

Snohomish River Estuary Monitoring Plan

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Aerial image of Quilceda Marsh in the lower Snohomish River estuary. Available: <https://fortress.wa.gov/ecy/shorephotoviewer/>
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Executive Summary:

This report describes the development, implementation, and management of a restoration monitoring plan for the Qwuloolt Estuary restoration project located within Snohomish River estuary in Puget Sound. The large capital investments typically required to restore tidal connectivity to previously diked lands, like those planned in the Snohomish River estuary, and the underlying goals of such restoration efforts highlight the need to develop and implement a restoration effectiveness monitoring programs that consider both individual project-scale and cumulative landscape-scale impacts of restoration (Diefenderfer et al. 2011). The Snohomish River estuary has become the focus of intense restoration planning and activity designed to support salmon recovery efforts for ESA listed Puget Sound Chinook salmon. The overarching goal of the monitoring plan described here is to provide a consistent monitoring framework from which restoration responses for key ecosystem components can be monitored and evaluated at both project- and landscape-scales to provide information that can be used to inform the design and management of estuary restoration projects. Collectively, the framework presented here is intended as a template for continued monitoring in the Snohomish River estuary as new projects are implemented, as well as a template that can be used to help develop restoration effectiveness monitoring plans for other estuary systems.

Introduction:

Salmon and Estuaries:

Estuaries are complex and dynamic ecosystems that provide valuable and highly productive habitats for a number of species. However, estuaries have also been the focus of intense human development and alteration throughout the world (Lotze et al. 2006). The Pacific Northwestern United State's Puget Sound region is no exception from global patterns of estuarine habitat loss, with an estimated loss of $\approx 90\%$ of tidal wetland habitats across Puget Sound's large river delta systems (Simenstad et al. 2011). Substantial losses of estuary habitats have been linked with declines in many estuarine-dependent fish populations in many regions of the world (Lotze et al. 2006; Magnusson and Hilborn 2003; Greene et al. 2015). Anadromous fishes, and Pacific salmon (*Oncorhynchus* spp.) in particular, are especially sensitive to estuarine habitat losses and population declines of Pacific salmon have been linked to estuarine habitat loss in the Pacific Northwestern United States (Beamer et al. 2005; Bottom et al. 2005; Simenstad and Cordell 2000; Simenstad et al. 1982; Greene et al. 2015).

Pacific salmon rely on estuary habitats to varying degrees depending upon species and life history types, but all anadromous species rely on estuaries as they migrate between freshwater and marine habitats throughout the life cycle. In addition, juvenile salmon may migrate relatively quickly through estuary habitats (e.g., hours to days) or may rear extensively in estuarine habitats (e.g., days to weeks or months). Estuaries provide juvenile Pacific salmon with salinity gradients necessary to complete physiological adaptations to transition from fresh to salt water, favorable conditions for growth prior to migration to the ocean (David et al. 2014), and refugia from predators and high flows (Healey 1982, Thorpe 1994, Simenstad and Cordell 2000, Beamer et al. 2005). Functional estuarine habitat can promote life history diversity for salmon populations (Beamer and Larsen 2004) and help buffer potential effects of freshwater density dependence (Greene and Beechie 2004); both of which have been positively linked to marine survival (Merrell and Koski 1978; Bottom et al. 2005; Bond et al. 2008; Craig et al. 2014).

Among the Pacific salmon species, Chinook salmon are particularly dependent upon estuarine habitat given their varied juvenile life history strategies throughout their range. Such dependence has made Chinook populations sensitive to estuarine habitat loss which has been implicated in local population declines (Beamer et al. 2005; Bottom et al. 2005; Simenstad and Cordell 2000; Simenstad et al. 1982; Greene et al. 2015). Subyearling Chinook migrate downstream within days to months after emerging from their redds (i.e., salmon nests) in the spring and may rear in estuaries for weeks to months before completing their migration to marine habitats (Simenstad et al. 1982; Simenstad and Cordell 2000; Beamer et al. 2005; Bottom et al. 2005). Subyearling Chinook, in contrast to yearling Chinook that overwinter in freshwater habitats and use estuary habitats to a lesser extent during their migration to the marine environment, represent the predominant life history type for Puget Sound Chinook populations, which are listed as Endangered under the Endangered Species Act (ESA). Given the link between Chinook salmon and population declines and the need to develop strategies to

support recovery of ESA listed salmon populations, restoration of Puget Sound's lost estuarine habitats has become a growing focus of Puget Sound population recovery efforts (e.g., Cornwell et al. 2001; Gray et al. 2002; Beamer et al. 2005; Diefenderfer et al. 2006; Ellings et al. 2016; Diefenderfer et al. 2011; Craig et al. 2014; Greene et al. 2016).

The Snohomish River Estuary:

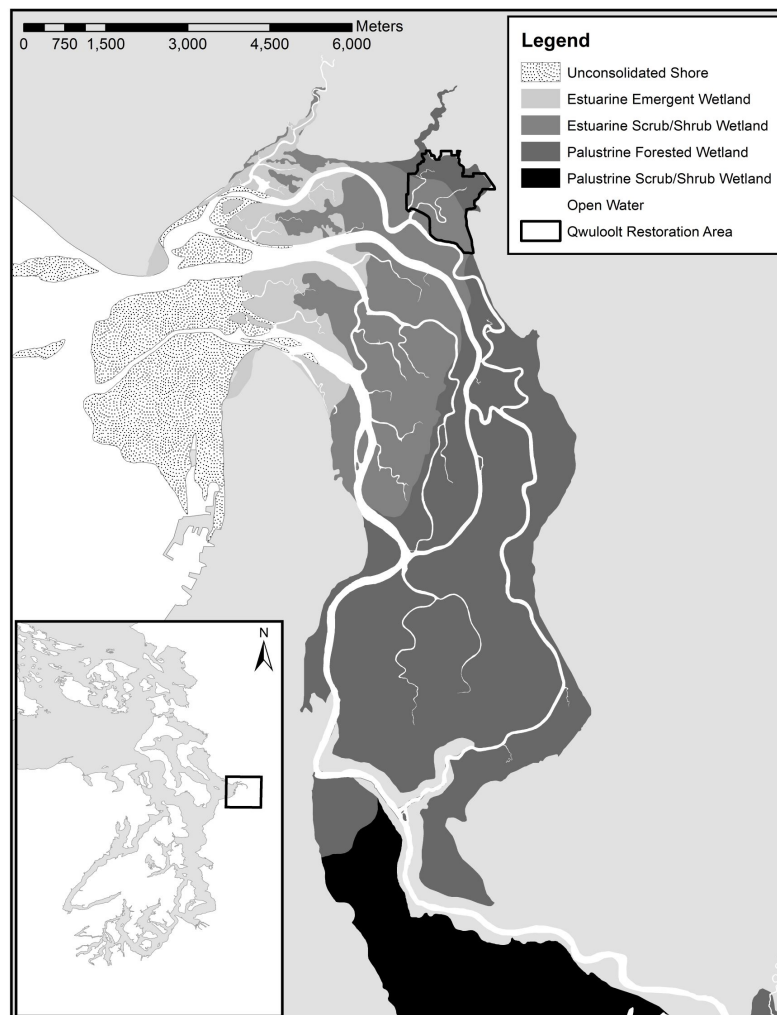
The Snohomish River estuary is the second largest river delta system within Puget Sound and has recently become the focus of intensive estuary restoration efforts and actions. The Snohomish River watershed drains approximately 4,600 km² into Puget Sound (Figure 1) and represents the second largest freshwater input to Puget Sound with a mean annual discharge of 271 m³ s⁻¹ (USGS 2011). The Snohomish River is formed by the confluence of the Snoqualmie and Skykomish Rivers, approximately 37 km upstream from the mouth of the Snohomish River. The Snohomish River flows into the Puget Sound through a complex system of braided distributary channels (Figure 1), and tidal influence can extend throughout the entire distributary network and up the mainstem channel to river kilometer (rkm) 27 (Collins and Sheikh 2005). The Snohomish River currently supports wild populations of anadromous salmon, including ESA listed Chinook salmon (*O. tshawytscha*), steelhead (*O. mykiss*), and bull trout (*Salvelinus confluentus*), as well as all species of Pacific salmon native to the region (i.e., pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), cutthroat trout (*O. clarkii*)).

Figure 1. The Snohomish River watershed (A) and the Snohomish River estuary with its braided distributary channel network (B).

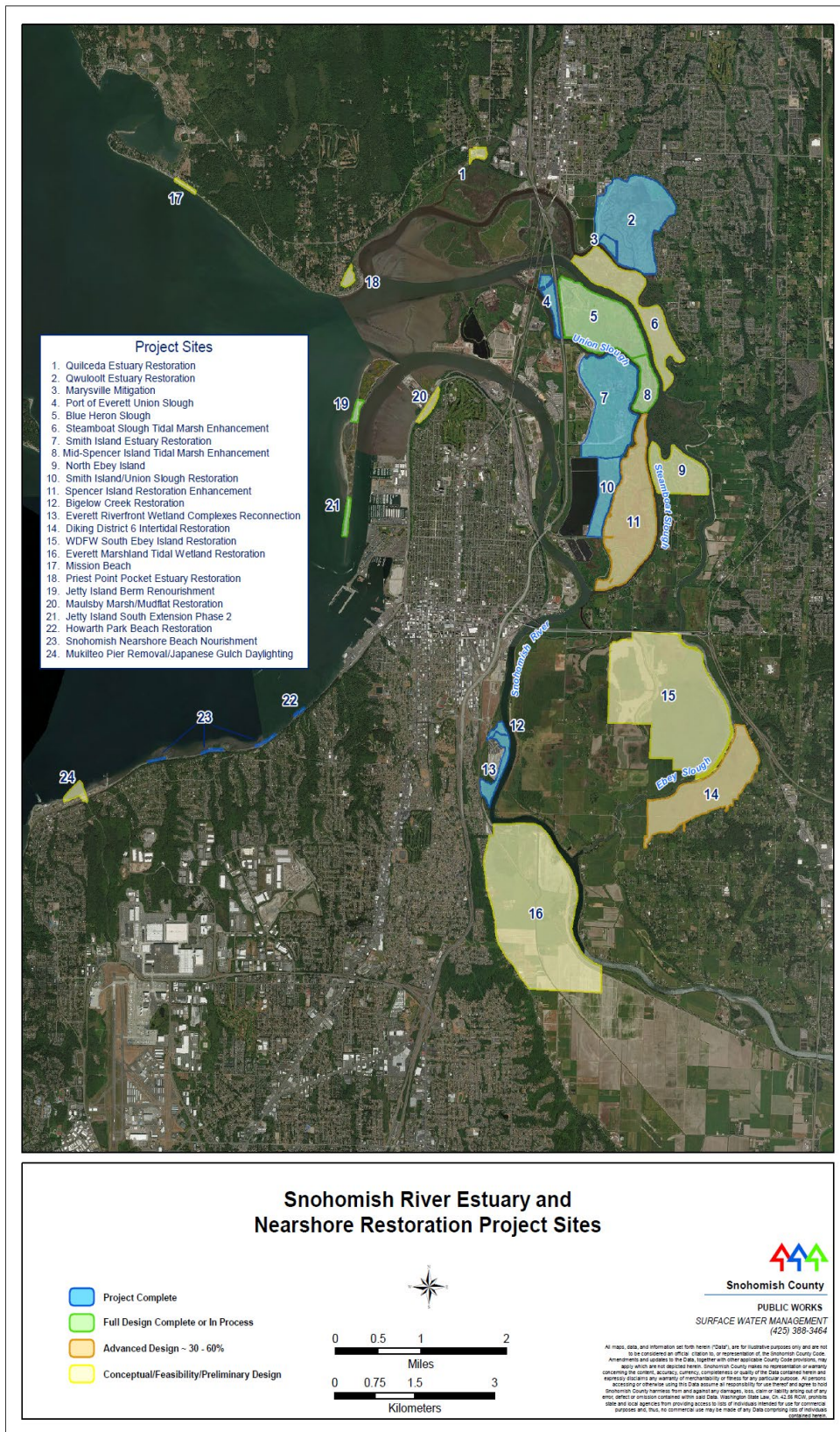


Prior to extensive development beginning in the mid-19th century, the Snohomish River supported approximately 64.1 km² of tidally influenced wetlands (Figure 2; Collins and Sheikh 2005). This represented the second largest estuary system in Puget Sound, and accounted for approximately 24% of tidal wetlands in Puget Sound prior to development of the region (Collins and Sheikh 2005). Like most of Puget Sound's large river deltas, substantial estuary habitat losses occurred following settlement of the area. Approximately 90% of pre-settlement habitat was converted through diking and filling at the peak of development (Collins and Sheikh 2005, Simenstad et al. 2011), which was primarily agricultural in nature with intense industrial development along the middle and lower mainstem channels. Despite these substantial losses, this estuary remained the second largest complex of vegetated tidal wetlands in Puget Sound (Collins and Sheikh 2005, Simenstad et al. 2011).

Figure 2. Map of estimated tidal wetland habitat extent by major habitat zones before development in the Snohomish River estuary. Data for this map were obtained from (Collins and Sheikh 2005). The Qwuloolt Estuary restoration project is shown for reference.



The large losses and degradation of juvenile salmonid habitat in the Snohomish estuary, as a result of anthropogenic activities, was identified in the Snohomish Basin Recovery Plan as a primary factor limiting Chinook salmon survival in the basin (SBSRF 2013). Fortunately, a number of potential habitat restoration opportunities have been identified within the Snohomish River estuary to support such recovery efforts (Figure 3). The suite of restoration opportunities are currently in various stages of planning (e.g., conceptual and feasibility planning), design, and implementation (Figure 3) and collectively represent restoration of tidal connectivity to approximately 50% of pre-settlement tidal wetland habitat extent.



The Qwuloolt Estuary Restoration:

Among the suite of potential and planned restoration projects within the Snohomish River estuary, the Qwuloolt Estuary restoration project represented one of the larger restoration projects available in the estuary (Figure 3). Historically, the project area was tidal emergent marsh and a mix of forested and scrub-shrub tidal wetland, interlaced by tidal channels with two small tributary streams draining through the site (Haas and Collins 2001). In the early 1900's, a levee was constructed on the north bank of Ebey Slough and tide gates were installed at the mouth of Allen and Jones Creeks to convert the land for agricultural use. Constructed levees and tide gates have prevented tidal processes within the project area and obstructed migration, transforming the site's ecological condition and severely reducing its ability to support native salmon populations and other estuarine biota. Over time, the project site had become deeply subsided (as is typical of previous tidal marshes that are disconnected from tidal and riverine flooding); dominated by invasive reed canary grass, thistle, and blackberry; and was no longer being used for agricultural purposes (Cereghino 2006).

Plans to restore tidal connectivity to the Qwuloolt Estuary began in the 1990's with the project representing compensation to the public for injuries to natural resources as a result of the Tulalip Landfill, a Superfund site (Adolfson Associates 2006). The project was designed to restore tidal flooding to approximately 142 hectares (360 acres) of former estuarine wetland (Collins and Montgomery 2001, Haas and Collins 2001) within the lower estuary. The key components of the restoration design included a single breach of an existing dike and lowering a section of the dike adjacent to the breach; construction of setback levees to protect municipal infrastructure; construction of wave attenuation berms; and the construction of starter channels, primary channels, and filling of some ditch lines (Figure 4). The original planned date of completion was delayed several times during the design and implementation phases, with the breach finally completed on August 28, 2015 (Figure 5).

Figure 4. Map of key design elements for the Qwuloolt Estuary restoration project. See Figure 3 projects for map of project location within the Snohomish River estuary.

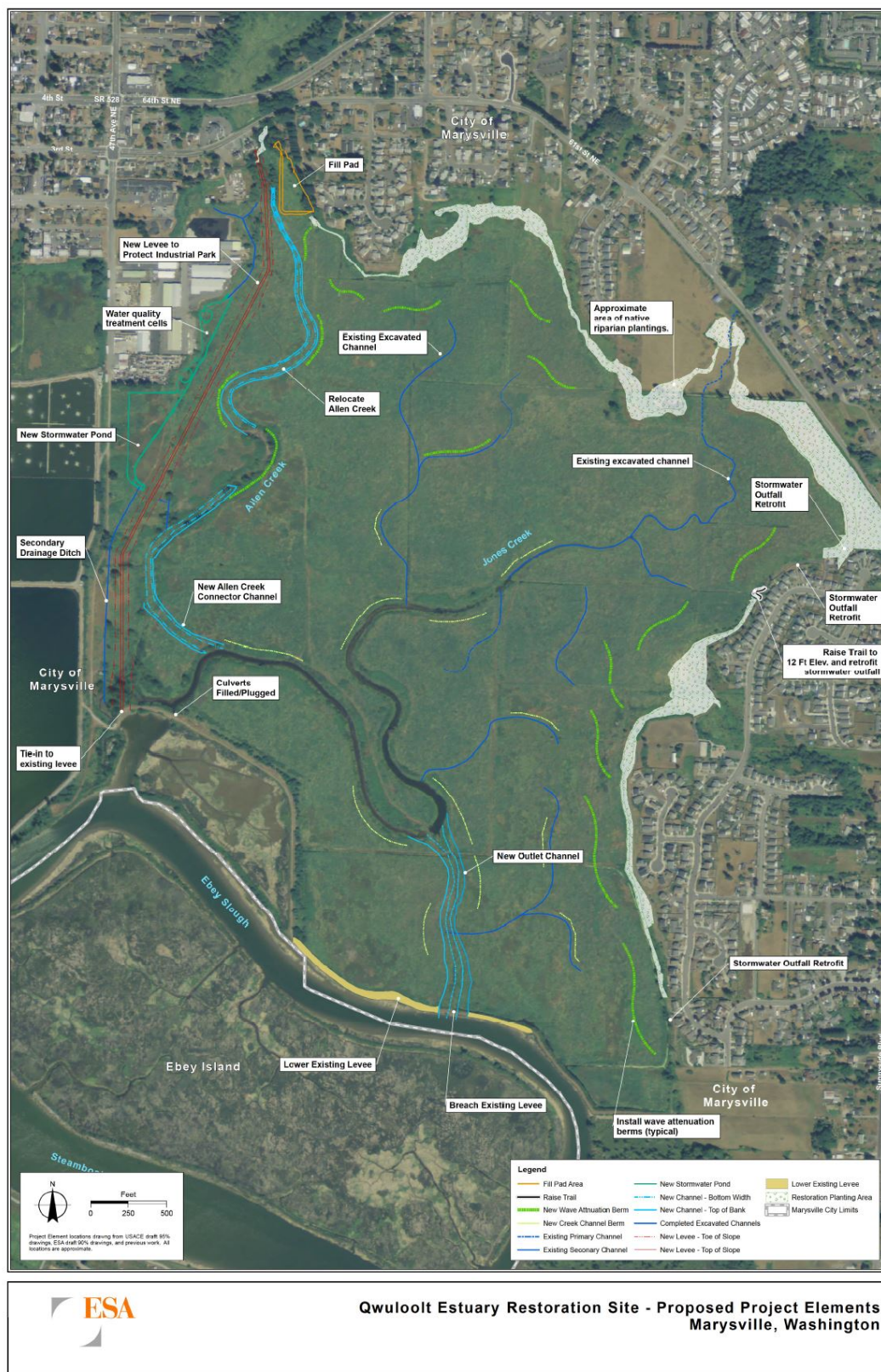


Figure 5. Photo of the final breach being cut for the Qwuloolt Estuary restoration project. This image was taken from the time lapse webcam installed at the site to provide a visual record of change over time and a public outreach tool.



With a growing focus on estuary habitat restoration as a recovery strategy for ESA listed Chinook salmon, development and implementation of a restoration effectiveness monitoring plan for the Qwuloolt Estuary project began in 2009 (Rice et al. 2011). Researchers with the National Oceanic and Atmospheric Administration's (NOAA) Northwest Fisheries Science Center (NWFSC) and the Tulalip Tribes sought to create a monitoring framework that would provide information to support the management of the Qwuloolt Estuary restoration project, evaluation of restoration effectiveness within a project-scale and landscape context, and provide a framework for understanding cumulative restoration impacts within the Snohomish River estuary. The framework should be temporally and spatially intensive and extensive and track/measure key physical and biological components necessary to answer important restoration effectiveness questions. A comprehensive monitoring framework can be used to evaluate project success as well as improve restoration design and aid prioritization of future restoration actions.

Adaptive Management Monitoring Framework:

Estuary restoration typically aims to restore tidal connectivity to previously disconnected areas requiring substantial capital investments and many years of planning across a number of federal, state, tribal, local, and private agencies and entities. Although the specific goals and design elements may vary among projects, they generally share the desire to increase salmon population abundance and resilience by increasing the quantity of estuary habitat. Yet, as with most complex ecosystems and resource management issues, uncertainties exist regarding anticipated outcomes of restoration actions. Such uncertainties are inherent where imperfect information exists for highly dynamic environments or habitats. Adaptive management strategies are predicated upon recognizing these uncertainties and revising management actions and/or decisions given increased precision or availability of information, in order to meet the original, or in some cases, revised project goals. Inherent within such a framework are appropriately scaled and focused monitoring programs designed to address potential uncertainties and provide information that can be used to adaptively manage projects as new information becomes available through effectiveness monitoring actions.

