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COMMENCEMENT BAY AQUATIC ECOSYSTEM ASSESSMENT

Ecosystem-Scale Restoration for Juvenile Salmon Recovery

C.A. SIMENSTAD
Wetland Ecosystem Team

to

CITY OF TACOMA
WASHINGTON DEPARTMENT OF NATURAL RESOURCES
U.S. ENVIRONMENTAL PROTECTION AGENCY

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KEY WORDS

chinook salmon, Commencement Bay, Endangered Species Act, juvenile salmon, Puyallup River delta, restoration, superfund sites

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INTRODUCTION

Background

The recent Endangered Species Act (ESA) listing for Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) highlights both the conflicts and the potential to restore estuarine ecosystems of juvenile salmon in Commencement Bay. In order to restore and sustain healthy wild Puyallup River chinook populations, remediation of contaminated sediments must proceed without further jeopardizing the opportunity for these salmon to respond positively to various recovery actions implemented in their natal watershed and Puget Sound. Conversely, under some scenarios remediation of contaminated sediments and associated mitigation actions have the potential to contribute significantly to salmon recovery by enhancing the health of the lower Puyallup River and Commencement Bay watershed, estuarine ecosystems and associated aquatic habitats that support Puyallup salmon production. Unlike many mitigation and restoration actions that have addressed impacts to aquatic habitats in Commencement Bay in the past, responding to the broader ESA mandate demands a more comprehensive, ecosystem-based approach to juvenile salmon requirements in a highly impacted estuarine and lower perennial riverine landscape.

To this end, the Record of Decision (ROD) for the Commencement Bay/Natural Trustees (CB/NT) site¹ documented eight problem areas in Commencement Bay that warranted source control and sediment remediation. Since the signing of that document, increasing concern has focused on how the design of these cleanup actions could further support the anticipated recovery program for salmon. Accordingly, the Principal Agencies (City of Tacoma [City], Washington Department of Natural Resources [WDNR], and U.S. Environmental Protection Agency [EPA]) are committed to make selection of future contaminant clean-up actions in

the Bay consistent with restoration efforts under the ESA, particularly with regard to salmonid habitat. The EPA has responded with a commitment to evaluate potential disposal sites in Commencement Bay to be consistent with the objectives and goals of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, commonly known as “Superfund”), the Clean Water Act (CWA), and the ESA. As stated in the ROD, the overall purpose of CERCLA actions at CB/NT sites is as follows:

To remediate contaminated Commencement Bay problem areas and, to the extent practicable, create, enhance, and/or restore the estuarine system within the lower Puyallup River/Commencement Bay watershed, with specific attention to habitats critical for salmonid species.

This report provides an ecological assessment of the potential contribution of restoration and mitigation to salmon recovery in the Commencement Bay watershed that should be considered under CERCLA clean-up and compensation for contaminated sediments in Commencement Bay. Unlike most remediation and mitigation plans based on individual Primary Responsible Party (PRP) sites and designs, this assessment is organized around broader landscape attributes and ecosystem processes (“landscape ecology”) that promote juvenile salmon utilization of existing and potential Puyallup River delta and Commencement Bay habitats. In many respects, this perspective is not entirely new but builds on the evolving views and recommendations of groups such as the Ad Hoc Duwamish Habitat Restoration Group (Weiner and Clark 1996) and Commencement Bay Natural Resource Trustees. For example, Commencement Bay Natural Resources Trustees (1997) argued in one of their four primary objectives (1.3.2 Integrate restoration strategies to increase the likelihood of success) to “Pursue a landscape ecology approach to habitat restoration projects by integrating the projects into their surrounding environment” (see also Appendix I in Weiner and Clark 1996).

This report is not designed to specify or set priorities on

¹Signed by the Regional Administrator of U.S. Environmental Protection Agency, Region 10 (EPA) on September 30, 1989.

discrete disposal or restoration sites, but is designed to identify criteria that could guide selection of both sites and actions in regions of the delta and Bay that are ecologically important to juvenile salmon. Also, this report is intended to build upon the extensive data already available on site-specific studies of mitigation and remediation sites. Even more contributory to this analysis are several emerging “visions” on broad-scale restoration of the delta/Bay (e.g., Commencement Bay Cleanup Action Committee [CBCAC] “Vision for Commencement Bay”; Puyallup Tribe, Pierce County and Pacific International Engineering “Restoration Opportunities on the Puyallup River, Restoration Site Catalogue”; WDNR “Commencement Bay—Baywide Ecological Assessment and Decision Making Framework for Long-Term Ecosystem Protection and Restoration”). My objective is to integrate the scientific basis of this diverse, expert knowledge into a more comprehensive view of requirements of juvenile salmon at the landscape scale. In the long term, I hope that the document will promote the incorporation of meaningful and effective salmon recovery goals and actions into future decisions on Commencement Bay remediation and restoration, as well as provide a template for similar urbanized estuaries in the region.

Objectives

Remediation of contaminated sediments within Commencement Bay is a desired future condition. This necessitates development and use of various disposal sites, some or all of which may be located within the delta/Bay. In light of their location in the landscape and potential to impair or improve/create aquatic habitats that contribute to salmon production, this analysis reviews and assesses the relative contribution of potential disposal sites to salmon recovery. An additional objective was to assess how compensation for unavoidable, adverse effects from specific remediation and disposal actions, as well as other development activities (i.e., permitted projects), can be incorporated into this “salmon landscape” perspective. Thus, this assessment is intended to contribute to an objective process of setting priorities and directing remediation and compensation decisions by the Principal Agencies to further restore the Bay and river ecosystem.

In order to incorporate salmon recovery into future decisions concerning activities in Commencement Bay, and particularly so that CERCLA-driven remedial actions are not delayed, the Principal Agencies have concluded that this Bay-wide habitat assessment must be completed expeditiously, and they have come together to fund this effort. This assessment relies entirely upon existing information and expertise of scientists and resource management stakeholders to provide an objective, scientifically based identification and evaluation of the following:

- current aquatic habitats types and their location in

the landscape of Commencement Bay and the lower Puyallup River,

- the ability of these existing aquatic habitats to function as an estuarine ecosystem contributing particularly to salmon productivity in the Commencement Bay/Puyallup River watershed,
- opportunities to create or enhance the functions of aquatic habitats (by habitat types and location in the landscape) that would contribute to recovery of sustainable salmon resources in the watershed, and
- priorities of those opportunities in terms of (a) contribution to recovery of salmon numbers and (b) sequence of implementation.

These evaluations should culminate in identifying critical regions of the landscape (by type, location, and priority) within the Commencement Bay and lower Puyallup River for proper ecosystem function to recover listed chinook stocks and enhance or sustain other salmon species. Also, non-salmonids will benefit from a more fully functional estuary. In addition, as a subcomponent of the evaluation described above, this document assesses the scientific soundness of the “Puyallup River Estuary and Delta Reserve” (Delta Reserve) concept—proposed by WDNR—and its role and significance in achieving proper ecosystem function to recover listed chinook stocks and enhance or sustain other salmon species. Furthermore, this assessment evaluates the scientific merits of the evolving mitigation plan for the proposed disposal site in St. Paul Waterway since it heavily relies on implementation of some key components of the Delta Reserve concept. The (reconnection) channel component of the mitigation plan is assessed from an ecosystem perspective, its value for fish passage, and as a source of freshwater.

Scope of Study

The study area includes all of Commencement Bay (east of a line connecting Brown’s Point and Point Defiance) and the lower Puyallup River valley eastward to State Highway 161, including Wapato and Hylebos creeks to their extent under tidal influence. While the focus of this study is the shorelines, wetlands, and other aquatic habitats of the delta and nearshore Commencement Bay, linkages in the form of drainages and streams to adjacent upland habitats are also considered.

Because of ESA (threatened) listing of the Puget Sound chinook Evolutionarily Significant Unit (ESU), this analysis is focused on the applicability of estuarine landscape restoration and remediation for that chinook salmon, and in particular “ocean type” chinook that tend to use estuaries and nearshore coastal areas more extensively than freshwater habitats for rearing early in their life history (Healey 1991). However, many of the principles and recommendations developed in this analysis equally apply to other

ocean-type salmon (e.g., chum [*O. keta*] salmon, some coho [*O. kisutch*] salmon) and will also indirectly benefit stream-type salmon and anadromous trout (*O. mykiss*)—for example, through water quality improvement, as well as enhancement of broader ecosystem processes (see below). While also potentially beneficial to other anadromous salmonids (e.g., coastal–Puget Sound bull trout, *Salvelinus confluentus*), the author’s area of expertise precludes extrapolating to these species.

Sources of Information

Primary sources of information contributing to this assessment are (1) published peer-reviewed scientific literature and technical reports, (2) the author’s personal experience and research results from studies of the estuarine ecology of juvenile salmon, and (3) current documents describing or prescribing the status and proposed management actions for contaminated sediment remediation and mitigation in Commencement Bay. In the latter category, the following were specific documents reviewed during the assessment:

- a. NOAA/Trustee Restoration Plan and Programmatic EIS and ROD (U.S. Fish and Wildlife Service and U.S. National Oceanographic and Atmospheric Administration 1996, Commencement Bay Natural Resource Trustees 1997);
- b. Legal documents describing City of Tacoma and WDNr Consent Decrees (U.S. National Oceanic and Atmospheric Administration, unpubl.²);
- c. Commencement Bay Cumulative Impacts Study (U.S. Army Corps of Engineers 1993);
- d. CBCAC “Vision for Commencement Bay” (Commencement Bay Cleanup Action Committee 1993);
- e. Commencement Bay—Baywide Ecological Assessment and Decision Making Framework for Long-Term Ecosystem Protection and Restoration (Graeber, in prep.);
- f. EPA Thea Foss/St. Paul Remediation and Mitigation Plans (including draft Biological Assessment) (City of Tacoma 1998);
- g. EPA Hylebos Disposal Site Mitigation Plan (Hartman Consulting Corp. et al. 1998);
- h. City NRDA Restoration Plan (e.g., City of Tacoma 1997);
- i. Middle Waterway shore restoration project analysis (McEntee et al. 1993);
- j. Port NRDA Restoration Plan;
- k. EPA Disposal Sites Forum (Sediment Disposal Site Forum 1996);
- l. DNR White Paper: Development of Habitat Man-

agement Plans for Urban Estuaries and Other Locations (Jamison 1998);

- m. Skagit River Restoration Document (Hayman et al. 1996);
- n. Tri-county Salmon Recovery Plan (Tri-County Executive Committee 1999);
- o. Executive Proposed Hylebos Creek and Lower Puget Sound Basin Plan: Plan At-A-Glance (King County 1991);
- p. Hylebos and Middle Waterway remediation areas and designs (Anchor Environmental, unpubl. data)
- q. Proposed Guidance for Focus Areas to Help Achieve the Commencement Bay Community Vision (Washington Department of Natural Resources, in prep.);
- r. Restoration Opportunities on the Puyallup River: Restoration Site Catalog (Puyallup Tribe et al. 1999);
- s. Washington Department of Fish and Wildlife (WDFW) “Salmon 2000” report (WDFW 1992);
- t. State of Washington, Governor’s Salmon Recovery Office draft Statewide Strategy to Recover Salmon (State of Washington 1999);
- u. Draft U.S. Army Corps of Engineers–Seattle District reconnaissance design report on feasibility of Puyallup River–Middle Waterway connection (HDR Engineering, Inc. 1999);
- v. monitoring or adaptive management reports for existing mitigation and restoration sites, including but not limited to Gog-Le-Hi-Te, Clear Creek, and St. Paul and Middle waterways, and compilations of research results on salmon distribution, abundance, and ecology (e.g., Ratté 1985, Duker et al. 1989, Pacific Environmental Engineering 1999)
- w. discussions with researchers and consultants who have recently conducted, or are presently conducting, studies on juvenile salmon and estuarine habitat in the delta/Bay.

JUVENILE SALMONID INTERACTIONS WITH THE PUYALLUP RIVER DELTA/ COMMENCEMENT BAY LANDSCAPE

Juvenile salmonids migrating through the Puyallup River Delta and Commencement Bay originate from 12 basic stocks that have somewhat different run and spawning timing, distribution, and genetic composition (SASSI; WDFW and Western Washington Treaty Indian Tribes 1994), including the following:

- Chinook
 - ⇒ White (Puyallup) spring
 - ⇒ White (Puyallup) summer/fall
 - ⇒ Puyallup fall
- Chum
 - ⇒ Puyallup/Carbon fall

²Conformed copies of the City of Tacoma and Washington Department of Natural Resources consent decrees file with U.S. District Court on May 28, 1997.

