An Assessment of Juvenile Chinook Salmon Population Structure and Dynamics in the Nooksack Estuary and Bellingham Bay Shoreline, 2003-2015

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Report to:
City of Bellingham and Bellingham Bay Action Team in participation with the WRIA 1 Salmon Recovery Team

Shoreline oblique photo courtesy WA Department of Ecology

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Contents

Executive summary

Puget Sound Chinook salmon were listed as Threatened under the Endangered Species Act (ESA) in 1999. In response, local watersheds throughout Puget Sound created recovery plan chapters which were submitted to the National Oceanic and Atmospheric Administration in 2005. The 2005 Water Resource Inventory Area (WRIA) 1 Salmonid Recovery Plan included recovery actions for the Nooksack River's estuary and nearshore. However, a lack of specific analysis of Nooksack juvenile Chinook salmon population dynamics led to uncertainties in determining the importance and priority of habitat actions within the estuary or nearshore compared to recovery actions within other parts of the Nooksack River basin. The City of Bellingham, recognizing the importance of filling this information gap, commissioned this study in partnership with Bellingham Bay Action Team and Lummi Nation to investigate the role of estuarine and nearshore marine habitats on Nooksack early Chinook productivity and abundance.

Specifically, this study fills knowledge gaps on juvenile Chinook salmon population structure, origin, and performance within the Nooksack tidal delta and Bellingham Bay nearshore habitats. Population structure refers to identifying temporal habitat use by natural and hatchery origin juvenile Chinook salmon, including at what size and relative abundance they occupy habitats. Origin refers to identifying which rivers or hatchery release sites juvenile Chinook are coming from. Performance refers to pressures on the juvenile Chinook population that limit abundance or productivity. In this study we identify whether natural origin juvenile Chinook are experiencing density dependence in the Nooksack tidal delta under contemporary habitat conditions and outmigration sizes. We also examine the relationship of food availability and habitat specific growth of juvenile Chinook that rear in Nooksack tidal delta and Bellingham Bay pocket estuary habitats.

This study quantifies habitat conditions of the Nooksack tidal delta and connectivity of habitats within and between the Nooksack tidal delta and Bellingham Bay nearshore to assist in analyses of juvenile Chinook salmon population dynamics and habitat preference. We utilized existing datasets provided by the Lummi Nation of Nooksack River juvenile Chinook outmigration over the years 2005-2015 and beach seine catches of juvenile Chinook salmon in the Nooksack tidal delta and Bellingham Bay nearshore over years 2003-2013. As part of this study we collected beach seine data of juvenile Chinook salmon in the Nooksack tidal delta and Bellingham Bay nearshore in 2014 and 2015. Overall, these extensive data are more than adequate to understand the role of estuarine and nearshore marine habitats on Nooksack early Chinook productivity and abundance. Below we highlight some of the study's most important findings and recommendations.

<u>Nooksack River natural origin juvenile Chinook outmigrants</u>

The recent eleven year average Nooksack River natural origin juvenile Chinook outmigration population is approximately 190,000 fish/year and consists of life history types that can take advantage of habitat opportunities within the Nooksack River, Nooksack tidal delta, and Bellingham Bay nearshore. Based on genetic analysis, Nooksack River natural origin spring and fall Chinook populations produce juveniles capable of expressing the life history types that rear extensively within their natal estuary or nearshore refuge habitat such as pocket estuaries. Overall, the Nooksack natural origin juvenile Chinook outmigration results demonstrate the Nooksack River basin's freshwater system is not at carrying capacity for parr migrants. The causes of underseeded freshwater habitat for parr migrants should be addressed, or studied if not known.

Natural origin juvenile Chinook outmigrants from independent Bellingham Bay streams

We investigated the possibility of natural origin juvenile Chinook outmigrating from Bellingham Bay independent streams. Whatcom Creek is likely the only stream of four examined with consistent annual presence of Chinook salmon spawners. We concluded that Chinook spawners in Whatcom Creek are likely producing juveniles that are rearing in nearby Bellingham Bay nearshore areas. We recommend spawner surveys for these streams be designed to better detect Chinook presence and abundance if WRIA 1 salmon recovery efforts want to account for natural origin Chinook contributions from independent streams draining into Bellingham Bay.

Natural origin juvenile Chinook use of the Nooksack tidal delta and Bellingham Bay nearshore

There is consistent use of Nooksack tidal delta and Bellingham Bay pocket estuary habitat by natural origin juvenile Chinook, but density results are lower in the tidal delta than in Bellingham Bay nearshore habitats. Even though there is consistent use of Nooksack tidal delta habitat by natural origin juvenile Chinook, we found no evidence of density dependence over the current natural origin juvenile outmigration range. The Nooksack tidal delta is underseeded by natural origin juvenile Chinook salmon.

Based on genetic analysis, natural origin juvenile Chinook caught in the Nooksack tidal delta were predominately Nooksack River origin fish comprised of early run (ESA-listed) fish in the fry migration period, followed by a combination of early and fall run fish in the parr outmigration period. Bellingham Bay nearshore and pocket estuary habitat catches were mostly comprised of Nooksack natural origin juvenile Chinook, especially early in the season. Out-of-system natural origin juvenile Chinook in Bellingham Bay nearshore habitats were primarily from the Whidbey basin and were generally not present prior to the summer months.

We found that functional habitat conditions exist for juvenile Chinook in all estuarine wetland zones of the Nooksack tidal delta and in Bellingham Bay pocket estuaries, based on adequate prey availability and suitable growth of juvenile Chinook. However, habitat-specific differences in juvenile Chinook salmon growth were substantial. Growth differences were largely an outcome of temperature differences between habitat types and were not due to prey quality or abundance differences between habitats. Because temperature patterns by habitat type varied by year, no single habitat type examined systematically offered better juvenile Chinook growth benefits. These findings suggest that habitat diversity is important to provide optimal temperatures across the juvenile Chinook rearing season in order to buffer impacts from particularly cold or warm time periods. Juvenile Chinook salmon are expected to naturally use a mix of habitat types during outmigration where habitat- and season-specific differences in growth opportunity exist. Because of this, restoration plans in estuary environments should seek a diversity of connected habitats.

Hatchery origin juvenile Chinook

The total juvenile Chinook population using the study area each year is dominated by releases of hatchery origin fish (over 5 million fish/year) from within or near the study area. Although millions of hatchery juvenile Chinook are released into the Nooksack/Samish Management Unit, fish marking practices are good so the effects of mistaking unmarked hatchery juveniles with natural origin juveniles are minimized.