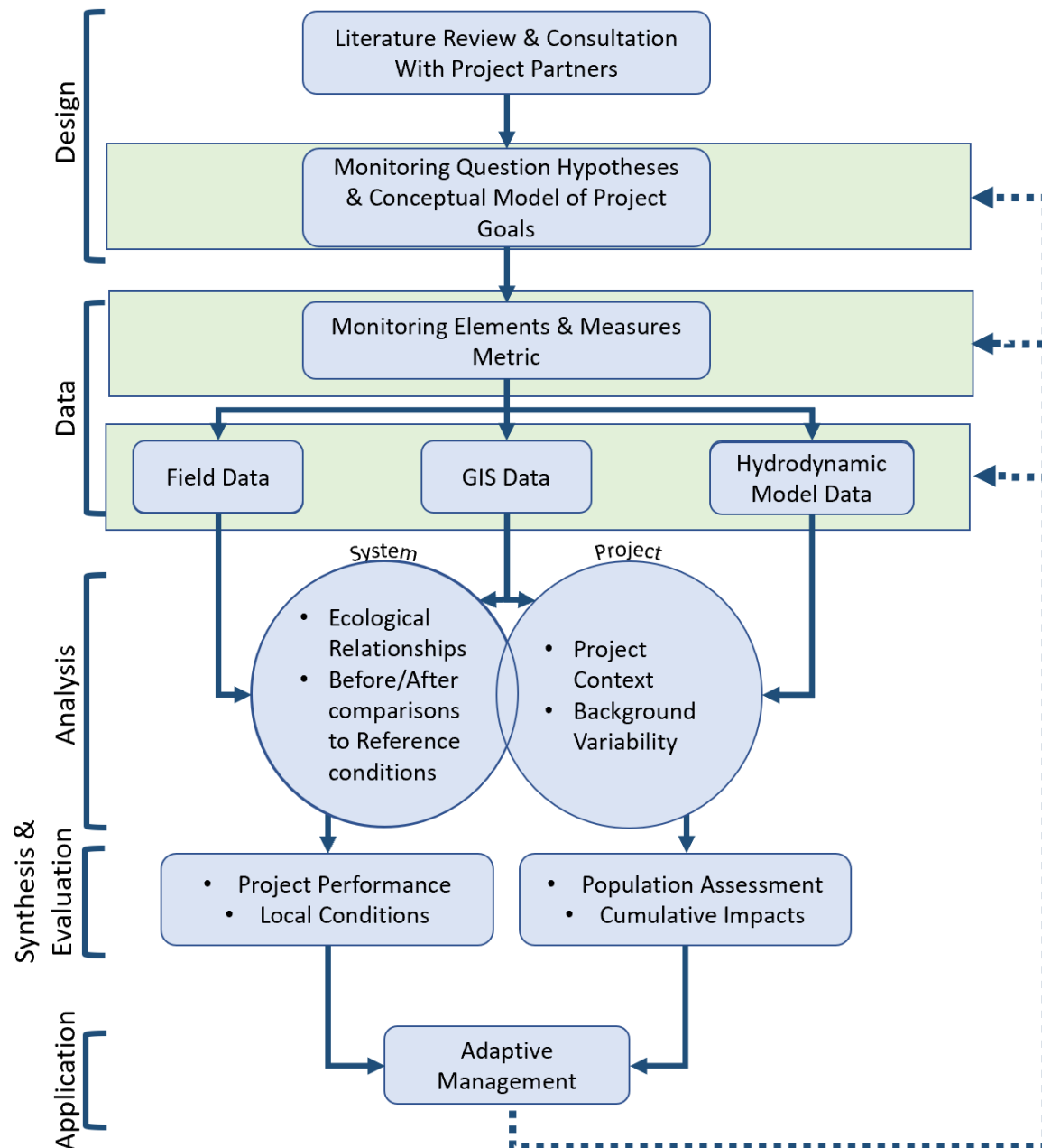
The complexity of estuarine ecosystem processes coupled with substantial capital investments and great uncertainties concerning restoration effectiveness highlight the need for restoration effectiveness monitoring. Despite the recognized importance of understanding restoration effectiveness, monitoring is frequently not a priority component of restoration project budgets or may not be included at all. The emphasis on “moving dirt” with an “if we build it, they will come” approach has contributed to continued uncertainties around estuary restoration effectiveness. Where monitoring is funded, such efforts are frequently insufficient in spatial extent, temporal duration, sampling frequency, and/or monitoring scope to detect restoration responses that can be used in a meaningful way to inform restoration science, design, and management. For example, juvenile salmon rearing and migration patterns can change dramatically on the scale of days to weeks with inter-annual variations in peaks, timing, and duration in estuaries (Beamer et al. 2005). Furthermore, the complexity of salmonid life histories is such that juvenile cohorts typically return as adults over a span of 2-5 years (Groot and Margolis 1991, Quinn 2018). To address such factors a monitoring program needs to be sufficiently intensive within years to capture rearing and migration patterns, and extensive across years to capture salmon population responses that require at least five years of monitoring before one cohort is captured. Furthermore, restoration projects are typically not isolated and occur within a larger landscape. Thus restoration effectiveness monitoring should attempt to evaluate site level conditions/changes within the context of the system as a whole. System-wide components of a monitoring design will not only aid evaluation of local conditions but provide a framework for evaluating cumulative impacts of multiple projects and larger scale landscape or regional patterns (e.g., climate change, interannual variations in climate or fish abundance, fisheries management, etc.) that may influence observed responses and recovery trajectories for a specific project.

Such restoration efforts typically involve land acquisition(s), permitting, multi-agency coordination, design and construction of setback levees to protect infrastructure, breaching and/or lowering of existing dike/levee structures, and construction of channel features. The complexity of these planning and design challenges are only rivaled by the inherent complexity of the dynamic ecosystem processes and population dynamics to which the restoration efforts are designed to impact. Furthermore, restoration of tidal connectivity presents unique challenges to restoration as decades of disconnection from tidal and riverine flooding typically results in substantial subsidence of lands behind dike and levee infrastructures. Surface elevation is a major driver of the physical and biological character of a tidal wetland, and there are great uncertainties as to the potential recovery trajectories associated with restoration of tidal connectivity in subsided areas that have been disconnected from tidal and riverine flooding for many decades.

Ideally, an estuary restoration effectiveness monitoring framework will be a long-term, interdisciplinary effort designed to assist in the management of a given project and consider cumulative impacts at landscape scales within these dynamic ecosystems. The development of our monitoring plan began as part of the project planning process (Rice et al. 2005; Roni 2005; Diefenderfer et al. 2011) whereby specific goals for the project were identified and hypotheses developed to match specific goals (Figure 6). Goals and hypotheses were created to address both the physical/biological attributes and conditions of a particular site as well as any infrastructure related components included within the project design/plan. Subsequently a suite of monitoring questions were identified to measure the progress toward meeting the project goals. Specific monitoring questions were then be linked to specific monitoring elements, likely interdisciplinary, that include specific metrics to be measured and evaluated using multiple sources and analytical techniques to incorporate elements across both project and system scale components of the monitoring framework. Lastly, the development, management, and execution of the monitoring framework incorporates adaptive management feedback loops that enable project managers to evaluate and revise goals, questions, and hypotheses as new information becomes available (Figure 6).

Given the momentum around estuary restoration as a salmon recovery tool, many regional recovery planning programs in Puget Sound region have recognized the need for monitoring in support of adaptive management strategies (e.g., Beamer and Larsen 2004; SBSRF 2013; PSP 2014; Greene et al. 2016; Beechie et al. 2017). Several long-term intensive estuary restoration effectiveness monitoring programs have been developed and initiated within the last decade within the Puget Sound region (e.g., Skagit River delta IMW, Greene et al. 2016; Nisqually River delta, Ellings et al. 2010) as components of adaptive management frameworks for particular projects or watersheds. Both individually and cumulatively, these monitoring programs may help inform design and management of future recovery actions (Rice et al. 2005; Roni 2005; Diefenderfer 2006; Thom et al. 2007; Peters et al. 2014) to improve our ability to support salmon recovery through estuary restoration.

Figure 6. Basic steps, progression, and feedback diagram for the development and application of a monitoring framework modified from Diefenderfer et al. (2011) and Roni et al. (2005).



Monitoring Framework:

The monitoring framework for the Qwuloolt Estuary restoration project was developed through consultation of a number of sources and with relevant project partners (e.g., Simenstad et al. 1991; Thom and Wellman 1996; Elzinga et al. 2001; Neckles et al. 2002; Thayer et al. 2003; Rice et al. 2005; Roni et al. 2005; Diefenderfer et al. 2011; Thom et al. 2007; Hood 2009; Roegner et al. 2009). The vision for this monitoring program was to develop an intensive project-scale monitoring framework focused on key monitoring elements that were nested within a landscape-scale framework with shared core monitoring elements. This approach was designed to allow project-scale responses to be evaluated within the context of larger landscape-scale patterns and trends, and to establish a monitoring framework applicable and adaptable to other projects as they are implemented throughout the delta. In this way, the monitoring framework would provide a consistent long-term project- and system-scale framework from which responses at both an individual project level and cumulative ecosystem responses to multiple projects across the landscape could be evaluated using a core suite of monitoring elements and standardized protocols.

Development and implementation of a restoration effectiveness monitoring plan for the Qwuloolt Estuary project began in 2009 (Rice et al. 2011) with the restoration originally scheduled for implementation in 2012. This would have allowed two years of pre-breach monitoring before tidal connectivity was restored to the site, but delays pushed the actual breach date to August 2015. These delays were fortunate in some regards as they allowed for continued development and refinement of a monitoring plan, and collection of more baseline project-scale and landscape-scale data prior to project implementation. The monitoring framework presented in this report serves as an update to the original monitoring plan (Rice et al. 2011). This framework details the monitoring goals; conceptual model; questions and hypotheses; scale and study design; monitoring elements and sampling design.

Presently, the approach to post-breach management of the Qwuloolt Estuary is passive with respect to ecological development of the site, relying on the return of tidal inundation to the site and subsequent natural biological colonization and ecosystem processes to restore the site to a functional tidal wetland habitat. However, there are limited active efforts to reduce invasive species and maintenance of native vegetation along the constructed berms within the site. The proposed monitoring framework was structured to focus efforts on documenting and explaining observed changes over time—regardless of the trajectory—and describing those changes in the context of reference information.

The following sections of this report describe the development, implementation, and management of a restoration effectiveness monitoring plan for the Qwuloolt Estuary restoration project. The monitoring framework for the Qwuloolt Estuary restoration project includes both project-scale and system-scale elements that provide the necessary context for measuring responses to restoration at the project site within the context of underlying patterns within the estuary system. Up to date monitoring results from this monitoring framework will be included as

a separate status and trends report, which will include preliminary pre- and post-breach results for the Qwuloolt Estuary project and system-scale patterns.

Restoration Goals:

The original project goal for the Qwuloolt Estuary restoration project was to “restore historic tidal circulation and processes and functions,” and objectives were identified by project managers in support of attaining this goal (Adolfson Associates 2006). We expanded this original goal to include reference to the desired biological function of the site while recognizing the implicit link between the physical and biological processes that will influence the recovery trajectory of the Qwuloolt Estuary. The revised goal for the Qwuloolt Estuary restoration project is;

“Restore historical tidal circulation processes and functions to the Qwuloolt Estuary, and move the biological integrity and function of the site towards comparable natural habitats of the region.”

Biological integrity can be defined as “a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region” (Karr and Dudley 1981). Implicit in biological integrity is the link between dynamic physical and biological processes that drive attributes that are used to measure different aspects of biological and system integrity. Recognizing these linkages, we developed goals for key focus areas that represent core ecosystem processes that control the biological and physical character of tidal wetland habitats (e.g., topography, hydrology, and biota), and key societal elements that are important at both the immediate site-scale and the broader field of restoration science. Key focus areas and goals are used to inform the monitoring questions, and thereby the monitoring framework, and include;

(1) Topography:

- A. *Allow maximum tidal inundation.*
- B. *Maintain and develop elevation, soil conditions, and hydrologic connectivity favorable to native biota historically present.*

(2) Hydrology:

- A. *Maximum tidal inundation.*
- B. *Temperature, salinity, and dissolved oxygen favorable to native biota historically present.*

(3) Biota:

- A. *Character of the biota onsite returns over time to a condition similar to that historically present.*

(4) Society:

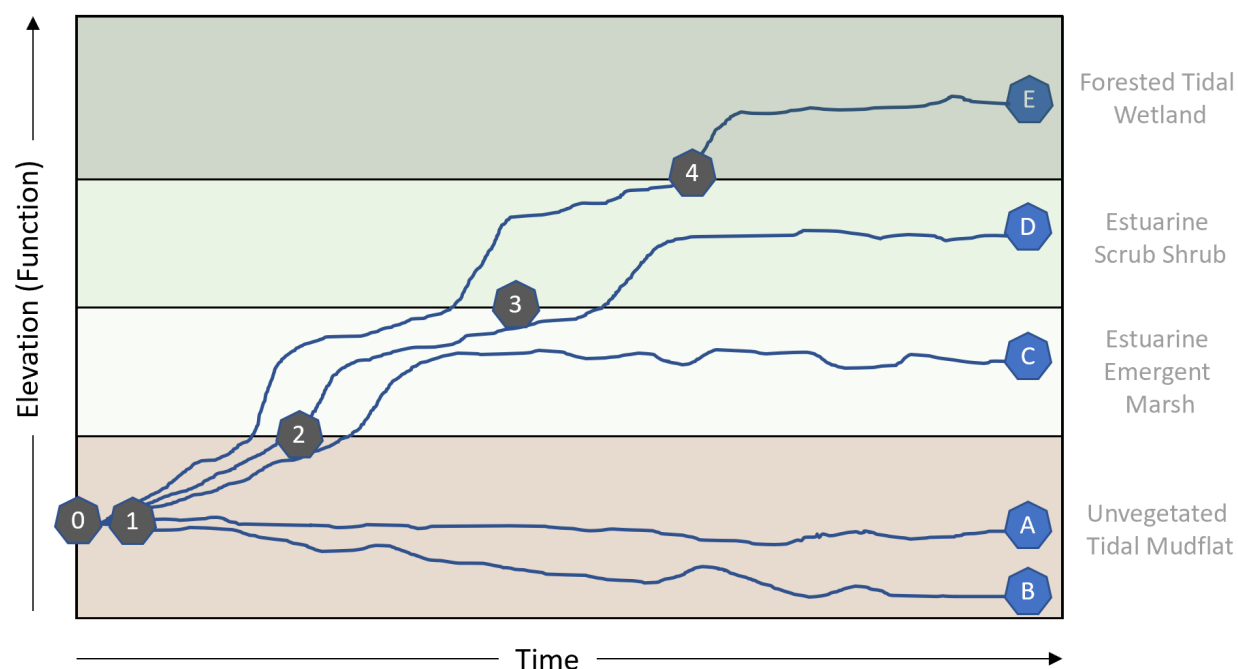
- A. *No major adverse effects to property and infrastructure.*
- B. *Positive contribution to natural and cultural heritage of the community in terms of conservation, education, and recreation.*
- C. *Positive contribution to restoration science and practice*

In developing and evaluating the project goals and recovery trajectory for the Qwuloolt Estuary restoration project, it must be recognized that return of a truly pristine pre-settlement state is not possible. Therefore, the project goals should be to restore the site to historical conditions within modern constraints (Wilbur et al. 2000; Simenstad et al. 2006b). These constraints include human modifications to watersheds (Simenstad et al. 1992), estuarine wetlands (Haas and Collins 2001), and fish populations (Pess et al. 2003). In addition, the design of the Qwuloolt Estuary restoration project itself will impose constraints due to the practical realities of, for example, protecting public infrastructure and controlling project costs. In the Qwuloolt Estuary design, breach versus removal of dikes, mounding and side-casting during excavation, and armoring of shorelines will all constrain natural processes to some extent. Finally, large-scale regional and/or global processes and forcing factors (e.g., climate change, sea level rise, deep subsidence, hydrostatic rebound, tectonic processes) have the potential to constrain the recovery trajectory of the Qwuloolt Estuary restoration project and should be considered in interpreting the monitoring results and adaptive management of the project.

Conceptual Model of Restoration:

A conceptual model of the system being restored is a critically important component of the monitoring framework for a restoration project (Thom and Wellman 1996, Simenstad et al. 2006a). Considerable uncertainty exists regarding the actual course of the project site, and both the nature and rate of change among the various attributes could take many forms. Monitoring to document and diagnose change of the site over time is critical to determine the trajectory of the project and to evaluate restoration effectiveness with respect to the project goals. In tidal marsh restoration, elevation of the marsh surface is closely related to ecosystem function as elevation is a primary driver of tidal inundation frequency and duration both of which influence the interdisciplinary biological conditions at the site. Therefore, a generalized conceptual model for estuary restoration can be framed in terms of changes in marsh surface elevation and thus vegetation over time (Figure 7).

Figure 7. Conceptual model for responses to restoration in a tidal marsh with time along the x-axis and elevation or function represented by the y-axis. The axis are not to scale and meant to generally represent elevations in the range of centimeters to meters along the y-axis and years to decades and centuries along the x-axis. Possible response trajectories are shown as lines, key stages are shown as grey octagons with numbers, and possible endpoints are shown as blue octagons with letters. The stages include the initial state or as-built stage (0), short-term post-breach state (1), vegetation establishment (2), and subsequent transitions in marsh vegetation structure (3 and 4). Possible response trajectories are shown as an unvegetated mudflat (A and B), estuarine emergent marsh (C), estuarine scrub-shrub marsh (D), and forested tidal wetland (E).



Conceptual models for individual tidal marsh restoration projects like the Qwuloolt Estuary will depend on the initial state and the interaction between tidally influenced hydrological and sedimentological processes. In many cases, including the Qwuloolt Estuary, the initial state is a subsided topography resulting from decades of disconnection from tidal and riverine processes. Depending on the severity of subsidence, the initial post-breach state may be an unvegetated tidal mudflat if initial surface elevations are not sufficient to support vegetation (Figure 7). The progression of recovery over time within the site will depend on this initial state and the interaction between tidal and riverine processes over time, and these changes may operate over time scales of years to decades to centuries (Figure 7).

Once levees and dikes are breached in tidal marsh restoration projects, the site will immediately be reconnected to tidal and riverine processes. This restoration of connectivity (riverine and tidal) will initiate some relatively rapid short term changes at the site. This initial phase may be characterized by relatively rapid dieback existing vegetation (e.g., reed canary grass in the Qwuloolt Estuary); changes in soil chemistry and hydrology; shifts in fish, insect, and other

animal community assemblages within the site; and initiation of channel development, cutting, and sediment redistribution. Constructed or natural higher elevation features (e.g., wave attenuation berms or setback levees in the Qwuloolt Estuary) may continue to support existing vegetation for longer periods after tidal inundation is restored to the site, but shifts in the overall vegetation community are likely for most of the site. These rapid short-term post-breach changes in the system stage are likely to occur on the scale of days to years (Figure 7).

Following this initial stage (Figure 7), there are a number of possible response trajectories that will be determined by interactions between several, likely long-term, processes. The balance between deep surface processes (e.g., deep subsidence or hydrostatic rebound), sedimentation and erosion, and channel formation over time could result in the maintenance of surface elevations or a lowering of the surface elevation over time. For example, if deep subsidence exceeds sedimentation rates we would expect surface elevations to decline over time. In either scenario of maintained surface elevations or lowering surface elevations, the site would likely remain an unvegetated tidal mudflat over time if the initial state of subsided topography was insufficient to support tidal marsh vegetation (Figure 7).

If sedimentation rates exceed erosion or deep surface processes, we would expect a net increase in elevation over time. The rate of change in surface elevations will depend on the net balance of these processes, and the trajectory may fluctuate over time depending on changes in system-scale processes (e.g., riverine and marine sediment loading and hydrology). Under these scenarios, we would expect surface elevations to attain a sufficient elevation to support the colonization of marsh vegetation (Figure 7). This is an important stage for restoration response, as establishment of vegetation is likely to accelerate increases in surface elevation and vegetation establishment itself by reducing surface water velocities and erosivity of the marsh surface. Therefore, we might expect a punctuated change in the marsh surface as vegetation establishes within the site (Figure 7).