- ⇒ Fennel Creek fall
- ⇒ Hylebos Creek fall
- Coho
 - ⇒ White (Puyallup) coho
 - ⇒ Puyallup
- Pink (*O. gorbuscha*)
 - ⇒ Puyallup
- Steelhead
 - ⇒ Mainstem Puyallup winter
 - ⇒ White (Puyallup) winter
 - ⇒ Carbon winter

Of these diverse stocks, those of chinook are of most concern to this analysis because of their endangered status (particularly the White River spring chinook), genetic dilution with hatchery stocks, and relative dependence on estuarine rearing habitat as migrating juveniles. In particular, the ocean-type chinook stocks will benefit the most from estuarine habitat restoration due to their extensive use of estuarine habitats (Congleton et al. 1981; Healey 1980, 1982, 1991; Levy and Northcote 1982; Simenstad et al. 1982; Shreffler et al. 1990, 1992). Although not necessarily as critical as some chinook stocks, the status of fall chum stocks should also be of concern because of this stocks' relative estuarine dependence (ibid.); however, the Hylebos Creek fall chum stock remains healthy. While juvenile coho were not originally considered as reliant on estuarine habitat as chinook and chum, the use of freshwater tidal areas of deltas by these fish also suggests that the habitat requirements of their fry should also be taken into account; in this case, the depressed Puyallup coho stocks should be of concern. Whether the healthy status of some stocks (e.g., Hylebos Creek fall chum) is related to existing estuarine habitat opportunities is unknown but should be considered.

APPROACH

Juvenile Salmon Use of Estuarine Ecosystems

As described in a number of scientific review papers about juvenile salmon in tidal floodplains and estuaries (e.g., Healey 1982, 1991; Simenstad et al. 1982; Tschaplinski 1982, 1987), the early life-history phase between freshwater and the ocean can often be very important in determining adult returns. Juvenile salmon use estuaries for physiological adaptation, foraging, and refuge. Some aspects are opportunistic, such as the physiological requirement to adapt from freshwater to saltwater. Other attributes of estuaries promote behaviors that enhance survival, such as minimizing mortality due to predation by seeking estuarine shallow-water, turbid habitats, as well as foraging on the typically high and concentrated densi-

ties of potential food organisms available in estuaries. Although we generally lack information on specific attributes of estuarine habitats important to juvenile salmon (Simenstad et al. 1991, Simenstad and Cordell in press), generalized habitat requirements include the following:

- shallow-water, typically low-gradient habitats with fine, unconsolidated substrates and aquatic, emergent, shrub/scrub or forested vegetation;
- areas of low current and wave energy; and
- concentrations of small, non-evasive invertebrates.

For assessment purposes, these ecological and structural characteristics of estuarine habitats may be grouped into three categories of attributes that promote salmon survival—*capacity*, *opportunity*, and *realized function* (Simenstad and Cordell in press). *Capacity* addresses habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality. Examples of capacity attributes include productivity and availability of selected invertebrate prey, physicochemical conditions that maintain these prey communities, salinities and temperatures that promote high assimilation efficiencies, and structural characteristics that provide protection from predators. *Opportunity* addresses the capability of juvenile salmon to access and benefit from the habitat's capacity. We distinguish capability from probability by assuming that probability includes many other aspects associated with the chance of juvenile salmon accessing the habitat (e.g., variability in salmon populations and life histories, the presence and practices of salmon hatcheries). Examples of *opportunity* attributes of habitats include tidal elevation, which directly influences the frequency and duration of tidal flooding; extent of important geomorphic features, such as total edge and penetration of tidal channels, that often dictate both the extent of fish access into habitats and the interface along which they feed; proximity to disturbance (e.g., noise, movement); actual or perceived (by the fish) refugia from predation, such as extent of overhanging vegetation, marsh vegetation height, and proximity to deepwater habitats; and the strength of cues that might attract juvenile salmon. *Realized function* is the net cumulative effect of the physiological or behavioral responses that can be attributable to fish occupation of the habitat and which promotes fitness and survival—essentially the consequence of the particular combinations of *capacity* and *opportunity*. The ultimate measure of *realized function* is survival, but related metrics include habitat-specific residence time, foraging success, and growth.

Guiding Concepts

The following analysis was predicated on some fundamental concepts about the way juvenile salmon interact with estuarine and nearshore landscapes. Aquatic fish and

wildlife species such as juvenile salmon often have identifiable habitat requirements that can be utilized to assess relative habitat “quality.” While many habitat attributes have been developed for juvenile salmon in freshwater systems, particularly for use in Habitat Evaluation Procedures (HEP) models, this information is not well developed for estuarine systems. Simenstad et al. (1991) compiled existing data to identify important attributes, principally prey resources, of fish and wildlife in discrete habitats of Pacific Northwest estuaries. But these “Protocols” are somewhat limited in that they could not identify physicochemical attributes important to juvenile salmon and are based entirely on small-scale habitat or community attributes. In the case of anadromous fishes such as salmon, *there is an overlying scale of dependence on the landscape structure of the land margin* that they must transcend between freshwater and open-ocean rearing ecosystems. This landscape perspective should be considered at least as equally important as the quantity and status of individual sites and habitats, but is perhaps more consequential to the early life history of salmon because landscape structure may dictate how effectively juvenile salmon can bridge these “habitat patches” during their migration (Simenstad and Cordell in press; Simenstad et al. in press, a). Salmon interactions with landscape structure and processes should provide direction and guidelines to identify restoration strategies as well as simple ranking of individual restoration opportunities. Adopting such a landscape perspective requires its incorporation into a large-scale and long-term planning process; simple incorporation into a modified regulatory permitting process will not address these salmon recovery needs. Furthermore, this approach implies that basing salmon recovery on simple estimation of restored or enhanced estuarine productivity, in the absence of landscape composition and arrangement, will not alone provide sufficient guidance to recovery actions.

This analysis is extensively based on the concepts of landscape ecology as applied to restoration in estuarine ecosystems (Simenstad and Thom 1992, Shreffler and Thom 1993) and of salmonid ecosystems in particular (Simenstad et al. in press (a)). Application of landscape ecology to salmon recovery, and the characterization of tidal floodplain and estuarine landscapes particularly important to salmon, often employs unfamiliar and complex terms and concepts that have been relatively uncommon in past discussions of salmon estuarine life history. These principles and definitions can be found in Forman and Godron (1986), Turner (1989) and other basic texts or journal articles. There are three fundamental definitions of landscape elements:

- *Patches*—non-linear surface areas, relatively homogeneous internally (with respect to structure, composition, successional stage, etc.), that differ in appearance from surrounding matrix (see following) in which they are imbedded; characterized by size,

shape, type, heterogeneity, and boundary characteristics (edges). Patches are determined by a combination of physicochemical/geomorphic/biological processes and disturbance; there are five types: (1) disturbance, (2) remnant, (3) regenerated, (4) environmental resource, and (5) introduced and ephemeral. For the sake of this analysis, habitats are usually patches.

- *Matrix*—surrounding area with different composition or structure from embedded patches; the most extensive, connected element in the landscape, typically controlling landscape dynamics and function; the dominant patch type. In the case of the modern delta/Bay, developed, and typically industrial, land forms the landscape matrix.
- *Corridors*—narrow strip of land (or water) that differs from the matrix on either side; usually isolated by a patch of somewhat similar composition; can also be considered a narrow and often long patch that provides a connection between two or more similar patches.

There are three fundamental reasons that landscape structure is of paramount importance:

1. Ecological functions in estuaries are determined primarily by interaction among physicochemical processes and landscape elements such as habitat patches, or among patches, but considerably less within patches;
2. while habitat patch area and other attributes (internal structure) can promote certain biological processes (e.g., primary macrophytic productivity, lower-level secondary productivity), it is the composition, distribution, and organization (arrangement) of landscape elements that regulate many ecological functions; and
3. juvenile salmon integrate the landscape over various scales of space and time that require high connectivity of landscape elements.

INTERACTION AMONG PHYSICOCHEMICAL PROCESSES AND SALMON HABITATS

Ultimately, estuarine habitats and the landscape within which they are imbedded are dependent upon physicochemical processes unique to land-margin ecosystems. One reason that estuarine habitat creation projects ultimately can be abysmal failures is that they do not account for the importance of physicochemical processes required to sustain them. Some of the more important processes include the following:

- Hydrology and geomorphology
 - ⇒ Frequency and duration of tidal flooding is one critical determinant of emergent vegetation composition; salinity (degree of mixing of freshwater with salt water) is another important factor.

- ⇒ Exposure to wave and current energy directly influences whether an environment will be accretionary or erosive, which are important determinants of marsh progradation, for instance.
- ⇒ The drainage area and tidal prism of tidal marshes are the primary controls on the complexity of a dendritic tidal channel system.
- ⇒ Hydrologic connections affect the input of plant and animal recruits, and the accumulation and residence time of detritus.
- Sedimentation
 - ⇒ Sediment accretion and erosion often involves distant sediment sources, mechanisms of sediment transport and delivery, and the processes of deposition and resuspension/erosion.
 - ⇒ Sediment accretion can be critical to the natural maintenance and “health” of a marsh, both from the standpoint of maintaining the marsh surface relative to sediment compaction and sea level rise as well as the supply of nutrients for marsh plant production.
- Nutrient cycling
 - ⇒ Nutrient delivery by river and tidal hydrology mediates nutrient-limited plant growth.
 - ⇒ Nutrients are transformed and regenerated by below-ground soil processes regulated in part by the extent of anaerobic microbiota and pore-water exchange, thus varying extensively between vegetated and unvegetated (e.g., mudflat) habitats at different tidal elevations.
 - ⇒ Trapping of detrital organic matter and incorporation into nutrient cycling pathways is directly linked to autochthonous and allochthonous sources and rates of supply, as well as features such as low energy side-channels and sloughs, which promote trapping.
- Disturbance
 - ⇒ Disturbance of estuarine habitats by hydrological (strong tides and freshwater flow) and physical (e.g., large woody debris scouring) forces maintains a diverse matrix of habitats at different successional stages and topography.
 - ⇒ Deposition of large woody debris is also presumed to enhance cover and refuge for juvenile salmon, but this remains to be validated.
- Primary Production
 - ⇒ The spatial distribution of primary production across the landscape affects not only the rates, sources, and pathways of organic matter (detritus) but also physical refuge for juvenile salmon in the case of emergent and other macrophytic vegetation.
 - ⇒ Temporal diversification provides diverse sources of organic matter to the detritus pool that sustain secondary production over time (Thom 1987).
 - ⇒ Nutrient cycling is tied to primary production not only as a source of nutrients but also it regulates nutrient cycling to some degree by affecting (through the extent of plant–root processes) anaerobic–aerobic geochemistry in soils.
- Retention and Decomposition of Organic Matter
 - ⇒ Detritus is trapped and retained differentially by different plant communities.
 - ⇒ The residence time of detritus, and thus the rate and opportunity for decomposition, is to some degree determined by geomorphic features such as dendritic tidal channels and other geomorphic/topographic features.
- Juvenile Salmon Growth and Survival
 - ⇒ Physiological adaptation zones at the transition between areas of no salinity and increasing levels of salinity are critical for juvenile salmon; this is especially the case for juvenile chinook that appear to require extended periods (e.g., often weeks).
 - ⇒ Low energy habitats are important for relatively weakly swimming fry and fingerling salmon to maintain a desirable position within or adjacent to a habitat.
 - ⇒ Refugia from predation requires structure and turbidity that minimizes exposure to piscivorous fish and birds.
 - ⇒ Sites of concentrated production of preferred prey appear in specific habitats, substrates, vegetation, and tidal elevations and vary over space and time, driven in part by the same processes that affect salmon distribution (e.g., juvenile salmon).
 - ⇒ Prey trapping can occur by hydrodynamic action and is a prominent feature of the tidal–freshwater and brackish regions of estuaries where current reversals occur (e.g., Tschapinski 1982, 1987)
- “Trophic Relay” Linkages (Prey Export)
 - ⇒ Prey organisms are exported from some habitats and supply food resources to larger invertebrates and small fishes, which are in turn preyed upon by larger nektonic organisms foraging in adjacent habitats and other regions of the estu-

LANDSCAPE ENHANCEMENT OF SECONDARY PRODUCTION PROCESSES SUPPORTING JUVENILE SALMON

In conjunction with factors that influence predation, secondary production processes that sustain rapid growth of juvenile salmon are critical to salmon survival because achieving maximal size before ocean entry can strongly determine successful return to spawning.

ary (Kneib 1997); salmon can fill several roles in this relay.