We found all coded wire tagged hatchery juvenile Chinook in the Nooksack tidal delta were from Nooksack River hatchery releases, while coded wire tagged hatchery juvenile Chinook in the Bellingham Bay nearshore were from a combination of release sites in the Nooksack, Samish, and Skagit River basins. We did not recover any coded wire tagged Chinook from nearby British Columbia, Central Puget Sound, South Puget Sound, or Hood Canal hatchery releases.

Hatchery and natural origin juvenile Chinook interactions

Ecological interactions between natural origin and hatchery origin salmon are possible. Ecological interactions occur when the presence of hatchery fish affects how natural origin fish interact with their environment. Possible negative ecological interactions of hatchery fish on natural origin fish include competition for available rearing habitat and food, increased predation, and introduction of disease and parasites. We did not directly study ecological interactions between natural and hatchery juvenile Chinook salmon within the Nooksack tidal delta or Bellingham Bay nearshore. This study does, however, present results showing where and when natural and hatchery juvenile Chinook comingle within the study area and discusses whether ecological interactions are possible or not likely. Whether there is potential for adverse ecological interactions between hatchery and natural origin juvenile Chinook depends on the extent that hatchery fish comingle with natural origin fish. This topic may need future study if adverse ecological interactions are suspected between hatchery and natural origin fish. A strong inference from the natural origin Chinook density results for the Nooksack tidal delta and Bellingham Bay nearshore along with hatchery juvenile Chinook release results suggest the comparatively few natural juveniles are actively residing in rearing habitats while the abundant hatchery juveniles are migrating quickly through the tidal delta system and largely avoiding the nearshore refuge habitats such as pocket estuaries. Comingling of natural and hatchery juvenile Chinook occurs after most natural fry and yearling Chinook have outmigrated and coincides with the natural parr outmigration.

Influence of Nooksack tidal delta habitat conditions on juvenile Chinook salmon rearing

Natural (logjam formation) and anthropogenic (restoration) causes have changed habitat conditions within the Nooksack tidal delta over the years included in this study. The total area of tidally influenced wetlands and channels in the Nooksack tidal delta was 894 hectares in 2008 and 920 hectares in 2013. Most of the increase in area is due to a habitat restoration project along Smugglers Slough. However, the biggest changes to habitat type between periods occurred in the connected Nooksack tidal delta when a distributary channel-spanning logjam fully developed after 2008. The logjam caused major changes to how water flows through the delta, including a reduction in the number and size of major distributary channels on the east side of the tidal delta.

The changes in tidal delta habitat extent influence juvenile Chinook carrying capacity while the changes in tidal delta distributary channels influence how migrating fish find habitat within the tidal delta and how they move though the delta to nearshore habitat. Nooksack River juvenile Chinook migrants have better access to western Nooksack tidal delta and western Bellingham Bay nearshore habitat in the post-logjam period compared to the pre-logjam period. Conversely, Nooksack River juvenile Chinook migrants have poorer access to eastern Nooksack tidal delta and eastern Bellingham Bay nearshore habitat in the post-logjam period compared to the pre-logjam period. Habitat areas within the upper tidal delta have experienced minor changes in connectivity as a result of the logjam. For each recent time period (before or after logjam), Nooksack River juvenile Chinook migrants can best access upper Nooksack tidal delta habitat and least access Lummi Bay habitat.

WRIA 1 Chinook salmon recovery strategies

Nooksack tidal delta and Bellingham Bay nearshore refuge habitats (pocket estuaries, small independent streams) are utilized by natural origin juvenile Chinook even at the current (underseeded) outmigration levels. The juvenile life history types exist in the overall system to capitalize on tidal delta and nearshore habitat opportunities. Restoration and protection of these habitats would benefit the comparatively few fish currently expressing these life history types and support resilience in the Nooksack natural origin Chinook populations as they move toward recovery.

Currently, use of Nooksack tidal delta habitats by natural origin juvenile Chinook is concentrated in only one area. Restoration of connectivity to the sub-delta areas of Silver Creek, Smugglers/Slater Slough, and Lummi Bay would vastly increase the use and carrying capacity for Nooksack natural origin juvenile Chinook salmon. It is also true the restored capacity of the Nooksack tidal delta will not be realized (much) at the currently low natural origin Chinook outmigration levels. Ultimately, restoration goals for Nooksack tidal delta and Bellingham Bay nearshore habitats should be determined by considering the habitat extent, connectivity, and quality needed for the desired future Nooksack Chinook populations.

Glossary of terms and acronyms

Term/acronym	Definition/description
AIC	Akaike information criterion: measure of the relative quality of statistical models for a given set of data.
AICc	Bias-corrected Akaike information criterion value. The lowest AICc value is best.
ANOSIM	Analysis of Similarity. A distribution-free method of multivariate data analysis widely used by community ecologists.
BBAT	Bellingham Bay Action Team
Blind channel	An entrenched pathway for water within an estuarine emergent marsh, scrub shrub, or riverine tidal zone that is inundated during all or part of the tidal cycle and/or during any stage of river discharge that terminates at the farthest upstream point of tidal erosion within that channel (they are 'dead ends'). Blind channels are single tidal channels or tidal channels connected to other tidal channels or distributaries, but are not river distributaries. Flow from one blind channel to the other is dependent on tidal flushing (in a river distributary the residual flow is not dependent on tidal flushing).
CE	Catch Efficiency of the sampling gear
Channel spanning wood	Logjam
COB	City of Bellingham
CV	Coefficient of Variation
CWT	Coded Wire Tag
Distributary channel	A fluvially created and maintained channel transferring river water into marine water across/through a delta fan or other type of estuary.
DO	Dissolved oxygen
EDT	Ecosystem Diagnosis and Treatment: a model procedure for developing salmon recovery plans. See Lichatowich et al. (1995)[1]
EEM	Estuarine Emergent Marsh (a tidal delta zone type): gently sloping salt marsh and brackish marsh wetlands found in the upper and mid part of the delta, created by fluvial and tidal channel networks forming marsh islands of herbaceous plants tolerant to daily tidal inundation (rushes, sedges, grasses, etc.).
ESA	Endangered Species Act: a federal law that provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend.
ESRP	Washington State's Estuary and Salmon Restoration Program
ESS	Estuarine Scrub Shrub (a tidal delta zone type): gently sloping wetland at the highest elevation of tides, broken up by a network of fluvial and tidal

[1] Lichatowich, J., L. Mobrand, L. Lestelle, and T. Vogel. 1995. An Approach to the Diagnosis and Treatment of Depleted Pacific Salmon Populations in Pacific Northwest Watersheds. Fisheries 20(1):10-18.

