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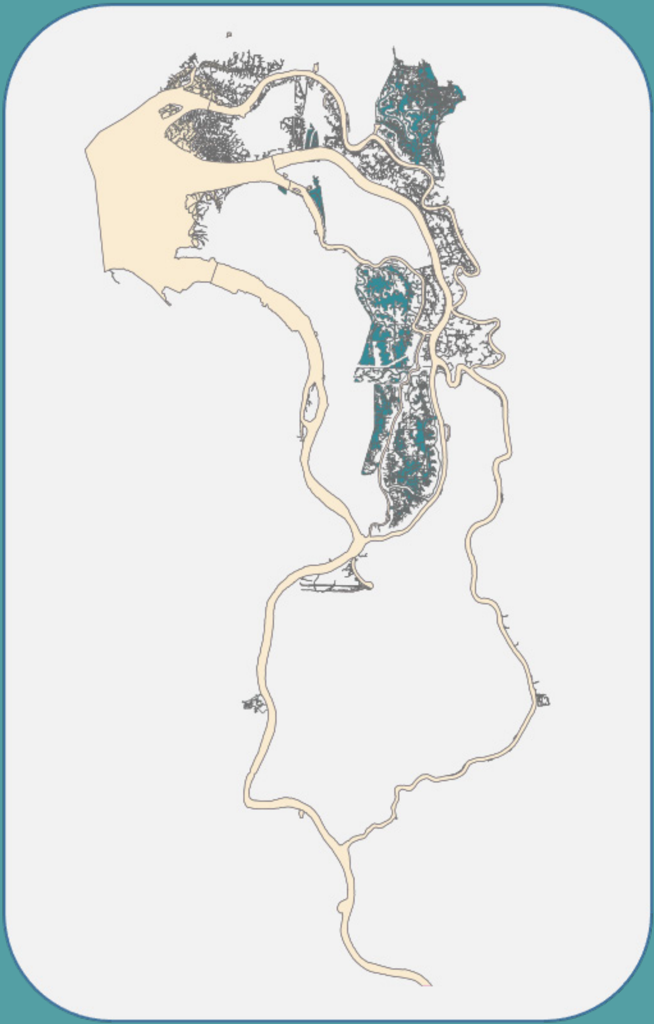
Chinook Salmon Use of Tidal Delta Habitats: Synthesis for Snohomish Recovery Plan Revision

Prepared for **Snohomish Basin Technical Forum** and **Tulalip Tribes**



June 2022

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National Oceanic and Atmospheric Administration
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Cover images: (top) Blind tidal channel at low tide in the Snohomish delta. Photo shows exposed banks, both vegetated and unvegetated, as well as a fyke trap removed after sampling for fish using the channel. Photograph by Motofish. (bottom) Map of the Snohomish delta displaying the channel network, including the mainstem Snohomish River on the western boundary, as well as three distributary sloughs (Ebey, Steamboat, and Union). Figure also shows wetland channel features to highlight the available rearing habitat across the delta. The majority of the rearing habitat is located along the distributary sloughs in the lower (north-central) portion of the delta. Figure by O.Stefankiv, NMFS/NWFSC.

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Chinook Salmon Use of Tidal Delta Habitats:
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Contents

1. Executive Summary

- Juvenile Chinook fry migrants are the “primary” users of tidal delta habitat. Yet the proportion of the population represented by this life history fluctuates year-to-year determining the number of Chinook salmon coming into and using the tidal delta.
- Linking restorations actions in freshwater habitat with goals and targets in the estuary are crucial for recovery planning. Increasing freshwater rearing habitat can influence the proportion of fish using tidal delta habitat for primary rearing purposes.
- Increased understanding of fish distribution and abundance in tidal delta habitats can help inform/revise recovery planning as well as aid project effectiveness evaluation. In particular, understanding the influence of landscape connectivity on fish density/distribution and capacity (see Section 5) may help managers evaluate and rank potential restoration projects and place project expectations (fish response) in the context of difference across the landscape.
- The vast majority of rearing habitat in the systems occurs in the lower estuary. Elevating potential projects in areas currently without available rearing habitat can have large impacts on current capacity and increase the connectivity of habitat within the system.
- The considerable presence of nan-natal basin fish found in the Snohomish estuary is novel and warrants further discussion. Recovery planning for Snohomish populations should consider the influence of non-natal populations on habitat use within the delta relative to natal populations.
- Both diet composition and prey assemblage differ among the three primary habitat types in the delta. Preserving/restoring resource (habitat) diversity can mitigate negative impacts on juvenile growth during periods of low prey productivity and/or high consumption demand (elevated fish densities).
- Terrestrial insects are an important component of juvenile Chinook diets in delta habitats. Terrestrial prey production is higher in FRT habitats which are extremely limited in the Snohomish delta.
- Thermal conditions can have large influence on juvenile Chinook salmon growth in the delta. Temperature variability across the estuary is generally greatest during the rearing season (Mar-Jun) and generally follows a gradient from cold to warm from upstream to

downstream within the delta. Concentrating rearing habitat in certain areas of the delta reduces the thermal diversity available for juvenile fish and may constrain the growth opportunity throughout the rearing period.

- Bioenergetics models indicate that growth opportunity for juvenile Chinook salmon is variable among habitat types during the rearing season. While no single habitat type consistently offers the highest growth potential for juvenile fish, each habitat type offered the highest potential during different periods of the rearing season. Growth opportunity varied considerably by week and weekly patterns among habitat types were variable throughout the season.
- Maintaining and creating habitat diversity in the delta likely offers the greatest range of growth opportunity for juvenile fish. Increased habitat diversity can likely be achieved by distributing available habitat (restoration projects) from upstream to downstream within the delta.
- Rearing capacity estimates using the revised methods were comparable, though not identical, indicating the current rearing capacity in the Snohomish delta between 232,047 and 306,022 tidal delta rearing migrants. These estimates likely offer a conservative estimate given they do not include tidal flats which account for the majority of current habitat within restoration sites. However, both methods account for landscape connectivity, a strong determinant of salmon distribution and abundance within tidal deltas throughout Puget Sound including the Snohomish estuary.
- Estimates of total outmigration abundance at estimated delta capacity range between 252,225 – 695,504 Chinook salmon when combining the habitat expansion method with the lower and upper proportion of fry migrants from 2001-2015, and estimated at >1.1million migrants using our data driven modelling approach. Both estimates are below the predicted outmigration abundance under recovered population conditions (3.3-5.6 million fish). While this suggests more estuary habitat capacity is certainly needed, restoration in freshwater habitats should also be incorporated into estuary planning given the connection between fry migrants, population abundance, and freshwater rearing habitat.
- Capacity estimates are not a hard line determinant of fish use in the estuary. Observation of Chinook density n the Snohomish delta suggest fish are using estuary

habitat even when density exceeds predicted/estimated capacity. Though the exact reasons for this are yet unclear, capacity estimates may reflect a baseline after which continued use of delta habitats at higher densities are tolerable (i.e. do not trigger movement out of the delta) but may have adverse impacts for some individuals. Furthermore, there may be an upper threshold for movement out of the delta that has yet to be determined from estuary observations.

- Capacity estimates are based solely on natural origin fry migrant use of tidal deltas. Other natural origin life history types, hatchery-origin fish, and non-natal populations use tidal delta habitat in the Snohomish to varying degrees. Further understanding the magnitude of habitat use by each of these groups will be necessary to determine how they may contribute to, or impact, recovery targets and goals for natural populations.
- Juvenile Chinook salmon were observed immediately after restoration at both the Qwuloolt and Smith Island sites. Densities were lower than reference blind channel habitats at both project sites though the difference has decreased at the Qwuloolt site 3-4 yrs post-restoration. The presence of fish within restored sites and the trend toward reference blind channel sites at Qwuloolt suggest a positive response to restoration for juvenile Chinook salmon in the delta.
- Seasonal patterns of juvenile Chinook density remain different within project sites compared to reference blind channel sites. Low Chinook salmon density at project sites early in the outmigration period (Feb-Mar) warrants further attention. Expectations for restoration projects should follow patterns of fish use similar to reference/natural tidal channel sites/habitat but may take several years to realize. As such we should expect restoration projects to support early use by fry migrants in the delta and thus densities at project sites in the early rearing season should increase in future years.
- Differences in average fork lengths for individuals captured within and adjacent to project sites were apparent for both Qwuloolt and Smith Island. Individual Chinook salmon captured within the Qwuloolt site were consistently larger than those captured in reference blind channel sites throughout the rearing season. While this may simply reflect use of these sites by larger individuals (yearling migrants), it is unclear if there are barriers to the site for smaller Chinook salmon (fry migrants) early in the rearing season.

2. Introduction

Establishing conservation plans for listed species requires synthesizing the best available science and using the information to establish goals for population recovery. Scientific information, along with current and emerging analytical techniques, provide the foundation for defining recovery targets and recommendations for restoration actions. Periodic revisions to recovery plans allow managers to evaluate progress, adjust targets, and provide new recommendations for future actions. As science and research evolve this new information is critical for the review process.

The goal of this document is to summarize research describing fish use of tidal delta habitats in Puget Sound with particular emphasis on the Snohomish estuary. The following synthesis will include published and unpublished data collected and/or analyzed primarily since 2005 when the initial Snohomish Chinook Conservation Plan was published. This synthesis largely focused on information regarding distribution, abundance, and habitat use which may be used to refine recovery targets/definitions and improve specificity for recommended actions within the delta. In addition, we use the updated state of knowledge to develop new methods and reassess current habitat capacity estimates for comparisons with previous recovery targets and to help inform revised/updated estuary recovery goals. Lastly, we provide project specific information for Qwuloolt and Smith Island restoration projects to evaluate how observed conditions compare with project expectations.

3. The Snohomish estuary

Habitat Extent and Classification

Historically, the Snohomish estuary was the second largest tidal delta in Puget Sound. Like most deltas throughout the region and along the West Coast, the extent of the Snohomish estuary has been greatly reduced compared to historic conditions (Brophy et al. 2019, Haas and Collins 2001). The greatest losses in habitat area occurred in the upper estuary along the mainstem Snohomish River and Ebey Slough though substantial degradation occurred in the lower estuary as well (below the confluence between mainstem Snohomish River and Steamboat/Union Sloughs). Current assessments of delta habitat extent in the Snohomish estuary indicate there exists 325.8 ha of habitat available for juvenile Chinook salmon (Fig 1,Table 1).

Figure 1.Current habitat availability in the Snohomish estuary. Distributary channels are colored red while tidal channels and tidal flats are colored gray and blue, respectively.

The estimate includes distributary channels (2m edge; see Greene et al. 2021, Beamer et al. 2005), tidal channels, tidal complex, and tidal flats. Tidal complexes generally occur at the delta-bay interface and are comprised of numerous, connected small channels. Channel area in tidal complexes scales linearly with total area of the complex (Beechie et al. 2017). Tidal flats within the vegetated delta footprint are features generally unique to restoration projects and are likely present due to the low initial elevations at project sites due to subsidence of the land after diking occurred. Restoration actions, including mitigation, have doubled the amount of tidal channel habitat available in the Snohomish estuary; the majority (~65%) added since 2015.

*Table 1. Current habitat area by feature before and after restoration actions within the Snohomish estuary. * includes projects that have occurred since 2005.*

	Habitat Area (ha)		
	Pre-restoration	With Restoration*	Total
Distributary	25.77	NA	25.77
Tidal channels	38.64	38.83	77.47
Tidal complex	43.7	NA	43.7
Tidal flats	NA	178.86	178.86

Along with habitat degradation, tidal deltas including the Snohomish estuary have suffered from habitat fragmentation. Current juvenile rearing habitat in the Snohomish estuary is not distributed evenly throughout the system (Fig). More than 98% of the total rearing habitat (not including distributary channels) and roughly 88% of all tidal channel habitat is located in the Lower Estuary. The mainstem Snohomish River contains only 4% of total habitat area (distributary + tidal channel) and 10% tidal channel habitat in the system. While restoration actions have done well to reconnect rearing habitat in the lower estuary, prioritizing actions in the upper estuary to increase connectivity and mitigate fragmentation may have disproportionate impacts/benefits for local populations.

Chinook salmon monitoring

Since 2002, extensive monitoring of Chinook salmon in the Snohomish estuary has occurred with the goal to document distribution and abundance of juvenile fish throughout the estuary during the outmigration period. The comprehensive monitoring program was also established to evaluate restoration project effectiveness and fish response to restoration actions (Hall et al. 2019). Sampling has occurred roughly biweekly in each year since 2002 at sites distributed throughout the delta and adjacent nearshore habitats. Site selection was initially intended to be representative current habitat types (EEM, EFT, FRT) within the estuary and included both distributary and blind channel sites. Beginning in 2011, sampling was expanded throughout the estuary based on a design that divided the estuary into “zones” that were designated based on major bifurcations in the system and correlated well with landscape connectivity (Fig 2).