SCALES OF JUVENILE SALMON INTERACTIONS ACROSS ESTUARINE LANDSCAPES

The scales over which juvenile salmon interact with landscapes such as the Puyallup River estuary and Commencement Bay vary hierarchically through their punctuated migration from freshwater to oceanic ecosystems (Fig. 1). There are at least five spatial scales:

- *Intra-habitat*
⇒ within habitat interactions, such as between the edge and interior of a marsh or mudflat, that occur over meters to 10s of meters
- *Inter-habitat*
⇒ among habitat interactions, such as from tidal channels to marsh surfaces, that occur over 10s to 100s of meters
- *estuarine gradient*
⇒ transitions among estuarine zones, or within zones during zone shifts, on the scale of kilometers
- *estuarine*
⇒ estuarine migration, from entry to estuary (tidal freshwater) to ocean entry, over 10s of km
- *land-margin*
⇒ freshwater–estuary and estuary–ocean transitions, including coastal ocean; often 100s of km

For the purpose of this analysis, the first four scales would be defined as encompassing the “juvenile salmonid estuarine landscape.” Similarly, juvenile salmon also interact with the estuarine landscape over at least six temporal scales, in some respects coincident with the spatial scales:

- Tidal
⇒ tidal cycles over hours
- Diel/diurnal
⇒ daylight cycles, within days
- Climatic events
⇒ storms, high runoff, usually occurring over days

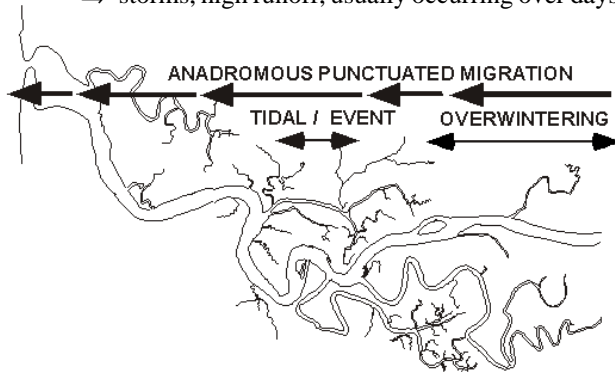


Figure 1 Scales of juvenile salmon interaction across estuarine landscapes. Modified from Kneib (1997) and Simenstad et al., in press (a).

- Neap/spring tidal
⇒ strong/weak tide cycles, on the order of weeks within (tidal) months
- Ontogenetic
⇒ growth, production, and physiological cycles occurring over weeks to months
- Seasonal
⇒ prolonged rearing such as overwintering in tidal freshwater reaches of floodplains

Assessment of Salmon Habitat Landscape Structure in Historical and Modern Delta/Bay

A landscape approach to assessing restoration of the Puyallup Delta/Commencement Bay landscape in the context of sediment contamination remediation demands analysis that is in most cases contrary to the normal approach of working from site opportunities to site designs and eventually to assessment of restored functions supporting juvenile salmon. In this instance, I advocate establishing estuarine landscape features and processes upon which juvenile salmon depend as an absolute prerequisite to examining the constraints and opportunities for restoration and remediation. This approach places selection of restoration alternatives that treat the requirements of juvenile salmon in the landscape as the highest priority, to be integrated with protection and restoration of natural physicochemical and ecological processes that sustain the landscape features and functions important to salmon. Site opportunities and constraints are of tertiary priority. While this may be understandably naïve when addressing the costs and practicalities of restoration on the scale of the Puyallup River delta and Commencement Bay, it does place the needs of an endangered resource as the foremost criterion. Also, the highly developed nature of the delta and Bay involves constraints and unique situations that should not necessarily be considered transferable to estuaries that are more structurally intact, such as those of the Snohomish, Nisqually, Skokomish, and Nooksack rivers.

The sequence of analysis was as follows:

1. Identify the historical structure of the Puyallup delta and Commencement Bay in the context of landscape requirements of juvenile salmon, particularly chinook salmon.
2. Characterize the physicochemical and ecological processes that sustain juvenile salmon habitats and the scope of habitat utilization by these fishes.
3. Describe the likely patterns of juvenile salmon use and migration through the historical delta/Bay landscape.
4. Characterize the modern use of the delta/Bay by juvenile salmon, including contrasts with the hypothesized historical use.

5. Identify existing contaminated (Superfund) and other problem sites.
6. Identify potential disposal sites for contaminated sediments.
7. Locate and characterize identified potential restoration sites.
8. Given the historical landscape template, constraints (e.g., "hard infrastructure," contaminated sediments, disposal sites), major habitat modifications and restricted restoration opportunities (e.g., including both undeveloped land, as well as contaminated and disposal sites), identify focus areas for estuarine juvenile salmon habitat restoration in the delta/Bay.

Whenever possible and appropriate, specific data were located geographically in the delta/Bay landscape using Geographical Information Systems (GIS). The data were provided by various sources (see Acknowledgments) and not derived from any unique GIS layers. Thus, to the degree that this analysis is dependent on geographic data about specific sites and features, it is only as good as the GIS data provided.

Restoration Criteria for Juvenile Salmon Habitat Landscapes

Given the previous descriptions of juvenile salmon dependence on landscape features and processes in the delta/Bay, I adopted the following criteria to guide analysis and priority= setting of restoration opportunities:

- Restore and enhance inter-habitat mosaics and linkages that accommodate refugia, feeding, and physiological requirements.
- Promote landscape structure and elements that result in diverse, productive primary- and secondary-producer populations that support juvenile salmon growth and survival.
- Take advantage of existing and restorable geomorphic structure that promotes the extent (opportunity, access) and utility (realized function) of habitat use.
- Preserve and augment fundamental estuarine processes that naturally build and maintain juvenile salmon habitats.
- Plan restoration and remediation that optimally addresses salmon life-history diversity to compensate for climatic variation, energy regimes, and disturbance.

These criteria are arrayed in approximate, but not absolute, order of consideration.

ANALYSIS

Historical Landscape Structure

The historical structure of the Puyallup River delta and

Commencement Bay landscape (Fig. 2) is not well documented but can be interpreted from the few excellent sources such as Bortleson et al. (1980) and early (1941–55) aerial photographs (Fig. 3). The Commencement Bay Cumulative Impacts Study (U.S. Army Corps of Engineers 1993) also provides an excellent characterization of changes in the historical structure over the delta/Bay development period. Historical photographs also assist in interpreting map features by identifying relict natural landscape elements from the 1940s to 1960s. Some of the important landscape attributes of this historical landscape follow:

- extensive tidal freshwater floodplain of the meandering Puyallup River, likely accompanied by extensive off-channel sloughs and wetlands;
- a prograding delta with numerous distributary channels braiding in southwest corner of Bay;
- well-developed dendritic tidal channels in the emergent marsh;
- extensive estuarine transition zone between upland habitats and emergent marsh; and
- broad, expansive mudflat habitat.

Important physicochemical and ecological processes (Fig. 4) can only be interpreted from the historical landscape structure and from our knowledge about the structure and functioning of less-developed estuaries, such as the Nisqually and Snohomish river deltas. One of the most important historical processes relative to modern transformations of the delta/Bay is that which takes place in the tidal-freshwater/brackish-salinity transition regions at the interface between the delta and the Bay. In particular, sediment delivery and deposition, nutrient cycling, detritus accumulation and decomposition in peripheral systems, and disturbance were likely distributed over a broad floodplain area. Sediment was trapped in sloughs, relict channels (oxbows), and riparian wetlands. Riparian ecosystems provided both detritus sources (e.g., leaf-fall) and large woody debris exported to the estuary, and were nourished by detritus and nutrients of salmon carcasses deposited from upstream spawning. At the delta/Bay interface, the river channel diverged into multiple distributary channels in a broad fan dispersing freshwater, sediments, organic matter, and organisms throughout the southern half of the Bay. Emergent marshes in this region were likely prograding at a moderate rate but also were prone to erosion and associated disturbances during periodic floods. This zone of Pacific Northwest estuaries often has extensive low/early successional marshes with high deposition of large woody debris from upstream.

Historical accounts and photographs indicate that where pervasive riverine input or peripheral drainage systems (e.g., Hylebos Creek) intersected the delta, the prevailing habitat was oligohaline–brackish emergent marsh dominated by sedge (e.g., Lyngbye's sedge, *Carex lyngbyei*) meadows, with broadleaf cattail (*Typha latifolia*) and creeping spikerush (*Eleocharis palustris*) at the freshwater–tidal

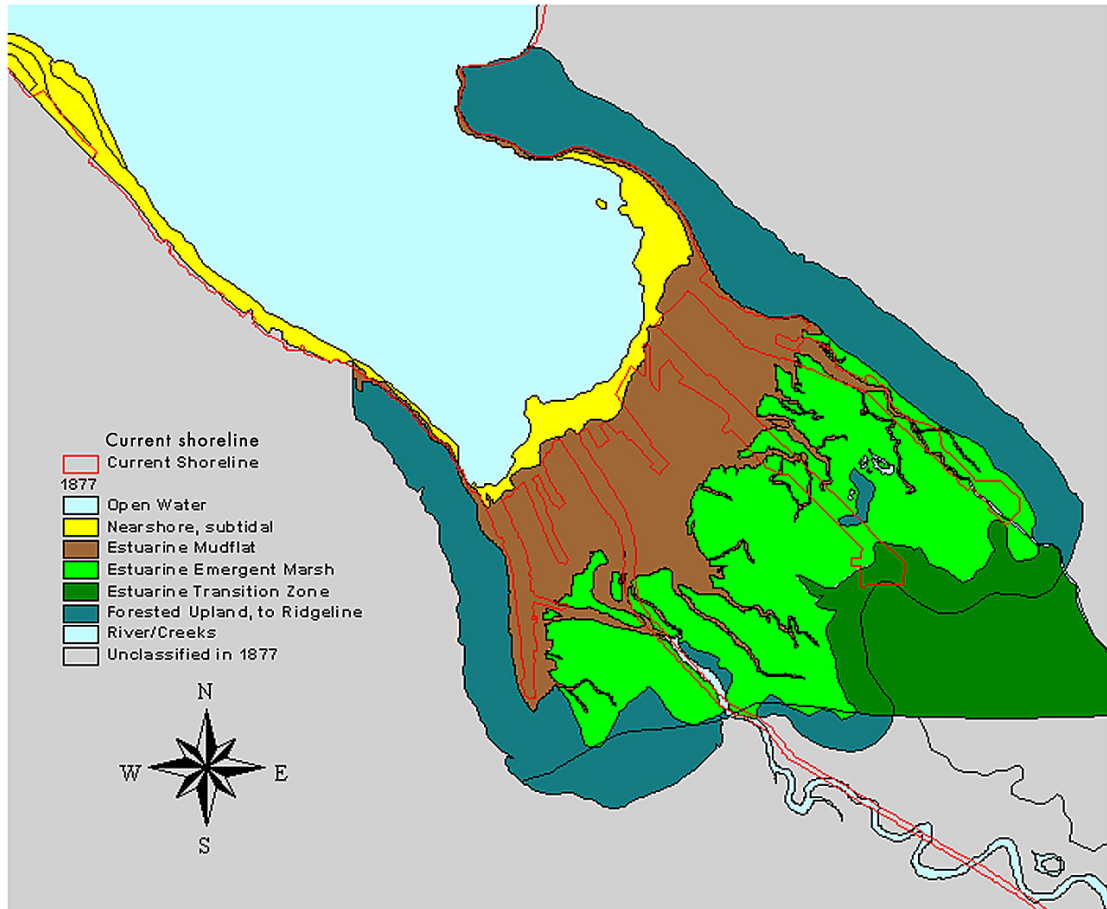


FIGURE 2. The GIS scene of historical landscape structure of Puyallup River delta and Commencement Bay (based on data from WDNr and USACE-Seattle District; see Graeber, in prep.).



FIGURE 3. Historical photograph of the upper end of Hylebos Waterway. Exact photo date unknown but is predicted to be mid-1940s. Photograph courtesy of the Tacoma Public Library.

boundaries. These brackish *C. lyngbyei* marshes would also have been common where disturbance effects (e.g., scouring and sediment deposition by river flooding, and scouring and sediment trapping by large woody debris) created substrate at lower marsh elevations. Where freshwater influence was weaker and more euryhaline conditions prevailed, or the marshes were able to build and maintain higher elevations, more mature marshes such as described by Cooper (1860) were characterized by a complex assemblage of tufted hairgrass (*Deschampsia caespitosa*), seashore saltgrass (*Distichlis spicata*), Baltic rush (*Juncus balticus*), Pacific silverweed (*Potentilla pacifica*), meadow barley (*Hordeum brachyantherum*), and bullrushes (*Scirpus* spp.). At the edges of the delta and along the marine shores of the Bay were located less expansive salt marshes of pickleweed (*Salicornia virginica*) and seashore saltgrass. At the mudflat margin of the delta, the leading vegetated edge was seaside arrowgrass (*Triglochin maritimum*).