Assuming a certain degree of subsidence at the initial state, the initial plant community is likely to be an emergent marsh and the site may remain as an emergent marsh depending on the balance of processes within the site (Figure 7). However, accelerated and continued increases in elevation over time are also possible and the site may transition from an emergent marsh to a higher elevation estuarine scrub-shrub (Figure 7) or even a forested tidal wetland (Figure 7). The formation of forested tidal wetlands (like the Sitka spruce forested wetlands that existed in portions of the Qwuloolt Estuary prior to development and currently exist in reference sites) would require substantial aggregation and likely many decades to centuries to occur, if such a response trajectory is even possible. It is also possible that a diversity of community structures may form over time within the site due to variations in topographic change within the site over time. For example, portions of the site may remain unvegetated tidal mudflat while portions of the site transition to emergent or scrub shrub marshes.

Parallel to the development of marsh vegetation communities, we also expect evolution of the channel network. The trajectories for channel network evolution are also dependent on the initial state (e.g., subsided topography, soil characteristics, constructed channel network, and relict

channel network) as a function of the as-built design and breach strategy. Some changes in the channel network may occur more rapidly in the initial post-breach stage in high energy areas as undersized channels and new channels are cut to handle tidal flooding and ebbing within the site. Initial vegetation die off rates and retention of organic matter (e.g., root structure) may also greatly influence channel evolution rates as well as erosion and sedimentation rates on the marsh surface during the initial phases of response. However, channel evolution, like vegetation responses, are likely to occur over potentially long and gradual time spans (e.g., years to decades).

The conceptual model for tidal marsh restoration should inform the monitoring framework, as well as the adaptive management framework, by identifying key focus areas (e.g., topography, hydrology, and biota) and important stages of response for the site. From this, we can identify key questions and hypothesis to be addressed by the monitoring framework. These hypotheses and questions are then used to identify core monitoring elements to answer specific questions and track changes in key focus areas.

Monitoring Questions:

In addition to creating a solid conceptual model to understand, or provide context for, restoration within a system, we developed a set of site/project specific questions aimed at addressing the goals of a particular project(s). These questions assessed project effectiveness as well as provide feedback for adaptive management strategies as implemented/evaluated according to the conceptual model. For example, we posed questions to help identify areas of concern with respect to observed responses, possible causes, and potential corrective actions. The questions for the Qwuloolt Estuary monitoring framework are divided into four primary themes that include implementation, status and trends, effectiveness, and diagnostic. Together the questions posed under these themes should evaluate the specific project goals/elements, initial changes to site conditions, and inform future, potentially corrective, actions to maintain an effective restoration project. The questions are as follows:

Implementation:

1. Were all elements of the final design implemented in the as-built condition?
2. Did the as-built design allow full tidal exchange to the interior site?
3. Did plantings on wave attenuation berms and levee edges survive?
4. Was the breach design sufficient to handle tidal processes within the site?
5. Are infrastructure protection features within the site (e.g., flood and wave control structures) maintaining their integrity?
6. Are infrastructure protection features within the site (e.g., flood and wave control structures) performing as designed?

Status and Trends:

1. What is the gross morphology and topography of the site (e.g., elevation, channel development, sediment accretion, and large wood recruitment), and how is it changing over time?
2. What are the patterns of surface water elevation, temperature, and salinity within the site, and how do these change over time?
3. What is the taxonomic composition and distribution of plant assemblages within the site, and how does this change over time?
4. What are the taxonomic composition, distribution, and density patterns of fish assemblages using the site, and how does this change over time?
5. What are adult population abundances of coho returning to Allen Creek, and how do they change over time?
6. What are the taxonomic composition and abundance patterns of macroinvertebrates in the site, and how do these change over time?
7. What are the taxonomic composition and abundance patterns of birds and beaver in the site, and how do these change over time?

Effectiveness:

1. How does the gross morphology and topography within the site compare with reference marshes?
2. How do surface water elevations, temperatures, and salinity compare to reference marshes and landscape patterns?
3. Are surface water temperatures, salinity, and velocities within favorable ranges for desired biota?
4. Have desirable marsh vegetation communities become established within the site?
5. How do plant assemblages and extent compare to reference marsh sites?
6. How do fish assemblages and densities within the site compare to reference marshes and landscape patterns?
7. Are desirable fish species and life histories using the site?
8. Are adult coho population abundances to Allen Creek increasing over time relative to the Quilceda Creek reference system?
9. How do the taxonomic composition and abundance patterns of macroinvertebrates in the site compare to reference marsh systems?
10. How do the taxonomic composition and abundance patterns of birds in the site compare to reference marsh systems?

Diagnostic:

1. What factors are causing changes in surface elevations (e.g., sedimentation, erosion, deep subsidence)?
2. Are changes in surface elevation sufficient to keep pace with deep surface processes (e.g., deep subsidence) or potential sea level rise scenarios?
3. What factors are causing water temperatures, salinity, or velocities to depart from favorable ranges?
4. Did the restoration project site change hydrology within the landscape?
5. What factors are driving observed status and trends in plant assemblages and extent within the site?
6. What factors are driving observed status and trends in fish assemblages, densities, and distributions within the site?
7. What factors are driving observed status and trends in the taxonomic composition and abundance patterns of macroinvertebrates in the site?
8. What factors are driving observed status and trends in the taxonomic composition and abundance patterns of birds in the site?

Study Design:

Together, the conceptual model and specific monitoring questions, will provide a framework for assessing and evaluating the project site. However, in order to answer the questions in a meaningful way it is necessary to measure core elements to document and diagnose change of the site over time. Therefore, it is necessary to develop a systematic study design around the monitoring components and guided by the specific monitoring questions. The study design and monitoring components for the Qwuloolt Estuary project monitoring framework are split into intensive project- and extensive system scale components that provide both detail and context for evaluating the restoration site within a highly dynamic system.

The Snohomish River estuary is a complex delta system with an extensive network of bifurcating and merging distributary network, and a large inland tidal prism that mixes with the second largest freshwater input to Puget Sound. The Qwuloolt Estuary site is embedded in the larger Snohomish River estuary and is one of several historical and future restoration projects that will likely influence each other (e.g., Yang et al. 2010) and these projects will have cumulative effects at the system level. The complexity of this system and the questions we seek to address with the monitoring framework requires a study design that can evaluate responses and patterns within both a project-scale and estuary-wide system-scale (Diefenderfer et al. 2011). Some processes and patterns observed at project-scales may be more directly linked to system-scale patterns and failure to account for larger scale patterns may result in failure to detect restoration responses or miss-interpretation of observations as restoration responses. Capturing and interpreting background variability is difficult at the project-scale without a complementary system-scale monitoring framework. Furthermore, a landscape scale framework can be used to support restoration effectiveness for additional restoration projects as they are implemented throughout the estuary. By plugging into this landscape-scale monitoring framework with the Qwuloolt Estuary monitoring plan as a template for project-scale intensive monitoring, we can efficiently address restoration effectiveness at both project-scale and cumulative scales for multiple projects.

In addition to a project-scale and system-scale focus, the study design for restoration effectiveness monitoring should also include basic elements of experimental design whereby we can address important response questions with comparisons (Schmitt and Osenberg 1996; Kingsford and Battershill 1998; Elzinga et al. 2001; Downes et al. 2002; Roni 2005). These may include comparisons of the site to before and after treatment conditions, control sites (sites that remain in the pre-treatment condition), and reference sites (which are typically sites that are pristine or the desired condition of the site). However, while few relatively undisturbed places remain in the delta in the same landscape position as Qwuloolt Estuary along the dominant environmental gradients (e.g., salinity, elevation, hydrologic connectivity), several sites within the estuary are potentially useful as reference sites given their condition in various stages of recovery (i.e. post treatment space-for-time designs; Roni and Quinn 2001; Gray et al. 2002) and location adjacent to the project site.

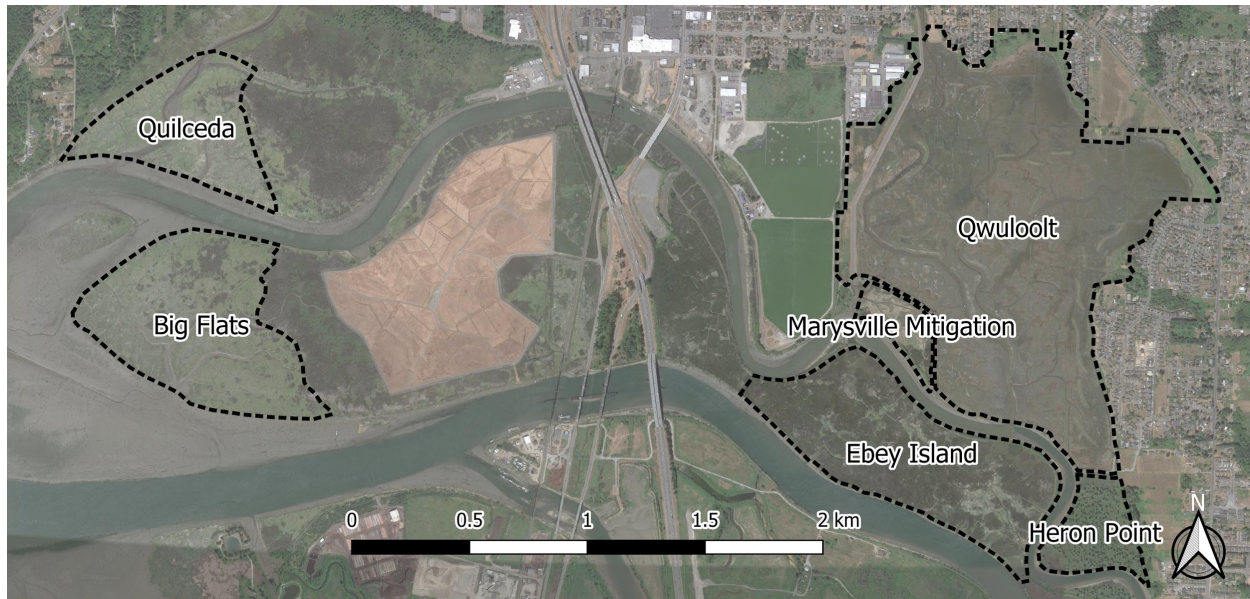
Furthermore, many of the primary biological response variables (e.g., attributes of juvenile salmon populations) are best assessed at spatial scales larger than an individual site (Simenstad et al. 2000, Beamer et al. 2005, Simenstad et al. 2006b, Rice 2007, Greene and Beamer 2009). For example, juvenile salmon rearing and migration patterns can change dramatically on the scale of days to weeks with inter-annual variations in peaks, timing, and duration in estuaries. Furthermore, the complexity of salmonid life histories is such that juvenile cohorts typically return as adults over a span of 2-5 years and adult returns can vary greatly from year to year due to larger scale factors (e.g., ocean conditions, climate oscillations, or fisheries patterns). These combined factors result in the need for a monitoring program that is sufficiently intensive within years to capture rearing and migration patterns and extensive across years to capture salmon population responses that require at least five years of monitoring before one cohort is captured.

Therefore, the Qwuloolt Estuary monitoring framework study design includes a project-scale intensive element with pre/post breach monitoring within the site and at reference marshes, which are nested within a system-scale monitoring framework to provide context for site level and landscape patterns. More detailed aspects of the project and system scale study design are described below. We then describe the core and supplemental monitoring elements that are used at project and system scales to address specific monitoring questions and to document and diagnose change over time.

Project-scale design elements

The project-scale study design includes intensive monitoring of key monitoring elements within the project site, areas immediately adjacent to the project site, and reference marshes. Few relatively undisturbed places remain in the estuary, but the Qwuloolt Estuary is uniquely positioned in the landscape such that sites in differing stages of recovery lie adjacent to, or near, the project area. These reference sites include Heron Point, Ebey Island, the Marysville Mitigation, Quilceda, and Big Flats (Figure 8).

Figure 8. Map of the project site (Qwuloolt) and reference marsh systems used in this monitoring framework.



Heron Point is a spruce-dominated forested tidal wetland that has remained largely intact and was recently acquired as a conservation area, and this area probably represents the closest match to what forested tidal wetlands within the project site may have looked like prior to development (Figure 8). Ebey Island, located immediately across Ebey Slough from the Qwuloolt Estuary project site (Figure 8), represents a scrub-shrub tidal wetland that has passively formed following natural dike failures in the 1960's that previously supported agricultural land uses on Ebey Island. The Marysville Mitigation site is a restoration project that was implemented in 1994 that is immediately adjacent to the Qwuloolt Estuary restoration site (Figure 8). Apart from some infrequent monitoring, this mitigation site has been progressing along a passive recovery trajectory with no active or adaptive management of the site (Jones and Stokes Associates Inc. 1999, Roni and Quinn 2001, Jones and Stokes Associates Inc. 2003). Further downstream and closer to the delta mouth, the Quilceda Creek marsh is a mostly undisturbed emergent marsh system that has a freshwater tributary influence like Allen and Jones Creeks that drain into the Qwuloolt Estuary project site (Figure 8). Across Ebey Slough, the Big Flats marsh provides an additional emergent marsh reference system that is not tributary influenced like the Quilceda Creek marsh (Figure 8).

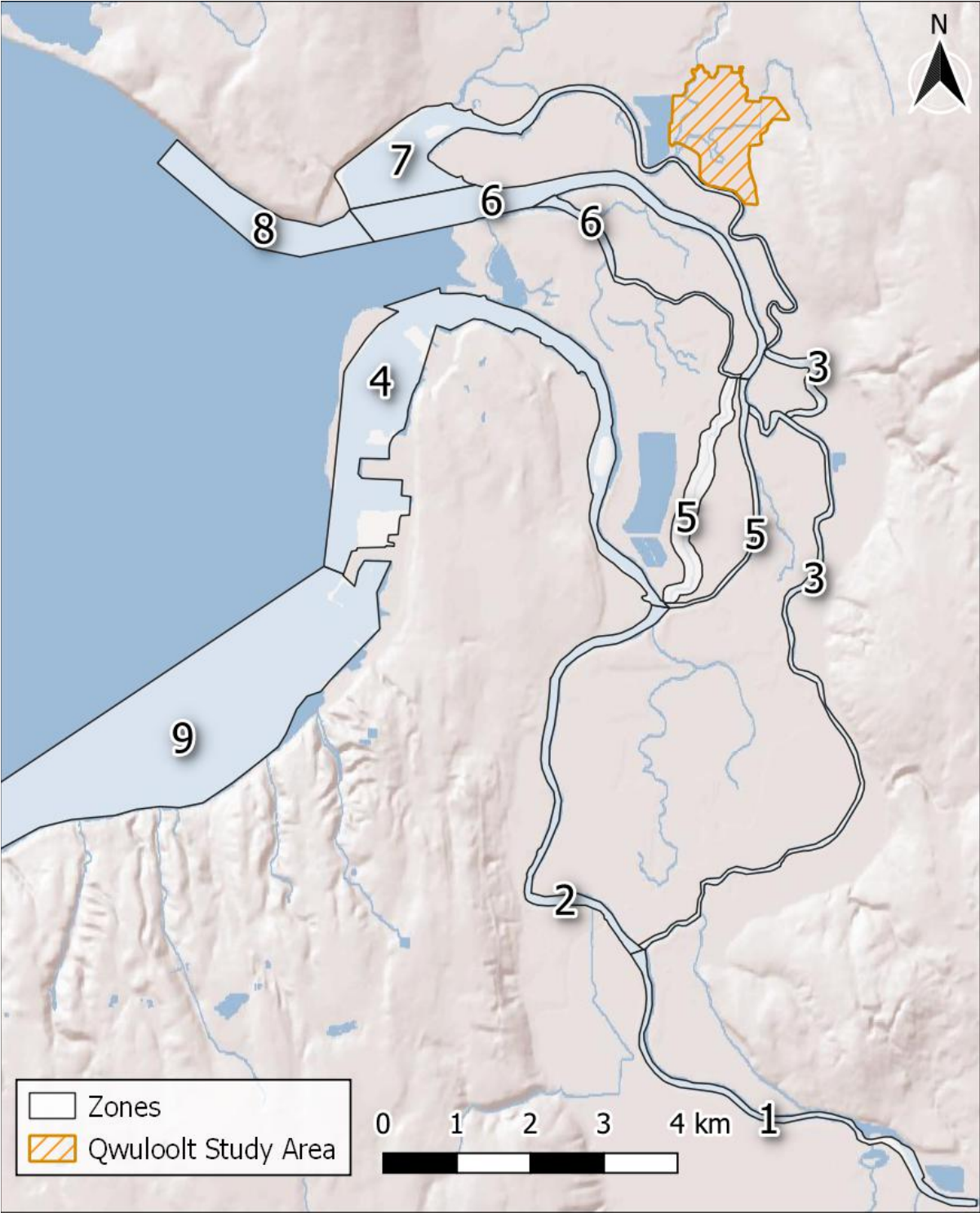
Collectively, these marsh systems were identified as reference sites for the analysis of restoration effectiveness for the Qwuloolt Estuary as they represent reference conditions along a gradient of recovery trajectories (e.g., time since natural dike failure or restoration) and ecosystem states (e.g., emergent marsh, scrub shrub, and forested tidal wetland).

System-scale design elements:

The system-scale framework was partially based on a previous long-term intensive landscape-scale fish monitoring program that began in the Snohomish River estuary in 2001 (Rowse and Fresh 2003). However, this monitoring framework only considered fish and basic physical attributes of water quality (e.g., water temperature, salinity, and dissolved oxygen) at the time of fish sampling. We expanded and adapted this previous effort to provide a more consistent and spatially balanced sampling design with additional core landscape-scale monitoring components.

The system-scale monitoring framework for this monitoring plan is designed to capture patterns of key monitoring elements at the scale of the larger estuary system and its primary channel network. The complex system of bifurcating channels were divided into zones to stratify monitoring efforts to capture patterns within each major component of the estuary channel system (Figure 9). These zonations were derived from upstream to downstream and are sequenced based on bifurcation orders (e.g., larger channels at bifurcations received a higher zone number, and bifurcations positioned farther downstream received a lower zone number). With this zone based stratification, our monitoring framework can capture major gradients in the system from upstream to downstream and within the primary distributary channel network.

Figure 9. Map of system-scale zones showing zone numbers and the Qwuloolt Estuary restoration site for reference.



Monitoring Elements and Components:

The Qwuloolt Estuary restoration effectiveness monitoring plan includes key monitoring elements with a suite of core and supplemental monitoring components that are sampled at either project or system-scales, or both. These core and supplemental elements are organized by key focus areas that include topography, hydrology, biota, and qualitative (Table 1). The specific methods for each monitoring element and component are described in this section, with each component being designed to address specific questions.

Table 1. Core and supplemental monitoring elements for project and system scale monitoring.

Focus Areas	Monitoring Element	Monitoring Component	Project Scale	System Scale
Topography	Sediment & Elevation	Marker horizons (MHs)	Core	Supp.
		RSETs with MHs	Core	Supp.
		UAV and LiDAR	Core	Supp.
		RTK/veg grid transects	Core	Supp.
		Sediment pins	Supp.	Supp.
		Soils	Supp.	Supp.
	Bathymetry	Multi/single-beam sonar	Supp.	Supp.
Hydrology	Temp & Salinity	Continuous water sensors	Core	Core
		Point measurements	Core	Core
		Water column profiles	Supp.	Supp.
	Inundation	Continuous water sensors	Core	Core
	Water quality	DO, pH, nutrients, contaminants	Supp.	Supp.
	Flow	River discharge	Core	Core
		Point measurements	Supp.	Supp.
		Channel cross-sections	Supp.	Supp.
Biota	Fish	Beach seining	Core	Core
		Smolt trapping	Core	Core
		Fyke trapping	Core	Supp.
		Otolith microstructure	Supp.	Supp.
		Tissue contaminants	Supp.	Supp.
		Genetic mark-recapture DNA	Supp.	Supp.
	Vegetation	RTK/veg grid transects	Core	Supp.
		Intensive quadrats	Core	Supp.
		UAV and Aerial Imagery	Supp.	Supp.
	Birds	Marsh bird point counts	Supp.	Supp.
	Invertebrates	Benthic coring	Supp.	Supp.
		Nueston sampling	Supp.	Supp.
		Fallout trapping	Supp.	Supp.
		Salmon diets	Supp.	Supp.
	Beaver	Dam, slide, and den surveys	Supp.	Supp.
Qualitative	Visual record	Photo points and observations	Core	Supp.
		Timelapse photography and video	Core	Supp.
		UAV and Aerial Imagery	Core	Supp.

Topography:

Development of the topography within the project site over time will be a key determinant of the response trajectory for the Qwuloolt Estuary. We consider topography with respect to two key monitoring elements; (1) Sediment and Elevation, and (2) Bathymetry (Table 1). Subsidence, sedimentation, channel formation, and potential sea level rise rates are perhaps the greatest sources of uncertainty for the recovery trajectory of the Qwuloolt Estuary. Fortunately, several monitoring tools are available that can measure surface and bathymetric elevations at the spatial and temporal scales needed to address key questions concerning patterns of topography within the site and over time. These monitoring components are described in detail below, with methods and study design descriptions for each monitoring component.

