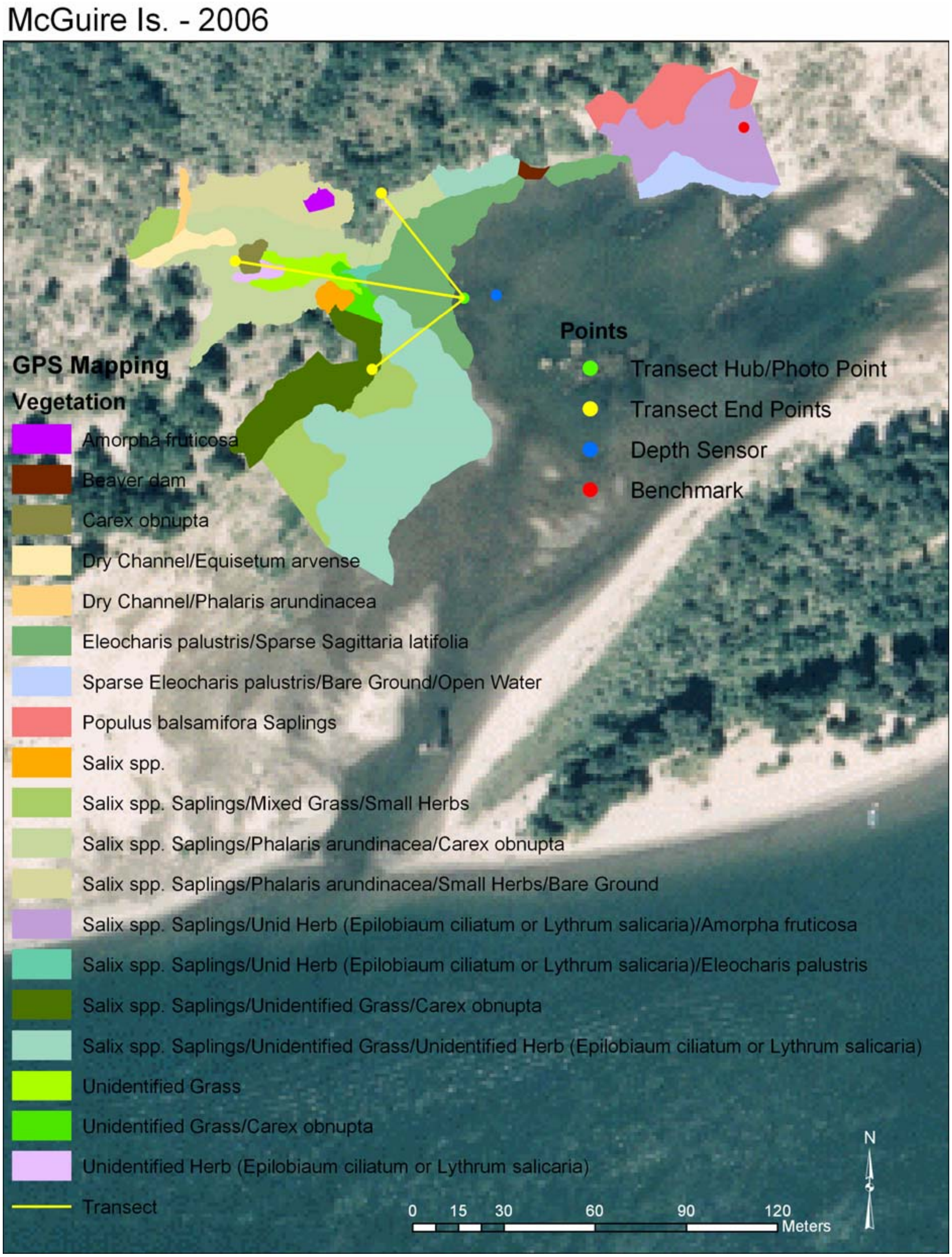

Figure 37: Site Map, McGuire Island in Reach G