Except in discrete, low intertidal areas, these marshes were also characterized by well-developed and often extensive dendritic tidal channel systems. A few of these

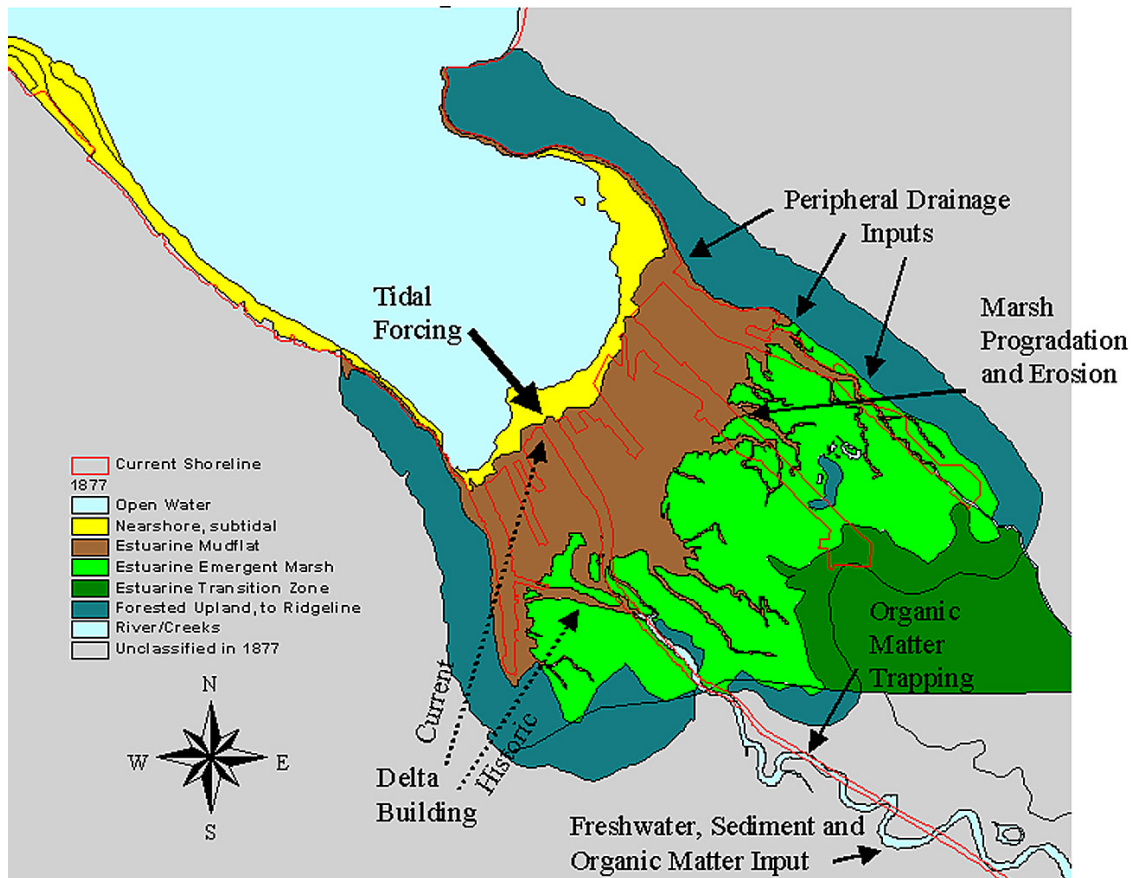


FIGURE 4. Historical physicochemical and ecological processes in the historic Puyallup River delta and Commencement Bay (based on data from USACE-Seattle District; see also Graeber, in prep.).

channels connected with freshwater sources (e.g., several originating from uplands along the northern margin of Bay, adjacent to Marine View Drive), so their structure was determined primarily by tidal forcing over the drainage area of each system. The strong tidal effect was evident from the landward extension of these tidal channels almost to the edge of the estuarine transition zone, which constituted extensive corridors between the mudflat and transitional shrub–scrub and tidal–freshwater habitats. In a few areas, such as along the northern shoreline and Hylebos Creek, there were peripheral inputs from steep hillside drainages that formed interconnecting corridors between delta and upland landscapes.

The front or foreshore of the delta's marsh "platform" was highly a convoluted edge that was likely prograding and eroding over space and time, depending upon the strength of interannual weather events. The extensive, low-gradient mudflats that separated the marsh edge from the subtidal portions of the Bay likely protected the marsh from extensive erosion; thus, we might assume that the marsh was naturally prograding with colonizing vegetation such as seaside arrowgrass. For the purpose of this analysis, I define the "delta front" as the intertidal and shallow subtidal

edge of the developing delta, including the unvegetated mud and sand flats and beaches that occur below (in terms of tidal elevation) the marsh edge.

Juvenile Salmon Utilization of the Historical Landscape

Juvenile salmon utilization of the historical delta/Bay landscape was likely prolonged and widely dispersed (Fig. 5). In the extensive tidal–freshwater flood plain, considerable side-channel, relict oxbow, and other low-energy environments provided extensive opportunities for overwintering by subyearling coho (Tschaplinski et al. 1982, 1987; Miller and Simenstad 1997) and possibly steelhead. Within the freshwater–brackish or oligohaline reach of the estuary, juvenile ocean-type chinook³ and to a lesser degree chum salmon had the opportunity to occupy low-energy

³Ocean-type (e.g., the most estuarine-dependent) chinook dominate the life-history composition of most Puget Sound fall chinook populations, but spring and summer chinook populations in Puget Sound watersheds are also known to have varying percentages of ocean-type migrants.

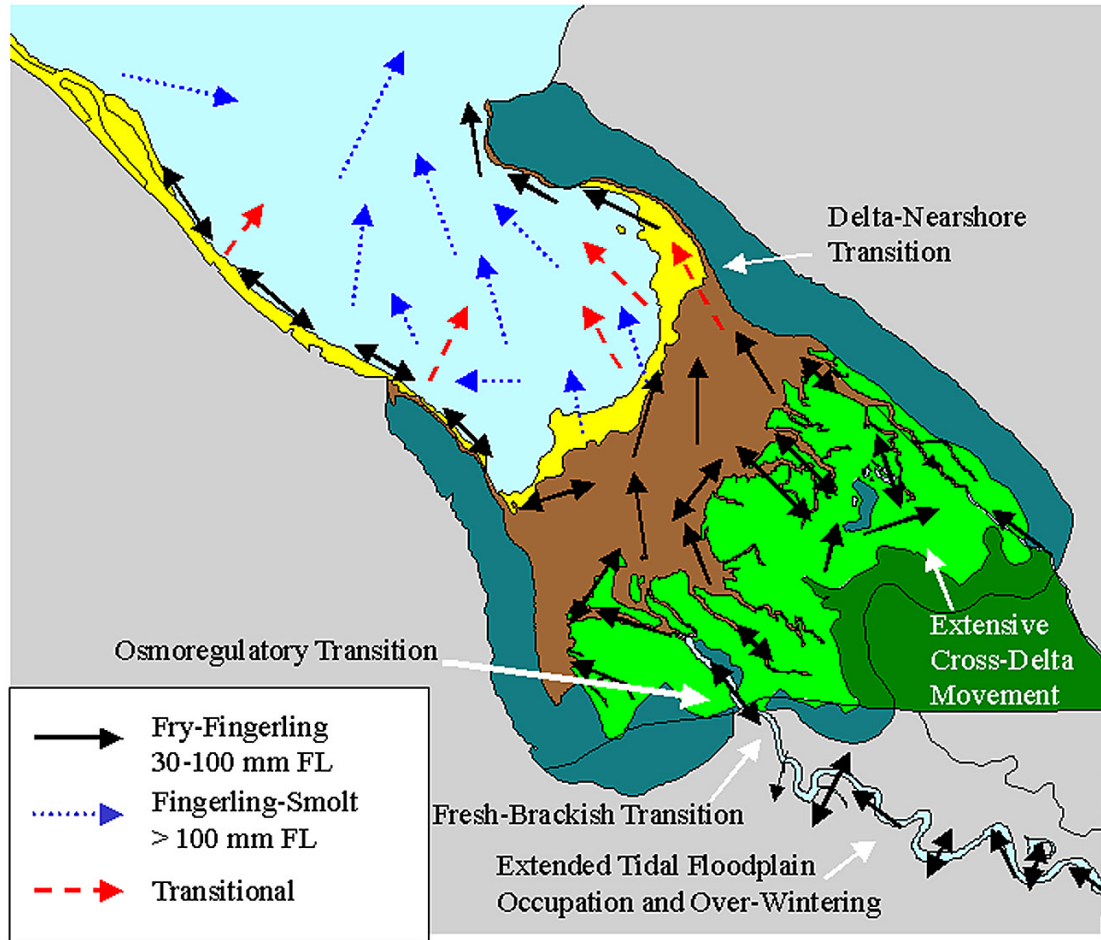


FIGURE 5. Hypothesized historical use of Puyallup River delta and Commencement Bay by juvenile salmon (modified from USACE-Seattle District).

side-channel and marsh habitats to accommodate the osmoregulatory changes that accompany exposure to salinity. Also salmon had considerable opportunities to move into expansive emergent marshes of the delta at high tides, where they were able to retreat to the complex dendritic tidal channel systems on ebbing tides. Once encountering the delta-front, emergent marsh-mudflat interface, juvenile salmon could follow contiguous shallow-water corridors along the marsh front either to the north or south. As is evident in data from more recent sampling of juvenile salmon (e.g., Duker et al. 1989), subyearling salmon fry and small fingerlings (30–80 mm FL) likely would have stayed within the influence of the river's buoyant turbidity plume or in shallow water. Fish movement within the delta was strongly dictated by tidal cycle, with the fish penetrating deep into the marsh along dendritic tidal channel networks on flood tides and continuing along mudflat and beach shorelines at the water's edge as the tide ebbs. Salmon fry and fingerlings that were still 50–80 mm FL upon encountering the northern shoreline likely continued to seek out shallow-water habitats along the beach

corridor at the delta-nearshore marine transition. Here, low intertidal and shallow subtidal eelgrass (*Zostera marina*) provided essential habitat as the fish moved around Brown's Point and out of the Bay. As they grew larger, or entered the Bay at a large size because of extended upstream rearing, salmon fingerlings and smolts moved farther offshore and were less dependent on shallow-water habitats.

In addition to the expanse of transitional habitats providing opportunity for physiological adaptation and refuge from predators, the historical habitats of the delta/Bay landscape would have produced an array of food organisms favored by the various salmon species, life-history types, and sizes during their estuarine migration. Although often ignored when considering estuarine foraging by salmon, the tidal floodplain's freshwater wetlands, side-channels, and riparian complexes would have generated a multitude of insects—both as aquatic larvae and pupae and as adults—that are prominent components of juvenile salmon diets as they emigrate from watersheds. Riparian shrub-scrub and forest vegetation would contribute measurably, through the fallout of a variety

of insects that were flushed into the floodplain (e.g., sucking insects such as aphids). Shallow-water, vegetated tidal–freshwater, brackish, and oligohaline marshes, and to a lesser degree mudflats, are notable for high production of dipterans flies, aphids, and other insects characteristic of salmon diets prior to entering more euryhaline habitats (e.g., Levy and Northcote 1982, Simenstad and Cordell in press). Within more euryhaline marshes and mudflats, benthic and epibenthic crustaceans were more important prey of juvenile salmon; certain taxa of gammarid amphipods, harpacticoid copepods, isopods and mysids—often preferred to other available prey—are characteristic of marsh vegetation, fine sediments, and tidal channels. In the more saline delta/Bay habitats, intertidal and shallow subtidal eelgrass and macroalgae supported another prominent assemblage of crustaceans, which are preferred by salmon fry still constrained to shallow-water habitats. Only as the salmon made the transition to open waters of the Bay as larger smolts did they begin to rely on planktonic prey. However, as we still see today, some species and life-history types (e.g., chinook) probably continued to feed upon surface drift insects exported by the river and delta wetlands even when they were in the open waters of the Bay.