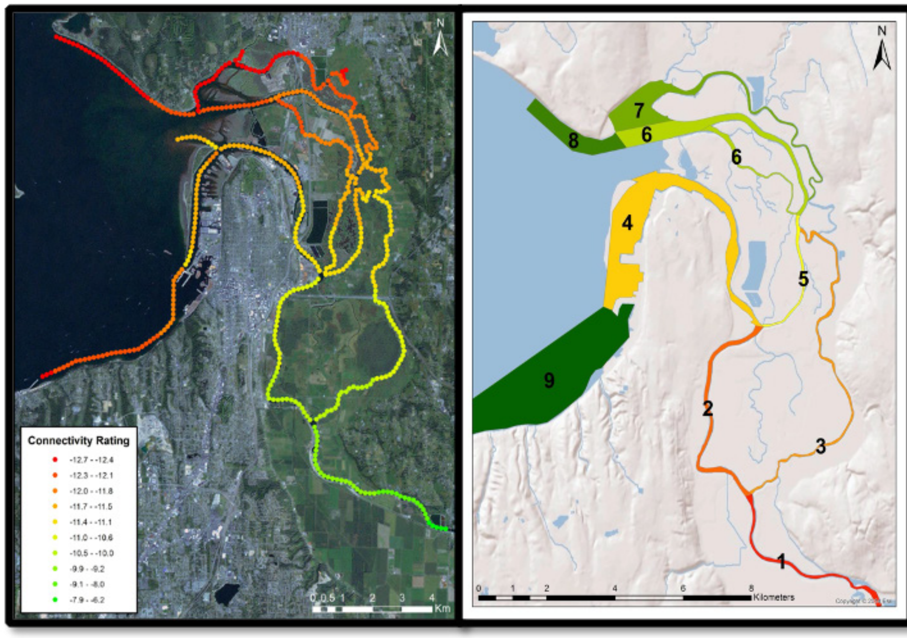

Figure 2. Landscape connectivity gradient (left) and estuary “zones” for grouping random site (right) in the Snohomsih estuary.

4. Abundance, timing and distribution of juvenile Chinook salmon in tidal deltas

While the importance of estuarine habitats for Chinook salmon is well documented, the benefits of river deltas are not ubiquitous across the entire population nor are they distributed uniformly across the entire delta. Population specific life history diversity and delta landscape attributes can influence the degree to which the estuary is used as well as the relative benefits offered by particular locations within the estuary. Consistent across deltas throughout Puget Sound, timing, distribution, and abundance of Chinook salmon are strongly dictated by life history type and influenced by landscape connectivity and habitat features (Greene et al. 2021).

Life History type and migration timing/abundance

Estuarine habitats support two common life history types observed for sub-yearling Chinook salmon: fry migrants and parr migrants (Healy 1980, Quinn 2018). Fry migrants generally migrate out of freshwater soon after emergence and are thought to be the primary life history type to use and benefit from estuary habitats. Fry migrants are small (<45mm) when they enter the estuary (Feb-Apr) and tend to reside for weeks to months before moving to nearshore marine habitats. Parr migrants generally spend weeks to months in freshwater habitats after emergence before migrating to the estuary at larger size (~55mm) and later in the season (~Apr/May). These differences in size and timing of migration in to the estuary can influence residence time and growth opportunity during estuary rearing.

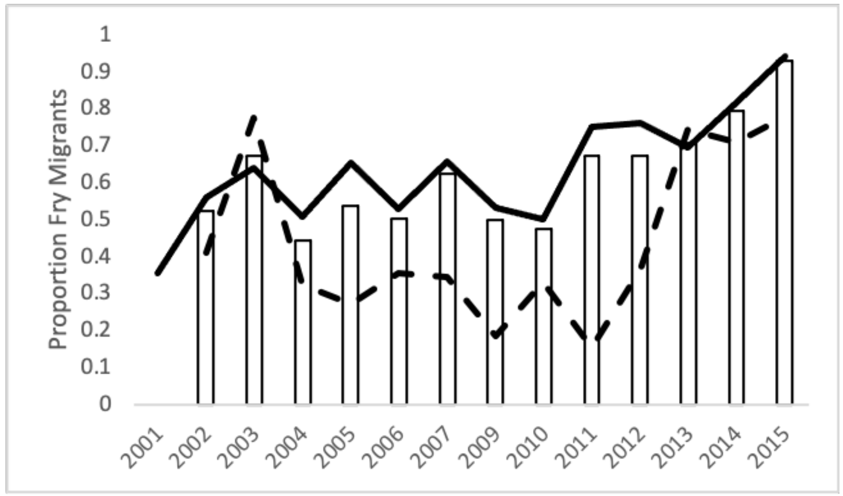

Figure 3. Proportion fry migrants by year the combined Snohomish outmigration (bars) and for the Skykomish (solid line) and Snoqualmie (dashed line) separately.

Within the Snohomish, fry migrants comprised 44 – 90% of the total outmigration (Skykomish + Snoqualmie) between 2003 and 2015 (Fig. 3; Tulalip Tribes, unpublished data). Only the Skagit River consistently produces more fry migrants than the Snohomish basin. The majority of fry migrants originate in the Skykomish which accounted for 71 – 97% of all fry migrants in the system by year. This is largely due to differences in total migrant production between rivers but also due to differences in the proportion of the population that migrates as fry. On average 63% of Skokomish Chinook migrate as fry compared to ~44% in the Snoqualmie (Tulalip Tribes, unpublished data). These percentages vary annually in both rivers though between 2001 and 2015 the proportion of fry migrants in the Skykomish has been increasing (Fig 3).

Timing of entry in to the estuary can also vary by year, and in the Snohomish, among the Skykomish and Snoqualmie Rivers. In general, the week at which 50% of fry migrants have migrated downstream to the estuary occurs between late March and mid April in any given year. This migration timing is consistent with other river deltas in Puget Sound and the greater Salish Sea (Chalifour et al. 2021, Anderson and Topping 2018, Zimmerman et al. 2015). However, inter-annual variability in the timing of the 50% fry migrant migration is considerable and can range from late Feb to late Apr between the two rivers. This variability in timing may be ralted to inter-annual variability in flows and/or associated water temperatures (Munsch et al. 2019, Achord et al. 2007). For example, Chamberlin et al. (2021) found an elevated early season juvenile Chinook salmon densities and a contracted period of presence in the Snohomish delta during 2015, a anomalously warm year (see Fig 7 below). Fry migration timing out of the Snoqualmie River is generally more variable than the Skykomish River from year to year. Juveniles that enter the estuary earlier in the season have been found to reside for longer periods in estuary habitats (Chalifour et al. 2021).

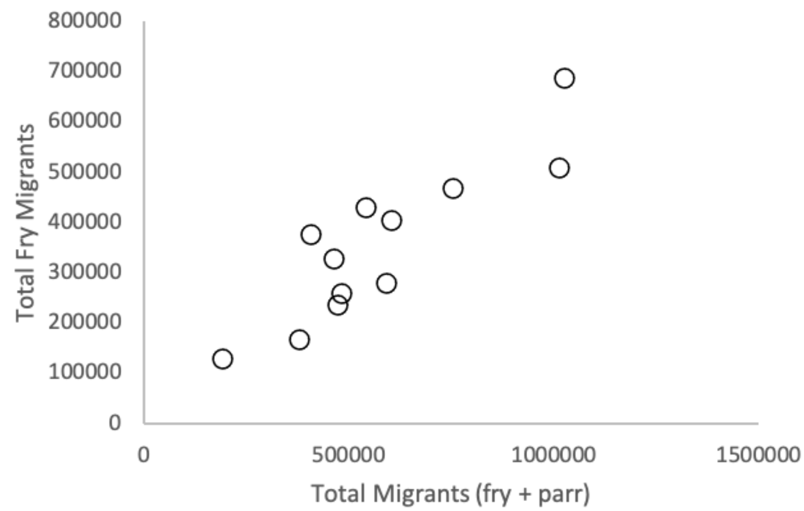

Figure 4. Total fry migrants as a function of total outmigration (fry + parr) for Snohomish River (i.e. Skykomish and Snoqualmie).

While these life history types are prevalent in systems throughout Puget Sound, the abundance or relative proportions vary by system and/or year and are likely related to population dynamics and freshwater productivity and habitat conditions for juveniles (Anderson and Topping 2018, Zimmerman et al. 2015, Beamer et al. 2005). Analyses of life history productivity in the Skagit and Green Rivers found production of fry migrants was a density-independent function whereby the total number of fry migrants increases with increased total population size. Such a relationship indicates fry production is not dictated by freshwater habitat conditions/capacity but rather by population productivity (i.e. early stage survival) and thus scales with total outmigration abundance. The total number of fry migrants in the Snohomish also scaled positively with the total outmigrant abundance indicating more fry migrants when outmigration abundances increased (Fig 4). In contrast, the production of parr migrants was density dependent suggesting freshwater habitat limitations control the total number of parr migrants in a given year or system. Therefore, should current freshwater habitat capacity stay the same (i.e. parr capacity remains unchanged), increasing population size will require considerably more delta habitat in the future as the production of fry migrants would theoretically increase. However, complimentary freshwater and estuarine restoration actions are likely needed to mitigate habitat limitations, restore capacity and maintain life history diversity.

Landscape connectivity

The ecological importance of habitat connectivity has been documented throughout the ecological literature (Hanski 1999, Urban and Keitt 2001).Within tidal delta habitats, landscape connectivity describes/quantifies pathways for diffusion which ultimately influences distribution of fish across the system. Specifically, landscape connectivity incorporates the complexity of the pathway to a particular site within the estuary by accounting for the distance traveled (from freshwater input) and the branching/ bifurcations of the distributary network across the system (see Beamer et al. 2005 for details on calculating connectivity). In addition, landscape connectivity describes the gradient from freshwater to marine and thus also correlates with other features of the tidal delta including within-year temperature/ salinity ranges and habitat types (Beamer et al. 2005). Together these elements can dictate the likelihood a site may be used/encountered by fish and inform expectations/evaluations for restoration projects and more accurate estimates of habitat capacity.

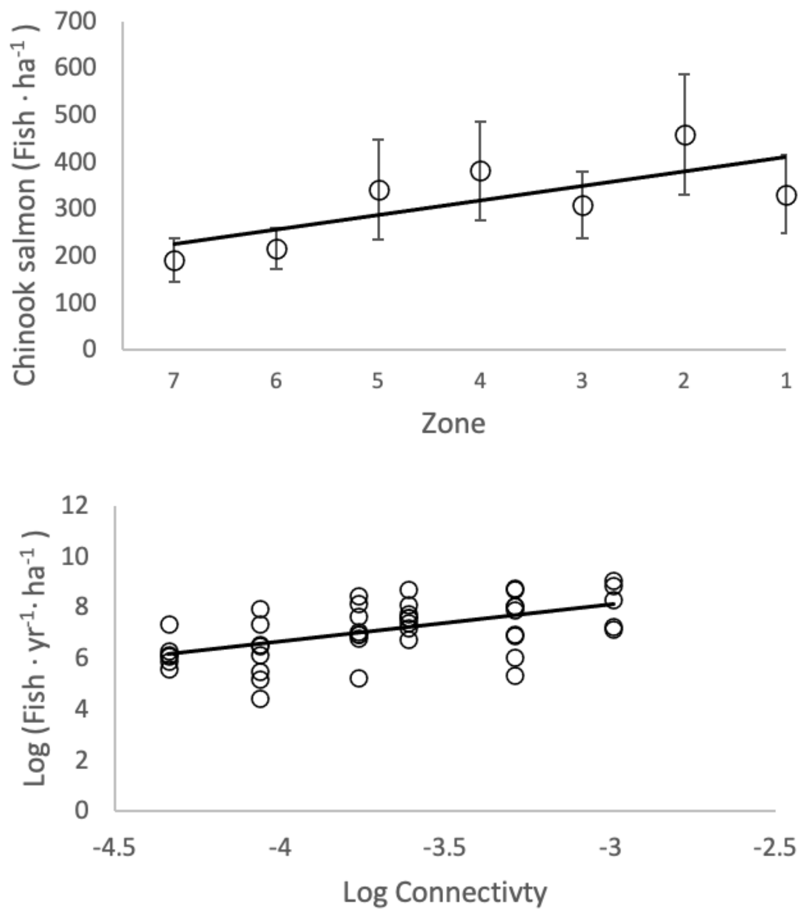

Figure 5. Mean Chinook salmon density by zone (top) and seasonal density as a function of site connectivity (bottom). Bottom figure included data from 6 index sites sampled regularly 2010-2019.

The influence of connectivity on juvenile Chinook salmon distributions/abundances has been documented for several tidal deltas in Puget Sound (Beamer et al. 2005, Ellings et al. 2016).Recent synthesis across four large river deltas in Puget Sound, including the Snohomish estuary, determined that after accounting for differences among systems (population size and habitat availability) and the seasonal fluctuations in abundance due to migration, landscape connectivity was the single largest influence on fish distribution and abundance (Greene et al. 2021). In general, juvenile Chinook salmon density in all deltas was higher at sites with higher connectivity. This pattern is true in the Snohomish where sites that were closer to the point of estuary entry, and with less complex pathways for fish to travel, had higher mean and seasonal densities of juvenile Chinook salmon (Fig 5).