Term/acronym	Definition/description
	channels, with marsh islands colonized by woody shrubs tolerant to brackish water and freshwater inundation from time to time.
FRT (a.k.a. riverine tidal forest)	Forested Riverine Tidal (a tidal delta zone type): Fresh water riverine wetlands, channels and distributaries that are hydraulically 'pushed' by the tides but are not within the mixing zone of salt and fresh water where vegetation is dominated by trees rather than emergent plants.
FW	Fresh Water
GAPS	Genetic Analysis of Pacific Salmonids. A specific genetic baseline of Chinook salmon derived from reference samples representing spawning aggregates in known geographic locations. Published as Moran et al. (2005)
GIS	Geographic Information Systems (computer mapping)
GLM	Generalized Linear Model (a statistical procedure)
GSI	Genetic Stock Identification
HGMP	Hatchery and Genetic Management Plan
HOR	hatchery origin recruit
Impoundment	Marine or brackish water pool accessible to fish via tidal channel, connected to tidal flow during all or part of the tide cycle, that remains wet even when disconnected from open water by low tides.
Intertidal fill	Anthropogenic structures or fill material in the intertidal zone.
Intertidal wood	Wracks of driftwood (three or more logs deep) that accumulate in the intertidal zone, usually on saltmarshes or behind (landward of) barrier beaches.
LLTK	Long Live The Kings
LNRD	Lummi Natural Resources Department
mg/l	milligrams per liter
MSE	mean square error
NMDS	Non-metric multidimensional scaling: an indirect gradient analysis approach which produces an ordination based on a distance or dissimilarity matrix.
NOR	natural origin recruit
NSEA	Nooksack Salmon Enhancement Association
PMR	Peterson Mark-Recapture
ppt	parts per thousand (a unit of measurement for salinity)
r^2	Statistic that gives information about the goodness of fit of a model. In regression, the r^2 coefficient of determination is a statistical measure of how well the regression line approximates the real data points. An r^2 of 1 indicates that the regression line perfectly fits the data.
RITT	The Puget Sound Recovery Implementation Technical Team: an independent science advisory group assisting federal, state, and local watersheds with regional- and watershed-level salmon recovery guidance. (https://www.nwfsc.noaa.gov/trt/puget.cfm#PSRITT)

Term/acronym	**Definition/description**
RMIS	Regional Mark Information System (http://www.rmis.org/rmis_login.php?action=Login&system=cwt)
SIMPER test	Similarity percentages. A non-parametric statistical test of assemblage data
SNPs	Single-Nucleotide Polymorphisms Chinook baseline. A specific genetic baseline of Chinook salmon derived from reference samples representing spawning aggregates in known geographic locations. Published as Warheit et al. (2014)
SRSC	Skagit River System Cooperative
SRT	self-regulating tidegate
SSMSS	Salish Sea Marine Survival Study
Tidal salt marsh	High density – densely vegetated tidal marsh wetland with species such as *Schoenoplectus pungens*, *Eleocharis palustris*, *Carex lyngbyei*, *Argentina egedii*, *S. tabernaemontani*, *Distichlis spicata*, *Typha angustifolia*, *Juncus balticus* (roughly in order from low to high elevation). Low density – sparsely vegetated, usually monoculture tidal wetland areas consisting of, for example, *S. pungens* at approximately 1/10 to 1/100 of the stem density of high density *S. pungens* dominated marsh. Dead plant roots (black) are often exposed in this zone.
Tidal scrub shrub	Flat or gently sloping tidal wetland colonized by salt-tolerant shrubs and small woody plants as well as herbaceous plants tolerant to brackish water and freshwater inundation from time to time.
Tidal wetland	Tidally-influenced wetland; includes tidal salt marsh, tidal scrub shrub, and riverine tidal forest (a.k.a. FRT).
WBM	Wisconsin Bioenergetics Model
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area

1.0 Introduction

1.1 Background and purpose

Puget Sound Chinook salmon were listed as Threatened under the Endangered Species Act (ESA) in 1999. Local watersheds created recovery plan chapters which were submitted to the National Oceanic and Atmospheric Administration (NOAA) in 2005 and adopted by 2007. Since 2005, salmon recovery actions listed in local recovery plans have been implemented, including actions related to improving the understanding of ESA-listed Chinook populations through an adaptive management process. Local watershed chapters of the Puget Sound Recovery Plan were developed with imperfect information and the adaptive management process is meant to allow for information gaps to be filled, resulting in new or modified recovery actions in order to more effectively or efficiently achieve the goals of local plans.

The 2005 Water Resource Inventory Area (WRIA) 1 Salmonid Recovery Plan used a generic Puget Sound Chinook salmon modeling approach called Ecosystem Diagnosis and Treatment (EDT) to identify and prioritize habitat actions for Nooksack Chinook salmon recovery, including actions for the Nooksack River's estuary and nearshore (i.e., Near-term Action #7, Appendix B of the WRIA 1 Salmonid Recovery Plan). Near-term Action #7's goal is to: "Protect and restore quantity and quality of properly functioning habitat conditions in the estuarine and nearshore marine habitats that will lead to the recovery of the Nooksack stocks of Chinook and other salmonids." Near-term Action #7 has multiple objectives and specific actions listed, but includes an action to "investigate the role of estuarine and nearshore marine habitats in Nooksack early Chinook productivity and abundance", which is in response to uncertainties about EDT's ability to predict benefits of recovery actions occurring in the estuary or nearshore on Nooksack Chinook salmon populations. The lack of specific analysis of ESA-listed Nooksack juvenile Chinook salmon population dynamics has led to uncertainties in determining the importance and priority of habitat actions within the estuary or nearshore compared to recovery actions within other parts of the Nooksack River basin. The City of Bellingham (COB), recognizing the importance of filling this information gap, commissioned this study in partnership with Bellingham Bay Action Team (BBAT) and Lummi Nation.