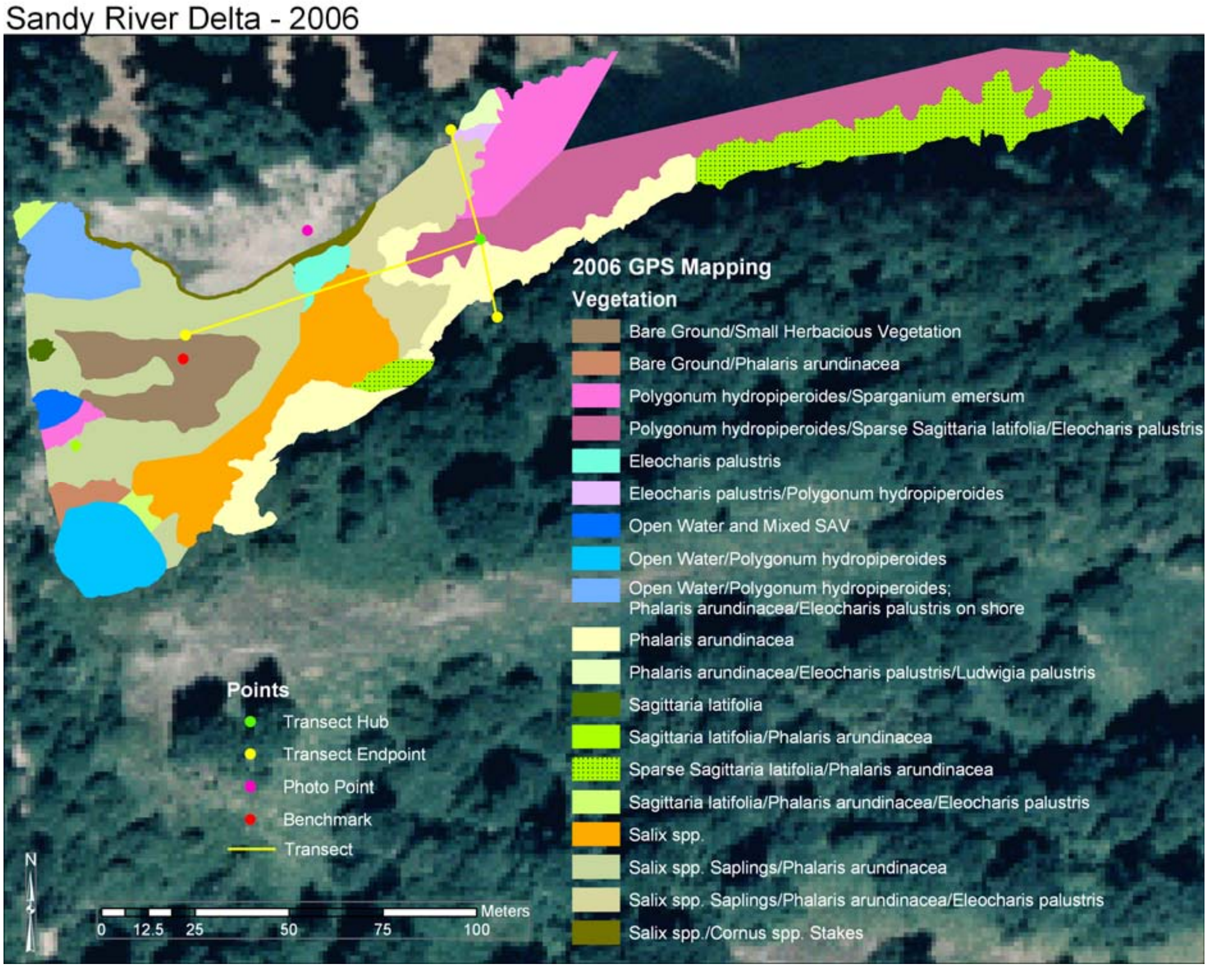

Figure 38: Site Map, Sandy River Delta in Reach G