However, there are nuances and variability in the relationship between landscape connectivity and fish density within and among systems. Within systems, predictions of Chinook salmon density using landscape connectivity metrics and over- and under-estimate density at the upper and lower extremes, respectively, of the connectivity gradient. This variability could be the result of several circumstances: 1) the nature of the log linear relationship may make predictions at the extremes less accurate, 2) sampling bias or non-uniform representation of sites across the connectivity gradient, 3) biological anomalies (hotspots or depression) within the system.

Distribution and abundance by channel type and wetland type

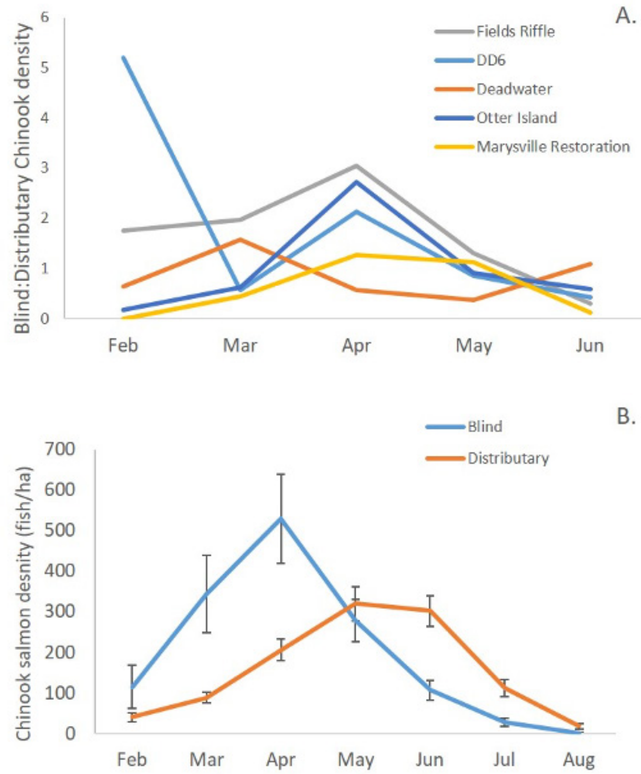

Figure 6. Ratio of Chinook salmon density for paired blind channel and distributary sites (top) and mean monthly Chinook salmon density for blind channel and distributary sites sampled intensively adjacent to Qwuloolt restoration project (bottom).

Landscape characteristics can also influence juvenile Chinook salmon distribution and abundance in tidal deltas. Large river deltas are generally comprised of a network of distributary channels which are the primary pathways by which water (freshwater and marine tidal), and fish, move through the system. Distributary channels are often wide and deep and remain wetted throughout the tidal cycle. Although fish use distributary channels for rearing during estuary residence, they are primarily used as important migration pathways within and through the tidal delta. Connected to these distributary networks are blind tidal channels (blind channels) which connect the distributary networks to tidal wetlands and act as the primary rearing habitat for juvenile Chinook salmon during estuary rearing. Blind channels, though they may empty on low tide, offer a low energy environment with more accessible food resources and refuge from potential predators. As such, the observed densities of juvenile Chinook salmon are typically higher in blind channels compared to distributary channels and seasonal distributions and abundances are influenced by the availability of blind channel habitats.

Across multiple tidal deltas in Puget Sound, the highest observed densities occur in blind channel habitats (Greene et al. 2021). In many cases the magnitude density in blind channels can be twice that of the observed density in distributary channels. Within the Snohomish estuary, densities of juvenile Chinook salmon in blind channel habitats can be 2-5x higher than associated distributary sites with the largest differences occurring during Feb-Apr coinciding with the prominent rearing period (Fig 6).

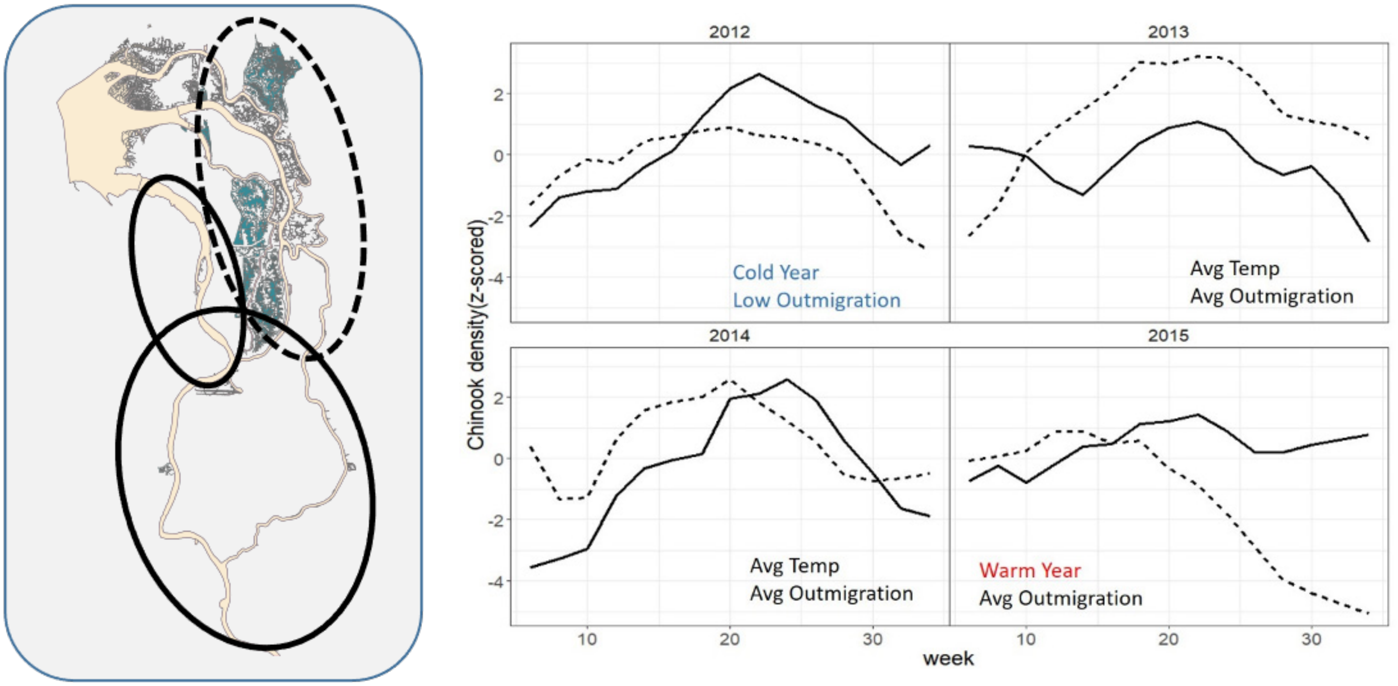

Figure 7. Seasonal trends in Chinook salmon density (normalized to mean = 0) in Lower (Zones 4-7; dashed) and Upper estuary (Zones 1-3; solid) from 2012-2015. Notation describes water temperature and outmigration abundance relative to average conditions 2012-2015. Solid and dashed lines on map of Snohomish delta depict locations where density trends predominate. Chamberlin et al. (2021).

As the primary rearing habitat in tidal deltas, availability of blind channel habitat can also influence the seasonal distribution of juvenile Chinook salmon in the system. Seasonal pattern of juvenile Chinook density vary by channel type whereby observed densities in blind channels are often higher in the early part of the rearing season before declining below observed densities in distributary channels later in the season when fish are presumably transitioning out of the delta (Greene et al. 2021;Fig 7). Therefore distributions of fish earlier in the outmigration period are likely to be associated with locations in the delta where blind channel habitats are available. These associations are likely representative of fry migrants from the Skykomish and Snoqualmie Rivers rearing within delta habitats. This relationship also reflects a general response to restoration in the Snohomish delta given >90% of all restoration actions have occurred within, and > 80% of the available blind channel habitat is located in, the lower estuary. The seasonal pattern of juvenile Chinook density in these zones of the delta are different than zones where blind channel habitat is not available (Chamberlin et al. 2021; Fig 7). The spatial patterns in juvenile Chinook density trends show where habitat is being used as well as potential locations where habitat is needed. Juvenile Chinook salmon are commonly observed along the mainstem Snohomish River through the delta yet there is almost no rearing habitat available in this portion of the estuary. Matching locations where juvenile Chinook salmon are commonly observed (in high abundance) with areas lacking available rearing habitat can help guide restoration prioritization and planning.

Tidal deltas throughout Puget Sound are dominated by three primary wetland types (ordered from freshwater to marine); forested riverine tidal (FRT), estuarine forest transition (EFT), and estuarine emergent marsh (EEM) (after Cowardin et al. 1979). These wetland types, given their locations relative to riverine and tidal processes, primarily vary with respect to vegetation communities as well as seasonal water temperature and salinity ranges (Hall et al. 2018). However, while the growth/foraging benefits of specific delta wetland types is well documented (see Section 4), the influence of wetland type on distribution and abundance of juvenile Chinook salmon is less clear and likely confounded by the effects of landscape connectivity.

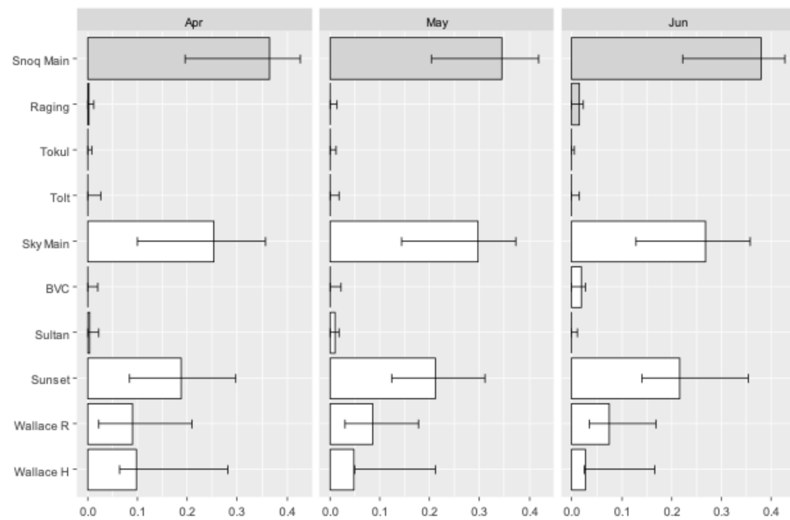

Figure 8. Proportions of Skykomish (white bars) and Snoqualmie (gray bars) Chinook salmon populations by month in the upper estuary (Zones 1-3; see Figure 2). Error bars represent upper/lower 95% CI's.

Population specific use of Snohomish Delta

The Skykomish and Snoqualmie Chinook salmon populations differ with respect to abundance, freshwater habitat conditions, and life history diversity (King County 2021). Documenting potential differences in timing and distribution within the tidal delta between populations could be informative for evaluating restoration effectiveness and recovery planning for natal populations. Between 2012 and 2014, fin tissue samples from

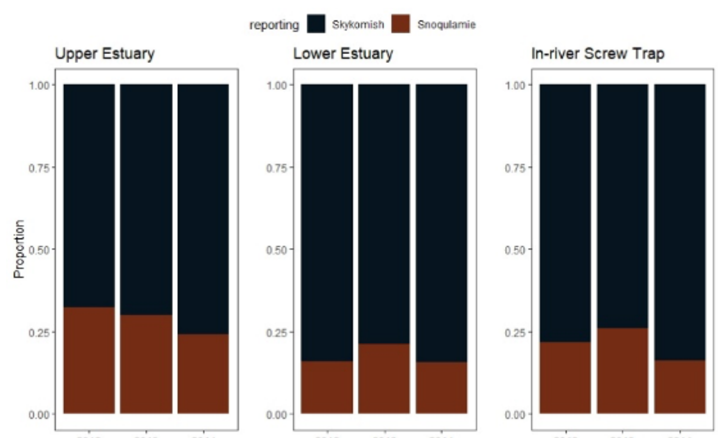

Figure 9. Relative proportions of Skykomish and Snoqualmie Chinook salmon populations estimated from genetic results and in-river screw trap sampling during 2012-2014.

natural origin juvenile Chinook salmon were taken from across the estuary throughout the rearing period to identify population specific use of tidal delta habitats with the Snohomish estuary and associated nearshore marine shorelines (Chamberlin 2022a). The seasonal patterns of population use within the upper delta were generally consistent. Though the Snoqualmie Mainstem population represented the single greatest contribution in all months, the collective group of populations from the Skykomish River represented >60% of all fish sampled (Fig 8). The proportion of Snoqualmie and Skykomish Chinook salmon in the upper and lower delta were also consistent with data collected at outmigrant screw traps operating in each river of origin (Fig 9). Snoqualmie Chinook were generally estimated to represent a higher proportion of the total sample in the upper estuary compared to either the lower estuary genetic results or the screw trap estimates. It is yet unclear whether this represents differential use of upper vs lower estuary among popualtions and warrants further attention.