Sediment and elevation:

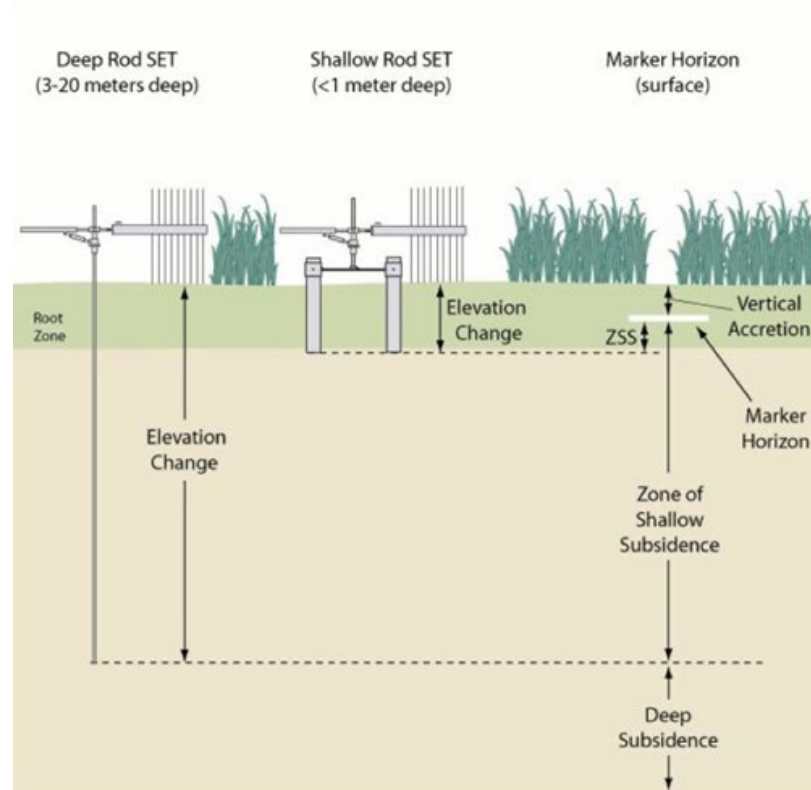
RSETs and Marker Horizons:

Approach:

A key determinant of a tidal wetlands response trajectory is the net trend in surface elevation for the wetland. It is crucial to quantify the vertical movement of coastal wetland surfaces, as elevation is the key determinant of vegetation in marsh systems. Monitoring net change in surface elevation over time, and the sources of these changes, also provides insight into the site's potential resilience to sea level rise (SLR). Measuring fine scale changes in long-term shallow and deep soil processes requires specific methodologies.

The USGS developed the Rod surface elevation table marker-horizon method (RSET-MH) to measure local surface elevation change measurements in a precise and repeatable way (see <http://www.pwrc.usgs.gov/set/>) (Figure 10). The RSET-MH method fills a critical need for measuring and analyzing changes in surface elevations within tidal marshes. RSETs are usually complemented with shallow accretionary monitoring using artificial soil marker horizons (MH) typically made of feldspar, which simultaneously quantify rates of vertical surface accretion (i.e., sediment deposition). The complete RSET-MH setup provides net surface elevation change above the benchmark depth; moreover, as it has been repeatedly shown that vertical accretion is not a valid substitute for surface elevation change.

Figure 10. Rod surface elevation table - marker horizon (RSET-MH) in both shallow and deep configurations. All installations associated with the current work will be deep.



The complete RSET-MH setup is necessary to identify the contribution of surface and shallow subsurface processes to surface elevation change at a specific site (Figure 10). Repeated measurements allow chronicling of net surface elevation change, which can be integrated with current and projected region-specific relative sea levels to determine whether the surface elevation is keeping pace with current or projected sea levels. Total surface height measurements from RSET-MH stations have confidence intervals of ± 1.3 mm, a figure well within the annual rate of eustatic SLR. RSETs are the only tool that can capture surface elevation change with this precision. However, the long-term nature of this monitoring approach requires commitment to monitoring and a long time series (e.g., years to tens of years) before monitoring will reveal meaningful patterns.

An RSET-MH involves very simple technology; it consists of a benchmark rod driven through the soil profile to resistance (typically 10-25 m depth) (Figure 11), and a portable horizontal arm that is attached at a fixed point anchored in concrete (Figure 12) to measure the distance to the substrate surface, using vertical pins (Figure 10).

Figure 11. Driving stainless steel benchmark rods through the soil profile. Typical refusal depth in Snohomish installations were approximately 18 meters.



Figure 12. RSET rod cap and datum secured at surface with concrete.



Once installed, a plank is used to span the post and allow the reader to access the post without stepping in the site and leaving footprints (Figure 13). The receiver arm is attached and leveled on the post and numbered pins are read at fixed bearings with the same pins being used in each position (Figure 13). This approach allows for the repeated measurement of the distance to the marsh surface at the same exact spots every visit. In addition to the RSET measurements themselves, feldspar marker horizons are installed at the corners of each plot. These MHs are

sampled with a liquid nitrogen cryocoring apparatus (Figure 14) that freezes a core of sediment to a copper tube (Figure 15) after pressurized liquid nitrogen is injected into the tube . The marker horizons are typically easy to see, allowing for measurements of sediment accumulation on top of the marker horizon since the MH was laid down (Figure 15). In this way, cumulative sediment accretion on the surface can be measured relative to the installation time to calculate accretion rates.

Figure 13. Reading RSETs in a reference marsh. A platform is used to prevent footprints from changing surface elevations within the monitoring site.



Figure 14. Cryocoring of MHs at an RSET site using a pressurized liquid nitrogen dewar. The liquid nitrogen is injected into a copper tube that is pushed into the sediment at the MH and this freezes the sediment core to the probe for easy removal.



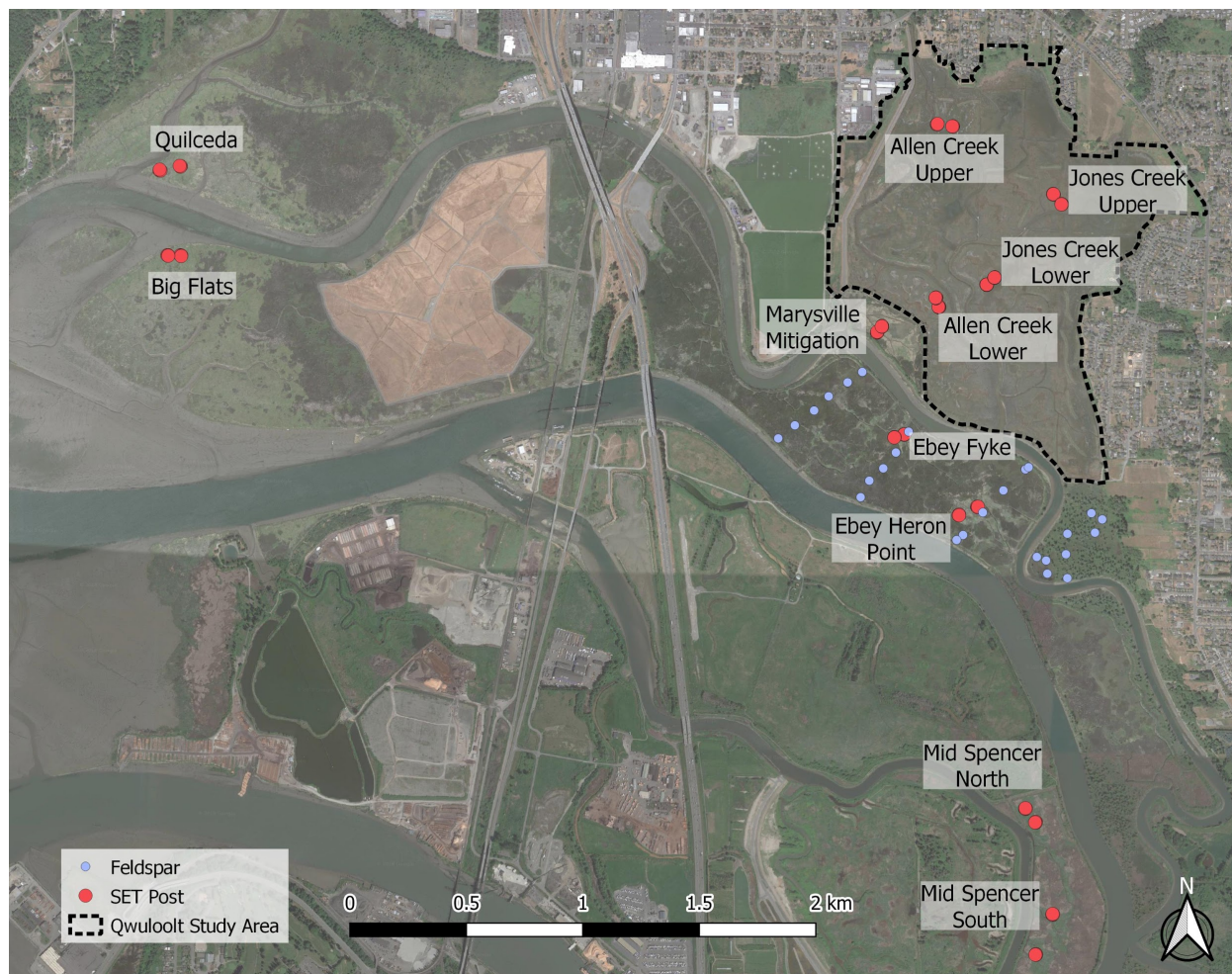
Figure 15. A sediment core taken with the cryocorer. The white line of the feldspar MH is visible on the core that is frozen to the probe. The distance from the surface to the top of the MH is measured on all four axis of the core.



Previous studies have revealed high across-site variability in the processes that contribute to surface elevation change, making assumptions of uniformity in processes across wetlands inappropriate (G. Guntenspergen, personal communication; Kairis and Rybczyk 2010; Woo et al. 2011). This highlights the need for site-specific data across a network of sites that accurately represent local and landscape contexts in order to evaluate the outcome of different sea level rise and sedimentation/erosion scenarios.

To address the issue of high spatial variability, we installed RSETs with MHs in pairs at reference marshes. We selected sites that were within reference marshes that at similar distances from channels, were in vegetation assemblages that allowed reading of the marsh surface, and represented a gradient of tidal marsh habitat types and reference conditions. We identified two reference sites in the lower estuary near the mouth of Quilceda Creek (Quilceda and Big Flats), two sites on Ebey Island across from the Qwuloolt Estuary (Ebey Fyke and Ebey Heron Point), and the Marysville Mitigation site for installation of RSETs and MHs (Figure 16). RSETs with MHs were installed in Quilceda, Big Flats, and Marysville Mitigation in 2013, Ebey Island RSETs and MHs (Ebey Fyke and Ebey Heron Point) were installed in 2014. We explored installation options within the Heron Point reference site, but marsh surface conditions were not conducive to reading surface elevations given the high amount of accumulated woody debris and organic materials on the marsh surface. RSETs and MHs inside Qwuloolt Estuary were not installed until 2018, as previous studies have found that RSETs can be destroyed and require reinstallation as a result of the rapid changes and high energy conditions that can occur in the initial phases of restoring tidal inundation to a site. These RSETs with MHs were installed in the main lobes of the channel system within the project site to provide a spatially balanced evaluation of sedimentation and surface elevation conditions (Figure 16). Similarly, MH transects will be installed within the site at a future date to provide more spatially extensive measures of sediment accretion rates within the site.

Figure 16. Map of existing RSETs with MHs (SET Post) sites in reference marshes and the project site, and MH transects in reference marshes (Feldspar).



It is worth noting that additional RSET with MHs reference sites were also installed at Mid-Spencer Island in 2018 as reference sites for the Smith Island restoration project (Figure 16). These sites were installed and will be monitored using the same methods as the Qwuloolt Estuary reference sites. While these sites are intended as reference sites for the nearby Smith Island project, these sites are being integrated into the larger system-scale monitoring framework such that evaluation of both projects will benefit from the collective network of reference sites. This demonstrates the intent of our monitoring plan whereby additional projects can plug into the system-scale monitoring framework and improve the ability of monitoring efforts to detect cumulative and individual responses to restoration.

Relevant Monitoring Questions:

RSETs and Marker Horizon monitoring components address multiple monitoring questions at both the project and system-scale (Table 2). This component specifically addresses Status and Trends, Effectiveness, and Diagnostic questions for project and system-scales.

Table 2: Monitoring questions addressed by the RSETs and MHs monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

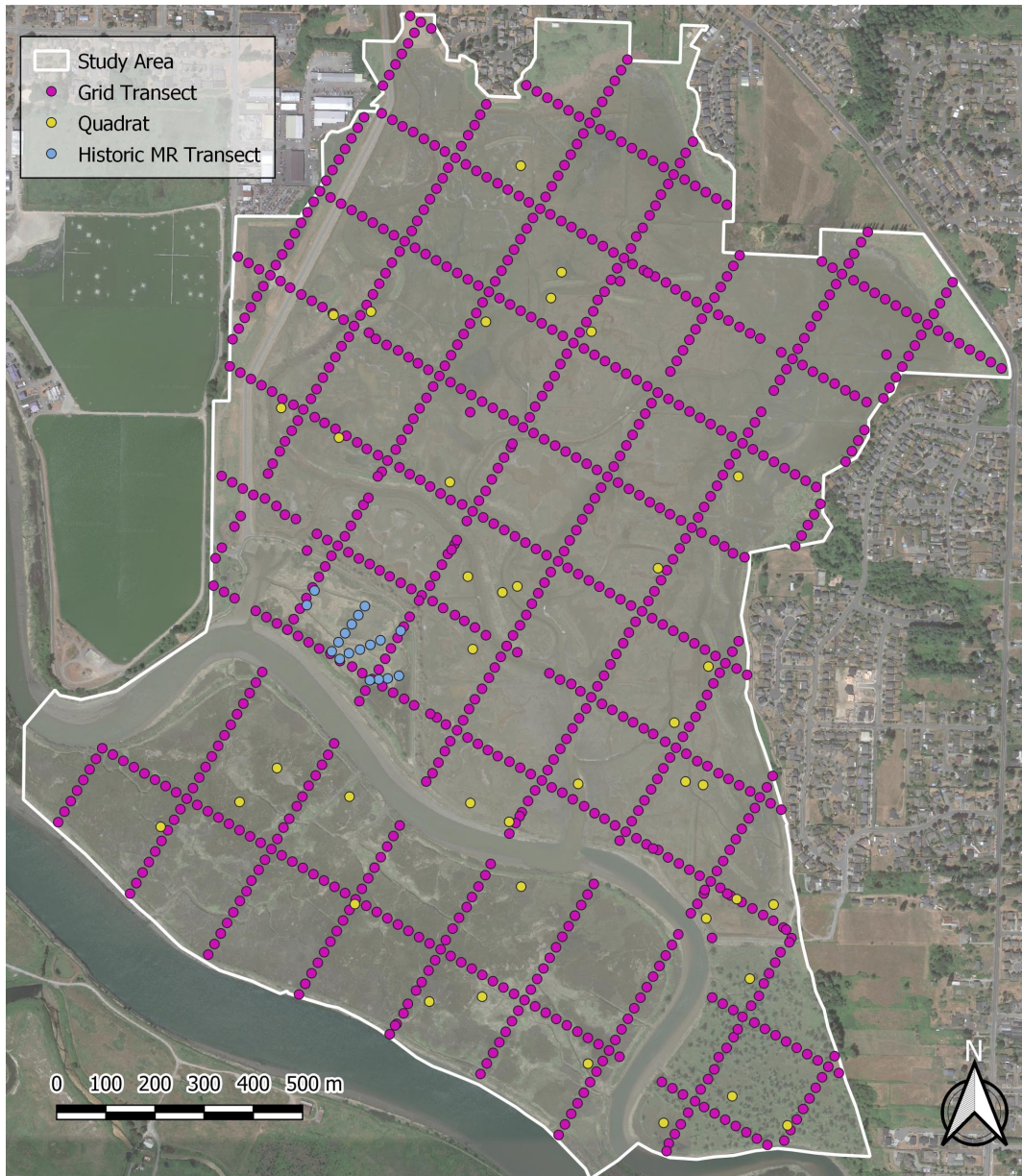
Question	Scale	Description
ST1	Project	Before/After comparison of post elevations and SET pins/MH
E1	Project, System	Compare post elevations and SET data among project and reference sites
D1	Project	Attribute changes to post elevation (deep) or SET pins (surface)
D2	Project, System	Projected elevation change due to trends in SET and RTK data

RTK/veg grid and transects:

Approach:

Status and trends in surface elevation will also be assessed using a systematic rapid survey approach given the high uncertainty regarding surface elevation responses within the site. A grid of perpendicular transects with a 200-meter spacing was established within the project site and adjacent reference marshes (Figure 17). The transect grid was oriented approximately 30.6° off true north to bisect the project site and adjacent reference sites with contiguous lateral and longitudinal transects. This 200-meter grid was subdivided into grid points along each transect at 25-meter intervals. This grid was designed to provide a framework for pre-breach and post-breach surveys within the project site and reference marshes that could be consistently repeated. In addition to the primary grid transect, additional transects within the Marysville Mitigation site were adopted in our monitoring framework as these points were previously monitored during post-breach monitoring of that site.

Figure 17. Map showing layout of grid points and transects for RTK surveys of surface elevation. In addition to this grid design, historic monitoring transect points inside the Marysville Mitigation site are shown for reference as these sites will also be monitored within this framework. Quadrat monitoring points are also shown as elevation data are collected at these quadrats even though vegetation is the primary focus of those points.



Considerable uncertainty exists regarding post-breach sediment accretion rates onsite, but research indicates that they are not likely to be more than 2-5 cm per year (Thom 1992, Cornu and Sadro 2002). In addition, considerable spatial variation in elevations can occur at very small scales (e.g., cm to meters). Therefore, survey grade RTK GPS equipment (Trimble R-8 GNSS Receivers) was selected for monitoring surface elevations within the project site and reference

marshes given the relatively accurate horizontal and vertical solutions possible with this equipment. The intent of this monitoring component was to use RTK GPS equipment to navigate to each grid point and measure surface elevations during pre-breach conditions and annually after the breach. Additionally, vegetation observations are recorded at each of the monitoring points as described in the vegetation monitoring section.

For the pre-breach survey, the grid was sampled in 2010 using a base station and rover survey style and post-processing corrections for points based on NGS OPUS solutions for established base stations. The pre-breach surveys were conducted in UTM WGS84 Zone 10N coordinate reference system (CRS) with a NAVD88 (GEOID09) vertical datum. Positional accuracy for these surveys ranged from 0.018 to 0.053 meters horizontal accuracy and 0.028 to 0.045 m vertical accuracy. Additional pre-breach surveys were not completed within the project site or reference marshes.

For post-breach surveys, advances in RTK GPS technology allowed us to conduct surveys using a rover with Virtual Reference Station (VRS) corrections in real-time through a mobile WiFi connection to the Washington State Reference Network (WSRN). These real-time VRS corrections can provide position solutions with a horizontal accuracy of 0.008 meters and a vertical accuracy of 0.015 meters. Trimble R-8 GNSS Receivers were also used for the post-breach surveys, but these surveys were conducted in the Washington North 4601 State Plane (US survey feet) CRS with the GEOID12AUS (NAVD88), as this is the native CRS for the WSRN. To compare elevations between pre-breach and post-breach periods, GEOID09 derived elevations were converted to GEOID12AUS elevations using online National Geodetic Survey conversion tools (available at https://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/geoid12B_prompt1.pr1 and https://www.ngs.noaa.gov/cgi-bin/GEOID_STUFF/geoid09_prompt1.pr1). These tools indicated that GEOID09 elevations for pre-breach surveys are 0.027 meters higher than GEOID12AUS elevations. Therefore, we adjusted pre-breach survey elevation data by subtracting 0.027 meters from all pre-breach survey data to compare elevation changes from RTK grid transect surveys during pre and post-breach periods.

Relevant Monitoring Questions:

RTK/veg grid and transects monitoring components address multiple monitoring questions at both the project and system-scale (Table 3). This component specifically addresses Implementation, Status and Trends, and Diagnostic questions for project and system-scales.

Table 3: Monitoring questions addressed by the RTK/veg grid and transects monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
I1 & I5	Project	Measure project feature elevations through time

ST1	Project	Before/After comparison of point elevations along grid transect
D2	Project, System	Estimate rate changes in RTK elevations and compare with expected SLR
D5	Project, System	Relate elevation changes to vegetation communities/distribution

UAV:

Approach:

The Tulalip Tribes uses a fixed-wing ebee UAV that can be equipped with a Canon S110 (true-color only) or Parrot Sequoia (multispectral) camera. Flights have been limited to the Qwuloolt Estuary site and only started after the breach. Imagery is stitched together into an orthomosaic with established ground control points and manual quality checks. Collectively, these flights can be used to produce true-color imagery (RGB), color infrared imagery (CIR), and Digital Surface Models (DSM) depending on the payload for each flight.