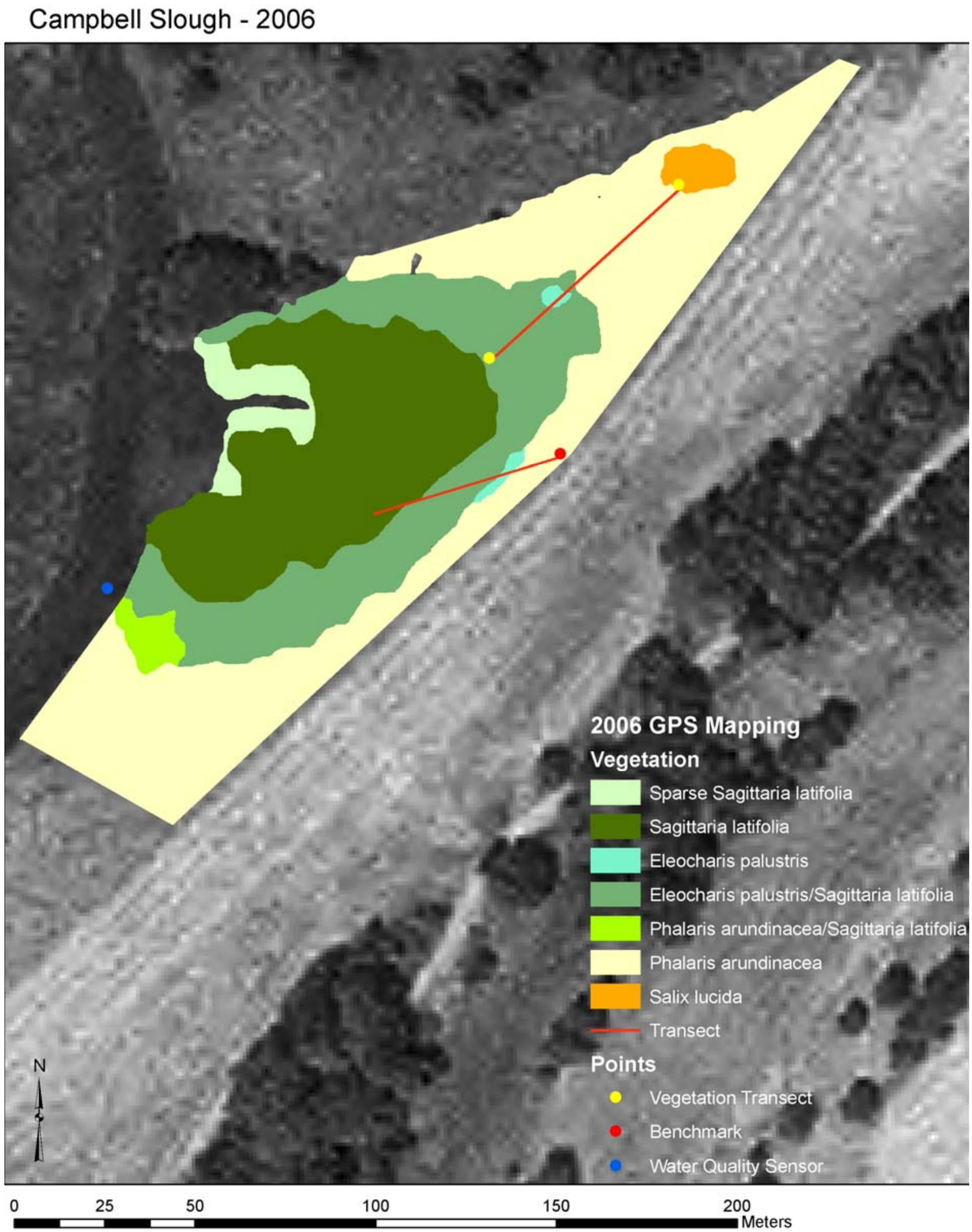

Figure 39: Site Map, Campbell Slough in Reach F.