This interpretation of juvenile salmon use of the historical delta/Bay landscape, debatably limited by the applicability of our knowledge about present-day salmon use of natural estuarine landscapes, suggests four features that could constitute restoration criteria important to the recovery of Puyallup watershed chinook and other salmon:

1. reestablish broad segments of tidal–freshwater floodplain supporting complex riparian wetland mosaics, with interconnecting slough and relict channel corridors;
2. provide an extensive marsh and distributary channel complex in the brackish “osmoregulatory transition zone” of the delta;
3. restore or create naturally convoluted emergent marsh edges at the interface with unvegetated (mudflat), low-gradient habitats along delta front; and
4. promote the development of shallow, highly complex dendritic channels that provide corridors among diverse habitat patches.

Current Aquatic Habitats Types and Locations

Relict natural aquatic habitats are highly fragmented and dispersed across the delta and Bay with few natural corridors linking them (Fig. 6). The few sites are typically small, surrounded by extensive development and vulnerable to a variety of stressors, from noise to toxic spills (U.S. Army Corps of Engineers 1993). The delta has essentially been displaced to the steep edge of Commencement Bay that historically constituted the western edge of the mudflat (Fig. 2) but there are no tidal floodplain, distributary channels or cross-delta flow of water, sediments, organic mat-

ter or animals. While freshwater from the river is still advected into the waterways as a relatively thin surface plume, the extensive spreading of that plume across the historical delta’s intertidal wetlands during high tides is not possible. Thus, the Bay’s estuarine wetland habitats are no longer bathed by *lateral* riverine outflow. This lateral outflow would have transported sediments, nutrients, food organisms and large woody debris into back marshes, and all the way to the edge of extratidal shrub–scrub upland that defined the eastern margin of the delta. Except for scale, some aspects of the changes in the Puyallup River delta parallel those in the Mississippi River Delta, where isolation of the river from the delta has contributed significantly to wetland loss (e.g., Boesch et al. 1994).

Regions of the delta and Bay still are appropriate *locations* of some basic estuarine habitat types (tidal–freshwater forested wetland, estuarine emergent/shrub–scrub transition, estuarine emergent marsh, mudflat, unconsolidated nearshore beach, shallow subtidal eelgrass), but many of the physicochemical processes that are required to *sustain* these habitats are missing or significantly modified. Flow of freshwater and sediments now contributes little to the historical delta, but is focused only at the mouth of the delta, where bedload sediments are building the Puyallup’s “neodelta” (Fig. 7). Suspended sediments are now exported to the Bay in the river’s buoyant turbidity plume, only a small portion of which inundates the nearshore and supplies sediments to intertidal or shallow subtidal habitats. The large subtidal gaps of the waterways fragment the once relatively contiguous intertidal face of the delta. “Planting” restoration and mitigation sites without considering these changes in landscape processes may ultimately result in unsustainable elements in the delta/Bay landscape, and deficient, long-term support of juvenile salmon that require them in perpetuity. While such habitat engineering is often the only alternative in highly industrialized areas of estuaries, where natural processes are suppressed, this risk of long-term uncertainty should be considered as an important factor in ranking, locating, and designing any estuarine habitat restoration that is expected to support long-term salmon recovery.

Existing Aquatic Habitat Ability to Function and Contribute to Salmon Productivity

The modern delta/Bay landscape constrains juvenile salmon utilization and the natural processes that support salmon production (Fig. 8). Except for comparatively miniscule, low-energy habitats at the Clear Creek and Gog-Le-Hi-Te mitigation sites, juvenile salmon are essentially “jetted” from the delta into the Bay because of the thoroughly channelized river. There are no opportunities for either floodplain rearing or extended occupation of low-velocity marshes and channels in the osmoregulatory tran-

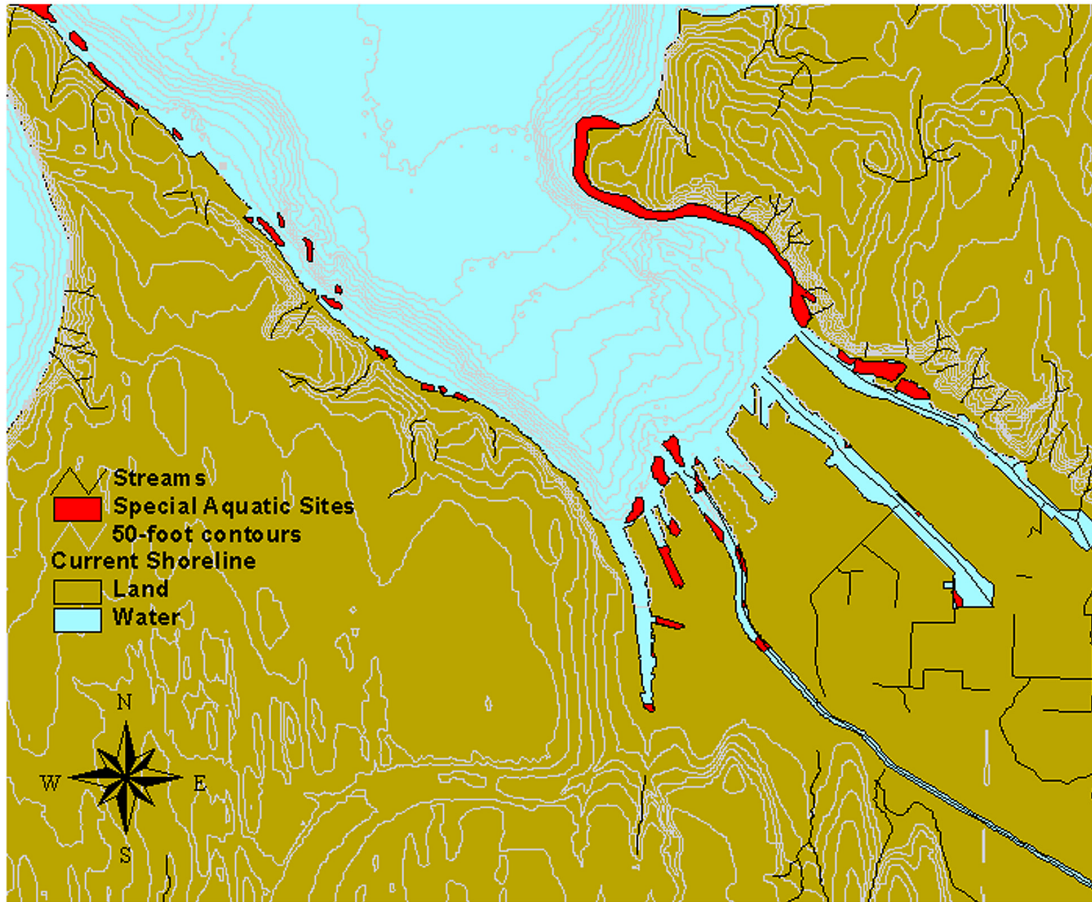


FIGURE 6. “Special aquatic sites” (vegetated shallows, mudflats, wetland marsh) existing in 1988, identified in 1993 Commencement Bay Cumulative Impact Study (US Army Corps of Engineers 1993; GIS data from USACE-Seattle District).



FIGURE 7. Aerial photograph from 1996 of the “neodelta” of the Puyallup River forming at the margin of Commencement Bay, with St. Paul, Middle, and Thea Foss waterways in the background. Photograph by D. Putman, Weyerhaeuser Company.

sition zone. The freshwater, tidal–brackish transition zone now occurs in a completely channelized river with heavily armored shorelines. There are essentially no low-velocity refugia and little riparian woody vegetation. Most osmoregulatory adaptation to salinity must take place along the brackish edges of the river plume as it spreads out over the Bay.

This is not to imply that juvenile salmon do not appear along heavily modified shoreline habitats, or in the habitat mitigation sites that to some degree have been targeted for juvenile salmon. Pacific International Engineering (1999) provides an effective data synthesis of nearshore fish catch information that indicates distribution of fish varies with seasonal timing throughout the Bay from the Ruston shoreline to Brown’s Point. Fish preferentially occupy shallow water, including mitigation and restoration sites (Miyamoto et al. 1980, Duker et al. 1989, Port of Tacoma and Puyallup Tribe of Indians 1998; G. Grette, Pacific International Engineering, Wenatchee, Washington, pers. comm.) north and south of the river mouth, although perhaps tending more to the north. Within Com-

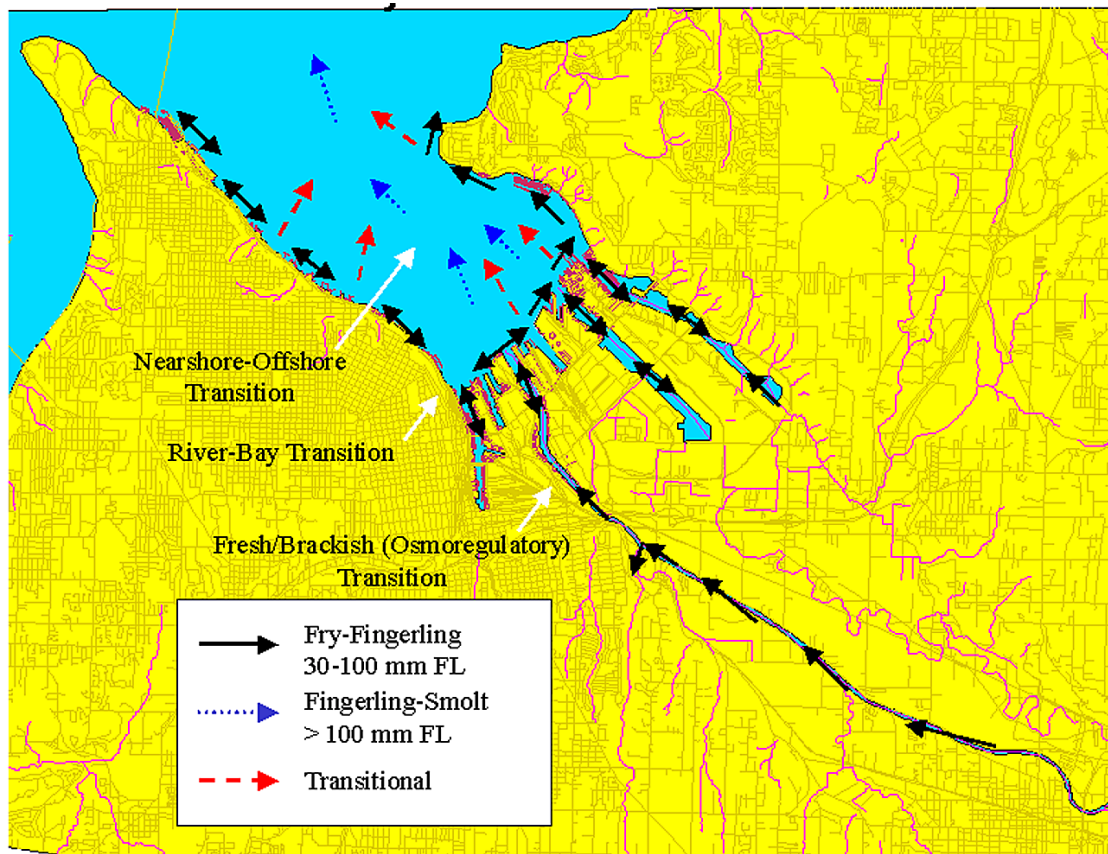


FIGURE 8. Modern use of Puyallup River delta and Commencement Bay by juvenile salmon (modified from GIS data from Washington Department of Natural Resources; see also Graeber, in prep.).

mencement Bay, juvenile chinook tend to be the most prominent species rearing within the system between May and June. Juvenile chum generally appear earlier but their abundances are often episodic. Juvenile coho appear to depart the Bay very rapidly. Preliminary results from recent mark-and-recapture studies indicate that juvenile chum salmon may reside along the face of the delta, including within the waterways, for several weeks (G. Grette, PIE, Wenatchee, Washington, pers. comm.); comparable information for juvenile chinook is pending final analysis, but may be complicated by the presence of unmarked hatchery chinook.

The fragmented habitat landscape is not the only constraint to juvenile salmon, as 10 major Superfund or Resource Conservation and Recovery Act sites, including six within the delta/Bay system, represent persistent contamination sources until effective remediation is achieved (Fig. 9). In addition, numerous permitted waste (e.g., National Pollutant Discharge Elimination System) and storm drains overflow into the Bay. In addition to the specified toxic sites, residual pollutants in sediments of Thea Foss, Middle, and Hylebos waterways (Fig. 10) also pose some level of

potential contamination to migrating salmon, whether directly or through food web pathways.