RGB imagery is useful for visually identifying current conditions in Qwuloolt as well as how it is changing and progressing over time. They are an excellent canvas over which to place other spatial data layers such as sampling sites for determining fish assemblages, vegetation sampling points, and locations of sensors. Qualitative analysis of locations, sizes, and changes in impoundments and channels have also been made by reviewing these images. Finally, these images have been extensively used to navigate throughout the site. CIR imagery is extremely valuable for developing and running computer-based vegetation classifications. The data collected from multispectral flights allow us to stratify the landscape and interpolate vegetation cover values for a continuous surface from data collected during the vegetation grid surveys. DSMs must be produced for any structure-from-motion software to be able to create a continuous mosaiced image. The digital surface model can be exported from these programs as a continuous raster. In cases like Qwuloolt, where vegetation tends to be low and sparse, a digital surface model can often be treated as representing the land surface. The digital surface models produced from the UAV flights over Qwuloolt are being used in quality control for bathymetry data; visualization of impoundments; and identification of channel development. Future refinement of DSM development and quality control may allow evaluation of surface elevation changes over time for a continuous surface.

Five UAV flights have been completed for the Qwuloolt Estuary, with DSMs and either RGB or CIR imagery being collected with each flight. In the future, UAV flights of the Qwuloolt Estuary will include both RGB and CIR acquisition for each year. To date, only one CIR image has been collected. The flights and payloads/products collected thus far are listed below;

- April 9, 2016 – RGB and DSM
- August 8, 2016 – RGB and DSM
- June 22, 2017 – RGB and DSM
- August 22, 2017 – RGB (lower resolution), CIR, and DSM (lower resolution)
- July 12, 2018 – RGB and DSM

Relevant Monitoring Questions:

UAV monitoring components address multiple monitoring questions at the project-scale (Table 4). This component specifically addresses Implementation, Status and Trends, and Effectiveness questions for project-scale.

Table 4: Monitoring questions addressed by the UAV monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
I5	Project	Gross changes to project features via aerial imagery
I6	Project	Qualitative assessment of feature performance (i.e. visual pooling, vegetation, etc.)
ST1	Project	Time series qualitative assessment of channel features
ST3 & E4	Project	RGB-IR analysis of veg communities/distribution

LiDAR:

Approach:

LiDAR are typically collected from fixed-wing piloted aircraft and are more expensive to collect than UAV data, but also provide a larger survey extent that can include the entire Snohomish River estuary. LiDAR uses laser pulses to determine the distance of a target from the sensor. When two distinct distances are recorded during an aerial flight, the “shortest” distance (first return) can be assumed to represent the tops of the vegetation and the “longest” distance the ground surface (elevation). The digital surface model produced by structure-from-motion software from UAV collected data is approximately equivalent to a LiDAR first return. With increased vegetation height and density, LiDAR with ground validation surveys becomes increasingly necessary to develop useful DSMs.

Only two LiDAR flights have been completed for Snohomish River estuary, both of which occurred during the pre-breach period; July 20 - 21, 2009 and November 21 - 22, 2013. Plans for future LiDAR data collection have not been developed, but future acquisitions will provide useful DSMs and RGB imagery at the system and project scales that will be useful for evaluating changes at the project site and reference marshes over time.

Relevant Monitoring Questions:

LiDAR monitoring components address multiple monitoring questions at the system and project-scale (Table 5). This component specifically addresses Status and Trends and Effectiveness questions for the system and project-scale.

Table 5: Monitoring questions addressed by the LiDAR monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
ST1	Project	Gross changes in surface elevation through time
E1	Project, System	Compare site elevation changes with reference/system elevation changes

Bathymetry:

Bathymetry monitoring protocols and methods are still under development and will be included in future updates to the monitoring plan.

Soils:

Soil salinity monitoring protocols are still in the development phase. Two test monitoring locations have been established to evaluate methods for deploying sensors within the study area (Figure 18) to monitor soil moisture, salinity, and temperature fluxes. Data loggers were installed within protective housings (Figure 19) to allow the data loggers to remain dry while being connected to the sensor cables. Data download and processing protocols as well as material list will be developed as this monitoring component is refined.

Figure 18. Map of Qwuloolt Estuary, CTD Logger, and Soil Pits.

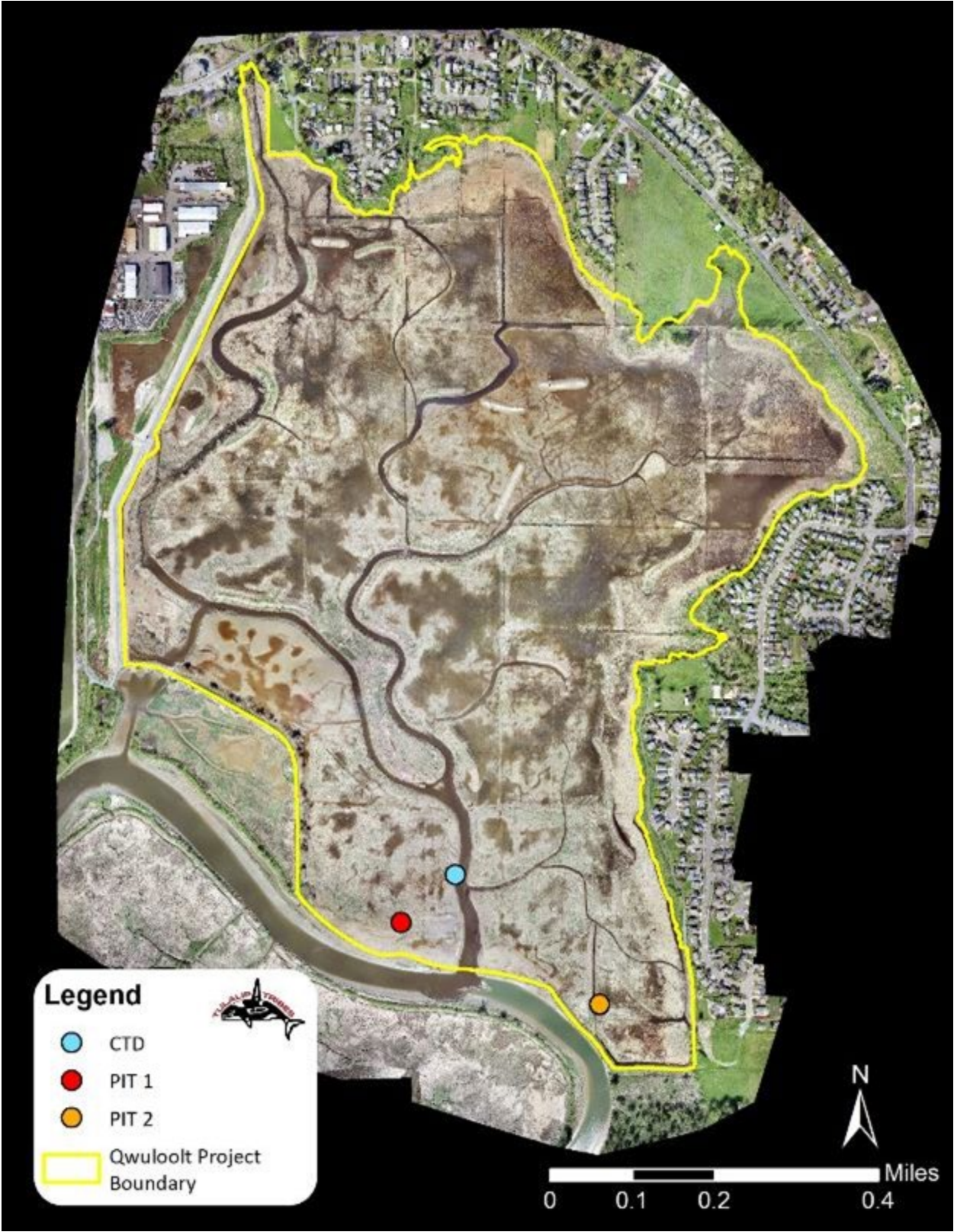
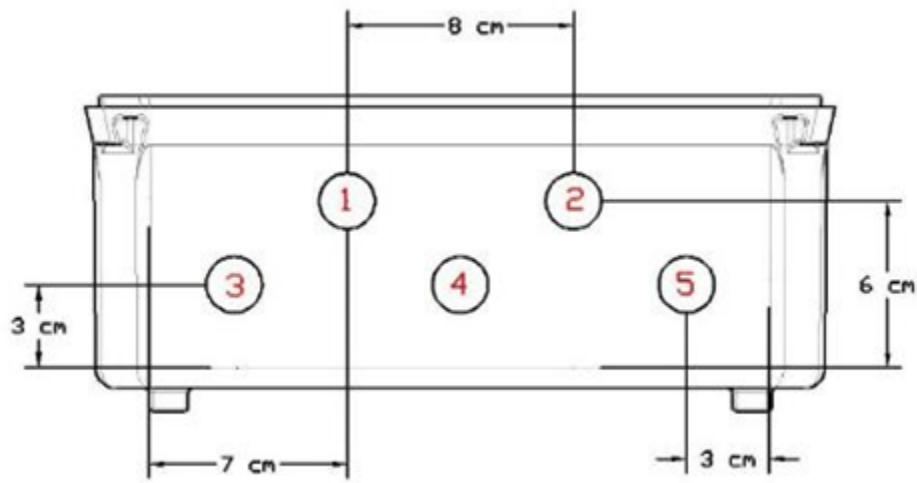


Figure 19. Cable gland configuration on Polycase® (Top) and housing shown after retrieval from the field (Bottom).



Hydrology:

Tidal flooding is a primary driver of physical attributes (e.g., hydrology, elevation, channel morphology, and soil chemistry) that determine the biological character of estuarine wetlands (e.g., vegetation and animal community assemblages), but many of the specific cause and effect relationships are not well established. Uncertainties concerning wetland processes, restoration responses/effectiveness, and climate change impacts in estuarine wetlands are often related to unquantified hydrological parameters. Monitoring and analyzing surface water dynamics could provide invaluable information for restoration effectiveness monitoring as well as inform future restoration project design. In addition, developing an understanding of the linkages between riverine and tidal hydrodynamics can be useful for examining climate change scenarios where changes in watershed precipitation and temperature dynamics may impact restoration effectiveness in the long term as a result in changes to estuarine hydrology and tidal influence.

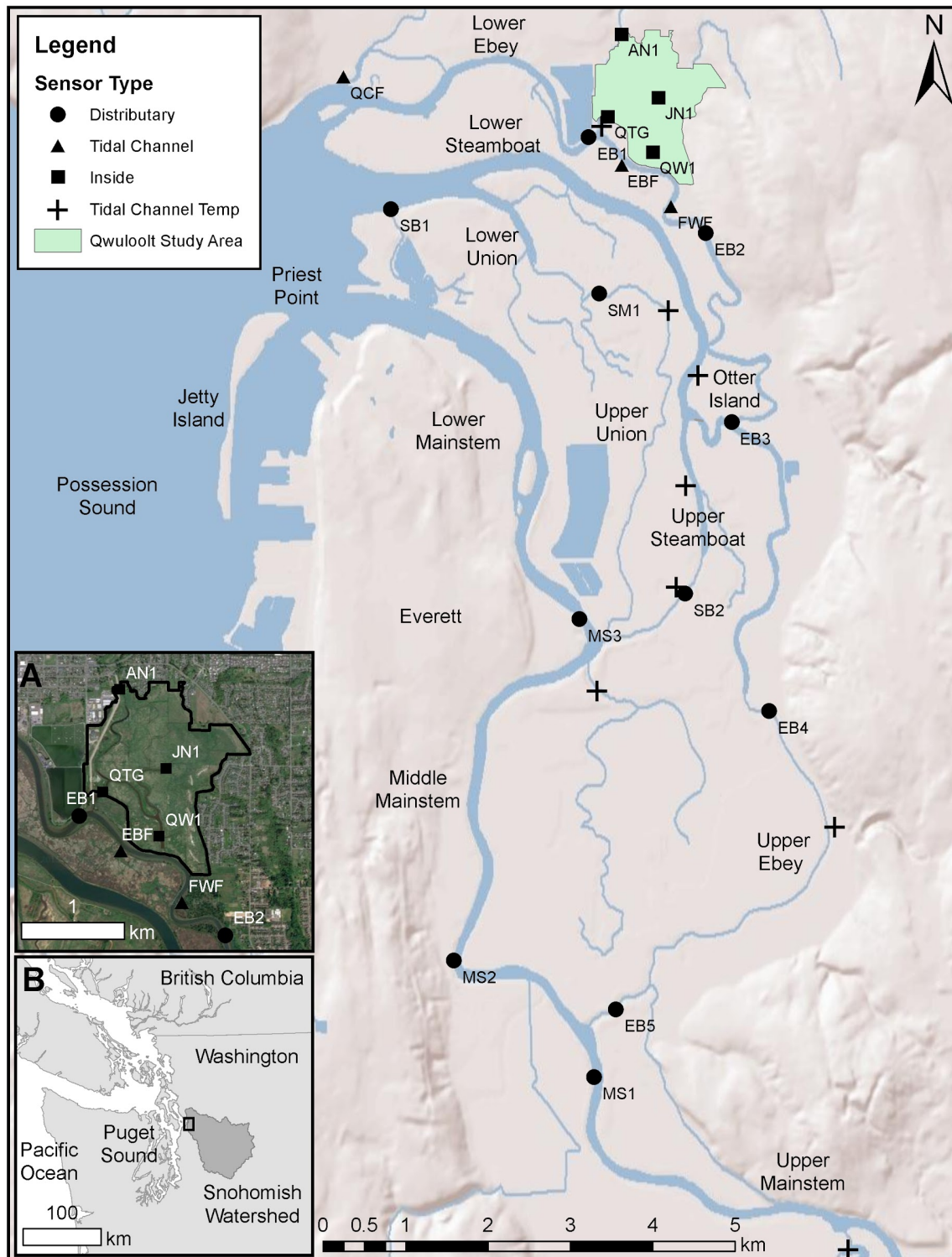
To evaluate important aspects of hydrology within the Snohomish River estuary, we rely on monitoring data collected from point surface water sampling, point water column profiling, continuous water sensors, hydrodynamic modeling, and river flow monitoring. These efforts are used to provide important information aspects of hydrology that include temperature and salinity, inundation, water quality, and flow. Collectively, these monitoring components are designed to provide baseline descriptions of important elements of hydrology within the estuary prior to implementation of the Qwuloolt Estuary restoration, and to provide a framework from which project level and cumulative restoration responses could be evaluated within the Snohomish River estuary over time.

Continuous water sensors:

Approach:

Continuous water sensors are a core monitoring component as they provide important project and system scale data on key hydrological attributes. A system-scale and project-scale monitoring framework was designed to continuously monitor water level, temperature, and salinity at 10-minute intervals have been deployed throughout the estuary (Figure 20). These sensors are designed to provide detailed spatial and temporal monitoring data on salinity, temperature, and tidal inundation patterns within the project site, for reference marshes, and at system-scales. The continuous water sensors have been deployed strategically to target the Qwuloolt Estuary restoration project area, ongoing fyke trap locations, and key hydrological features and transition zones (e.g., major bifurcations and estimated salinity intrusion limits) (Figure 20). The geographic extent of the deployments is also designed to fall within the zone of tidal influence, with respect to water elevation. Gage readings at USGS Station 12155500 indicate that tidal influence on water elevation extends above the town of Snohomish, WA.

Figure 20. Continuous water sensor sampling framework. Sensor IDs are shown for each monitoring point, as well as symbology for where they were installed. Locations of continuous temperature sensors deployed in off-channel habitats are also shown.



All continuous water sensors were installed at a fixed-depth at each site, with the goal of keeping sensors from becoming dewatered throughout a range of tidal and river conditions. Solinst brand sensors (LTC Junior) were initially used exclusively for continuous water sensor monitoring within the Snohomish River estuary. These sensors have proven unreliable in an estuary environment, with multiple sensor failures and data loss events occurring throughout the monitoring period as well as difficulties associated with regular sensor calibrations. Monitoring points were eventually replaced with Schlumberger brand (CTD Diver) sensors, which have proven to be more reliable in estuarine applications. IButton and Hobo Water Temp Pro sensors have also been used to monitor surface water temperatures in off-channel habitats within the estuary (Figure 20).

All sensors were hung inside 5.1 cm diameter slotted PVC well casings with downrigger line (braided Dacron), which were fixed to existing pilings or metal pipes constructed on site. The sensors at these sites were installed in the deepest point of channels at tidal channel and fyke sites so that the sensor was approximately 10 cm above the channel bottom; however, these channels may dewater with certain tidal cycles and flow conditions. The rest of the sensors were installed on existing pilings near the primary distributary channel edges such that the sensors would remain wetted throughout all tidal cycles and river flows. The temperature only sensors are also deployed in similar fashion inside PVC casings or affixed to existing infrastructure with the goal of keeping sensors wetted during all tidal cycles. High resolution Global Navigation Satellite System (GNSS) position solutions from Real Time Kinematic (RTK) corrections were obtained for all continuous water sensor monitoring points to determine the elevation of each sensor.

During sensor deployments, all continuous water sensors were uploaded, cleaned, and calibrated (if needed) approximately every 90 days. Pressure readings from submerged sensors were corrected to water elevation (NAVD88) using atmospheric pressure data collected at nearby facilities (NOAA research station at Mukilteo, a nearby Tulalip Tribes facility, and the Arlington Airport) and the surveyed sensor elevations. These water surface elevations were used to determine inundation profiles as well as to filter data if sensors became dewatered. By comparing surface water elevation data with measured marsh surface elevations, tidal inundation patterns and extent can be evaluated. All sensor data (temperature, conductivity, and water elevation) were also manually reviewed for QA/QC issues that may impact data quality, with all suspect data being flagged so that analyses include only valid data (Table 2).

Table 6. Data flags for processing continuous water sensor data.

DataFlag	Temperature	Conductivity/ Salinity	WaterLevel/ WaterHead	Description
NONE	YES	YES	YES	Indicates that there are no known data issues.
DEWD	NO	NO	NO	Used when sensor has less than 10 cm of WaterHead. Indicates that WaterLevel, WaterHead, Temperature, Conductivity, and Salinity data are not accurate. Temperature values may represent air temperature.
FREZ	NO	NO	NO	Used when sensors dewatered (less than 10 cm of WaterHead) and temperatures fell below 0 degrees C. Indicates that WaterLevel, WaterHead, Temperature, Conductivity, and Salinity data are not accurate. Pressure spikes result from freezing, which biases WaterLevel and WaterHead data. The sensor may require some time after resubmergence to thaw, thus data are suspect until the sensor has equilibrated to the water temperature.
CONF	YES	NO	YES	Used when conductivity sensor has failed or has drifted too far out of calibration. Indicates that conductivity and salinity data are not accurate. All other data are not suspect.
PRSF	YES	YES	NO	Used when the pressure sensor has failed. Indicates that WaterLevel and WaterHead are not accurate. Salinity may also be affected since pressure is used to calculate salinity from conductivity. May include dewatering periods if conductivity and temperature data can not be used to discern when the sensor has become dewatered.
DEWP	YES	YES	NO	Used when the pressure sensor has failed, but dewatering can be determined from the temperature and conductivity data. Indicates that WaterLevel and WaterHead are not accurate. Temperature, Conductivity, and Salinity data should still be valid except that salinity may be biased due to the failure of the pressure sensor.
TEMF	NO	YES	YES	Used when the temperature sensor has failed. Indicates that temperature data are not accurate. Salinity values may be affected given that temperature is used to calculate salinity from conductivity.
NCOM	YES	YES	NO	Used when pressure data has not been compensated for barometric pressure due to missing barometric pressure data. Indicates that WaterLevel and WaterHead data are missing. Temperature, Conductivity, and Salinity data should still be valid. May include dewatered periods if they can not be determined from Conductivity and Temperature.
TLCF	NO	NO	NO	Used when all channels spike or fail. Indicates that Temperature, Level (WaterLevel and WaterHead), Conductivity, and Salinity data should not be used.
ELEV	YES	YES	NO	Well damaged or sensor elevation compromised. WaterLevel data suspect. All other channels should be valid.
NSVY	YES	YES	NO*	No elevation survey so no water level data. *water head data still available. Conductivity and Temperature data are good.

Prior to 2013, CWS deployments were restricted to fyke trap sites (QCF, EBF, FWF, and SP1), lower Ebey Slough (EB1 and EB2), and inside Qwuloolt (QTG and JC1) (Figure 20). In January 2013, the continuous water sensor monitoring plan was expanded to include key locations within the mainstem (MS1, MS2, and MS3), Steamboat Slough (SB1 and SB2), and upper Ebey Slough (EB3, EB4, and EB5) as well as the active fyke trap sites (QCF, EBF, and FWF) and lower Ebey Slough sites (EB1 and EB2) (Figure 20). Prior to the breach and after channel construction was completed, additional sensors were installed within the Qwuloolt Estuary with sensors in both forks of the main channel system (AN1 and JN1) and the main channel (QW1) (Figure 20). In addition, continuous water sensor monitoring sites were recently installed within and near the Smith Island restoration project areas by Snohomish County (SM1), and these data will be integrated into the monitoring framework as is the plan for integrating future restoration projects to the overall system-scale monitoring framework.