Non-natal populations of juvenile Chinook salmon represented 45—50% of samples analyzed between 2012 and 2014 (Fig 10). Out-of-basin Chinook salmon were captured in all months/years in the Snohomish delta. Fish representing 5 major river basins were captured in the estuary with individuals from the Skagit basin representing 45—50% of all out-of-basin juvenile Chinook in each year (Fig 10). Individuals from the Skagit, and to a lesser degree the Stillaguamish, basin were captured earlier in the rearing period (~March) and were present longer (Mar-Jun) than individuals assigned to Nooksack, Hood Canal, or South Sound rivers. Such a pattern suggests Skagit and Stillaguamish fish are actively using tidal delta habitats in the Snohomish estuary for rearing throughout the spring in addition to the documented use of pocket estuaries within the Whidbey Basin. The considerable presence of non-natal fish in the Snohomish estuary warrants further investigation and

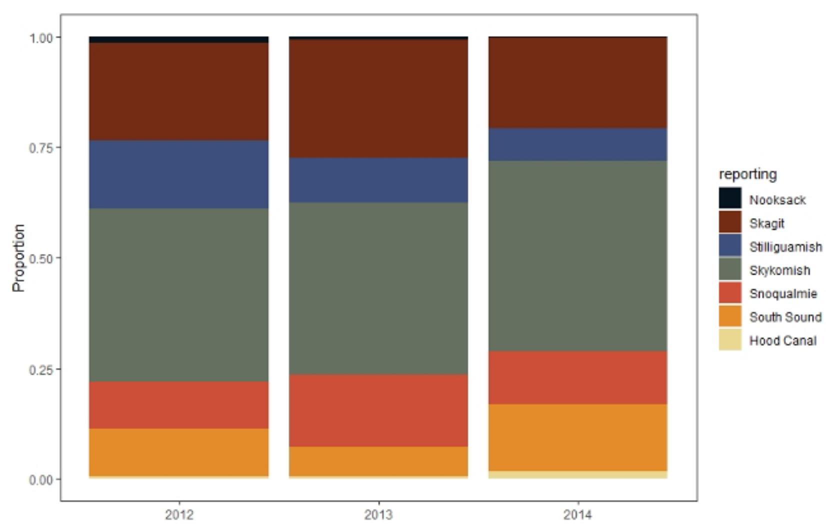

Figure 10. Relative proportion of juvenile Chinook salmon reporting groups sampled in the lower Snohomish estuary (Zones 4-7; see Fig 2).

discussion especially relevant to interpreting habitat capacity and restoration targets as discussed below in Section 5.

Implications for recovery planning

- Juvenile Chinook fry migrants are the "primary" users of tidal delta habitat. Yet the proportion of the population represented by this life history fluctuates year-to-year determining the number of Chinook salmon coming into and using the tidal delta.
- Linking restorations actions in freshwater habitat with goals and targets in the estuary are crucial for recovery planning. Increasing freshwater rearing habitat can influence the proportion of fish using tidal delta habitat for primary rearing purposes.
- Increased understanding of fish distribution and abundance in tidal delta habitats can help inform/revise recovery planning as well as aid project effectiveness evaluation. In particular, understanding the influence of landscape connectivity on fish density/ distribution and capacity (see Section 5) may help managers evaluate and rank potential restoration projects and place project expectations (fish response) in the context of difference across the landscape.
- The vast majority of rearing habitat in the systems occurs in the lower estuary. Elevating potential projects in areas currently without available rearing habitat can have large impacts on current capacity and increase the connectivity of habitat within the system.
- The considerable presence of nan-natal basin fish found in the Snohomish estuary is novel and warrants further discussion. Recovery planning for Snohomish populations should consider the influence of non-natal populations on habitat use within the delta relative to natal populations.

5. Chinook salmon foraging, growth and residence time in tidal delta habitats

A primary benefit of tidal delta habitat is providing rearing opportunities for juvenile Chinook salmon during the transition from freshwater to marine environments. Growth is mediated by prey resources and environmental conditions that interact to influence growth opportunity. Below we discuss how estuary habitat influences diet composition and growth as well as discuss current state of knowledge regarding residence time for juvenile Chinook salmon in tidal deltas.

Diet composition

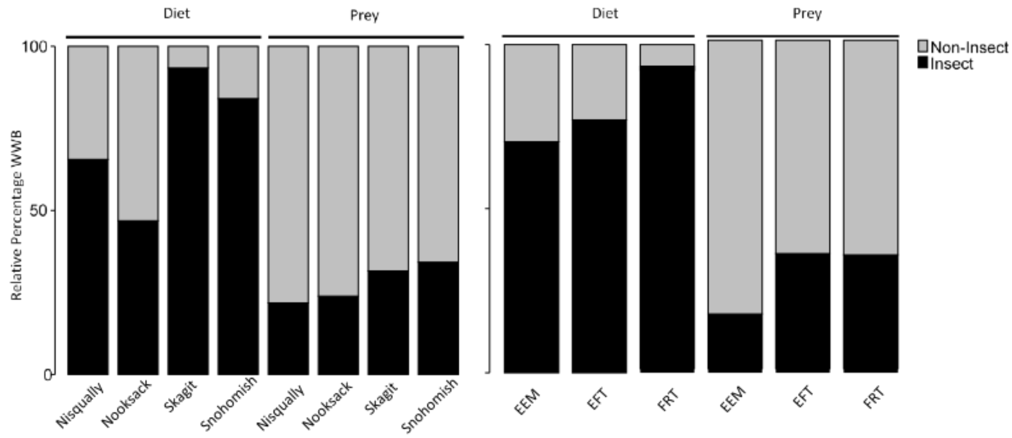

Figure 11. Relative proportions of wet weight biomass (WWB) of insect and non-insect taxa in Chinook salmon diet and prey samples across four Puget Sound tidal deltas. Comparisons among habitat types are for pooled samples across individual tidal deltas. Greene et al. 2021

Diet composition of juvenile Chinook salmon in tidal delta habitats throughout Puget Sound and the greater Salish Sea has been well documented (Greene et la. 2021, Davis et al. 2020, Davis et al. 2019, David et al. 2014). Chinook salmon are largely considered opportunistic feeders and diets generally incorporate a variety of terrestrial and aquatic taxa during delta residence. Although diet composition can be highly variable, the importance and reliance upon terrestrial insects during estuary residence is ubiquitous across multiple deltas (Greene et al. 2021, Davis et al. 2018, Cordell et al. 2011; Fig 11). Insects typically occur disproportionately in Chinook slmon diets compared to prey assemblage samples and in some cases account for >90% of diet wet weight biomass. Within the Snohomish, Skagit, and Nooksack deltas, flies (order Diptera) alone can represent 20-60% of overall diet composition (Davis et al. 2020).

Variability in diet composition is strongly connected to habitat type. As noted above, habitat types primarily differ by vegetation communities but also lie along the gradient from freshwater to marine influencing both temperature and salinity ranges. These differences can influence invertebrate communities and thus diet composition for juvenile Chinook salmon. Generally, terrestrial insects decrease as marine inverts increase along the gradient from FRT to EEM habitats. Both invertebrate assemblage and diet composition in EFT habitats reflects an intermediate mix of both terrestrial and marine taxa. Seasonal differences in diet composition may be the result of resource production (e.g. seasonal hatching) and/or as a function of fish migrating through the delta and progressively shifting composition from terrestrial (i.e. insects) to marine-derived prey (e.g. mysids, amphipods; Davis et al. 2018, Woo et al. 2019).

Differences in diet composition can influence the energy content (i.e. quality) of the diet which can directly impact individual growth. Energy densities of Chinook salmon diets can be highly variable and are sensitive to both the amount of and quality prey consumed. Terrestrial insects, in general, are more energy-rich than marine derived resources (David et al. 2014, Gray 2005) yet marine derived prey tend to occur in greater densities within specific habitat types (Woo et al. 2019). These differences are directly related with the amount of food consumed by juvenile Chinook salmon across habitat types (Davis et al. 2018). Therefore while some habitats offer primarily energy-rich prey (FRT), others offer higher densities of invertebrates and thus a more abundance prey resources (EEM). Neither of these attributes necessarily makes one habitat better than the other, persevering/restoring prey diversity can mitigate impacts to individual growth during periods of low prey availability and/or high consumption demand throughout the rearing period (Greene et al. 2021, Woo et al. 2019).

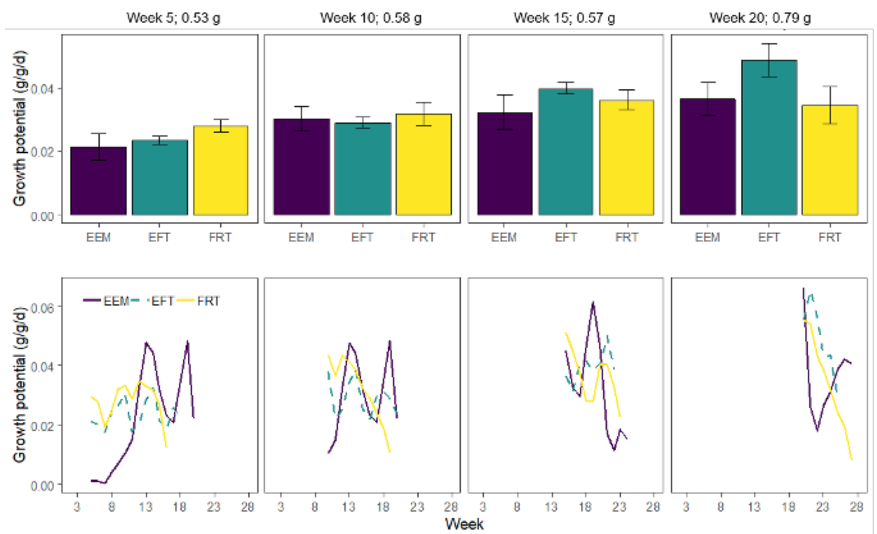

Figure 12. Mean growth potential for Chinook salmon by habitat type for the season (top) and by week (bottom). Columns represent fish entering estuary at different sizes and during different weeks of outmigration period. Greene et al. 2021

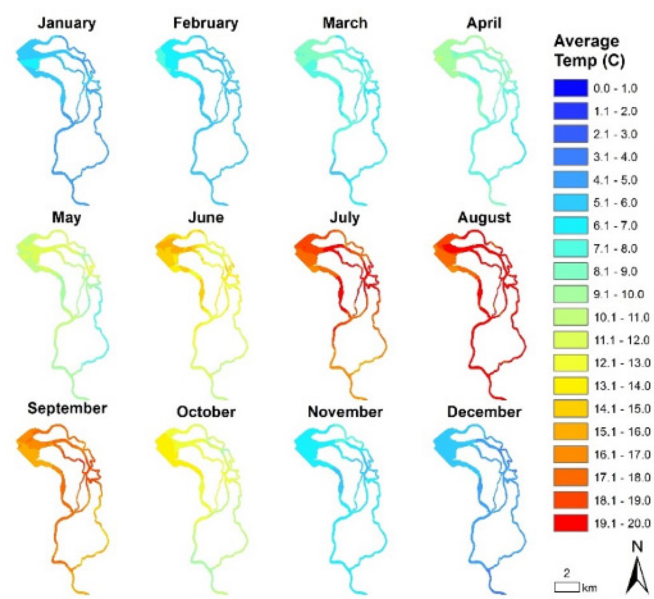

Figure 13. Mean monthly water temperature for the Snohomish delta. Data are from continuous water sensor network (see Hall et al. 2018).

Ultimately, individual growth during estuary residence is the primary benefit conferred to juvenile salmon in tidal delta habitats. Growth is a function of several processes and conditions including, but not limited to, diet (quality and quantity) and temperature. The amount and quality of prey control the potential energy availability while temperature controls metabolic processes that mediate growth potential. As with diet composition and prey energy density, growth can also fluctuate throughout the season and differs among habitat types (Greene et al. 2021, Davis et al. 2018; Fig 12). Using bioenergetics models estuary growth of juvenile Chinook salmon varies between 0.02 and 0.05 g/g/day (growth in grams per gram of fish wt per day) on average across habitat types and throughout the season in several tidal deltas throughout Puget Sound including the Snohomish. No single habitat type consistently provides the highest growth potential throughout the rearing period and weekly growth potential is extremely variable. FRT habitats tend to have higher growth potential earlier in the season relative to other habitat types but decline relatively rapidly in the latter part of the rearing period. The opposite is true for EFT habitats whereby growth opportunity appears to increase through the later portion of the rearing period. Within the Snohomish, FRT habitat is extremely limited which may limit the early season growth potential for Chinook salmon in the system.