Although degraded at the landscape scale, some modified and relict habitats and most mitigation habitats along the delta front and in the waterways still support juvenile salmon by providing attributes such as food and refuge. The benefit or cost to juvenile salmon of occupying these habitats remains unverified. Whether juvenile salmon suffer decreased growth and condition, and thus increased mortality, by their migration through and residence in the delta/Bay system remains essentially unresolved, and certainly not quantified. Although there is some indication through stomach contents analyses (Simenstad et al. unpubl.) that the diet composition of juvenile chinook and chum salmon is different from comparable fish in other, more natural estuaries, the fish are certainly feeding and finding alternative prey. Whether these fish are finding *sufficient* prey resources, or whether these prey are energetically “optimum” is presently unknown. This critical caveat needs to be addressed with more extensive studies of juvenile salmon fitness and bioenergetic modeling of their ability to convert foraging success into growth and survival.

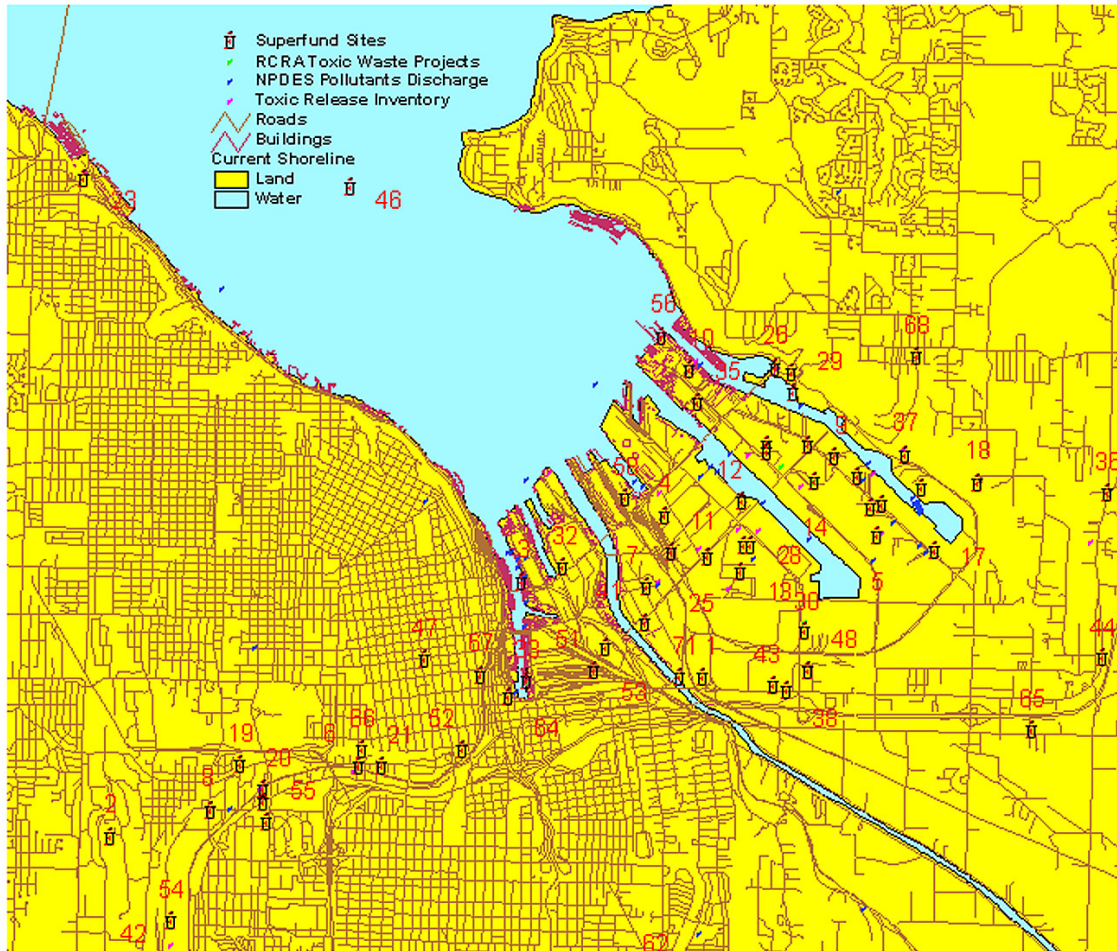


FIGURE 9. Superfund and other problem sites affecting restoration of juvenile salmon landscapes in the Puyallup River delta and Commencement Bay (based on GIS data from US EPA).

Opportunities to Create or Enhance the Functions of Aquatic Habitats that Would Contribute to Recovery of Salmon

Both the CERCLA remediation actions and associated mitigation actions could measurably contribute to increased habitat for juvenile salmon in the Puyallup River delta and Commencement Bay. *Whether they will function effectively in restoring part of the historical juvenile salmon habitat landscape will depend on how these actions are organized and implemented at the landscape and watershed scale within realistic constraints of the highly developed delta/Bay.*

The constraints upon restoration, in the strictest sense of the scientific definition (National Research Council 1992), are extreme in this environment, even without considering the historical variations in the watershed (e.g., permanent “capture” of the White River watershed). In addition to the complete reorganization of the delta and the existing contamination and pollutant inputs, the “hard

infrastructure” of roadways, utility corridors, bridges, large structures, and industrial plants confines the reality of restoration on many fronts. Nonetheless, the relative position of important landscape elements (rather than habitat sites, per se) and preservation or restoration of some landscape processes are still viable and could contribute—to some unknown degree—to recovery of Puget Sound chinook and other salmon stocks.

Under this landscape perspective, seven strategies would offer the greatest contribution to chinook and other salmon estuarine life history in the Commencement Bay watershed:

1. Preserve and build on existing, viable landscape elements
 - ⇒ Preserve and enhance relict natural habitat patches as building blocks for future mitigation.
 - ⇒ Expand on successful habitat development and restoration.
2. Preserve, enhance, and incorporate natural estuarine processes

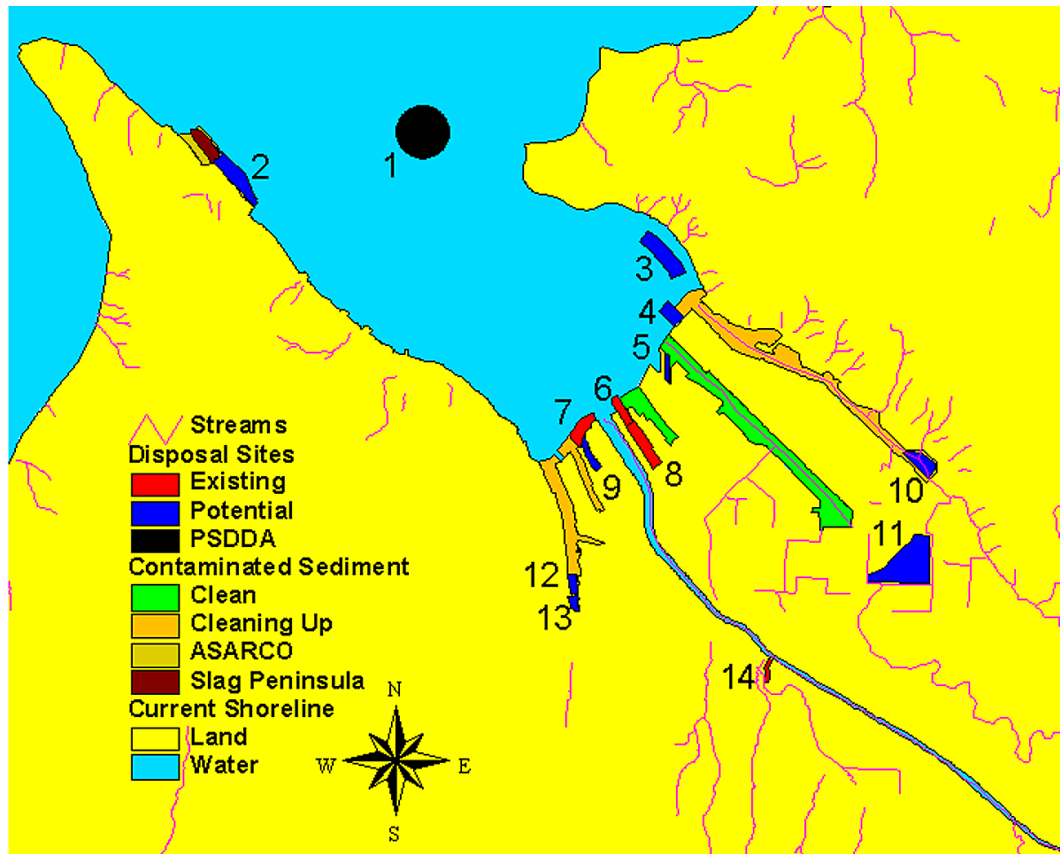


FIGURE 10. Potential disposal sites and contaminated sediments affecting juvenile salmon restoration in the Puyallup River delta and Commencement Bay (see Table 2 for names of numbered sites) based on data from Washington Department of Natural Resource; see also Graeber, in prep.).

- ⇒ Protect and enhance freshwater flow and quality.
 - ⇒ Use the time-varying distribution of the Puyallup River plume to link restoration and mitigation sites.
 - 3. Address critical gaps in the continuum of the estuarine landscape utilized most intensively by juvenile salmon
 - ⇒ Focus restoration and mitigation in relatively ignored regions of the estuary.
 - ⇒ Combine both elements and processes in landscape restoration, such as establishment of forested wetland and riparian floodplains as well as the natural supply of large woody debris.
 - 4. Take advantage of the naturally developing “neodelta”
 - ⇒ Develop a conservation plan to ensure protection of the existing (and future) “neodelta” in accordance with the WDNR Delta Reserve Concept (see below).
 - ⇒ Use the promise of continued expansion of the “neodelta” developing at the mouth of the Puyallup River, and its potential succession to vegetated estuarine wetland, to increase connectivity to peripheral restoration and mitigation habitats, such as Milwaukee and Middle waterways.
 - 5. Restore natural delta edges
 - ⇒ Even where protecting human infrastructure in the delta, develop natural alternatives to hardened shorelines and restore low-gradient natural sediment and vegetated edges.
 - 6. Restore cross-delta hydrologic and vegetated corridors and distributary channels
 - ⇒ Reconnect or create connections, and enhance hydrologic flow across the delta.
 - 7. Link to natural upland habitats
 - ⇒ Use or restore natural drainages that link to undeveloped upland habitat as corridors for wildlife and fish as well as restoration of freshwater, detritus, and prey organism fluxes to the estuary and nearshore.
- Of the broad universe of potential restoration sites that has been identified through a variety of agency, tribal, and other initiatives, approximately 17 parcels or groups of parcels have been specifically targeted as potential NRDA restoration sites (Table 1; Appendix Table 1; Fig. 11). Of these sites, restoration has been proposed for six, specific

restoration actions are pending at four, restoration has already occurred at three, and mitigation actions have been applied to three sites. Many of these became priority sites based on the early (1992) inventorying and screening by the Restoration Technical Panel and Commencement Bay Plan/EIS (see ranking in Appendix Table 1). This does not include the 11 of the 13 potential habitat restoration sites in the Puyallup River floodplain identified in the "Restoration Site Catalogue, Restoration Opportunities on the Puyallup River" (Puyallup Tribe, Pierce County, and Pacific International Engineering 1999) which were excluded from the Commencement Bay Cumulative Impact Study (U.S. Army Corps of Engineers 1993).

These sites represent viable building blocks to expand already functioning habitat patches. Many of these miti-

gation sites have been documented to be used, often extensively, by juvenile salmon and support their prey resources (Thom et al. 1986), although the intensity of utilization may to some degree be dependent upon the age and design of the site (e.g., Grette 1998). Sites that appear to support rapid development (within 3–5 yr) of the appropriate intertidal estuarine communities (see below) are typically those that incorporate or take advantage of natural processes (such as sediment and organic matter accretion, and natural vegetation colonization) and promote reduction of current and wave energy.

Among the active processes fundamental to restoring and sustaining natural estuarine habitats, sediment delivery by the Puyallup River has already accounted for the natural development of a "neodelta" that serves as a fun-

TABLE 1. The NRDA high or medium ranking restoration sites involving potential disposal of contaminated sediments in the Puyallup River Delta and Commencement Bay and assessment of their potential contribution to estuarine landscape characteristics supporting juvenile salmon. H = high, M = medium, L = low, and N = no effect, where the primary criteria were proximity to restoration focus areas, taking advantage of natural processes and features and restoring important landscape elements. Revised from original US Army Corps of Engineers GIS data (US Army Corps of Engineers 1993) and Commencement Bay Natural Resources Trustees (1997) in accordance with more recent NRDA Trustees information (J. Lantor, USFWS, and R. Clark, National Oceanic and Atmospheric Administration).