Relevant Monitoring Questions:

Continuous water sensor monitoring components address multiple monitoring questions at the system and project-scale (Table 7). This component specifically addresses Implementation, Status and Trends, Diagnostic, and Effectiveness questions for the system and project-scale.

Table 7: Monitoring questions addressed by the continuous water sensor monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
I2	Project	Compare water levels inside/outside site after breach
ST2	Project	Water level, salinity, temperature patterns before/after breach
E2	Project, System	Compare project sensor data with reference sites and system network
E3	Project	Evaluate ranges for all CWS metrics and compare with target ranges
D3	Project	Determine location/direction of potential changes and identify plausible causes
D4	System	Evaluate changes in water level, temp, salinity across the system after site breach
D5-7	Project	Compare CWS data with fish, plant, and invert data to establish correlations

Point measurements:

Approach:

Point measurements of surface water conditions are a core monitoring component that is conducted in tandem with fish monitoring. Discrete samples of surface water salinity and temperature measurements have been collected during fish monitoring efforts in the Snohomish River estuary since 2001 using YSI® brand sensors. Measurements are taken within the upper meter of the water column near the channel edge during fish sampling and are meant to characterize surface water conditions at the time of sampling at the sampling site. These

measurements provide a more spatially extensive measurement of surface water conditions but are temporally limited to the sampling windows for fish monitoring (e.g., daytime ebbing tides on spring tide series). Depending on the sensor being used at the time, dissolved oxygen and pH measurements may also be collected during these sampling events.

Relevant Monitoring Questions:

Point monitoring components address multiple monitoring questions at the system and project-scale (Table 8). This component specifically addresses Status and Trends, Diagnostic, and Effectiveness questions for the system and project-scale.

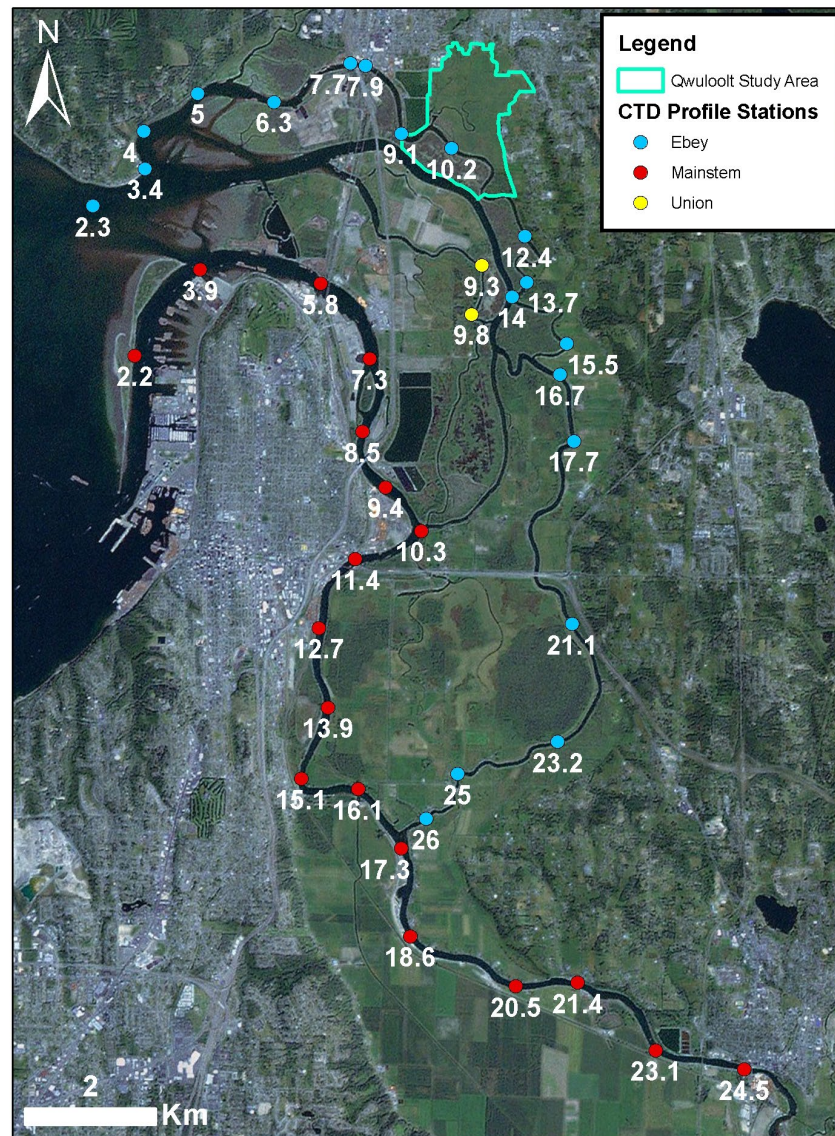
Table 8: Monitoring questions addressed by the point monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
ST2	Project	Additional observations of temperature, salinity, DO, and flow
E2	Project, System	Compare measurements among project and reference sites as well as across system
E3	Project	Compare point observations with desired ranges
D5-7	Project, System	Paired data with fish, plant, and invert data to establish correlations/associations

Water column profiles:

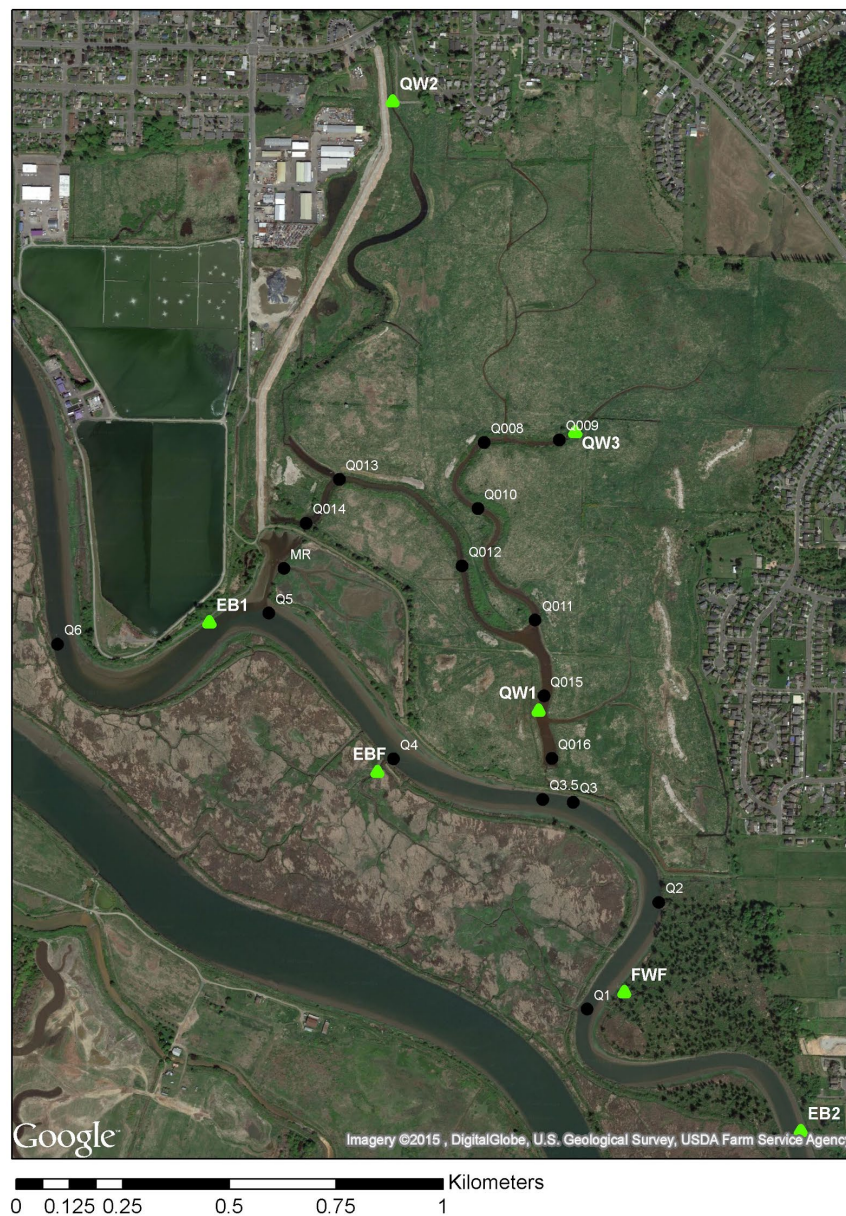
Vertical profiles are a supplemental monitoring component and have been collected opportunistically during key events at the project site and within the estuary distributary system. We established a system-scale monitoring framework of stations throughout the main distributary network of the Snohomish River estuary to measure water column conditions. These stations are approximately 1 – 2 km apart and are sampled at mid-channel (Figure 21). This system-scale sampling framework was designed to provide water column characterizations within the primary distributary channel network during key events (e.g., extreme low flows, high flow pulses, spring tides). Therefore, this monitoring component is designed to provide descriptive information on landscape patterns for key attributes like maximum extent of salt intrusion.

Figure 21. System-scale water column profile sampling framework. Sampling stations are color coded by primary distributary channel and labeled with distance from the delta mouth (kilometers).



An additional sampling framework was also developed for the project-scale, that included stations above and below the breach site for the Qwuloolt Estuary and stations within the main channel system inside the restoration project (Figure 22). This project-scale sampling framework was designed to evaluate pre and post breach conditions within and near the project site.

Figure 22. Water column profile stations for the Qwuloolt Estuary. Sampling stations are shown as black circles with site IDs. Continuous water sensor locations are shown for reference as green triangles.



For both system-scale and project-scale water column sampling, a CTD (SeaBird SEACAT SBE19Plus V2 Profiler) is lowered from the side of a skiff at the thalweg of the channel using a davit with a descent and ascent rate of approximately 0.25 m/s. The CTD was soaked at the surface for one minute before each cast. To maintain station at each site, the skiff motor was engaged to match river velocity. Lead weights were added as needed to reduce angular drift of the CTD during each cast. Upcast data were processed in 0.5 m bins to produce vertical water profiles of salinity, temperature, and density at each station. Onboard instrument packages may vary between sampling events, but each water column profile would at least include

measurements of at conductivity, temperature, and density. Additional water quality sensors may also be included in the instrument package (e.g., dissolved oxygen, PAR, pH, and turbidity).

Water quality:

Water quality is a supplemental monitoring element for which a consistent monitoring framework has not been developed for the Snohomish River estuary, or the Qwuloolt Estuary restoration site. The Qwuloolt Estuary restoration site is located in an a relatively urbanized area where there is a potential risk of contaminant exposure and associated injury of the biota, as the former Tulalip landfill, and the City of Marysville wastewater treatment plant are nearby. Furthermore, and the site may also be affected by stormwater and agricultural runoff from the city of Marysville and Allen and Jones Creek watersheds. Furthermore, land use history within the Qwuloolt Estuary prior to breaching may have important impacts on water quality within the site after restoration. Therefore, water quality monitoring components could provide useful insights into restoration responses observed at the site. Important indicators of water quality and water quality monitoring components may include contaminants such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDTs), polybrominated diphenyl ethers (PBDEs), organochlorine (OC) pesticides, and polycyclic aromatic hydrocarbons (PAHs) (Sloan et al. 2005); heavy metals such as copper, lead, and zinc; nutrients such as nitrates and phosphates; and basic indicators of water quality such as dissolved oxygen and pH. Data collection to date on such monitoring components have been opportunistic and not systematic within the estuary, and therefore any results from such efforts are meant to be qualitative and descriptive in nature. Development of a project-scale and system-scale monitoring framework for water quality components could be developed within the adaptive management framework based on monitoring results.

Flow:

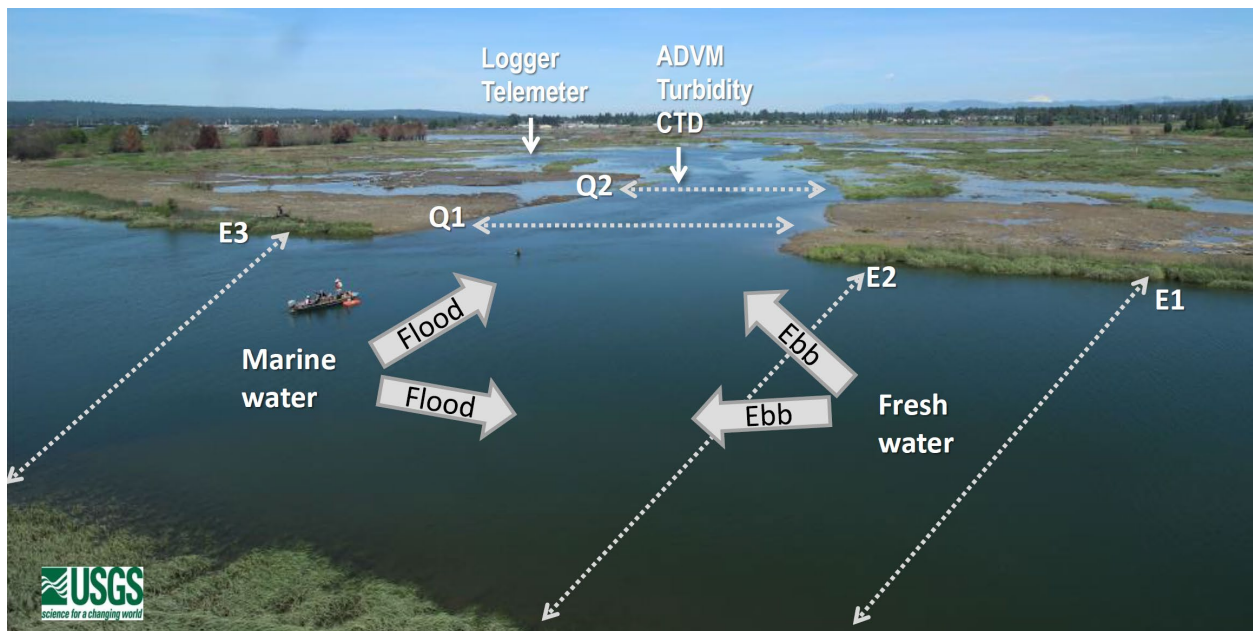
Given that salt intrusion, thermal conditions, and habitat connectivity in an estuary are strongly influenced by river flows, we used daily river flow data to provide context for many monitoring components. River discharge is a core monitoring element, although river discharge is monitored by an outside agency and is not monitored explicitly for this project. Daily river flow data are available for all water years since 1964 to present for the mainstem Snohomish River at USGS Station 12150800, which is located approximately 34 kilometers upriver of the delta mouth, and just downstream of the confluence of the Skykomish and Snoqualmie Rivers that form the mainstem Snohomish River. Using Indicators of Hydrological Alteration software Version 7.1, we classified daily river flows as extreme low flow, low flow, high flow, or flood conditions. This software uses an algorithm to first classify daily flows as either a low flow ($\leq$ 50th percentile of daily flows) or a high flow ($\geq$ 50th percentile of daily flows). Floods were events with a recurrence interval of at least two years, and extreme low flows occurred when flows fell below the 10th percentile of daily flows (TNC 2009).

Point measurements of flow are considered a supplemental monitoring component, but small scale measurements of flow direction and magnitude can provide important information on habitat conditions, processes, and use. Therefore, point measurements of flow are collected in

tandem with fish sampling events (Figure 23). These data are used to characterize conditions during the sampling event and can be used to evaluate differences in catches with respect to observed habitat conditions as well as differences in habitat conditions based on flow given the spatially intensive sampling nature of the fish monitoring framework. Flow readings are taken at the surface and near the bottom after each fish sampling event using a OTT Hydromet MF Pro flow meter.

Discrete measurements of flow at the mouth of the Qwuloolt Estuary have also been included as a supplemental monitoring component. Time-series and discrete measurements of hydrodynamics (conductivity, temperature, depth, and velocity) and sediment transport (turbidity) have been made to determine if there is a net flux of sediment into the Qwuloolt Estuary, the budget available for marsh accretion, and the habitat responses to restored tidal processes. This monitoring component also provides cross-sections and time series of velocity that are useful to evaluate habitat function given that habitat access can be limited by velocity for fishes, especially juvenile salmonids or other weak swimming fishes.

Figure 23. Project scale sampling framework for flow, showing the fixed ADVm transect (Q2) where time series of flow and turbidity were collected, and other transects located at the mouth and in Ebey Slough above and below the mouth. This figure was obtained from Eric Grossman at the USGS.



Biota:

Ideally, biological response variables should be integrative measures of overall assemblage or community condition (Karr and Chu 1999). High priority candidates are ecologically diverse major taxa that are responsive to restoration, relevant to goals, and measurable. Thus, we consider several major elements to biota in the monitoring framework that include; fish, vegetation, birds, invertebrates, and beaver. The monitoring components for each of these elements emphasize measurement of composition and abundance for whole assemblages as primary response variables, while also focusing on target species of interests (e.g., Chinook salmon).

Fish:

Surveillance monitoring of wild salmon populations during juvenile life stages provides critical information for salmon recovery efforts, but the complex life history and large and dynamic nature of estuaries makes effective monitoring challenging. In addition, beneficial effects of estuarine restoration on juvenile salmon at the population level have never been conclusively demonstrated. Collecting information that might reflect such positive changes in realized function of restored habitats (Simenstad and Cordell 2000) requires extensive and intensive sampling in space and time, and, ideally, the collection of data on diet, residence time, growth, life history diversity, and disease.

Fish/habitat relationships cannot be characterized effectively without intensive sampling in space and time because of strong seasonal heterogeneity of fish use of estuarine habitat, protracted—even multimodal—distributions of wild juvenile Chinook in estuarine habitats (Beamer et al. 2005, Rice 2007), and influences in one habitat may not be evident until downstream, later in the life cycle. We developed several core fish monitoring components that are spatially and temporally intensive at both the system and project-scales to assess overall assemblage species composition and abundance patterns, and individual attributes of selected species, especially salmon. A number of supplemental monitoring components have also been identified and integrated into the system and project-scale monitoring framework that provide other useful information to address specific questions.

Core Fish Monitoring Framework:

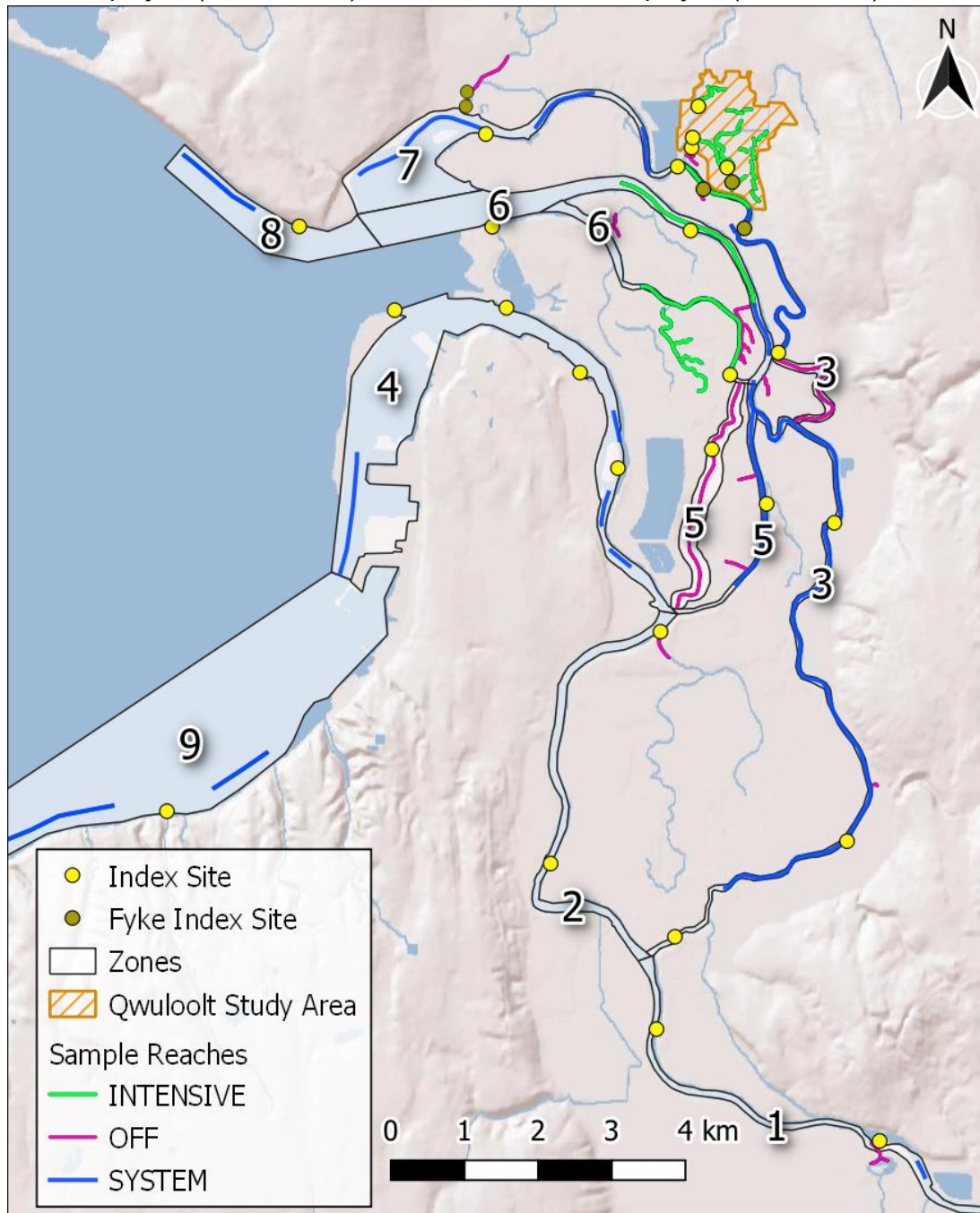
The monitoring framework for fish combines a system-scale index site and stratified random sampling design with intensive index and stratified random sampling at the project-scale using beach seining and fyke trapping. The system-scale index site scheme was based on a subset of historically sampled NOAA index sites (Rowse and Fresh 2003), which was modified in 2010 to improve spatial balance and coverage among the primary distributary channel systems and the project site. The final system-scale and project-scale design includes 26 index sites sampled by beach seine or fyke trap with at least one site in each of the zones (Figure 24).