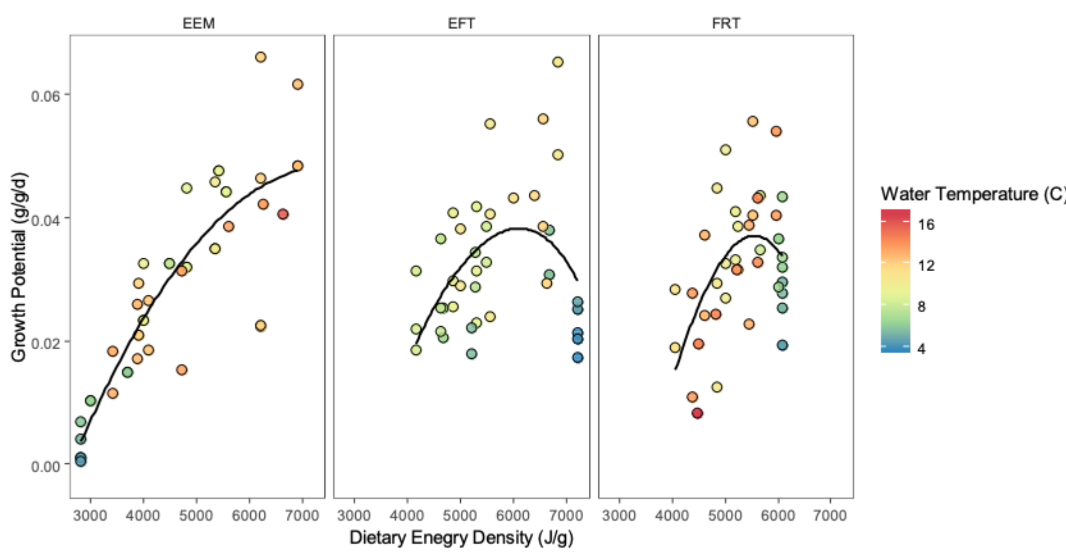

Figure 14. Chinook salmon growth potential as a function of the covariation between temperature and prey quality (energy density) among three primary habitat types. Greene et al. 2021

Annual and seasonal fluctuations in water temperatures can also influence growth opportunity for juvenile Chinook salmon. Variability in water temperature from year to year can potentially influence the period or duration during which Chinook salmon use tidal delta habitats. Chamberlin et al. (2021) found an abbreviated, or shifted (i.e. earlier) period of tidal delta use by Chinook salmon during 2015, an anomalously warm year across the region. Seasonal temperature ranges may be linked to habitat type (i.e. differences between FRT, EFT, and EEM) but are likely correlated with landscape connectivity and position within the delta relative to freshwater and marine inputs as well. Within the Snohomish delta, temperatures generally increase throughout the rearing period (Feb-Jul) but can also vary spatially within the delta during a given month (Hall et al. 2018, Fig 13). This spatial variability creates thermal diversity within the delta that can promote variable growth opportunity especially during peak rearing period (Mar-May). However, the degree to which fish are able to take advantage of this thermal heterogeneity is limited by the location/concentration of accessible rearing habitat in the lower estuary. Spatial/temporal variability in growth potential appears driven by concomitant fluctuations in water temperature and prey quality such that growth potential is maximized during periods of moderate water temperature and relatively high quality prey assemblages (Fig 14). Again, this argues in support of maintaining/restoring habitat diversity to maximize growth potential for juvenile Chinook salmon in tidal deltas.

Residence time also plays an important role in the growth of juvenile Chinook salmon in the tidal delta. Otolith-based analytical approaches in the Skagit delta suggest that delta rearing individuals reside for an average of 35 days in the estuary (Beamer and Larsen 2004). Analysis of Chinook density in multiple tidal deltas as a function of outmigrant production found the best relationship with outmigrant abundance over an 8 week period suggesting residence time of up to 56 days (Greene et al. 2021). Residence time is likely highly variable at the individual level though fish that enter earlier in the season may reside for longer period of time (Chalifour et al. 2021). Both temperature patterns and density dependent processes could influence residence time within tidal deltas (Greene et al. 2021). There are few data on residence time for Chinook salmon in the Snohomish.

Implications for recovery

- Both diet composition and prey assemblage differ among the three primary habitat types in the delta. Preserving/restoring resource (habitat) diversity can mitigate negative impacts on juvenile growth during periods of low prey productivity and/or high consumption demand (elevated fish densities).

- Terrestrial insects are an important component of juvenile Chinook diets in delta habitats. Terrestrial prey production is higher in FRT habitats which are extremely limited in the Snohomish delta.
- Thermal conditions can have large influence on juvenile Chinook salmon growth in the delta. Temperature variability across the estuary is generally greatest during the rearing season (Mar-Jun) and generally follows a gradient from cold to warm from upstream to downstream within the delta. Concentrating rearing habitat in certain areas of the delta reduces the thermal diversity available for juvenile fish and may constrain the growth opportunity throughout the rearing period.
- Bioenergetics models indicate that growth opportunity for juvenile Chinook salmon is variable among habitat types during the rearing season. While no single habitat type consistently offers the highest growth potential for juvenile fish, each habitat type offered the highest potential during different periods of the rearing season. Growth opportunity varied considerably by week and weekly patterns among habitat types were varible throughout the season.
- Results suggest that maintaining and creating habitat diversity in the delta likely offers the greatest range of growth opportunity for juvenile fish. Increased habitat diversity can likely be achieved by distributing available habitat (restoration projects) from upstream to downstream within the delta.

6. Estuary habitat capacity for Chinook salmon

Ecological analyses conducted to guide the initial Chinook recovery plan in the Snohomish basin identified estuary habitat as limiting and recommended increasing juvenile capacity in the delta to aid population recovery (Scheuerell et al. 2006, SBSRF 2005). Estuary restoration targets were then set based on the estimated capacity added through delta restoration actions toward a recovered population size. These targets were milestones by which progress toward restoration and recovery goals were measured within the estuary and across the Snohomish basin.

Implicit in these analyses and subsequent recommendations for recovery targets, are estimates of habitat capacity. Estuary-specific capacity estimates were derived from the best available information and published literature at the time (Hay et al. 1996, Beamer 1998) and were specific to each habitat type. Since then there has been extensive sampling and monitoring of Chinook salmon in the Snohomish delta and within deltas throughout Puget Sound which can further inform accurate estimates of habitat capacity. Information presented in previous sections can be used to refine the tools and methods used to calculate capacity and provide more accurate estimates for making informed decisions. Most notably, with respect to Chinook salmon density and distribution, is the concept of landscape connectivity and the role it plays in fish distribution and abundance that help determine accurate capacities. As discussed above, landscape connectivity is an important driver of local Chinook salmon density within the delta and thus an appropriate scalar for estimating capacity. Landscape connectivity has been used to further refine estimates of carrying capacity in the Skagit delta (Beamer et al. 2005) and more recently for the Chehalis life cycle model (Beechie et al. 2021). In addition, capacity estimates can be adjusted to reflect preferences for blind channel habitats and to accurately capture the usable area for distributary channels (e.g. 2m edge vs. entire channel area). Lastly, as the goal is to estimate rearing capacity within the delta, models need to incorporate a residence time parameter to account for fish that may be observed over a period throughout the outmigration season. These methods can be applied to the Snohomish estuary to help refine/revise current capacity estimates, predict capacity at current or planned restoration sites throughout the delta, and to determine future targets/goals.

Delta capacity estimates for the Snohomish have been updated using two primary methods: 1) habitat area expansions incorporating connectivity and habitat effects, and 2) data driven stock-recruit modeling exercise using estuary Chinook monitoring data 2002-2016 (Chamberlin et al. 2022b). While the approaches differ considerably, the resulting estimates, though not identical, are comparable. For detailed description of methods for each approach see Chamberlin et al. (2022b).

Using the habitat expansion methods the current rearing capacity of the Snohomish estuary is estimated at 306,022 (CIs: 233,035 and 414,341) juvenile Chinook salmon fry per

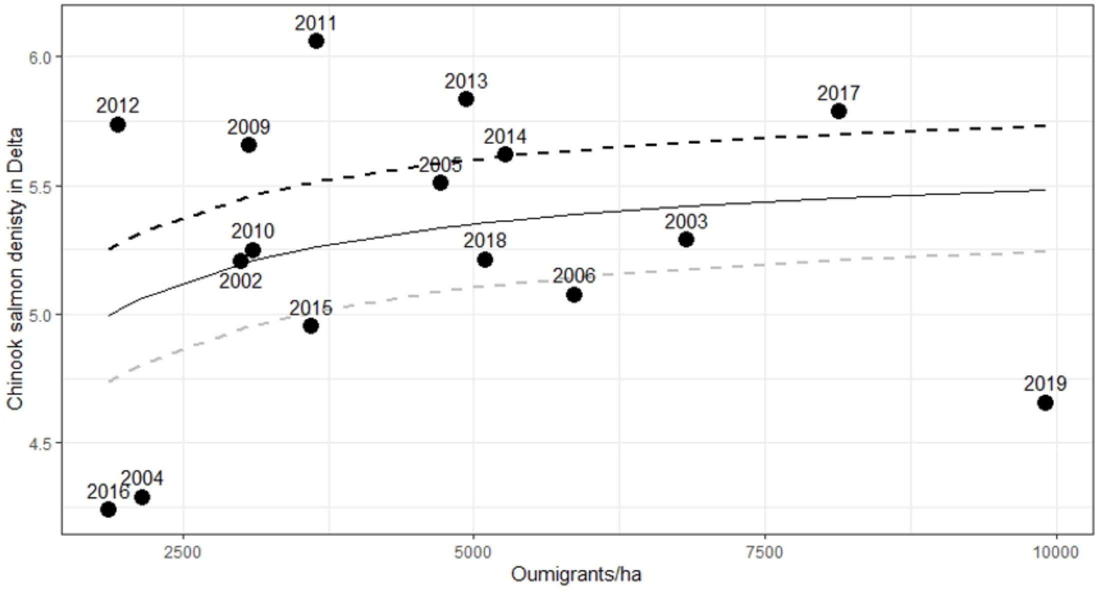

Figure 15. Yearly average Chinook density in the Snohomish delta as a function of total outmigration abundance per hectare of tidal channel habitat in the delta 2002-2019. Lines represents best fit form Beverton-Holt stock recruit function for the median (solid) and 90th percentile (black dashed) and 10th percentile (gray dashed) posterior estimates for annual indices.

year, not including tidal flats (Table 1). These estimates do not include tidal flats features. Approximately 94% of tidal flats in the Snohomish occur in restoration sites and are largely created when subsided land behind a dike is reconnected with tidal inundation. These features have a higher rate of change compared to tidal channels and are predicted to decrease over time hypothetically becoming vegetated wetland or parts of tidal channels. The result of this progression is the likely loss of tidal flat habitat area therefore using this feature for capacity estimates should be approached with caution.

Using the range of fry production percentages from Section 3 (Fig 3) we can back-calculate the total outmigration abundance at capacity of 306,022 fry migrants. Fry proportions ranged between 0.41 and 0.94 from 2001-2015 which would result in total outmigrant abundance estimates of 332,632 – 695,504 Chinook salmon. Since 2001 only 4 years have surpassed a total outmigration size of the upper estimate. However, these estimates are far below the recovered population outmigration abundance which ranges between 3.2 and 5.6 million fish at low and high productivity, respectively (SBSRF 2005).

A useful application of the habitat expansion method is that it can be used as an accounting tool whereby capacity of an individual tidal channel or restoration project can be estimated. This could be used to set targets/expectations for current projects and also to predict capacity at future sites. A similar tool has been used in the Skagit delta for restoration panning purposes (Beamer et al. 2016). Restoration projects in the Snohomish estuary currently account for ~32% of the total available tidal channel habitat, yet these sites account for only ~15% of the total capacity of the delta. The discrepancy between the proportions of habitat area and total capacity are driven by the locations of restoration and the influence of landscape connectivity on fish distribution and abundance. Generating capacity estimates for future/potential projects in the Snohomish may also be useful and could inform cost-benefit analyses and future capacity and restoration targets/goals.

The second approach for estimating capacity combines biweekly observations of Chinook salmon density within the delta and outmigration abundances from screw trap operations over multiple years to estimate current rearing capacity of the delta. Using this method the current rearing capacity of the Snohomish delta is estimated at 232,047 (183,293 – 294,585) fish/yr. This method can also be used to estimate the outmigration abundance at which the delta reaches capacity and suggests delta capacity is reached when outmigration abundance approaches 1.1 million Chinook salmon migrants (~10,000 outmigrants/ha; Fig 15).

Important considerations and uncertainties

It should be noted that capacity estimates do not represent hard cutoffs to fish use within the delta. Observations of juvenile Chinook densities in the delta can often exceed the estimated density at capacity in certain years or during certain periods throughout the outmigration season (Greene et al 2021). Whether these observation reflect demographic (e.g. fry migrant production) and environmental (e.g. temperature patterns) conditions, or variability in distribution is yet unclear and needs further evaluation. Similarly, the potential impacts of elevated density should also be considered found that both foraging (diet composition and prey selectivity) as well as growth were negatively impacted when Chinook salmon density increased in tidal delta habitats (Greene et al. 2021, David et al. 2016).

All estimates produced for this report are focused on delta rearing migrants from natural origin Chinook salmon populations within the Snohomish basin. Yet it is important to recognize and acknowledge other Chinook salmon life history types (parr and yearling migrants), origins (hatchery fish), and populations (out-of-basin Chinook salmon; see

Section 3) that may use the delta at times throughout the rearing season. These groups of fish, while not considered the “primary” users of tidal delta habitat, spend some period of time within these habitats and contribute to resource consumption and observed densities within the system (Greene et al. 2021).