Cunningham Lake - 2006

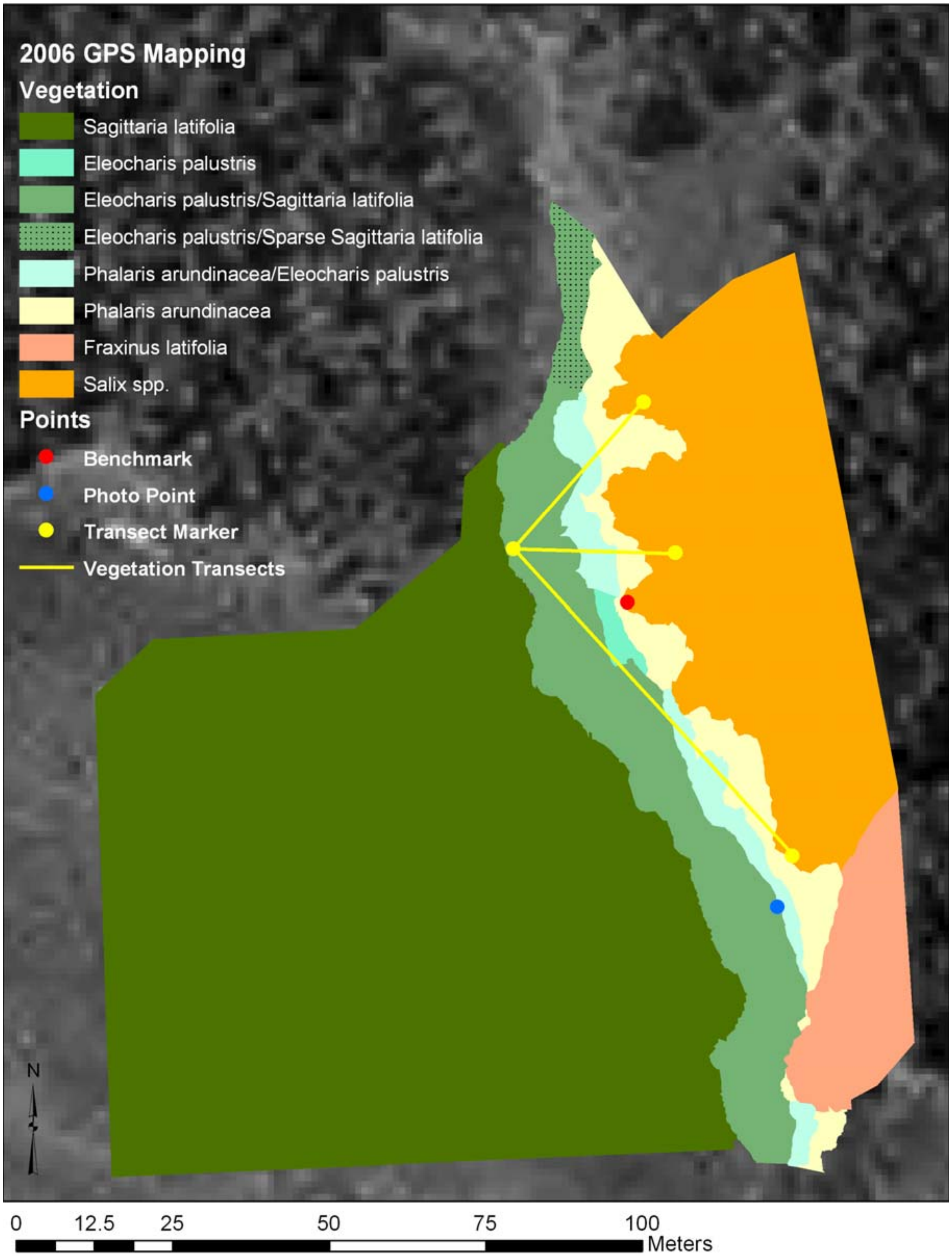

Figure 40: Site Map, Cunningham Lake in Reach F.

Habitat Monitoring Summary

While the first year of habitat monitoring sampling in 2005 established the primary sampling methods, PNNL refined both the transect sampling and mapping capabilities in 2006. In addition, PNNL relied more heavily on the use of RTK GPS and less so on traditional survey methods such as using a stadia rod and an autolevel. PNNL is still trying to gauge the error associated with each of these methods and this is an area of development not just with this project, but in the field in general. There are some challenges to surveying in these environments including overhanging vegetation, which interferes with satellite communication, and areas of soft sediment which causes the survey pole to sink. A flat aluminum disk was placed on the ground to increase surface area of the tripod, which helped reduce sinking but did not completely solve the problem. The amount of sinking, or disc sink, was recorded at each point and applied to the antenna height value during post-processing to provide a more accurate elevation measurement.

While riparian vegetation is not included in the habitat monitoring surveys (transects typically end at the edge of the emergent marsh), PNNL did make note of which trees were typically observed along the upland border. While Oregon ash (*Fraxinus latofolia*) and willow (*Salix* spp.) were the dominant species in Reaches D and F, cottonwood (*Populus balsamifera*) and willow (*Salix* spp.) were encounter4ed more often in Reach G. Additionally, Pacific dogwood (*Cornus nuttallii*) was noted at the Sandy River site. Two invasive species, indigo bush (*Amorpha fruticosa*) and Himalayan blackberry (*Rubus discolor*) were also present along the upland borders at sites in Reach G. Riparian vegetation is ecologically important (Naiman et al. 2005) and PNNL will continue to make efforts in future surveys to note the riparian vegetation communities.