The stratified random sampling design for system-scale sampling within the primary distributary network and a subset of blind tidal channel systems (off-channel habitats) were based on fishable reaches that were identified using a combination of aerial imagery and local area

knowledge for the entire distributary channel network (Figure 24). Shorelines with pilings, large wood accumulations, armoring, and boat moorage were classified as not fishable, which resulted in a spatially uneven distribution of fishable reaches among the zones. This uneven distribution of fishable area by zone and channel is mainly due to a lack of fishable area in the mainstem channel where shorelines are heavily modified (Figure 24).

Random stratified sampling reaches were also identified for intensive project scale sampling in the distributary immediately outside of the project extending above and below the planned breach, within the primary channel network, and interior berm edges (Figure 24). Preliminary intensive reaches have been identified for two restoration projects that are scheduled for implementation after the Qwuloolt Estuary and include the Smith Island and Blue Heron Slough projects (Figure 24). Additional intensive reaches will be integrated into the monitoring framework as restoration projects are implemented throughout the estuary. Connectivity has been shown to be strongly related to juvenile fish densities in estuary systems (Beamer et al. 2005), and we developed connectivity estimates for points within the system to support analysis of fish monitoring data. Connectivity grids for the primary distributary network were derived as described in Beamer et al. (2005) at a 152 meter (500 ft) resolution along the center flow path (Figure 25). Each random and index sample point are attributed with the closest connectivity value along this grid.

Figure 24. System and project scale sampling framework for fish. Polylines show fishable shorelines for system-scale, project-scale intensive, and off-channel sites for stratified random sampling with beach seines. Fyke trap locations are also shown and index beach seine sites for system and project-scale monitoring. Sampling zones are shown for reference and are used to stratified random sampling effort each cycle. Note that project-scale intensive reaches for the Qwuloolt Estuary are shown in addition to intensive reaches identified an additional restoration project (Smith Island) and a future restoration project (Blue Heron).



System-scale fish sampling in the Snohomish River estuary occurs approximately twice per month between February and August on the neap tide cycle. Distributary sites are sampled during these two-week neap tide cycles during falling tides, while system-scale off-channel habitats are sampled on flooding tides. Intensive sampling occurs on the same intervals, but includes sampling of fyke trap index sites. In addition, these project-scale intensive sampling efforts are continued through the entire year, with sampling frequency reduced to once per month from September through January.

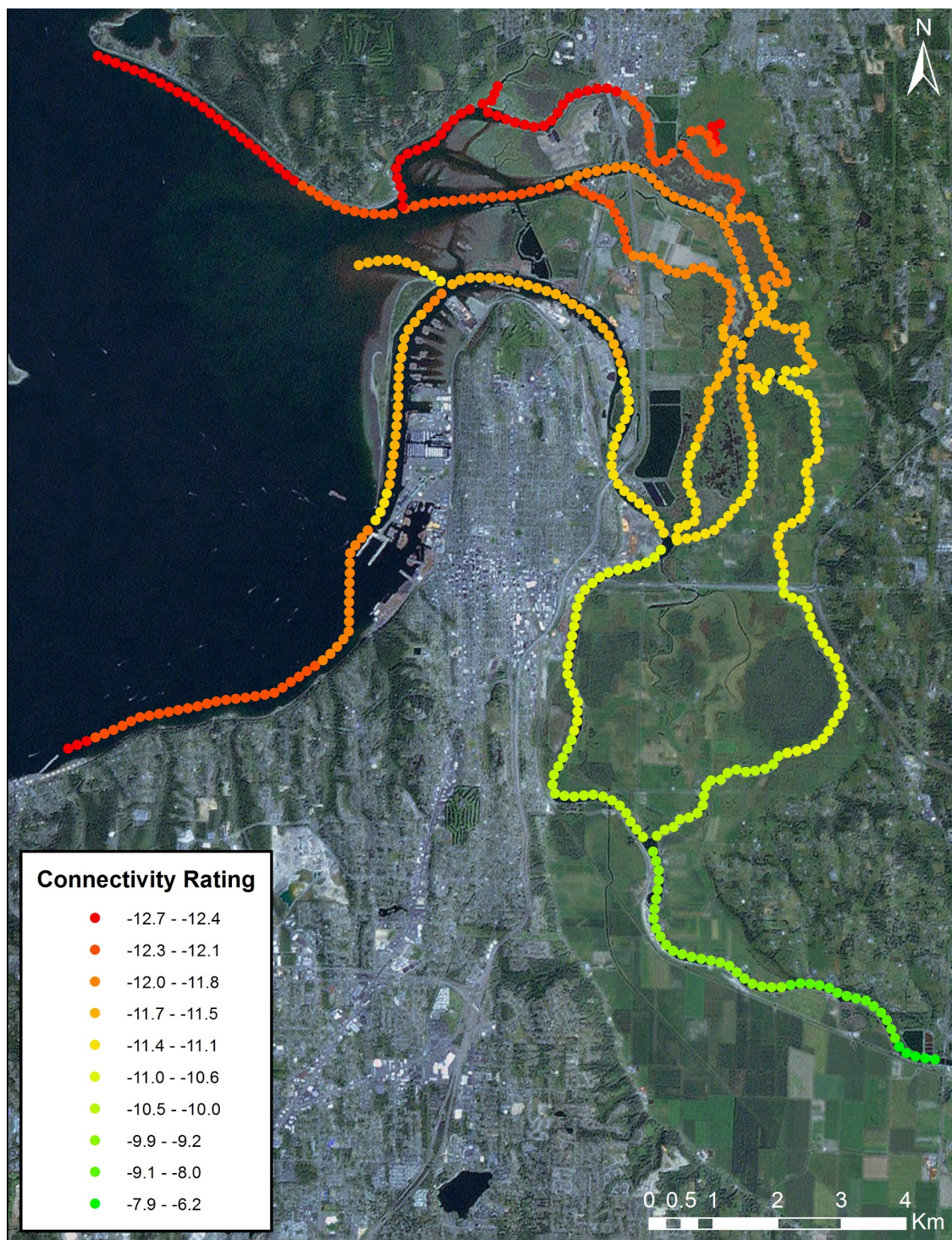
Allocations of random sample sites within each zone, channel, and project scale were based on the number of fishing days available per cycle; the number of sites that could be sampled per fishing day; a minimum target of two to three random sites per zone for system scale and six for project scale monitoring; and the length of the channel within each zone relative the entire channel network (Table 3). For each monitoring year, random sample stations are generated within each fishable segment based on the assigned allocations (Table 3) using ArcMap (Version 10.0). This allocations and monitoring framework shown in Table 3 and Figure 24 has not been implemented in all years, but represents the full monitoring design for system and project scale monitoring.

Smolt trapping is also recognized as a core system and project-scale monitoring component, although this monitoring plan does not govern the operation of these traps or collection of the data. Estimates of weekly and annual downstream outmigrant abundance, size, and species composition provided from the monitoring efforts at the Skykomish and Snoqualmie River smolt traps provide critically important monitoring context for patterns observed in the estuary (Greene et al. 2014). Therefore, we acknowledge in our fish monitoring framework that the data provided by continued operation of the smolt traps on the Snoqualmie River and Skykomish River represent core monitoring components for the Snohomish River estuary and the Qwuloolt Estuary project. The Snoqualmie River and Skykomish River smolt traps maintained by the Tulalip Tribes, and the methods and results of these ongoing smolt trap monitoring efforts are described elsewhere (e.g., Pouley and Zackey 2016a; Pouley and Zackey 2016b).

Table 9. Full monitoring design for beach seine and fyke sampling allocations for index and random sites within each zone and channel by project scale.

Project Scale	Channel	Zone	Index	Random
System Distributary	Mainstem	1	2	1
	Mainstem	2	2	0
	Upper Ebey	3	3	4
	Mainstem	4	4	4
	Upper Steamboat	5	1	2
	Lower Steamboat	6	2	3
	Lower Union	6	1	3
	Lower Ebey	7	3	5
	Priest Point	8	1	2
	Mukilteo	9	1	3
Qwuloolt Intensive	Inside Channels	7	3	5
	Inside Berms	7	0	6
	Outside (Ebey)	7	1	6
	Fyke Reference	7	4	0
	Fyke Inside	7	1	0
Smith Island Intensive	Inside	6	TBD	TBD
	Outside (Union)	6	1	6
	Fyke Reference	6	TBD	TBD
	Fyke Inside	6	NA	NA
System Off-Channel	Fields Rifle	1	0	3
	Deadwater	2	0	3
	DD6	3	0	3
	Otter Island Slough	3	0	3
	Spencer Duck Pond	5	0	3
	South Spencer	5	0	3
	Otter Island	6	0	3
	Union Restoration	6	0	3
	Mid Spencer	6	0	3
	Quilceda	7	0	3
	Marysville Mitigation	7	0	3

Figure 25. Connectivity ratings for points within the primary channel network of the Snohomish River estuary. Connectivity values were derived based on the approach outlined in Beamer et al. (2005).



Core Fish Monitoring Methods:

Approach:

For all beach seine sites, a modified Puget Sound beach seine measuring 36m in length and 1.8m (wings) to 3.0m (bag) in height made of 3mm (wings) to 1.5mm (bag) knot-less nylon is used, except where channels are too small to deploy the net. In these small channels, a pole seine is used to sample the channel edge in similar fashion. For each beach seine set, the nets are set in a semi-circle from upstream to downstream with one end held on shore and the other set from the boat or shore. In the nearshore zones, nets are deployed parallel to shore at a distance of ~27 meters with lines extending to shore. Once the nets are set, both sides are pulled in together with three or four individuals until the entire catch was consolidated in the bag (i.e. center of the net) (Figure 26). The percent of the net used in the set is recorded so that the density of fish captured can be adjusted based on the amount of water that was sampled (e.g., densities are adjusted for a set where only 80% of the net was deployed verses a set that reached the shore using 100% of the net). Surface water temperature, salinity, and water velocities are recorded at each site after each set in about 1-meter of water from the shore.

Figure 26. Example of a beach seine net deployed from a boat and being pulled into shore in the Snohomish River estuary.



A subset of off-channel index sites are also sampled using fyke traps at index sites. These traps are set at high slack water and spanned the entire channel (Figure 27). The traps are left in place for the ebbing tide, thus all fish in the channel at the time the trap was set are theoretically funneled into the trap. The area of the channel network above the fyke trap is used to estimate the density of fish captured in the traps. Fyke trap deployment times, including setting and retrieval, are recorded along with surface water temperature and salinity. Capture efficiencies of fyke traps are also measured occasionally using fin-clipped marked fish released above traps.

However, capture efficiencies are not assessed systematically or regularly as part of the monitoring program and are therefore not used to adjust densities of captured fish at this time.

Figure 27. Picture of a fyke trap deployed at Ebey Island. This image was taken near the end of the ebbing tidal cycle after which the net will be retrieved, and captured fish processed.



Fish captured by beach seine or fyke trap are processed the same way. Fish were immediately removed from the bag or trap and placed into 5-gallon buckets or larger totes with fresh water from the site. Up to 25 individuals of each species captured per set are measured to fork length, or total length when no fork is present, to the nearest mm. Where possible, all Chinook, coho, and Steelhead encountered are measured for fork length. Additional individuals of each species not measured for length are counted. Chinook, coho, and Steelhead were identified as marked fish by checking for the presence of an adipose fin clip and/or coded-wire tag. These marked fish were measured and enumerated separately. Collectively, these data are used to monitoring basic temporal and spatial patterns of species assemblages (e.g., presence/absence, diversity, richness); abundance (e.g., density); age, size, and life history structure (e.g., length frequency distributions, age classes, and origins). Additional supplemental monitoring components are also collected as part of the system and project-scale monitoring effort.

Relevant Monitoring Questions:

Core fish monitoring components address multiple monitoring questions at the system and project-scale (Table 10). This component specifically addresses Status and Trends, Diagnostic, and Effectiveness questions for the system and project-scale.

Table 10: Monitoring questions addressed by the core fish monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
ST4	Project	Fish assemblage abundance and distribution before/after breach within the site
E6	Project, System	Compare assemblages among project and reference sites as well as across system
E7	Project	Evaluate/compare size and timing of Chinook presence between project and reference sites
D6	Project, System	Evaluate relationships among trends in core metrics with fish abundance/distribution

Supplemental Fish Monitoring Components:

A subset of captured Chinook are sacrificed for additional processing, although the intensity and sampling design has varied over time depending on project funding, permits, and needs. Generally, lethal sampling has included up to five marked and five unmarked juvenile Chinook salmon from each zone for system-scale sampling, for each fyke trap, and for project-scale intensive sampling inside and outside of the project area. Any individuals that appeared unduly stressed or dead upon retrieval of the net were selected before healthy individuals were sacrificed. For all lethal sampling, fish were sacrificed with a lethal dose of MS-222. Sacrificed individuals were taken to the lab to have otoliths, stomachs, and coded wire tags removed and archived for future analysis and all individual carcasses were subsequently frozen. Otoliths are removed and placed dry into 20mL scintillation vials labeled with sample number, site name, date of collection and individual lengths and weights. Individual stomachs are removed and placed into 20mL scintillation vials and fixed with a neutral buffered formalin solution for preservation of gut contents until analysis. Stomach vials are labeled with sample number, site name, date of collection and individual lengths and weights. Once otoliths and stomachs are removed from each sample, carcasses are placed in individual Ziploc bags labeled with sample number, site name, date of collection and individual lengths and weights and immediately frozen and archived for stable isotope or genetic analysis. These samples have been used, and archived samples already collected may be used in the future, to analyze various supplemental monitoring elements including fish age, rearing patterns, tissue contaminants, stable isotopes, and genetic information.

Non-lethal caudal fin clip samples from captured juvenile Chinook salmon have also been collected at times as part of the system-scale and project-scale monitoring efforts as a supplemental monitoring component. These efforts have been coordinated with sampling efforts at upstream smolt traps maintained by the Tulalip Tribes on the Snoqualmie and Skykomish Rivers. Paired sampling of fin clips during fish monitoring efforts and at the smolt traps are designed to provide information on the natal system of origin of juvenile Chinook in the estuary and mark-recaptures of individuals that can be used to estimate growth between capture events. Previously clipped individuals identified during fish sample processing were targeted for

fin clip sampling, but entire catches of juvenile Chinook were clipped when possible. All clips were preserved in alcohol in vials for later processing.

Vegetation:

As a dominant biological component in its own right, a major influence on other taxa, including juvenile salmonids, and an important influence on site development and other wetland functions, vegetation was characterized both before and after breaching using a combination of remote sensing and ground surveys. Current elevations at the Qwuloolt site show that the site has subsided and much of it is too low for native vascular plants to establish. This problem is common in agricultural fields returned to tidal influence (Zedler 2001). Literature values and field surveys in the Snohomish estuary indicate that vegetation in brackish marshes generally grows from about 2 meters above mean lower low water (MLLW) to approximately 3m MLLW in the Pacific Northwest, though lower salinities may result in plants growing at lower elevations (Ewing 1986). Except for berms created during the excavation of starter channels, most of the Qwuloolt site is at elevations below 2 meters MLLW. Considerable uncertainty exists regarding post-breach sediment accretion rates onsite but they are not likely to be more than 2-5 cm per year (Thom 1992, Cornu and Sadro 2002). Depending on dieback of existing vegetation and the changes in elevation onsite as a result of surface and subsurface processes, it could take decades for the majority of the site to become vegetated. Consequently, pre-breach and immediately post-breach monitoring focuses on spatial distribution and species composition at Qwuloolt and at reference sites, and immediate post-breach will track the dieback process, colonization by vascular plants at elevations likely to support them, and algae. Therefore, our vegetation monitoring framework includes two core project-scale monitoring components designed to evaluate changes in community composition and vegetation cover over time within the project site and reference marshes. Additional supplemental monitoring components using remote sensing methods are also being developed, but these are still under development and are not currently part of the regular monitoring framework.

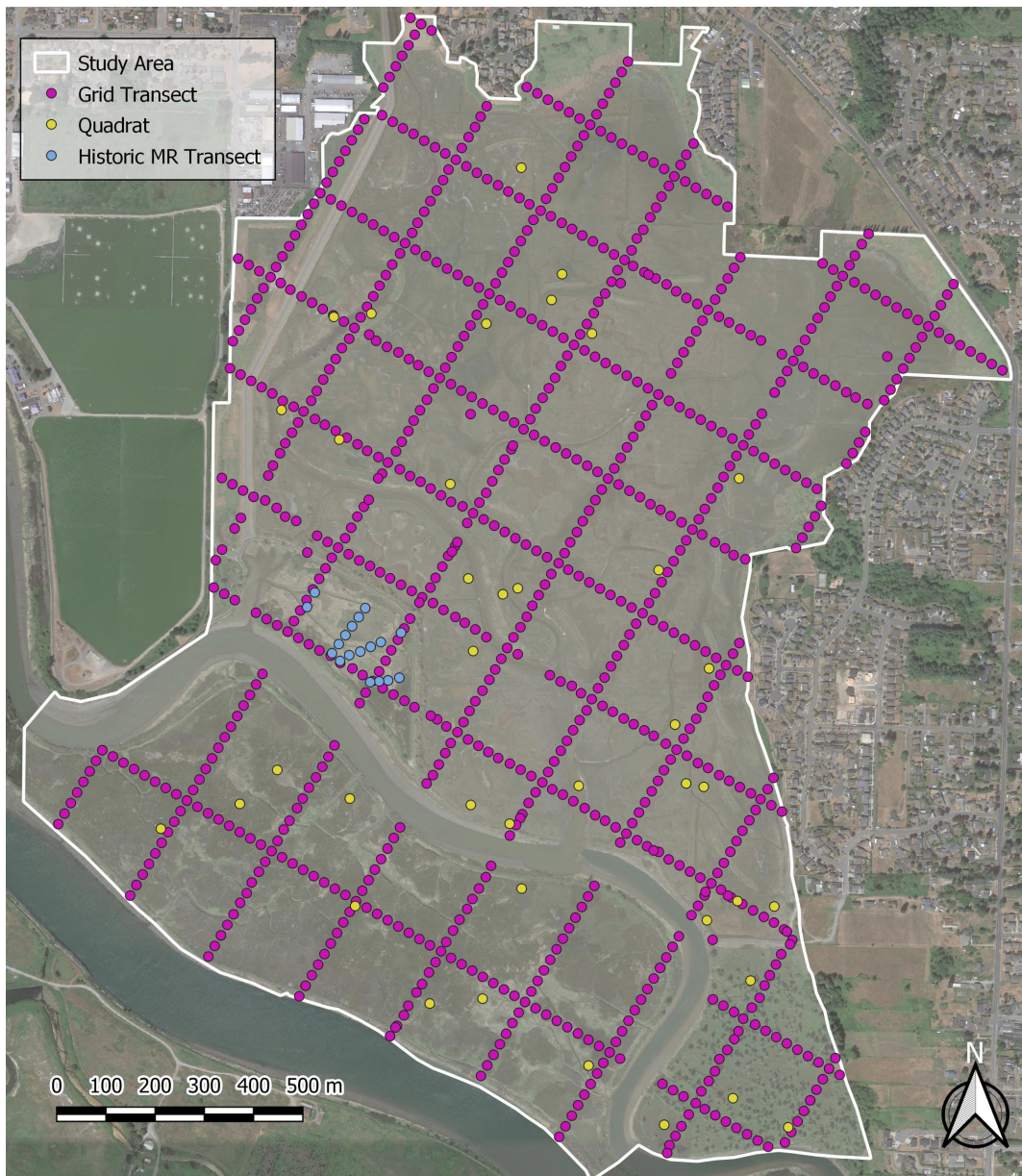
Core Vegetation Monitoring Framework:

Approach:

Our core vegetation monitoring framework is part of the RTK grid transect monitoring component described for topography. A preliminary survey of surface elevations and dominant vegetation was implemented in the spring and fall of 2009 using a transect and grid approach with survey grade RTK GPS equipment. These surveys focused on reference marshes at Quilceda, Big Flats, Ebey Island, Otter Island, and the Marysville Mitigation site. However, this sampling effort was designed to provide baseline data for these reference sites and survey points were not included in the final grid transect sampling design described here. At each grid transect point, basic attributes of vegetation are recorded along with the elevations collected at each point. As described in the RTK/veg grid and transect monitoring section for topography, a grid transect of points was established throughout the project site and adjacent reference marshes (Figure 28). These points are sampled annually during the post-breach phase (2015 and later) in the late summer/early fall using a rapid survey approach, with one pre-breach survey in 2010 with the assumption that plant communities were not changing dramatically prior to implementation of the restoration project. Survey grade RTK GPS equipment is used to navigate to fixed points so that elevation and vegetation at each point can be repeatedly sampled over time. We also include historically monitored transect points established within the

Marysville Mitigation site that were previously monitored as part of that project's monitoring plan (Figure 28).