Lastly, models that estimate rearing capacity in the tidal delta incorporate some measure of average residence time for juvenile Chinook salmon. Including this parameter accounts for fish that contribute to delta density over a period of time rather than at a specific point in time. As such, the overall estimate of rearing capacity is extremely sensitive to the estimate of residence time. As discussed in Section 5, there is relatively little empirical data on residence time of juvenile Chinook in tidal delta habitats. What is available suggests that the average residence time is 35 days (Beamer and Larsen 2004, Hering et al. 2010, McNatt et al. 2016) which is the value used in our current models to estimate capacity. However, should average residence time vary by year or within a year throughout the rearing period, estimates of rearing capacity could change. Future research directed toward evaluating variability in residence time for juvenile Chinook salmon representing all life history types and origins in tidal deltas is highly recommended to further refine capacity estimates for recovery planning.

Implications for recovery

- Rearing capacity estimates using the revised methods were comparable, though not identical, indicating the current rearing capacity in the Snohomish delta at 306,022 and 232,047 tidal delta rearing migrants. These estimates likely offer a conservative estimate given they do not include tidal flats which account for the majority of current habitat within restoration sites. However, both methods account for landscape connectivity, a strong determinant of salmon distribution and abundance within tidal deltas throughout Puget Sound including the Snohomish estuary.
- Estimates of total outmigration abundance at estimated delta capacity range between 393,247 – 822,245 Chinook salmon when combining the habitat expansion method with the lower and upper proportion of fry migrants from 2001-2015, and estimated at >1.1million migrants using our data driven modelling approach. Both estimates are below the predicted outmigration abundance under recovered population conditions

(3.3-5.6 million fish). While this suggests more estuary habitat capacity is certainly needed, restoration in freshwater habitats should also be incorporated into estuary planning given the connection between fry migrants, population abundance, and freshwater rearing habitat.

- Capacity estimates are not a hard line determinant of fish use in the estuary. Observation of Chinook density n the Snohomish delta suggest fish are using estuary habitat even when density exceeds predicted/estimated capacity. Though the exact reasons for this are yet unclear, capacity estimates may reflect a baseline after which continued use of delta habitats at higher densities are tolerable (i.e. do not trigger movement out of the delta) but may have adverse impacts for some individuals. Furthermore, there may be an upper threshold for movement out of the delta that has yet to be determined from estuary observations.
- Capacity estimates are based solely on natural origin fry migrant use of tidal deltas. Other natural origin life history types, hatchery-origin fish, and non-natal populations use tidal delta habitat in the Snohomish to varying degrees. Further understanding the magnitude of habitat use by each of these groups will be necessary to determine how they may contribute to, or impact, recovery targets and goals for natural populations.

7. Chinook salmon response to restoration in the Snohomish estuary

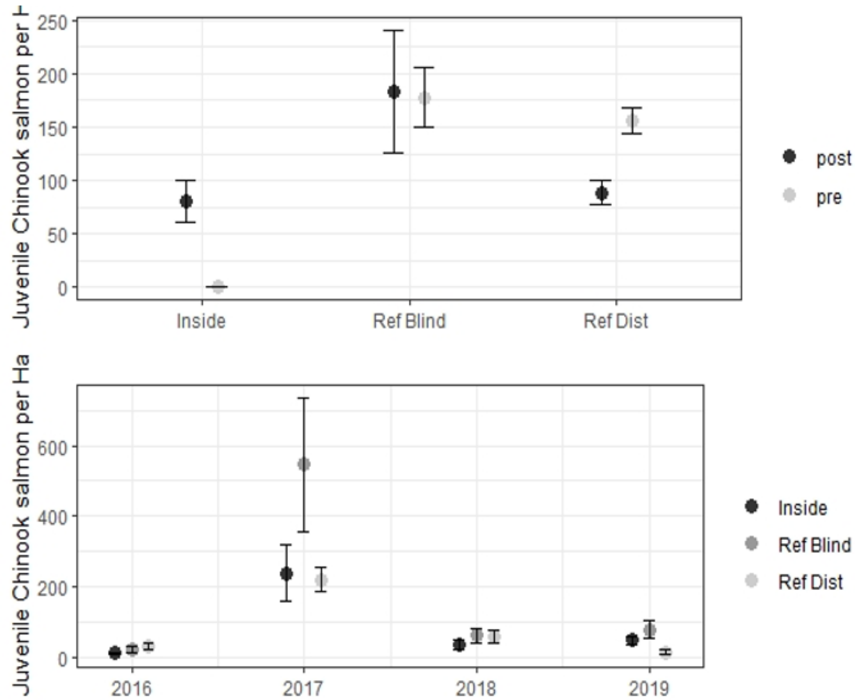

Figure 16. Average juvenile Chinook salmon density for the Qwuloolt site (Inside) and adjacent reference sites pre- and post-restoration (top) and by year post-restoration (bottom). Error bars represent standard errors.

Since the 2005, ~217 ha of usable tidal wetland habitat has been created through restoration within the Snohomish delta reconnecting >38 ha of tidal channel habitat for juvenile fish rearing (See Table 1). System-wide estuary monitoring conducted collaboratively since 2002 has monitored fish use associated with, or adjacent to, many of the restoration projects in the delta.

Two recently completed project sites, Qwuloolt and Smith Island, have been intensively monitored since their completions in 2015 and 2018, respectively. Monitoring data collected within and adjacent to these project sites can be used to track fish use/distribution both before and after completion, providing some indication of restoration effectiveness. Juvenile Chinook salmon are commonly found within restoration sites immediately after reconnection to tidal distributary networks. Abundance of juvenile Chinook salmon increased markedly at several restoration sites within the Skagit delta after restoration (dike removal/setback, tide gate operation) occurred (Beamer et al. 2017, Beamer et al. 2018). Similarly in the Nisqually delta, juvenile Chinook presence and abundance increased in the first year after restoration in the delta (David et al. 2014, Ellings et al. 2016).

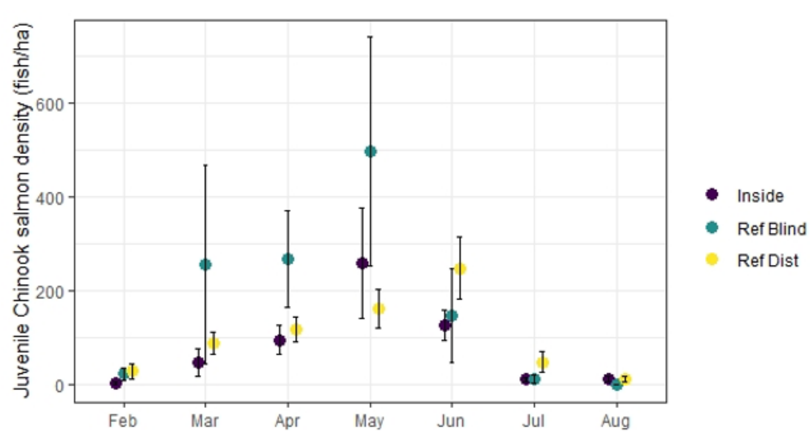

Figure 17. Average juvenile Chinook salmon density for the Qwuloolt site (Inside) and adjacent reference sites by month. Averages are for post-restoration years 2016-2019. Error bars represent standard errors.

Qwuloolt

Inside the Qwuloolt site, juvenile Chinook salmon abundance increased from zero pre-restoration to an average of 89.1 fish/ha post-restoration which was similar to observed densities in reference distributary sites adjacent to the project (Fig 16). The seasonal average Chinook salmon density did fluctuate from year to year across all categories however, densities within the Qwuloolt site became more similar to reference blind channels in 2019 (Fig 17). In addition, the observed densities at the project site are very close to those predicted with the habitat expansion capacity model. Seasonal capacity estimated for the Qwuloolt site is 794 fish/yr/ha while the estimate using our observed densities was 425 fish/yr/ha. Excluding average densities in the first year post-breach, the estimate for the Qwuloolt site based on observations in the delta becomes 653 fish/yr/ha.

As noted in Section 2, fish that migrate to the estuary early (i.e. fry migrants) likely represent individuals that rely more heavily on estuary habitat for rearing. Tracking monthly density and individual size of fish in project and reference sites can help inform how juvenile Chinook salmon may use particular sites. Mean juvenile Chinook salmon density varied by month within and across project and reference sites adjacent to Qwuloolt (Fig). Peak densities inside Qwuloolt and reference blind channel sites occurred in May across all years, earlier than in reference distributary sites which peaked in June. However, Chinook salmon densities in reference blind channels increased sharply in March and remained higher than associated distributary and project sites through the peak in May. This pattern was evident for all mature tidal channel habitat across the estuary (Chamberlin

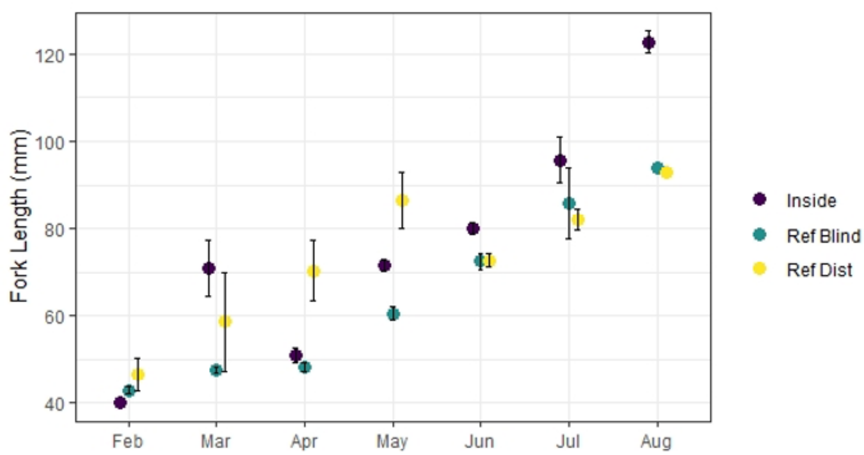

Figure 18. Average juvenile Chinook salmon fork lengths for the Qwuloolt site (Inside) and adjacent reference sites by month. Averages are for post-restoration years 2016-2019. Error bars represent standard errors.

et al. 2021, see Figure 6). Mean size of individuals captured in reference blind, reference distributary, and project sites also differed by month across all year of post restoration monitoring (Fig 18). The higher densities of fish in reference blind channel sites early in the season correspond with fish of smaller mean size than both project and reference distributary sites. The larger mean size of Chinook salmon in those sites indicates the presence of larger yearling Chinook salmon though the absence in reference blind channel sites is notable. While the differences in size among reference blind channel and inside project sites decreased considerably in 2019, further monitoring of potential causes of these differences (e.g. environmental conditions) is warranted and discussed briefly below.

To evaluate spatial variability in Chinook salmon within Qwuloolt the site was divided into five separate “regions”: Allen and Jones Creeks (large tidal channels with freshwater input), Qwuloolt channel (main channel through breach and below confluence of Allen and Jones Creek), Cut Channel (small tidal channel), and Qwuloolt berms (constructed landforms representing interior of project site). Mean juvenile Chinook salmon density within the Qwuloolt varied considerably among locations and were magnififed when evaluating only events with fish present (Fig 19). Allen Creek and Qwuloolt berm sites had the highest mean Chinook salmon density post restoration though observations were also highly variable (Fig 19). However, estimates for these locations were highly influenced by observations during 2017 when sampling was not distributed evenly across the site and Chinook salmon abundance was elevated across the estuary. The lowest mean densities were observed in the Qwuloolt channel while the other regions were somewhat moderate and less variable than the Qwuloolt berms.

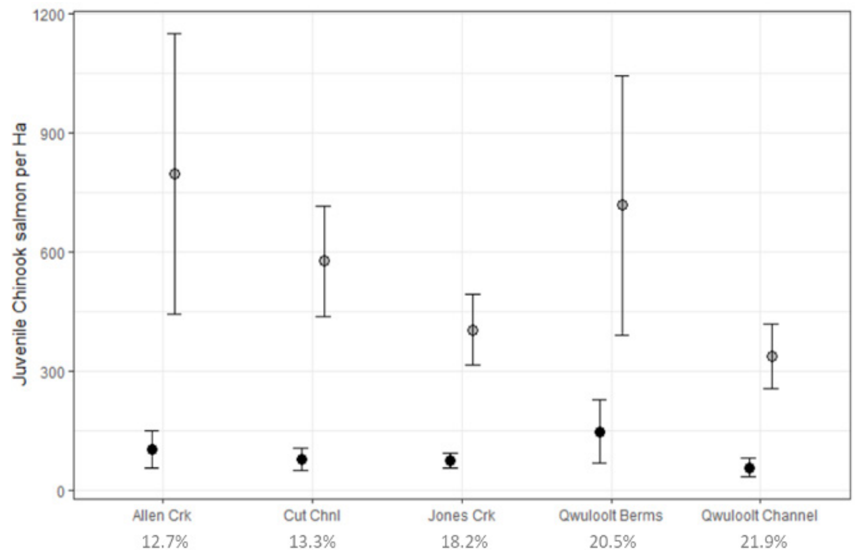

Figure 19. Average juvenile Chinook salmon density for all sampling events (black) and events only with fish present (gray) inside the Qwuloolt site for post-restoration years 2016-2019. Error bars represent standard errors. Map at the left for referencing sampling regions. Percentages represent the percent of samples with fish present for each location.