No.	Name	Restore tidal-freshwater	Expand osmo-regulatory transition	Build on natural "neodelta"	Enhance habitat connectivity	Restore natural delta edges and channels	Link to natural uplands and drainages
1	Wasser-Winter	L	M	N	L	L	L
2	Hylebos Conservancy Area	N	L	N	L	L	H
3	Meaker Beach Marsh	N	L	N	M	M	M?
4	Middle Waterway Shore Restoration SE	N	L	M	L	M	N
5	Middle Waterway Shore	N	L	M	L	M	N
6	Tahoma Salt Marsh	N	N	N	L	M	L?
7	Hylebos Conservancy Area	N	L	N	M	M	M?
8	DNR Marine View Drive Reserves 1-3	N	N	N	M	M	H
9	Slip 5	N	N	L	M	H	N
10	Gog-Le-Hi-Le	M	H	N	H	N	L
11	Swan Creek	H	M	N	M	N	H?
12	Dickman Mill Shore Park	N	N	N	L	H	L?
13	Olympic View	N	L	M	H	H	N
14	Olympic View Beach	N	L	M	H	H	N
15	Clear Creek Slough	H	M	N	M	N	H?
16	Milwaukee Waterway	N	L	H	H	M	N
16a	Milwaukee Waterway w/ natural connector channel	N	M	H	H	M	N
17	St. Paul Cap	N	L	H	M	L	N

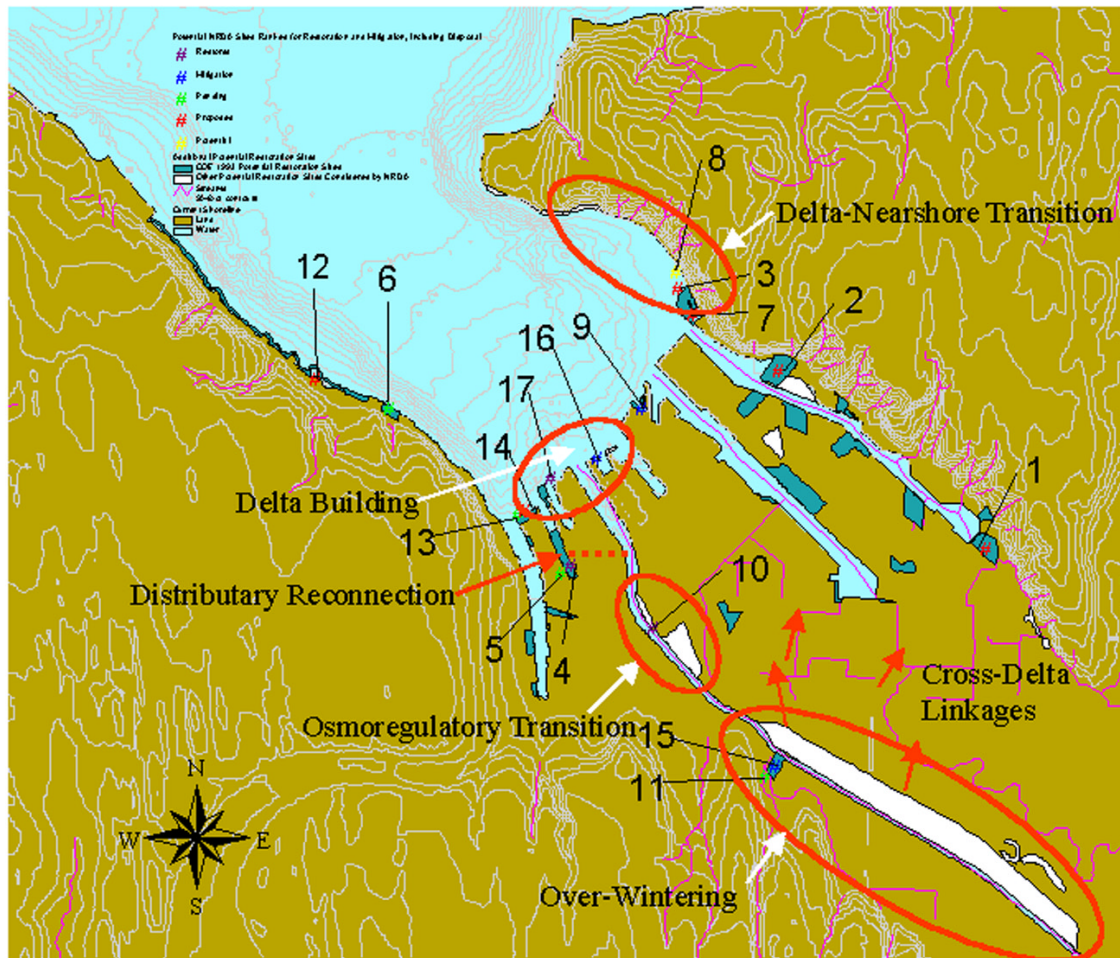


FIGURE 11. Areas of juvenile salmon habitat focus in the Puyallup River delta and Commencement Bay landscape, with potential, pending and active NRDA restoration and mitigation sites involving disposal, as well as additional restoration sites (see Table 1 for names and data on numbered sites) potential NRDA restoration and mitigation sites modified from GIS data from Washington Department of Natural Resources; see also Graeber, in prep.).

damental building block at the single delta/Bay transition point for juvenile salmon. These mud- and sandflats appear to be sustainable and increasing despite the steep delta front bathymetry, and are incorporating organic matter and tidal channel geomorphology that are important characteristics of intertidal habitat used by juvenile salmon (Fig. 12). As described effectively in Graeber (in prep.) and other documents, preservation of this “neodelta” can provide a critical building block for natural and constructed expansion of mudflat (and potentially later marsh) habitat on both sides of the “neodelta.” Continued sediment delivery by the river also should guarantee the maintenance and expansion of such a “Delta Reserve” (see below).

RELATIVE CONTRIBUTION OF POTENTIAL DISPOSAL SITES

Among the 10 potential disposal sites originally identified for Commencement Bay (Fig. 10; Table 2), some of

which have already been utilized for mitigation and disposal, more than half could be developed for salmon habitat if reintroduction of contaminants was effectively prevented or toxicity was eliminated over time by natural geochemical and biological remediation processes. Given this critical assumption, disposal sites in locations such as the St. Paul Waterway, as well as the completed Milwaukee Waterway habitat development, which are within close proximity to the emerging “neodelta,” would likely contribute significantly to an expanded shallow-water mudflat and vegetated intertidal habitats.

Habitat development at other disposal sites would likely contribute less if significantly displaced from existing shallow-water habitat, especially if located within the waterways. The proposed disposal site at the freshwater end of Hylebos Waterway would be an exception because of the existing and future potential of juvenile salmon entering the delta/Bay from that watershed. Optimally, contami-



FIGURE 12. View of developing tidal channel in mud/sand flat lobe of the Puyallup River “neodelta” forming offshore of the Simpson Mill, 1999. Photograph by K. Weiner, Preston Gates & Ellis.

nant disposal should result in a net gain in quantity and quality of intertidal habitat of juvenile salmon. In this respect, disposal and mitigation sites and designs should rank high if they will result in development of important habitat attributes appropriate to focus areas (Fig. 13).

SOUNDNESS OF THE “PUYALLUP RIVER ESTUARY AND DELTA RESERVE” (DELTA RESERVE) CONCEPT AND SCIENTIFIC MERITS OF THE EVOLVING MITIGATION PLAN FOR PROPOSED DISPOSAL SITE IN ST. PAUL WATERWAY AND CREATION OF NEW DISTRIBUTARY CHANNEL

As described preliminarily (Washington Department of Natural Resources, in prep; Graeber, in prep.), many aspects of the Washington Department of Natural Resource’s “Delta Reserve Concept” are scientifically sound and should receive strong consideration for restoring juvenile salmon habitat in Commencement Bay. As described earlier, the most ecologically effective aspect is the protection and directed augmentation of habitat development adjoining the active “neodelta.” The potential effective-

TABLE 2. Disposal sites identified in Figure 10.

Site no.	Site name
1	PSDDA Deepwater Disposal
2	ASARCO CAD
3	Outer Hylebos CAD Disposal
4	Mouth of Hylebos Creek CAD Disposal
5	Slip 1 Nearshore Fill
6	Outer Milwaukee Mitigation Site
7	St. Paul Cap
8	Milwaukee Waterway Disposal Site
9	St. Paul Nearshore Fill Disposal Site
10	Head of Hylebos CAD
11	Taylor Way Upland Disposal
12	Head of Thea Foss Cap
13	Head of Thea Foss CAD
14	Clear Creek Mitigation Site

ness of this approach is that it will take advantage of existing processes, naturally expanding shallow-water habitat, and opportunities to expand that habitat further at a critical delta/Bay transition point for juvenile salmon.

In absolute terms of restoring an important landscape attribute of the historical system (i.e., distributary channels at the mouth of the river), reconnecting the river to Middle Waterway by restoring a “natural” distributary channel would significantly enhance habitat creation and restoration actions within that waterway; it would also provide a connective corridor to the “neodelta” across existing and potential habitat development sites at the mouth of St. Paul waterway. It would increase the brackish osmoregulatory zone from a potentially very low function presently by a modest increment (as reflected by the increase in rank in site 16a, Table 1). The long-term sustainability and success of contaminated sediment disposal at St. Paul Waterway, and new shoreline habitat development at Middle and St. Paul waterways, may in fact be contingent to a diversion of Puyallup River water. This is because restoring freshwater and suspended sediment input to these sites would reestablish the natural delivery of mineral and organic matter and nutrients to mudflat and marsh systems, in addition to developing a strong salinity gradient, depending upon the extent of freshwater flow. Given the present, highly restricted or lacking delivery of freshwater, sediments, and nutrients to the restoration sites in Middle Waterway, the prospect of long-term sustainability of brackish–oligohaline marshes appropriate to this region of the delta is uncertain. Mudflats may be the more feasible habitat to be restored in this system if river water input cannot be reestablished.

The question of how much and how to control river water is critical to any decision about the feasibility and viability of this proposal (Table 3). Given the river’s potential to scour a channel, the only alternative to prevent redirection of a significant portion of the river flow and bedload sediments would be to construct a major and ex-

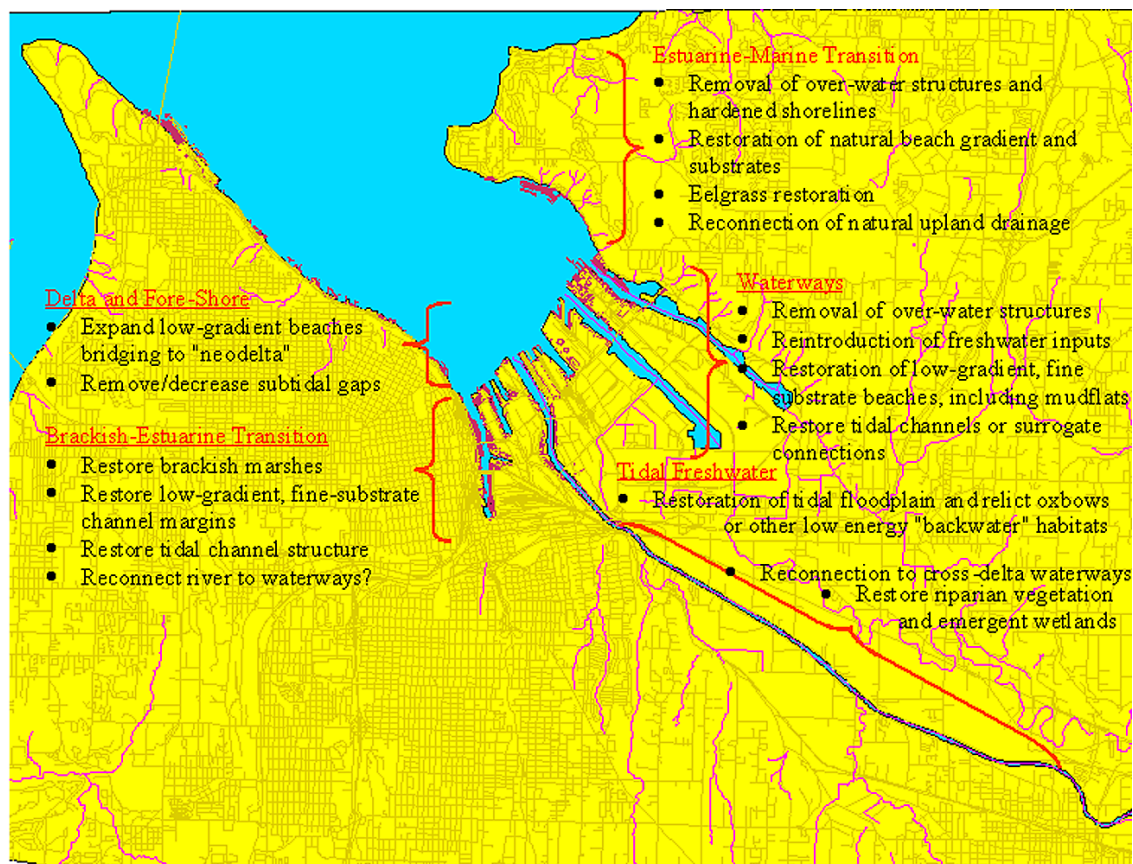


FIGURE 13. Appropriate actions for enhancement of juvenile salmon rearing in the Puyallup River delta–Commencement Bay (modified from GIS data from Washington Department of Natural Resource; see also Graeber, in prep.).

tremely costly control structure. Extensive diversion of the river might also jeopardize the continued development of the "neodelta" if a significant proportion of the bedload were to be diverted. Highly restricted flow, such as from pumping from the river, will allow freshwater, suspended sediments, and nutrients but will eliminate the opportunities for fish diversion into restoring marsh and mudflat sites. Pumping from wells, however, would provide only freshwater and little or no suspended sediments. Juvenile

salmon access would be fully supported under only a few of these alternatives, while development of a diverse, productive marsh community would be relatively enhanced under even the pumped (river) water alternative.