Figure 28. Map showing layout of grid points and transects for RTK surveys of surface elevation and vegetation. In addition to this grid design, historic monitoring transect points inside the Marysville Mitigation site are shown for reference as these sites will also be monitored within this framework. Quadrat monitoring points are also shown, although additional sites may be established over time.



At each grid point sampled, elevation (using RTK-GPS measurements), dominant species and subdominant species present (up to 5 spp.), relative abundance of each (dense, 90-100% cover; medium, 40-90%; low 10-40%; and rare <10%), and 3) height, and qualitative condition (robust, medium, stressed, senescing, dead) of the dominant plant species within a 1 m² area at 25 meter intervals along the transect grid. Post-breach surveys also recorded: 1) cover of bare earth, 2) presence of large wood, and 3) presence of an entrained canopy within the 1 m² quadrats.

Our core vegetation monitoring framework also includes monitoring of established plots outside of the grid transect within the project site and reference marshes (Figure 28). These extensive monitoring plots, otherwise referred to as quadrats, were established in major assemblages and key locations within the project site and reference marsh systems (based on channel networks and surface elevation gradients) to intensively evaluate changes in plant communities over time. Additional plots may be added over time as conditions change to capture changes in community structure and distribution. Each plot consists of a 5 x 5 meter square with 1 m² cells that are marked out with PVC and line (25 cells in total per quadrat), and each plot is located for repeat sampling using survey grade RTK GPS. Within each cell, the presence of all species are recorded with categorical condition (robust, medium, stressed, senescing, dead) and percent cover, and whether the species is growing on locally raised woody debris. When trees are present in a plot, each species will be recorded if its drip line falls within each 1 m² cell. Though it is difficult to estimate vertical projection of trees into such small quadrats, the 2011 results were consistent with tree cover estimates for the plots as measured through remote sensing data.

The U.S. National Vegetation Classification (USNVC) is a standard hierarchical vegetation classification, with physiognomic units at the higher levels and floristic units at the lowest levels. The most basic levels of the USNVC are the association and alliance units. An alliance is an aggregate of associations based upon one or more diagnostic species, typically with at least one from the uppermost or dominant vegetation stratum (Jennings et al. 2009). Regional surge plain wetland alliances are currently under review (NatureServe 2011). It may be possible to calculate normalized estimates of cover from the extensive data, then use ordination and clustering analysis (McCune and Grace 2002) to define associations, and fit them into regional alliances as they become available. Otherwise, % canopy cover of species in a scale convertible to the commonly used Braun-Blanquet scale (Braun-Blanquet 1932) should be recorded for each monitoring plot. For grid point samples, overall cover of dominant species is sufficient (Jennings et al. 2009). Species nomenclature for all vegetation data will follow protocol in the USNVC (Jennings et al. 2009).

Relevant Monitoring Questions:

Core vegetation monitoring components address multiple monitoring questions at the system and project-scale (Table 11). This component specifically addresses Implementation, Status and Trends, Diagnostic, and Effectiveness questions for the system and project-scale.

Table 11: Monitoring questions addressed by the core vegetation monitoring components. The monitoring questions are identified as Implementation (I), Status and Trends (ST), Effectiveness (E), and Diagnostic (D) questions and the question number identified in the monitoring questions section.

Question	Scale	Description
I1	Project	Document initial plantings within the project site
I3	Project	Documents and evaluate conditions of plantings after site breach
ST3	Project	Evaluate plant assemblages/community distribution/condition before/after breach
E4	Project	Compare established plant assemblages with targets for project site
E5	Project, System	Compare plant communities/distribution among project and reference sites
D5	Project, System	Compare plant assemblage data with hydro and topographic data to establish correlations

Supplemental Vegetation Monitoring Components:

A variety of remotely sensed data have been collected as part of the system and project-scale monitoring plan that can be used to inform vegetation monitoring questions. UAV and Aerial imagery and remotely sensed data offer the most potential for long-term monitoring of vegetation conditions and responses. LiDAR and natural light 3-band orthophotos were collected in summer 2009, but repeat flights have not been planned and are expensive. More recently, UAVs have been used to collect elevation and multispectral imagery for the project site on an annual basis since 2015. These data have the potential to provide high resolution time series of elevation and vegetation assemblage/coverage data for the project, but the methods and approach for this component are still under development. Pairing annual UAV data acquisitions with the data collected through the RTK/veg grid monitoring components may provide the calibration data to develop seamless maps of elevation and vegetation communities within the project site over time.

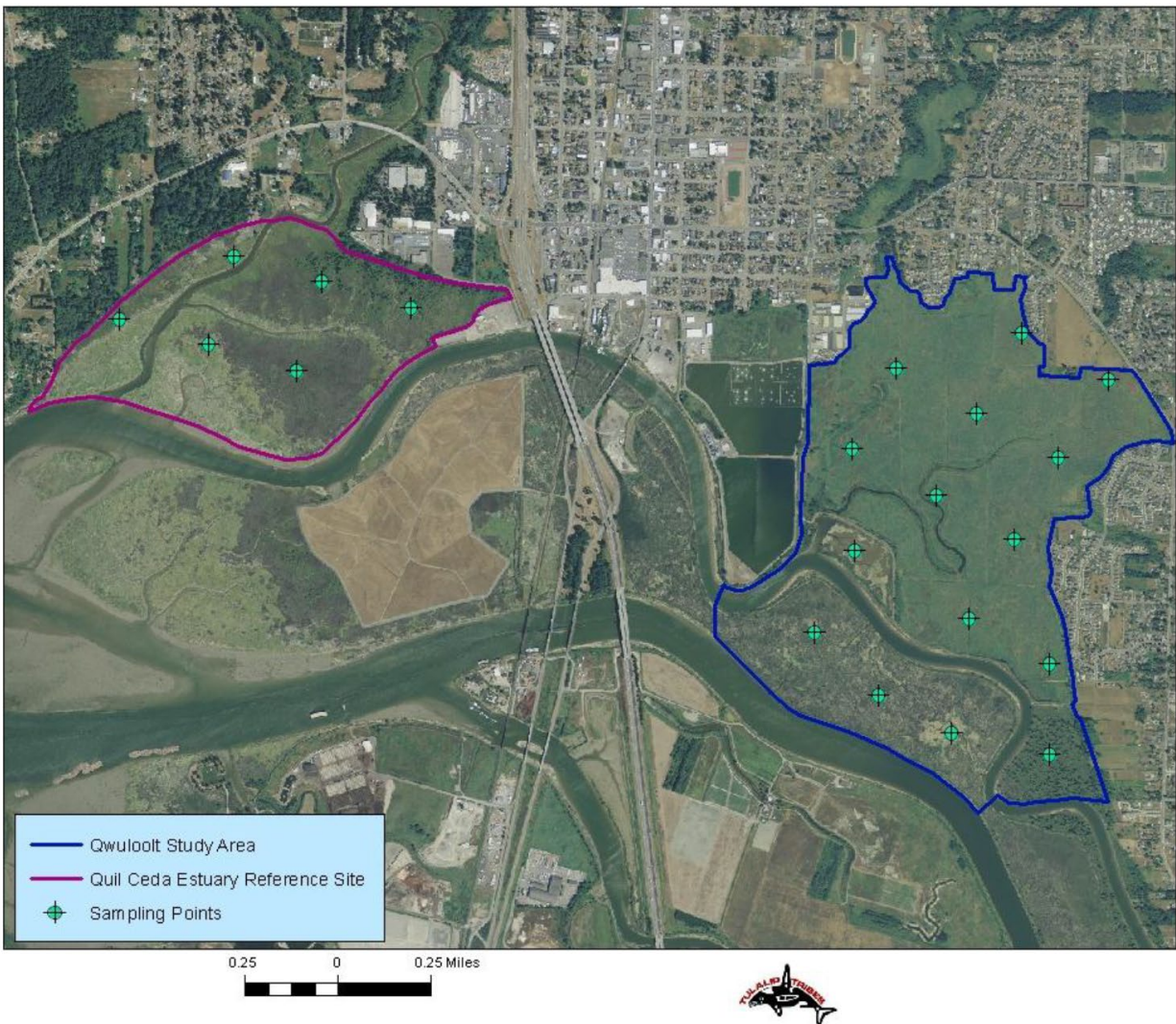
Birds:

Birds are a major taxon that provide information on overall biological condition, has high public appeal (Furness and Greenwood 1993), and is also relatively efficient to sample. Marsh bird abundance and distribution over space and time indicate habitat quality and can be used as measures of restoration success (Neckles et al. 2002; U. S. EPA 2002). The effects of tidal marsh restoration on bird communities have been documented in other parts of the country (Brawley et al. 1998; Seigel et al. 2005; Athearn 2009) but not in the Puget Sound area. Tidal salt marsh bird populations are currently undersampled and in need of a focused monitoring effort (Conway and Droege 2006). Although bird monitoring is an ongoing element of the monitoring framework, this element is supplemental and is largely implemented through collaborative monitoring between the Audubon Society citizen science groups and led by Tulalip Tribes Wildlife Program.

Standardized monitoring protocols for marsh birds have been developed (Conway and Droege 2006; Conway et al. 2008) to facilitate a large-scale monitoring effort and database for assessing regional or range-wide population trends and identifying declining species before they become endangered. Because bird assemblages are heavily influenced by seasonal and tidal conditions, as well as offsite influences, we recommend a combination of point and line transect surveys (Bibby et al. 2000) on an annual basis with bimonthly monitoring during the non-breeding season (July - May), combined with three survey events during the breeding season.

Point count surveys are conducted following Standardized North American Marsh Bird Monitoring Protocol (Conway 2011) and A Unified Strategy for Monitoring Changes in Abundance of Terrestrial Birds Associated with North American Tidal Marshes (Conway and Droege 2006). The project area and the reference sites were divided into 16-hectare or 400 meter grids (Figure 29). Point count surveys occur at the center of each grid, with observations conducted from 30 minutes prior to sunrise to three hours after sunrise. Surveys consist of two parts: 1) a 5-minute passive listening period during which all species seen or heard are recorded 2) playback recordings of secretive marsh birds, including sora, Virginia rail, American bittern, American coot, and pied-billed grebe, during which all species seen or heard are recorded. Digital vocalizations of each secretive species were broadcast for 30 seconds, followed by 30 seconds of silence. Ancillary information such as tidal stage, weather, and temperature are also recorded during these observations.

Figure 29. Grid sampling scheme for point bird counts.



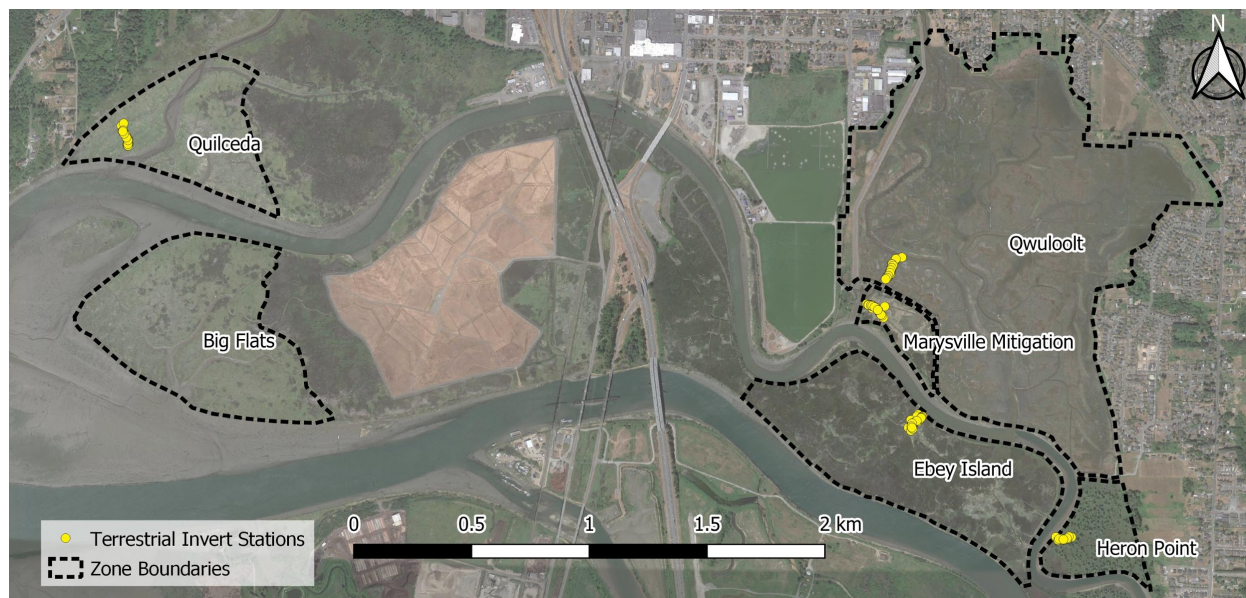
Additional management decisions and strategies will also play an important role in reestablishing decreased populations of threatened, endangered, or even hunted avian species. Improving cavity nesting lost from tidal inundation effect on coniferous tree species will prove beneficial for species such as bald eagle (*Haliaeetus leucocephalus*), purple martin (*Progne subis*), swallows (*Hirundinidae*), wood duck (*Aix sponsa*), Western Screech-owl (*Megascops kennicottii*). Strategies to improve cavity nesting may include installing snags, platforms, small wood nest boxes, and purple martin gourd trees. Management strategies to improve hunting opportunities would be to limit hunting within newly established Qwuloolt restoration.

Invertebrates:

Invertebrate monitoring is a supplemental monitoring component of the monitoring framework. However, invertebrates represent potential prey for fish species and also represent ecosystem function response metrics that are linked to the abiotic and biotic characteristics of the habitat (e.g., vegetation community assemblage, density, and distribution). Therefore, continued monitoring and analysis of invertebrate components could provide useful information to evaluate restoration responses at the Qwuloolt Estuary. We have identified four supplemental monitoring components that would characterize important aspects of invertebrate assemblages and abundance, which include benthic coring, fallout trapping, nuston sampling, and salmon diet analysis. These components would provide information on the availability and use of invertebrate prey in juvenile salmon diets, and information on the overall ecosystem function of different habitats based on the assemblages and abundance of invertebrate taxa.

Benthic core and fallout samples have only been collected during a limited series of pre-breach sampling (September 2009, May 2010, and July 2010) inside the Qwuloolt Estuary and at reference marshes (Ebey Island, Heron Point, Marysville Mitigation, and Quilceda) (Figure 30). No post breach sampling of benthic or terrestrial invertebrates have been completed since the breach at Qwuloolt. Nuston sampling was not implemented prior to the breach and has also not been implemented to date during the post-breach period.

Figure 30. Map of invert sampling stations for benthic cores and fallout trapping. All sampling was conducted in 2009-2010 before the breach at Qwuloolt. No post breach sampling has occurred.



Benthic coring samples invertebrates in the top 10 cm of substrate in the channel bed during a low tide using a PVC core sample of 0.0024m² (Cordell et al. 2001, Cordell et al. 1994). Three replicate samples are taken along the channel within each site and placed into a sample jar. The samples are then washed successively through a 500 micron and 153 micron sieve using

pressurized water to remove sediment from the sample. The samples were fixed in neutral buffered formalin solution for preservation until analysis. Samples are processed to lowest possible taxa and densities estimated for each taxa based on invertebrate abundance and core volume. Future monitoring would likely occur in similar locations or be expanded to include additional habitat types or areas within the project site or reference marshes as conditions develop over time.

Fallout trap samples target terrestrial invertebrates and are collected on a falling tide at three replicate sites along a primary channel edge. Shallow totes (60cm x 35cm x 15cm) are secured to two PVC pipes with zip ties, such that the PVC pipes allow the tote to float at the surface level and move down with the tide. The bottom of the tote is filled with a ~5 cm of water and dish soap is mixed into the water to reduce surface tension and trap insects that land in the water. The traps are retrieved at the following low tide, strained into sample jars, and fixed with fixed in neutral buffered formalin solution for preservation until analysis. Samples are processed to lowest possible taxa and densities estimated for each taxa based on invertebrate abundance and trap surface area. Future monitoring would likely occur in similar locations or be expanded to include additional habitat types or areas within the project site or reference marshes as conditions develop over time.

Preliminary nuston sampling methods have been tested but not fully developed for this project.

Beaver:

North American Beaver (*Castor canadensis*) are a major influence on the physical, hydrologic, and biological attributes of wetland ecosystems. Consequently, beaver can be an important factor in wetland restoration, including estuaries, where beaver are known to occur but are rarely considered in restoration planning and monitoring. In estuaries, beaver dams are usually built in channels of shrubby or forested areas, causing slower drainage of tidal outflow, higher low tide levels, and the accumulation of nutrients, sediments, and permanent ponds (Hood 2007, Polvi and Wohl 2012). Because tidal channels flood daily, beaver may not need to build dams for the purpose of inundating floodplains as they do in rivers and streams. Instead, their dam building in estuaries most likely serves to create a safe way to travel during low tide periods (Hood 2007).

In the Pacific Northwest, estuarine restoration projects are often driven by salmon recovery, especially Puget Sound Chinook (*Oncorhynchus tshawytscha*), the most estuarine salmon species and listed as Threatened under the Endangered Species Act. Since beaver activity may dramatically affect estuarine rearing capacity for juvenile salmonids, improved understanding of the role of beaver in estuary restoration can better define potential and target conditions for project sites, enhance restoration actions through facilitation of beaver activity where appropriate, and improve management restoration projects where beaver are present.

Given the potential importance of beaver in estuarine restoration, our monitoring framework includes supplemental monitoring components designed to document beaver presence and distribution within the project site and reference marshes. These surveys would primarily be visual surveys of channels combined with ancillary observations of beaver during the course of other survey efforts to document the presence and distribution of beaver within the project site and reference marshes. More focused surveys, including GPS surveys of dam, slide, or den locations at reference marshes or throughout the system may also provide useful information on how beaver distributions change over time in the system.

Qualitative:

Qualitative monitoring by still photography at established photo points and observations of interest, time series of aerial imagery, video of important observations, and time lapse photography provide visual records of overall project condition that are useful for project management, scientific, and outreach. Collection of visual records is a core monitoring, and both should be core monitoring components for the Qwuloolt Estuary.

A series of photo points was established at the project site prior to breach to document change in conditions within the Qwuloolt Estuary over time. We recommend a minimum of semiannual, high and low tide panoramic photographs at seven stations around the Qwuloolt Estuary site. Post-breach photos have been collected as obliques and aeriels during UAV surveys of the site. A time lapse camera was also installed across the channel looking towards the breach and the interior of the Qwuloolt Estuary prior to the breach, which records still images every 15-minutes during daylight hours. Plans are being developed to install a similar time lapse camera at

another location to look into the project site from another angle. These time lapse images will be catalogued through online servers that are accessible to the public and can be reviewed to document changes over time.

Additional still images and video of observations are core monitoring elements that provide useful visual records, but are not conducted as a standalone monitoring element and are opportunistically collected as part of other monitoring efforts. These images and video can be used to show important observations and conditions observed during surveys, such as observations of flow conditions (e.g., high flows or cascading flows during an ebbing tide), animal observations (e.g., beaver, birds, or seals using the site), or formation of habitat features (e.g., establishment of vegetation or dieback of vegetation).

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