Specifically, this report answers the following questions:

1. What are the conditions (i.e., area by habitat type, water properties) and connectivity of the Nooksack tidal delta and Bellingham Bay nearshore habitats?
2. What is the population structure of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore?
3. What is the origin of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore?
4. What is the performance of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore?

1.2 Location

The geographic scope of this study includes an area encompassing the historic Nooksack tidal delta (including the tidally influenced portions of Lummi River and Lummi Bay) and the Bellingham Bay nearshore from Post Point to Portage Island (Figure 1.1). We divided the area into habitat types based on a classification system described in, and shown on maps in, Chapter 2. We used existing fish data from 2003-2013, and collected fish data in 2014 and 2015 by beach seine from many sites within the area. The sites are described, and shown by map figures, in Chapter 3 of this report.

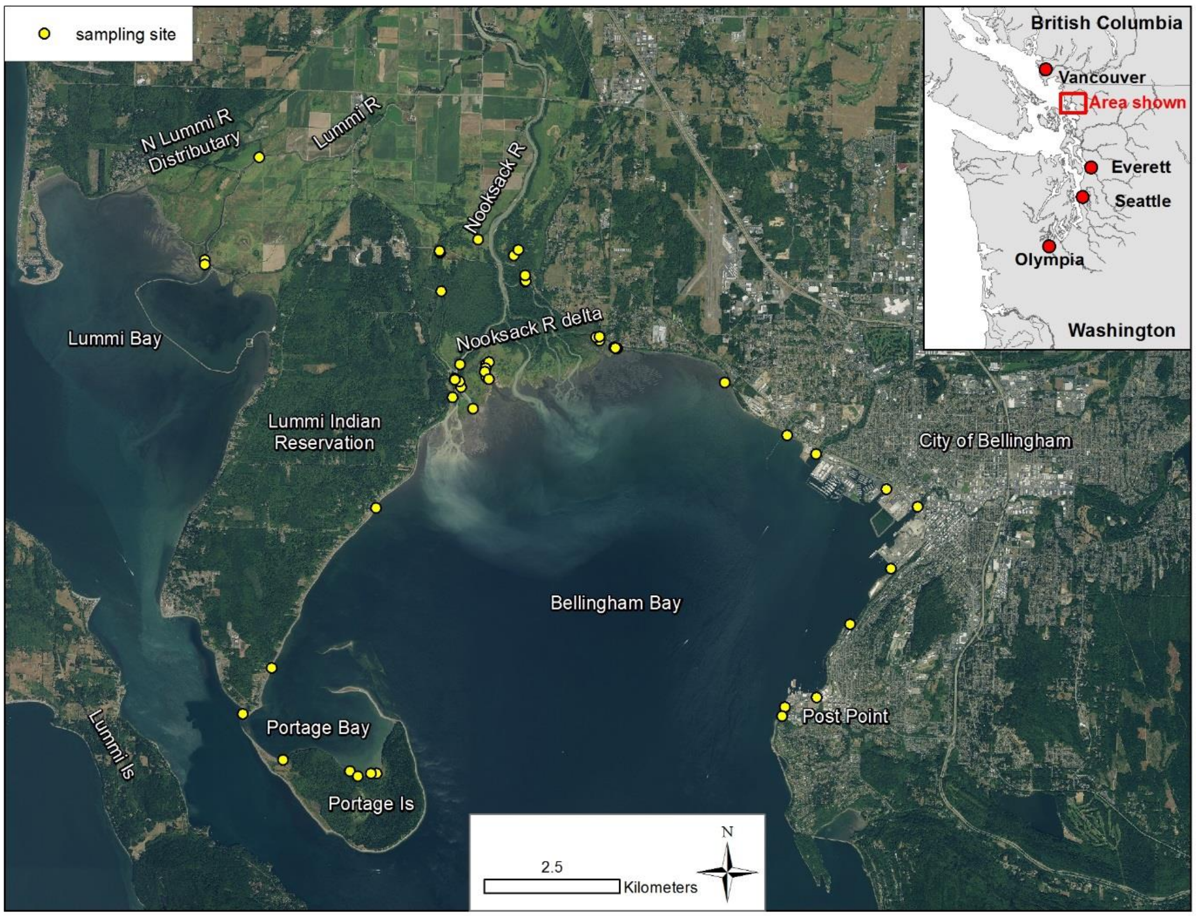

Figure 1.1. General location map of the Nooksack estuary and Bellingham Bay 2003-2015 project. All sampling sites from which data are used in this report are shown over a 2013 airphoto.

1.3 Data used and organization of report

To "investigate the of role of estuarine and nearshore marine habitats in Nooksack early Chinook productivity and abundance" (i.e. fill the information gap of Near Term Action #7), this study used fish datasets spanning from 2003 through 2015 from Lower Nooksack River smolt outmigration trapping efforts and beach seining efforts in the Nooksack estuary and Bellingham Bay nearshore. We also created GIS (Geographic Information Systems)-based habitat data for the Nooksack estuary to match the time period of the fish data. All data were used to examine factors influencing population dynamics of juvenile Chinook salmon using the Nooksack River estuary and Bellingham Bay nearshore.

The primary purpose of this report is to answer the four questions listed in subsection 1.1 above. We first address question 1 by quantifying habitat conditions of the Nooksack tidal delta because habitat results are necessary to determine which fish data to utilize for analysis (existing data from 2003-2013 and additional data collected in 2014 and 2015). We also needed habitat data for analyses of juvenile Chinook salmon population dynamics and habitat preference. Habitat conditions (extent, connectivity, water quality) of the study area are described in Chapter 2. In Chapter 3 we present the methods used for site selection and fish data collection and processing. Chapter 3 also includes methods for collecting and lab processing of juvenile Chinook prey availability (i.e., what fish could eat) and diet (i.e., what fish did eat).

Next, we summarize the juvenile Chinook salmon population structure in Chapter 4, which addresses question 2 by showing when natural and hatchery origin juvenile Chinook salmon are within the Nooksack tidal delta and Bellingham Bay nearshore, and at what size and relative abundance. Chapter 5 addresses question 3 by describing the origins of natural and hatchery juvenile Chinook salmon using the study area.