Smith Island

Pre-project monitoring associated with the Smith Island project has occurred since 2016. After the project site was breached in 2018, additional sampling within the project area was conducted concurrent to distributary and blind channel reference sites. Data presented here reflect only 1 year post-breach and therefore should be considered a preliminary response to restoration at the site and likely to change with more post-project monitoring.

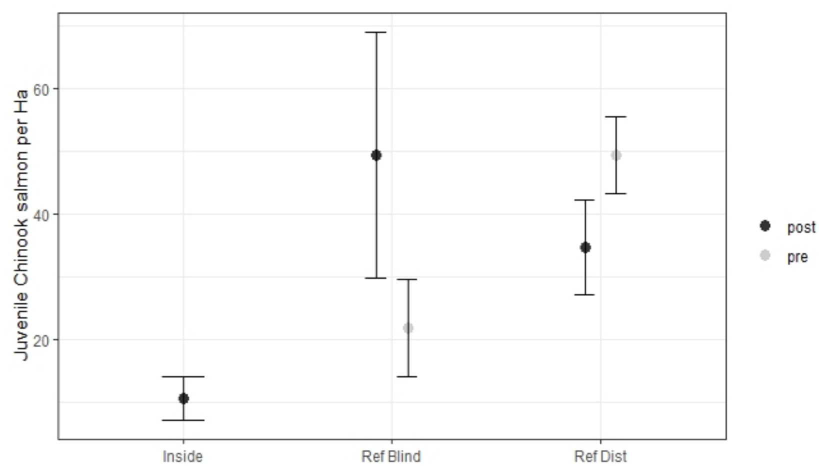

Figure 20. Average juvenile Chinook salmon density for Smith Island project site (Inside) and adjacent reference sites pre- and post-restoration. Post restoration points include only sampling year 2019. Error bars represent standard errors.

Abundances within the Smith Island project were also similar to those observed at reference distributary sites though there was no pre-restoration monitoring within the project site for comparison (Fig 20). Similar to the Qwuloolt site, juvenile Chinook salmon abundances within Smith Island one year post-breach were lower than those observed at reference blind and distributary sites. Ongoing monitoring of the Smith Island site will inform whether juvenile Chinook densities move toward reference sites in future years as is expected. Comparing seasonal rearing densities from intensive monitoring of Smith Island with those predicted by our capacity models suggest observed densities are below expectations both within and outside the site. Expected seasonal rearing density at the project site is 1271 fish/yr/ha. Rearing densities calculated from delta sampling are 61 fish/yr/ha within the site and 280 fish/yr/ha at reference blind channel sites.

Post-breach monthly densities of juvenile Chinook salmon were generally highest in reference blind channel sites followed by reference distributary and then within the project site (Fig 21). Chinook salmon were not present within the project site in February and only twice in March and April. While the absolute densities of Chinook salmon within the project site were considerably lower than reference blind channel sites in May, densities within the site peaked at the same time suggesting fish use within the site was initiated once densities began to peak in reference sites.

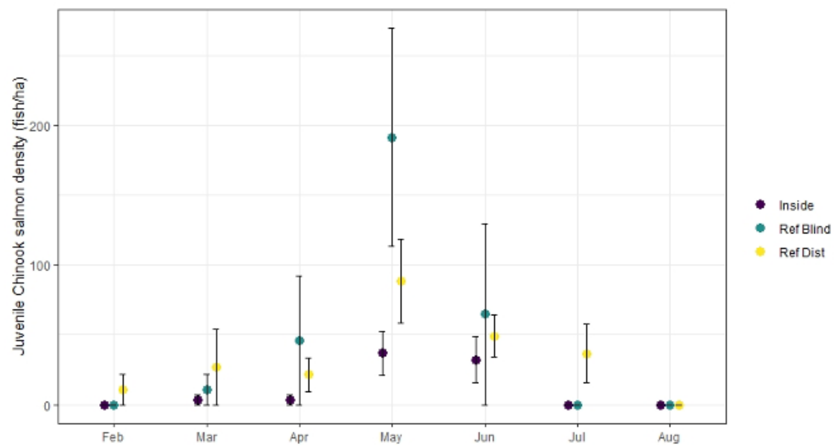

Figure 21. Average juvenile Chinook salmon density for Smith Island project site (Inside) and adjacent reference sites post-restoration (2019). Error bars represent standard errors.

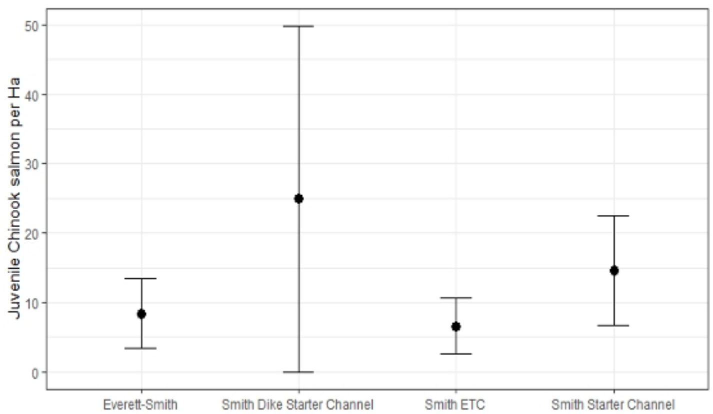

Figure 22. Average juvenile Chinook salmon density for sampling regions inside Smith Island project site for sampling year 2019. Error bars represent standard errors.

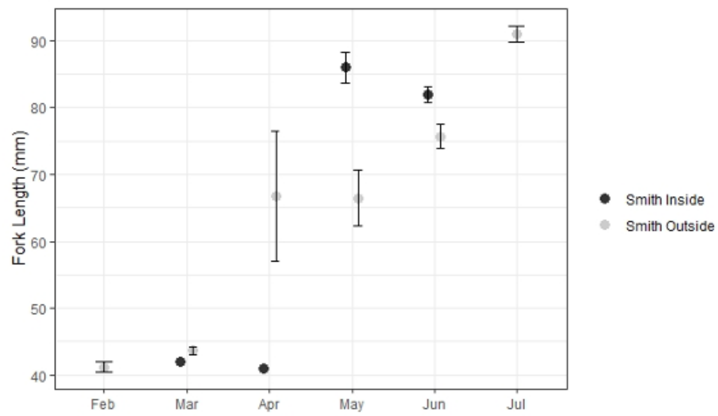

Figure 23. Average juvenile Chinook salmon fork lengths for Smith Island project site (Inside) and adjacent reference sites (Outside) for sampling year 2019. Error bars represent standard errors.

Juvenile Chinook salmon were effectively absent from the project site and reference blind channel sites by July. Spatial variability in juvenile Chinook salmon density within the Smith Island project site(s) was similar to that observed at Qwuloolt whereby average densities across the site were similar but the variability within a particular location was quite different (Fig 22).

Juvenile Chinook salmon size within and outside the Smith Island project site in the first year post-breach is inconclusive for Feb-Apr given the extremely low catch rate for Chinook salmon inside the project site. However, comparison for May and June, when densities of juvenile Chinook salmon increased both inside and outside the project site suggest individuals captured inside the site were considerably larger than those caught outside the site (Fig 23).

Environmental conditions

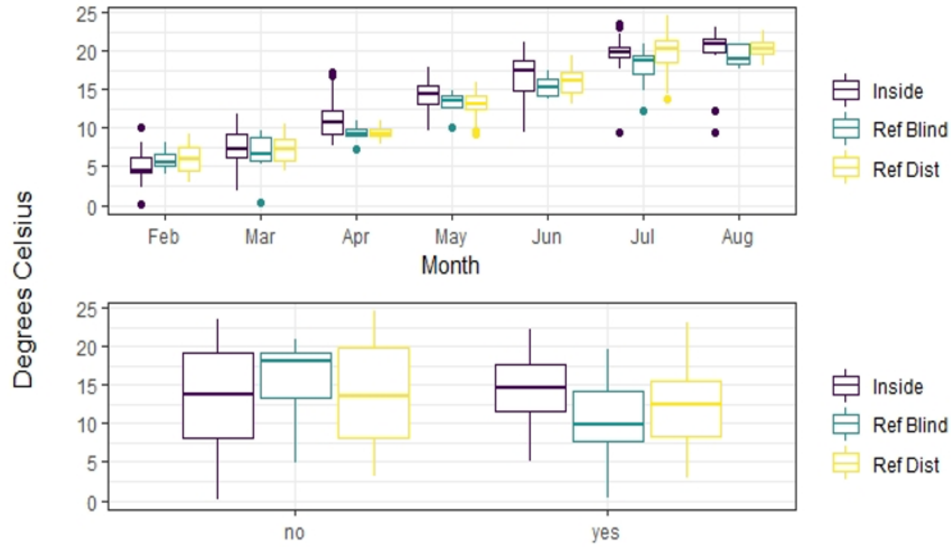

Figure 24. Boxplots of water temperature by month (top) and juvenile Chinook presence/absence (bottom) for the Qwuloolt site (Inside) and reference sites 2016-2019. Horizontal lines within boxes represent median, boxes are 25th – 75th percentiles, and whiskers are 5th and 95th percentiles.

Environmental conditions (e.g. temperature, salinity, dissolve oxygen, flow) can influence fish presence, density and rearing benefits (see Section 3) of sites within tidal deltas (Beamer et al. 2015, David et al. 2014). Environmental conditions among Qwuloolt project and reference sites were not statistically different though there was seasonal variability within each group and noteworthy patterns with respect to temperature and flow. Differences in temperature were the most pronounced among site groups and within the project site (Fig 24). Temperature, in particular, can be a barrier to fish use and influence metabolic processes that affect growth. While there were no consistent relationships between fish density and temperature patterns among locations there were some notable occurrences with respect to fish presence. Reference blind channel sites had the highest overall juvenile Chinook densities and water temperatures tend to remain lower than project sites and reference distributary sites throughout the season. Juvenile Chinook salmon were rarely present in reference blind channels at temperatures that exceeded 15C. However, fish more often experienced temperatures over 15C within the Qwuloolt site as compared to other reference sites. Future research to understand how this may impact or influence growth potential is recommended.

The exact relationship between observed current flow and juvenile Chinook density within or adjacent to the Qwuloolt site is yet unclear however several aspects are worth exploring. Extremely high flows have been recorded at the entrance to the site which may impact fish use at the site. Currents near 2m/s on the ebb tide and 1.5m/s on the flood tide were recorded at the entrance (Qwuloolt Channel) to the site (E. Grossman USGS, unpublished data). Generally fish move into tidal channels on the flood tide and exit with the ebb tide.

However, movement into restoration sites against the tide has been noted (Hering et al. 2010) Whether the extreme current velocities observed inside the breach at the Qwuloolt site creates a barrier to fish movement into or within the site is yet undetermined but of interest for determining restoration effectiveness at the site.

Implications for recovery

- Juvenile Chinook salmon were observed immediately after restoration at both the Qwuloolt and Smith Island sites. Densities were lower than reference blind channel habitats at both project sites though the difference has decreased at the Qwuloolt site 3-4 yrs post-restoration. The presence of fish within restored sites and the trend toward reference blind channel sites at Qwuloolt suggest a positive response to restoration for juvenile Chinook salmon in the delta.
- Seasonal patterns of juvenile Chinook density remain different within project sites compared to reference blind channel sites. Low Chinook salmon density at project sites early in the outmigration period (Feb-Mar) warrants further attention. Expectations for restoration projects should follow patterns of fish use similar to reference/natural tidal channel sites/habitat but may take several years to realize. As such we should expect restoration projects to support early use by fry migrants in the delta and thus densities at project sites in the early rearing season should increase in future years.
- Differences in average fork lengths for individuals captured within and adjacent to project sites were apparent for both Qwuloolt and Smith Island. Individual Chinook salmon captured within the Qwuloolt site were consistently larger than those captured in reference blind channel sites throughout the rearing season. While this may simply reflect use of these sites by larger individuals (yearling migrants), it is unclear if there are barriers to the site for smaller Chinook salmon (fry migrants) early in the rearing season.