Thus, while diverting juvenile salmon into Middle Waterway would provide direct support for rearing and osmoregulatory adaptation, alternatives that provide little or no diversion would still enhance restoring habitat use by fish volitionally accessing the waterway from the Bay *vis*

TABLE 3. Alternative benefits of different approaches to diverting Puyallup River water to Middle Waterway; H = high, M = medium, L = low, N = no benefit..

Method	Divert juvenile salmon	Transport bedload sediment	Transport suspended sediment	Provide freshwater, nutrient, and detritus input	Promote diverse, productive marsh community
Full restoration of distributary channel	H	H	H	H	H
Diversion control structure	M	M?	H	H	H
Overflow channel	M-L	N	H	H	H
Pumped (river) water	N	N	M-H	L-M	M-H

a vis the Puyallup River plume. Fish access may actually be a secondary issue because present data on juvenile salmon distributions in the Bay (e.g., Duker et al. 1989, Pacific International Engineering 1999) indicate that high densities of juvenile chinook will likely access Middle Waterway after passing through the building delta and following the river plume or shoreline to the south. However, in the absence of any freshwater input into Middle Waterway, the function of this area for osmoregulatory adaptation will be more dependent upon the extent and duration of intrusion of river plume water into the Waterway. Conversely, the loss of direct flow from the river not only will reduce or eliminate fish passage but will eliminate a desirable element of disturbance to the restoring habitats in the waterways (e.g., by eliminating large woody debris, flood flows).

Priorities of Opportunities in Terms of Contribution to Salmon Recovery and Sequence of Implementation

The preceding discussion has emphasized the major landscape structure and process requirements of juvenile salmon, the ecological discontinuities in the existing delta/Bay system, and in some respects the commensurate gaps in restoration and remediation that could be contributing to salmon recovery. In particular, (1) tidal–freshwater overwintering habitat, (2) osmoregulatory transition, (3) the “neodelta,” and (4) delta–nearshore transition elements of the delta/Bay landscape represent the principal gaps and future building blocks, in a landscape-based approach to estuarine restoration for salmon recovery (Fig. 11).

Utmost priority should be given to restoring floodplain, riparian, and relict oxbow channels above the mouth of the estuary. This is undoubtedly the most significant habitat gap in the juvenile salmon landscape continuum between the river and Puget Sound. Given the critical landscape transitions of juvenile salmon passing through the delta/Bay system, it is readily apparent that tidal–freshwater regions of the delta have received virtually no emphasis except for the Swan Creek and Clear Creek Slough projects. Preliminary results of juvenile salmon monitoring at the Clear Creek Habitat Mitigation Area indicate that juvenile chinook and chum salmon and cutthroat trout do occupy the mudflat, pond, and wetland habitats, often in abundance, within a few years of its creation (M. Boyle, Pacific International Engineering, unpubl. data). Additional opportunities for restoration and enhancement of juvenile salmon habitat in the tidal–freshwater habitat reaches of the delta have been identified in the Puyallup Tribe, Pierce County, and Pacific International Engineering (1999) inventory, which describes at least 10 projects, potentially totaling over 123 acres of low-energy wetland and off-

channel habitat that could be reconnected with the tidal floodplain. Similarly, only the small Gog-Le-Hi-Te restoration site presently addresses juvenile salmon habitat requirements in the region of osmoregulatory adaptation and transition to the Bay and delta-front environments (Shreffler et al. 1990, 1992). However, considerable expansion upon Gog-Le-Hi-Te is feasible through restoration of presently undeveloped land (although filled to some degree) upstream from the present restoration site.

Particularly high priority should be allocated to preserving the Puyallup River’s expanding “neodelta” and restoring and remediating habitat patches and corridors that link to it. The neodelta illustrates that many of the dynamic processes that structured and maintained the original delta still operate to build intertidal habitat and food webs. As long as these processes continue with little disruption of upriver water and sediment sources and the expanding new delta can be accommodated in Bay-wide planning, restoration and creation of intertidal habitats that link peripherally to this focus zone have a high probability of contributing to juvenile salmon recovery.

Many of the waterway mitigation and restoration sites appear to be functioning adequately as juvenile salmon habitat and offer only more opportunities for future mitigation that could involve continuing connectivity of “soft-edge” shallow-water habitats along the delta face. To some degree, priority should also be given to the delta–nearshore transition region in the northeastern corner of Bay because of the importance of that relatively abrupt habitat transition and existing Puyallup Tribe and WDNr sites that could form a critical mass for restoration in that region. As the geomorphic template and processes still persist to a certain degree, basic enhancement actions such as removing shoreline structures and reconnecting upland drainages could make substantial contributions to landscape function for salmon in this focus area. Additional priority should be provided to actions that would promote linking both restoration sites and existing relict aquatic sites with watercourses across the delta, such as Wapato Creek.

These priority recommendations are not intended to discount other restoration actions that do not necessarily fit within this landscape context of the greater delta/Bay system. While juvenile salmon are likely to benefit to the greatest degree from these landscape-scale actions, the cumulative effect of restoration or creation of individual segments of shallow-water habitat throughout the delta/Bay cannot help but to contribute to salmon production. Juvenile salmon will derive some benefit both from direct use and indirect contributions to epibenthic food webs or water quality that result from beach restoration, riparian planting, debris removal, storm-water separation, and other actions wherever they occur. Many widely distributed initiatives such as the proposed restoration of the Puget Creek beach (Alder Way Street and Ruston Way, along Ruston Way shoreline) can

make a landscape difference in how juvenile salmon are able to utilize the delta/Bay, particularly since Pacific International Engineering (1999) and other sources provide evidence that the Bay's western shoreline is used by juvenile salmon, perhaps originating from both the Puyallup River watershed and other sources in southern Puget Sound.

RECOMMENDATIONS

1. BEGIN AT LANDSCAPE AND WATERSHED PERSPECTIVE

Contrary to most earlier approaches to strategizing and planning for estuarine habitat restoration in the delta/Bay (although, see earlier citations of more landscape-based initiatives), restoring juvenile salmon habitats must begin at landscape and watershed perspectives. We cannot afford emphasize one life history aspect or landscape focus area while disregarding others. While some segments of the estuarine landscape have been virtually disregarded in terms of restoration (e.g., tidal–freshwater), emphasis in this region must be supplemented by increased connectivity among the other critical transitions regions of the delta/Bay. This suggests that preserving restoration opportunities in these regions should be of exceptionally high priority.

2. SEQUENCING OF RESTORATION

Ranking and assessment of restoration alternatives would benefit from a systematic approach that incorporates landscape metrics in addition to feasibility and policy factors. A desirable approach would be to incorporate GIS data as a method of setting priorities for selecting restoration sites using quantifiable criteria, such as adopted by Simenstad et al. (in press b) for identifying high-priority breached-dike sites in Tillamook Bay. Although designed for salmon recovery actions in freshwater, Bilby et al. (in prep.) involves a GIS-based analysis process that incorporates many of the same steps (e.g., determining landscape attributes associated with specific salmon population segments and identifying disrupted and functioning ecosystem processes). Their analytical approach would be particularly appropriate for evaluating estuarine habitat restoration actions because it addresses life-history variations in habitat requirements. While these approaches are designed around ecological criteria, other factors such as site availability should also be considered as secondary ranking criteria.

3. NEW DATA ANALYSIS AND ACQUISITION

There are still considerable gaps in our information on juvenile salmon use of the delta/Bay ecosystem. Although the recent mark and recapture studies by Pacific Interna-

tional Engineering will contribute significantly to this knowledge, especially in conjunction with its synthesis of historical salmon catch data, individual-based marking and other methods are still needed to acquire individual resident time and growth data. In addition, diet composition and consumption rate data need to be gathered systematically and over the long term, instead of opportunistically, to resolve whether engineered, created, and natural habitats are comparable in terms of supporting juvenile salmon production.

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APPENDIX: RESTORATION RANKINGS

APPENDIX TABLE 1. Background data on potential NRDA high or medium ranking restoration sites in the Puyallup River delta and Commencement Bay. Revised from original US Army Corps of Engineers GIS data (US Army Corps of Engineers 1993) and Commencement Bay Natural Resources Trustees (1997) in accordance with more recent NRDA Trustees information (J. Lantor, USFWS, and R. Clark, NOAA).

Site no.	Name	NRDA designation	NRDA Trustees site and ranking	Area (acres)	Owner	Value	Proposed	Contamination
1	Wasser-Winter	proposed	H-11; high	19.41	Port of Tacoma	\$151,000	Excavate to create/restore intertidal flats and marsh associated with mouth of Hylebos Creek; currently WDOE Model Toxics Cleanup Act site; 100 ft buffer left along creek to conduct restoration	Confirmed metals
2	Hylebos Conservancy Area	proposed	H-9; high	27.53	Port of Tacoma; Puyallup Tribe of Indians; William Sny	\$97,000	Restoration scheduled for summer 2000; preserve existing mudflat; plant marsh vegetation, excavate to create/restore intertidal habitat.	Unknown?
3	Meaker Beach Marsh	proposed	H-10A; high	17.47	Foss Maritime; Puyallup Tribe of Indians	\$46,600	Preserve existing mudflat; plant marsh vegetation.	Unknown?
4	Middle Waterway Mudflats	restored	M-2; high		Simpson and Champion		Restored as part of NRDA settlement with Simpson and Champion in 1995; mudflat and marsh	Unknown?
5	Middle Waterway Shore	pending	M-2; high		City of Tacoma		NRDA settlement with City of Tacoma; scheduled restoration construction summer 2000	Unknown?
6	Tahoma Salt Marsh	pending	RU-2; medium	6.36	City of Tacoma	\$122,500	NRDA settlement with City of Tacoma; remove riprap buildings and asphalt; excavate to intertidal elevation; plant marsh vegetation.	Unknown?
7	Hylebos Conservancy Area	proposed	H-10; high		Puyallup Tribe of Indians; Foss Maritime		Preservation of mudflat; enhancement of fringing marsh vegetation	Unknown?
8	Marine View Driver Reserves 1-3	potential	H-10A; high		WDNR		Preservation of mudflat; enhancement of beaches	Unknown?
9	Slip 5	mitigation	B-9; medium	3.44	Port of Tacoma	\$75,600	Existing mitigation beach; proposed expansion of mitigation	Unknown?
10	Gog-Le-Hi-Te	restored	PR-5	36.65	Port of Tacoma; U.S. Govt. (for Puyallup Tribe of Indians)	\$75,500	Dike breach to create/restore intertidal marsh and flats, forested and scrub/shrub wetlands.	None
11	Swan Creek	pending	PR-7; medium		City of Tacoma		NRDA settlement with City of Tacoma; construction schedule for summer 2000; breach dike	Unknown?