The answers to question 4 is addressed in Chapter 6. Chapter 6 is divided into three parts: Section 6.1 examines whether natural origin juvenile Chinook are experiencing density dependence (e.g., competition for habitat or food leading to limitations in residence or growth) in the Nooksack tidal delta under contemporary (2003-2015) habitat conditions and outmigration sizes. Section 6.2 explores the relationship of food availability and juvenile Chinook diet within the Nooksack tidal delta and Bellingham Bay nearshore habitats in 2014. Section 6.3 uses a bioenergetics model to examine habitat specific growth rates of juvenile Chinook that reared in Nooksack tidal delta and Bellingham Bay pocket estuary habitats during 2014 and 2015. We end the report with a summary chapter (Chapter 7) of the study's findings and recommendations for WRIA 1 salmon recovery efforts. A crosswalk of data used by study topic is shown in Table 1.1.

Table 1.1. Summary of data type, source, and year used in this study organized by analysis question.

General topic	Specific topic	Data description	Data source and year(s)	Where used in report?
Habitat and connectivity conditions of the Nooksack tidal delta and Bellingham Bay nearshore habitats	Habitat extent of the Nooksack tidal delta?	GIS polygons	Created this study 2008, 2013	Section 2.1
	Fish migration pathways within the Nooksack tidal delta and Bellingham Bay nearshore	GIS lines	Created this study 2008, 2013	Section 2.3
	Water properties in Nooksack tidal delta and Bellingham Bay	Field measured water temperature, salinity, and dissolved oxygen at fish sampling sites	Collected this study 2014, 2015	Section 2.4
Population structure of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore	Nooksack River natural origin juvenile Chinook outmigrants	Rotary screw trap fish counts	LNRD 2005-2015	Section 4.2
	Natural origin juvenile Chinook outmigrants from Bellingham Bay independent tributaries	Spawner surveys of fish and redd counts	WDFW, COB, NSEA 2001-2015	
	Hatchery origin juvenile Chinook releases into the Nooksack/Samish Management Unit	Counts of hatchery fish released	RMIS, LNRD 2004-2014	
	Natural and hatchery origin juvenile Chinook in the study area by habitat type	Beach seine based fish density data	Collected this study 2014, 2015	Section 4.3
	Influence of habitat connectivity on natural origin juvenile Chinook density	Beach seine based fish density data Landscape connectivity results for fish sampling sites	LNRD 2003-2013; collected this study 2014, 2015 Created in GIS this study 2008, 2013	Section 4.4
Origin of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore	Hatchery origin juvenile Chinook within the Nooksack tidal delta and Bellingham Bay nearshore	Coded wire tag results of beach seined fish	Collected this study 2014, 2015	Section 5.1
	Genetic assignment of natural origin juvenile Chinook outmigrants from lower Nooksack River	DNA analysis of tissue from rotary screw trap caught fish using SNPs Chinook baseline	LNRD 2013	Section 5.2
	Genetic assignment of natural origin juvenile Chinook in the Nooksack tidal delta and Bellingham Bay nearshore	DNA analysis of tissue from beach seine caught fish using GAPS Chinook baseline DNA analysis of tissue from beach seine caught fish using SNPs Chinook baseline	LNRD 2008, 2009 Collected this study 2014, 2015	
Performance of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore	Juvenile Chinook density dependence within the Nooksack tidal delta	Nooksack natural origin juvenile Chinook outmigration population estimate Beach seine based natural origin juvenile Chinook densities in Nooksack tidal delta	LNRD 2005-2015 LNRD 2005-2013 Collected this study 2014, 2015	Section 6.1
	Natural origin juvenile Chinook diet and prey availability within the study area	Diet samples from natural origin juvenile Chinook Neuston and epibenthic plankton net samples	Collected this study 2014 Collected this study 2014	Section 6.2
	Bioenergetics of juvenile Chinook in the Nooksack tidal delta and Bellingham Bay pocket estuaries	Continuously monitored water temperature data by habitat types Juvenile Chinook diets by habitat types	Collected this study 2014, 2015 Collected this study 2014, 2015	Section 6.3

2.0 Habitat and connectivity conditions

This chapter describes the amount, type, and connectivity of Nooksack tidal delta and Bellingham Bay nearshore habitats, including water quality characteristics collected while fish sampling during 2014 and 2015. Habitat condition results for the study area are needed for analyses of juvenile Chinook salmon population dynamics and habitat preference.

2.1 Nooksack tidal delta

This section describes current habitat conditions of the Nooksack tidal delta. Specifically, we created habitat results that represent conditions (type, extent, fish migration pathways) spanning the period of fish data used for analysis in this study (2003-2015).

Methods

We digitized in GIS polygons and arcs for the vegetated portion of the Nooksack tidal delta exposed to river and tidal hydrology according to a classification scheme that attributes areas within the delta that vary by habitat types.

Time periods digitized

Tidal delta habitat conditions can change over time because of natural (e.g., movement of sediment, water, wood) and anthropogenic (e.g., land use changes resulting in habitat loss or restoration) causes. Under ideal circumstances habitat condition results for each year of fish data used in this study (2003-2015) would have provided the best analyses, but this was impractical due to limited resources and data sources. Therefore, we examined the orthophotos available for the Nooksack tidal delta to qualitatively determine whether large natural or anthropogenic changes in tidal delta habitat type or distribution occurred over the 2003 – 2013 period[2]. We found large log jams formed and significant restoration occurred within the Nooksack tidal delta during our analysis time period so we created habitat conditions results representing before/after logjam and before/after restoration using the best orthophotos for each period. The before logjam and before restoration period is represented by the 2008 orthophotos. The after logjam and after restoration period is represented by the 2013 orthophotos.

Classification system

To classify the Nooksack tidal delta into habitat types, we adopted a hierarchical approach shown in Table 2.1.1. This approach is consistent with the nested scale classification developed by the Puget Sound Recovery Implementation Technical Team (RITT) Common Framework (i.e. Bartz et al. 2013) which has been adopted by the Puget Sound Partnership for tracking implementation of Puget Sound Chinook recovery plans. We modified the RITT Common Framework approach by including tidal delta zone. We also classified the Nooksack tidal delta based differences in hydrologic muting and sub-delta areas with hypothesized differences in accessibility by juvenile salmon originating from the Nooksack River.

[2] Orthophotos taken after 2013 were not available when work on this study began in 2014.

Tidal delta zone

The vegetated tidal delta is that portion of the delta that is: 1) exposed to tidal and riverine hydrological process; and 2) dominated by one of the three delta zones: estuarine emergent marsh, estuarine scrub shrub, or forested riverine tidal (after Cowardin et al. 1979 and used by Collins and Montgomery 2001). The delta zones and habitat types shown in Table 2.1.1 are described in the Glossary.