Overall, the sampling efforts in Reach G were successful and showed that general patterns of wetland vegetation are consistent with downstream sites sampled previously. The most interesting findings in 2006 pertained to the re-surveys at Campbell Slough and Cunningham Lake in Reach F. By developing an understanding of inter-annual variability at each site, an effective long-term monitoring program can be established. The variability in vegetation boundaries observed from one year to the next, despite the slight difference in sampling timing between the two years, suggests that increasing the number of sampling periods may be necessary to capture fully the vegetation communities at these sites. Ephemeral plants are likely over- or under-represented, depending upon the survey season. Thus, a better understanding of seasonal differences should be a goal of future habitat monitoring efforts. This will also be critical for drawing the linkage between vegetation and habitat structure as it relates to salmonid use of these wetland habitats.

Ecosystem Monitoring Project Summary

A great deal of work has been completed in both the toxics and habitat monitoring portions of the Ecosystem Monitoring Project. Toxics information collection was completed in September 2005 and complete details of Year 2 and Year 3 salmonid sampling and refinement of the three toxics models will be available on the Estuary Partnership's web site in fall 2006. The water quality monitoring data analysis will continue through Year 4 and an integrated report with the findings of the salmonid sampling will be produced in August 2007. In terms of habitat monitoring, field work will continue in an additional Reach of the Columbia River Estuary in summer 2007 and the results will be available in August 2007. Moreover, the Columbia River Estuary Ecosystem Classification System will be completed in early 2007 so that future sampling efforts can be better informed by ecosystem processes. Both the habitat and toxics monitoring teams will continue to work closely to make sure efforts are not duplicated and resources can be shared to maximize the efficiency of the Ecosystem Monitoring Project.

Bonneville Power Administration
2003-007-00 LCREP Ecosystem Monitoring
Contract #24617 / Cost Reimbursement contract
Performance Period **(Year 3 of 3)**: Sept. 1, 2005 - August 31, 2006

BUDGET TRACKING

Budget Items	Original Contract	Amendment #1	Amendment #2	Funds Received To Date	Contract Balance
I. Direct Costs					
Personnel	$35,907.00	$35,907.00	$35,907.00	$36,929.93	-$1,022.93
Travel	$900.00	$900.00	$900.00	$580.52	$319.48
Vehicles	$2,900.00	$2,900.00	$2,900.00	$1,172.70	$1,727.30
Supplies / Equipment	$4,500.00	$4,500.00	$4,500.00	$4,898.89	-$398.89
Rent Utilities	$4,181.00	$4,181.00	$4,181.00	$4,550.64	-$369.64
Sub Total	*$48,388.00*	*$48,388.00*	*$48,388.00*	*$48,132.68*	*$255.32*
Overhead *(20% on above)*	$9,678.00	$9,678.00	$9,678.00	$9,626.53	$51.47
Capital Equipment	$4,729.00	$4,729.00	$4,729.00	$4,735.65	-$6.65
Sub Total Direct Costs	*$62,795.00*	*$62,795.00*	*$62,795.00*	*$62,494.86*	*$300.14*
II. Sub Contracts					
Pt 1: Ecosystem/Habitat Mon					
Battelle	$95,358.00	$95,358.00	$95,358.00	$95,358.00	$0.00
Univ of Washington	$44,194.00	$44,194.00	$21,840.03	$21,840.03	$0.00
Pt. 2: Water Qual/Toxics Mon.					
NOAA	$175,500.00	$224,428.00	$224,428.00	$195,368.36	$29,059.64
USGS	$58,705.00	$58,705.00	$58,705.00	$58,705.00	$0.00
Technical Consultants	$0.00	$0.00	$0.00	$0.00	$0.00
Sub Contracts Sub Total	*$373,757.00*	*$400,331.03*	*$371,271.39*	*$371,271.39*	*$29,059.64*
Project Management	$56,221.00	$65,337.00	$65,337.00	$65,337.02	-$0.02
Totals	**$492,773.00**	**$528,463.03**	**$499,403.39**	**$499,103.27**	**$29,359.76**

(1) Funds expensed include invoices submitted to BPA prior to 9/25/06 and Year 3 Subcontractor accruals to be billed to BPA after 9/25/06

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