8. Thinking ahead: future research themes and information gaps

- Revised restoration targets and informed restoration planning in the delta will require accurate assessments of habitat capacity in the Snohomish delta. Our revised methods for estimating rearing capacity in the delta can be used to help determine the capacity for and prioritization of, future restoration projects. Once habitat areas of proposed sites has been estimated, revised models can be used to estimate rearing capacity at each site within the delta. These estimates can be used to rank projects and revise restoration targets/goals for Chinook salmon recovery in the Snohomish basin.
- The sensitivity of capacity estimates to residence time by tidal delta rearing juvenile Chinook salmon suggests future research should focus on exploring the variability around residence time as a function of conditions within and across tidal deltas. Current efforts to expand our knowledge of residence using otolith microchemistry are underway and should increase the resolution of residence time estimates from multiple deltas. While these efforts will add important information, more targeted studies to evaluate additional questions regarding residence time are recommended. Does residence time differ among tidal deltas? Does residence time vary within the season for juvenile Chinook salmon? Does residence time vary with respect to temperature or outmigrant abundance/density in the delta? This is extremely important for fry migrants as the primary users of tidal deltas habitat but should also include evaluating residence time for natural origin parr life history as well as hatchery origin fish that use tidal delta habitat. More accurate estimates of mean residence time and the variability among individuals will help restoration and recovery efforts considerably.
- Evidence of non-natal population use of the Snohomish estuary is novel and worth further evaluation with respect to habitat use, restoration, and capacity in the delta. Individuals representing 5 non-natal river basins were captured in the estuary in every month and year from 2012-2014. The majority of non-natal fish were assigned to Whidbey Basin rivers with the overwhelming majority from the Skagit basin. Skagit River Chinook salmon were capture din the estuary as early as March and through June suggesting overlap with natal Chinook populations throughout the rearing season. Further studies to quantify the number of non-natal fish present in the system and their

use (consumption, residence time, etc.) will be useful for recovery planning both within and outside (Skagit) the Snohomish basin.

- Observations of juvenile Chinook salmon density in the Snohomish estuary suggest fish are present in densities that exceed estimated capacity. While these occurrences in themselves warrant further attention, evaluating potential impacts of elevated densities in the delta are also worth pursuing. Previous research has evaluated consumption demand by natural and hatchery-origin Chinook salmon across multiple tidal deltas in Puget Sound (Greene et al. 2021). While results indicated consumption did not surpass resource availability, the authors identified important caveats that should be addressed by future research activities to improve models and estimates of consumption demand. Additional efforts related to the initial study are underway to incorporate consumption demand from other species in the estuarine assemblage as well as for outmigration years that have above/below average outmigration abundances and thermal conditions. The goal of this work will be to more accurately account for consumption of prey resources by species that are known to overlap in delta habitat with juvenile Chinook salmon and to assess the variability in consumption and growth with respect to variable population abundances and environmental conditions that may influence growth.
- Predicted sea level rise may have impacts on both current and future (planned) estuary habitat within the Snohomish delta. These impacts could potentially alter the total available habitat, habitat distribution, and environmental conditions within the delta. Understanding how sea level rise may change/shift habitat availability in the delta will be important for panning future restoration activities such that habitat both remains available under predicted conditions and provides the intended function to support rearing for juvenile Chinook salmon.
- Updated information, with respect to Chinook salmon ecology and capacity in tidal deltas, will be critical inputs for life cycle models evaluating salmon population recovery in Puget Sound. Models to assess restoration strategies and impacts due to climate change on local populations will require revised estimates of habitat capacity, residence time, and potentially Chinook salmon growth in tidal deltas.

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References

Achord, S., R. W. Zabel, and B. P. Sandford. 2007. Migration Timing, Growth, and Estimated Parr-to-Smolt Survival Rates of Wild Snake River Spring–Summer Chinook Salmon from the Salmon River Basin, Idaho, to the Lower Snake River. Transactions of the American Fisheries Society 136(1):142-154.

Anderson, J. H., and P. C. Topping. 2018. Juvenile Life History Diversity and Freshwater Productivity of Chinook Salmon in the Green River, Washington. North American Journal of Fisheries Management 38(1):180-193.

Bartz, K. K., K. M. Lagueux, M. D. Scheuerell, T. Beechie, A. D. Haas, and M. H. Ruckelshaus. 2006. Translating restoration scenarios into habitat conditions: an initial step in evaluating recovery strategies for Chinook salmon (Oncorhynchus tshawytscha). Canadian Journal of Fisheries and Aquatic Sciences 63(7):1578-1595.

Beamer, E., R. Henderson, K. Wolf, J. Demma, and W. G. Hood 2018. Juvenile Chinook salmon response to dike setback restoration at Fir Island Farms in the Skagit River tidal delta, 2015 – 2018. Report to Washington Department of Fish and Wildlife under Interagency Agreement Number 15- 02641. Skagit River System Cooperative, La Conner, WA 98257.

Beamer, E., R. Henderson, C. Ruff, and K. Wolf. 2017. Juvenile Chinook salmon utilization of habitat associated with the Fisher Slough Restoration Project, 2009 - 2015. Report prepared for The Nature Conservancy, Washington.

Beamer, E., R. Henderson, and B. Brown. 2015. Juvenile Chinook salmon utilization of habitat associated with the Wiley Slough Restoration Project, 2012-2013. Skagit River System Cooperative, LaConner, WA.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, a. C. Rice, and K. Fresh. 2005. Delta and Nearshore Restoration for the Recovery of Wild Skagit River Chinook Salmon: Linking Estuary Restoration to Wild Chinook Salmon Populations. Appendix D of the Skagit Chinook Recovery Plan, Skagit River System Cooperative, La Conner, WA.

Beamer, E. M., and K. Larsen. 2004. The importance of Skagit Delta habitat on the growth of wild ocean-type Chinook in Skagit Bay–Implications for delta restoration. Skagit River System Cooperative, La Conner, WA.

Beechie, T. J., O. Stefankiv, B. Timpane-Padgham, J. E. Hall, G. R. Pess, M. Rowse, M. Liermann, K. Fresh, and M. J. Ford. 2017. Monitoring Salmon Habitat Status and Trends in Puget Sound: Development of Sample Designs, Monitoring Metrics, and Sampling Protocols for Large River, Floodplain, Delta, and Nearshore Environments. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-137.

Beechie, T. J., C. Nicol, C. Fogel, J. Jorgensen, J. Thompson, G. Seixas, J. Chamberlin, J. Hall, B. Timpane-Padgham, P. Kiffney, S. Kubo, and J. Keaton. 2021. Modeling Effects of Habitat Change and Restoration Alternatives on Salmon in the Chehalis River Basin Using a Salmonid Life-Cycle Model. U.S. Department of Commerce, NOAA Contract Report NMFS-NWFSC-CR-2021-01.

Brophy, L. S., C. M. Greene, V. C. Hare, B. Holycross, A. Lanier, W. N. Heady, K. O'Connor, H. Imaki, T. Haddad, and R. Dana. 2019. Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. Plos One 14(8):e0218558.

Chalifour, L., D. C. Scott, M. MacDuffee, S. Stark, J. F. Dower, T. D. Beacham, T. G. Martin, and J. K. Baum. 2020. Chinook salmon exhibit long-term rearing and early marine growth in the Fraser River, British Columbia, a large urban estuary. Canadian Journal of Fisheries and Aquatic Sciences 78(5):539-550.

Chamberlin JW, JE Hall, WT Zackey, F Leonetti, M Rustay, and CA Rice. 2021. Spatial and Temporal Variability in Chinook Salmon Abundance Reflects Opportunity to Support Life History Diversity in an Estuarine Landscape. Estuaries and Coasts.

Chamberlin, J.W., W.T. Zackey, A. Spidle, T. Seamons, M. Crewson, M. Totman. 2022a. Population-specific distribution, individual growth, and residency of juvenile Chinook salmon in the Snohomish estuary. ESRP Project report 14-2303.

Chamberlin, JW, WT Zackey, and O. Stefankiv. 2022b. Revised estimates of habitat capacity for Chinook salmon in tidal deltas: Implications for recovery planning in the Snohomish delta.

Cordell, J. R., J. D. Toft, A. Gray, G. T. Ruggerone, and M. Cooksey. 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary. Ecological Engineering 37(2):343-353.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitat of the United States. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

David, A. T., C. S. Ellings, I. Woo, C. A. Simenstad, J. Y. Takekawa, K. L. Turner, A. L. Smith, and J. E. Takekawa. 2014. Foraging and Growth Potential of Juvenile Chinook Salmon after Tidal Restoration of a Large River Delta. Transactions of the American Fisheries Society 143(6):1515-1529.

Davis, M. J., J. W. Chamberlin, J. R. Gardner, K. A. Connelly, M. M. Gamble, B. R. Beckman, and D. A. Beauchamp. 2020. Variable prey consumption leads to distinct regional differences in Chinook salmon growth during the early marine critical period. Marine Ecology Progress Series 640:147-169.

Davis, M. J., I. Woo, C. S. Ellings, S. Hodgson, D. A. Beauchamp, G. Nakai, and S. E. W. De La Cruz. 2019. Freshwater Tidal Forests and Estuarine Wetlands May Confer Early Life Growth Advantages for Delta-Reared Chinook Salmon. 148(2):289-307.

Ellings, C. S., M. J. Davis, E. E. Grossman, I. Woo, S. Hodgson, K. L. Turner, G. Nakai, J. E. Takekawa, and J. Y. Takekawa. 2016. Changes in habitat availability for outmigrating juvenile salmon (Oncorhynchus spp.) following estuary restoration. Restoration Ecology 24(3):415-427.

Gray, A. 2005. The Salmon River estuary: restoring tidal inundation and tracking ecosystem response. University of Washington.

Greene, C.M., E. Beamer, J. Chamberlin, G. Hood, M. Davis, K. Larsen, J. Anderson, R. Henderson, J. Hall, M. Pouley, T. Zackey, S. Hodgson, C. Ellings, and I. Woo. 2020. Landscape, density-dependent, and bioenergetic influences upon Chinook salmon in tidal delta habitats: Comparison of four Puget Sound estuaries. ESRP Report 13-1508.

Haas, A., and B. D. Collins. 2001. A Historical Analysis of Habitat Alteration in the Snohomish River Valley, Washington since the mid-19th Century: Implications for Chinook and Coho Salmon. Report for Snohomish County., Everett, WA.

Hall, J. E., T. P. Khangaonkar, C. A. Rice, J. Chamberlin, T. Zackey, F. Leonetti , M. Rustay, K. Fresh, A. Kagley, and M. Rowse. 2018. Characterization of Salinity and Temperature Patterns in a Large River Delta to Support Tidal Wetland Habitat Restoration. 92 %J Northwest Science(1):36-52, 17.

Hall J, J Chamberlin, W Zackey, H Zox, M Tottman, and C Rice. 2019. Snohomsih estuary monitoring plan. Report to ESRP 14-2303.

Hanski, I. 1999. Habitat Connectivity, Habitat Continuity, and Metapopulations in Dynamic Landscapes. Oikos 87(2):209-219.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. . Pages 315-341 in V. S. Kennedy, editor. Estuarine Comparisons. Academic Press, New York.

Hering, D. K. H. K., D. L. B. L. Bottom, E. F. P. F. Prentice, K. K. J. K. Jones, and I. A. F. A. Fleming. 2010. Tidal movements and residency of subyearling Chinook salmon (Oncorhynchus tshawytscha) in an Oregon salt marsh channel. Canadian Journal of Fisheries and Aquatic Sciences 67(3):524-533.

King County. 2021. Snoqualmie River Juvenile Chinook with Extended Freshwater Rearing. Prepared by Josh Kubo, Water and Land Resources Division. Seattle, Washington.

McNatt, R. A., D. L. Bottom, and S. A. Hinton. 2016. Residency and Movement of Juvenile Chinook Salmon at Multiple Spatial Scales in a Tidal Marsh of the Columbia River Estuary. Transactions of the American Fisheries Society 145(4):774-785.

Munsch, S. H., C. M. Greene, R. C. Johnson, W. H. Satterthwaite, H. Imaki, and P. L. Brandes. 2019. Warm, dry winters truncate timing and size distribution of seaward-migrating salmon across a large, regulated watershed. Ecological Applications 29(4):e01880.

Quinn, T. P. 2018. The behavior and ecology of Pacific salmon and trout. American Fisheries Society, Bethesda, MD.

Scheuerell, M. D., R. Hilborn, M. H. Ruckelshaus, K. K. Bartz, K. M. Lagueux, A. D. Haas, and K. Rawson. 2006. The Shiraz model: a tool for incorporating anthropogenic effects and fish–habitat relationships in conservation planning. Canadian Journal of Fisheries and Aquatic Sciences 63(7):1596-1607.

Snohomish Basin Salmon Recovery Forum. 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Department of Public Works, Surface Water Management Division. Everett, WA.

Urban, D., and T. Keitt. 2001. Landscape connectivity: a graph-theoretic perspective. Ecology 82(5):1205-1218.

Woo, I., M. J. Davis, C. S. Ellings, S. Hodgson, J. Y. Takekawa, G. Nakai, and S. E. W. De La Cruz. 2019. A Mosaic of Estuarine Habitat Types with Prey Resources from Multiple Environmental Strata Supports a Diversified Foraging Portfolio for Juvenile Chinook Salmon. Estuaries and Coasts 42(7):1938-1954.

Zimmerman, M. S., C. Kinsel, E. Beamer, E. J. Connor, and D. E. Pflug. 2015. Abundance, Survival, and Life History Strategies of Juvenile Chinook Salmon in the Skagit River, Washington. Transactions of the American Fisheries Society 144(3):627-641.

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