Tidal delta zone, within the nested scale hierarchy, is based on wetland classifications after Cowardin et al. (1979) and was used by Collins and Montgomery (2001) but was not included in the RITT Common Framework (Bartz et al. 2013) classification hierarchy for large river deltas. We included delta zone in our nested scale hierarchy for three main reasons:

1. Some Puget Sound salmon recovery plans have goals related to the estuarine wetland zones within their river deltas (not just the delta as a whole);
2. Juvenile Chinook salmon rearing success in natal estuaries may vary due to abiotic (salinity, temperature) and biotic (prey availability and energy content of food) differences in estuarine wetland zones; and
3. Not all tidal delta wetland zones respond to pressures and stresses the same way (e.g., scrub shrub wetlands have a greater potential for bio-engineering to change habitat conditions than do the other zones (Hood 2012); sea level rise may affect one zone more than others depending on climate change adaptation strategies).

We included tidal delta zone within the classification hierarchy because the Estuary and Salmon Restoration Program (ESRP) Learning Objective Project# 13-1508P (project name: Estimating density-dependent rearing limitations) is studying juvenile Chinook salmon rearing differences between tidal delta wetland zones in four Puget Sound river deltas, which may result in changes to local recovery plan strategies if a specific wetland zone is found to be more strategic than others with respect to achieving Chinook salmon recovery.

Hydrologic muting

Hydrologically muted was defined as areas upstream of structures (e.g., tidegates, undersized culverts) that restrict tidal or river flow but don’t block it. All hydrologically muted areas mapped are in the Smugglers Slough area or channels upstream of leaking tidegates in Lummi Bay. Mapping hydrologically muted areas separately from areas not muted was hypothesized as important biologically for juvenile Chinook salmon. Juvenile Chinook salmon presence and abundance has been found to be much lower in habitat upstream of hydrologic muting structures (Greene et al. 2012; Scott et al. 2016).

Sub-delta area

We included the four sub-delta areas as an attribute within the Nooksack tidal delta extent polygon dataset. The four sub-delta areas vary in hypothesized juvenile Chinook salmon access to tidal habitat. The four sub-delta areas are: Silver Creek, Smugglers Slough, Lummi/Red River, and connected Nooksack tidal delta.

1. <u>Silver Creek</u>: Access to Silver Creek habitat by juvenile salmon is not directly from the Nooksack River due to the levee adjacent to the river's eastern bank. Fish must swim into Marietta Slough and then swim upstream into the Silver Creek habitat complex, or be seeded directly from spawners in Silver Creek.
2. <u>Smugglers Slough</u>: Access to Smugglers Slough habitat by juvenile salmon is via backwatering from Kwina Slough. Fish must then swim upstream in Smugglers Slough, passing the culvert (pre 2010) or self-regulating tidegate (SRT) (post 2010) at Marine Drive. Fish could exit the Smugglers Slough complex the same way they came in, or through a tidegate that drains into Lummi Bay.
3. <u>Lummi/Red River</u>: For juvenile salmon to access Lummi/Red River habitat, the fish must either: a) go through a 3-foot diameter pipe that only has water flow during Nooksack River flood events located well upstream of Slater Road; b) take the Smugglers Slough pathway (described above); or c) exit the Nooksack delta and traverse west in Bellingham Bay into Hale Passage and then into Lummi Bay.
4. <u>Connected Nooksack tidal delta</u>: Access to connected Nooksack tidal delta habitat by juvenile salmon is generally downstream with branching-off distributary channels. Some blind channel areas along the Bellingham Bay front would have to be accessed by fish traversing flooded marshes during high tide or by moving briefly into the bay and swimming into the mouth of a blind channel complex.

Digitizing equipment and scale

We digitized polygon features on a Wacom DTU-2231 interactive pen display tablet in ArcGIS (v. 10x) at a scale ranging between 1:150 and 1:1,500, depending on the scale of the habitat feature and the pixel resolution of the 2008 and 2013 orthophotos used.

Results and discussion

Map figures showing the four different levels (i.e., tidal delta wetland zone, sub-delta areas, habitat type, and hydrologic muting) are provided as examples of the GIS layers available from this study. The Nooksack tidal delta estuarine wetland zones in 2013 are shown in Figure 2.1.1. The four sub-delta areas are shown in Figure 2.1.2. Figure 2.1.3 is an example of the polygon dataset showing the habitat types present and their detail. Figure 2.1.4 is an example of the polygon dataset showing areas hydrologically muted or not.

Total habitat area in the Nooksack tidal delta was 894 hectares in 2008 and 920 hectares in 2013 (Tables 2.1.2 and 2.1.3). Most of the increase in area is due to a habitat restoration project along Smugglers Slough. Across sub-delta areas, the connected Nooksack tidal delta has the largest total area and most habitat diversity, followed by Silver Creek, Lummi/Red River, and Smugglers Slough. All habitat mapped in the Smugglers Slough and Silver Creek fish migration pathway polygons is hydrologically muted, as is approximately 8 hectares of the Lummi/Red River sub-delta area.

The biggest changes to habitat type between periods occurred in the connected Nooksack tidal delta. A distributary channel-spanning logjam fully developed after 2008 and has resulted in major changes to how water flows through the delta, including a reduction in the number and size of major distributary channels on the east side of the tidal delta (Figure 2.1.5). Prior to the logjam three distributary channels existed within the east fork branch of the delta. Post logjam, the two smaller distributaries have begun to act as blind channels while the larger distributary channel is less than a third of its original width (Figure 2.1.6). Due to the 5.4-hectare logjam, blind channel area increased in the connected Nooksack tidal delta by 5.6 hectares (+70%) and distributary channel area decreased by 13.9 hectares (-15%). The estuarine emergent marsh zone decreased as the estuarine scrub shrub zone prograded towards Bellingham Bay.

The increase in habitat stemming from the restoration project in Smugglers Slough and from natural conditions, i.e., the log jam, has resulted in an increase in carrying capacity in the tidal delta for Chinook salmon: there is more area for the fish to occupy.

Conclusions and recommendations

1. Natural (logjam) and anthropogenic (restoration) causes have changed habitat conditions within the Nooksack tidal delta within a relatively short and recent time period.
2. Changes in tidal delta habitat extent influence juvenile Chinook carrying capacity.
3. Changes in tidal delta distributary channels affect opportunities for migrating fish to find habitat within the tidal delta and to move though the delta to nearshore habitat.
4. The GIS habitat results from this study add two new time periods (2008, 2013) to results for earlier time periods (e.g., Brown et al. 2005) and are useful for monitoring status and trends of estuarine, including common indicators for Puget Sound Recovery (Beamer et al. 2015; Fore et al. 2015).
5. We recommend continued status and trends monitoring of Nooksack tidal delta habitat conditions if WRIA 1 salmon recovery efforts have actions meant to improve: a) juvenile Chinook tidal delta rearing habitat capacity, and/or b) connectivity to existing tidal delta habitat and adjacent nearshore habitat. Habitat status and trends monitoring results are necessary to determine the effect of implemented restoration and habitat protection strategies on the entire tidal delta system as well as to document the influence of natural changes to the tidal delta.

Table 2.1.1. Classification of the Nooksack tidal delta based on RITT Common Framework (see Table 11 of Bartz et al. 2013) used to attribute GIS polygons of estuarine habitat extent. **Bold** font entries were classified for the vegetated Nooksack River tidal delta.

Broad habitat	System type	System subtype	Shoreline type	Tidal delta zone	Habitat type (subtype)
Estuarine	Major river system	Natal Chinook estuary	Tidal delta	Unvegetated	• Not digitized for this project
				Estuarine emergent marsh	• **Blind channel** • **Channel spanning wood** • **Distributary channel** • **Impoundment** • **Intertidal wood** • **Intertidal fill** • **Tidal wetland**
				Estuarine scrub shrub	
				Riverine tidal forested	

Table 2.1.2. Tidally influenced habitat extent (in hectares) of the vegetated Nooksack tidal delta in 2008 by habitat type and fish migration pathway polygons.

Connected Nooksack tidal delta				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	4.459	0.869	2.707	8.034
distributary channel	25.779	11.856	69.310	106.945
impoundment	0.000	3.048	0.000	3.048
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	8.733	1.026	0.000	9.759
intertidal fill	0.000	0.000	2.139	2.139
wetland	135.373	62.861	371.386	569.62
total	**174.344**	**79.659**	**445.542**	**699.545**
Lummi/Red River				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	9.177	0.000	0.000	9.177
distributary channel	11.851	1.568	0.608	14.027
impoundment	0.000	0.000	0.000	0.000
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.007	0.000	0.000	0.007
intertidal fill	0.000	0.000	0.000	0.0000
wetland	27.445	1.389	0.000	28.834
total	**48.481**	**2.958**	**0.608**	**52.047**
Silver Creek				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	0.000	0.000	14.253	14.253
distributary channel	0.000	0.000	0.000	0.000
impoundment	0.000	0.000	0.467	0.467
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.000	0.000	0.000	0.000
intertidal fill	0.000	0.000	0.000	0.000
wetland	0.000	0.000	109.497	109.497
total	**0.000**	**0.000**	**124.218**	**124.218**
Smugglers Sl				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	6.404	0.000	6.951	13.355
distributary channel	0.000	0.000	0.000	0.000
impoundment	0.000	0.000	0.000	0.000
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.000	0.000	0.000	0.000
intertidal fill	0.000	0.000	0.000	0.000
wetland	4.558	0.000	0.000	4.558
total	**10.962**	**0.000**	**6.951**	**17.913**

Table 2.1.3. Tidally influenced habitat extent (in hectares) of the vegetated Nooksack tidal delta in 2013 by habitat type and fish migration pathway polygons.

Connected Nooksack tidal delta				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	4.260	1.651	7.815	13.726
distributary channel	18.554	11.261	63.247	93.062
impoundment	0.054	0.144	3.395	3.593
channel spanning wood jam	0.337	0.000	5.104	5.441
intertidal wood	7.533	1.696	0.111	9.340
intertidal fill	0.000	0.000	2.707	2.707
wetland	117.544	74.192	379.376	571.112
total	**148.281**	**88.945**	**461.754**	**698.979**
Lummi/Red River				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	9.104	0.000	0.000	9.104
distributary channel	11.879	1.568	0.608	14.055
impoundment	0.000	0.000	0.000	0.000
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.000	0.000	0.000	0.000
intertidal fill	0.000	0.000	0.000	0.000
wetland	27.064	1.389	0.000	28.453
total	**48.047**	**2.958**	**0.608**	**51.613**
Silver Creek				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	0.000	0.000	13.930	13.930
distributary channel	0.000	0.000	0.000	0.000
impoundment	0.000	0.000	0.418	0.418
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.000	0.000	0.000	0.000
intertidal fill	0.000	0.000	0.000	0.000
wetland	0.000	0.000	109.921	109.921
total	**0.000**	**0.000**	**124.270**	**124.270**
Smugglers Sl				
Tidal habitat type	**estuarine emergent marsh**	**estuarine scrub shrub**	**forested riverine tidal**	**total**
blind channel	6.622	0.000	12.066	18.688
distributary channel	0.000	0.000	0.000	0.000
impoundment	0.000	0.000	0.000	0.000
channel spanning wood jam	0.000	0.000	0.000	0.000
intertidal wood	0.000	0.000	0.000	0.000
intertidal fill	0.000	0.000	0.000	0.000
wetland	4.306	0.000	22.112	26.418

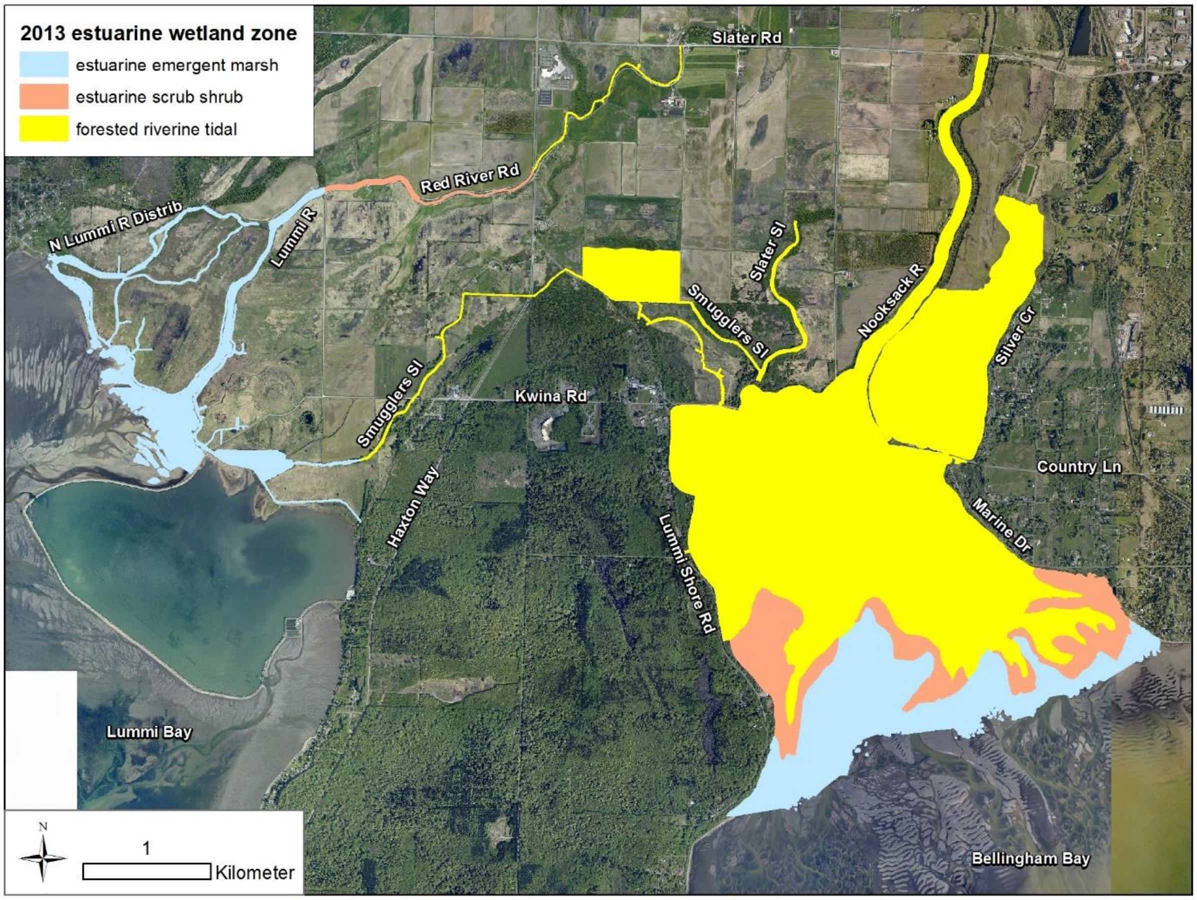

Figure 2.1.1. Tidally influenced areas of the vegetated Nooksack tidal delta in 2013 by estuarine wetland zone.

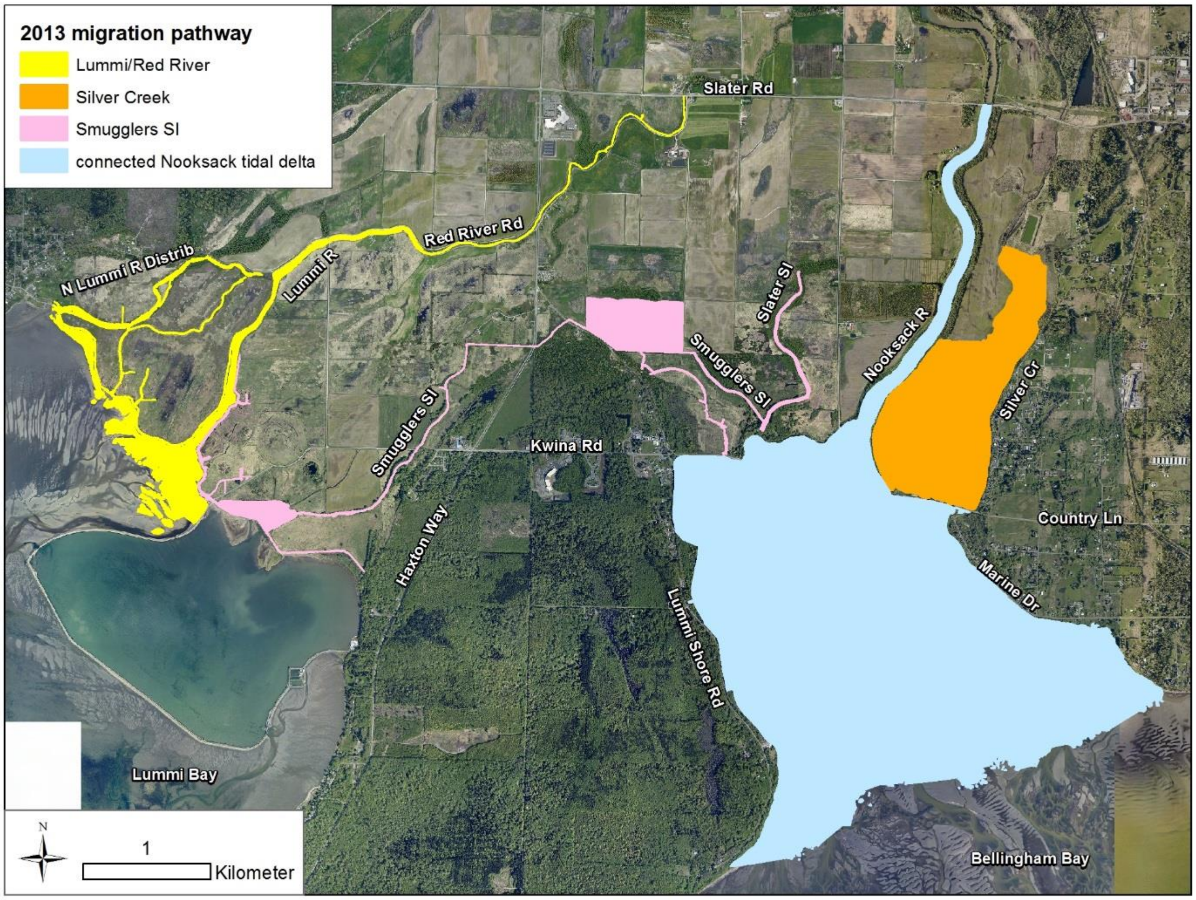

Figure 2.1.2. Tidally influenced areas of the vegetated Nooksack tidal delta in 2013 by fish migration pathway polygons.

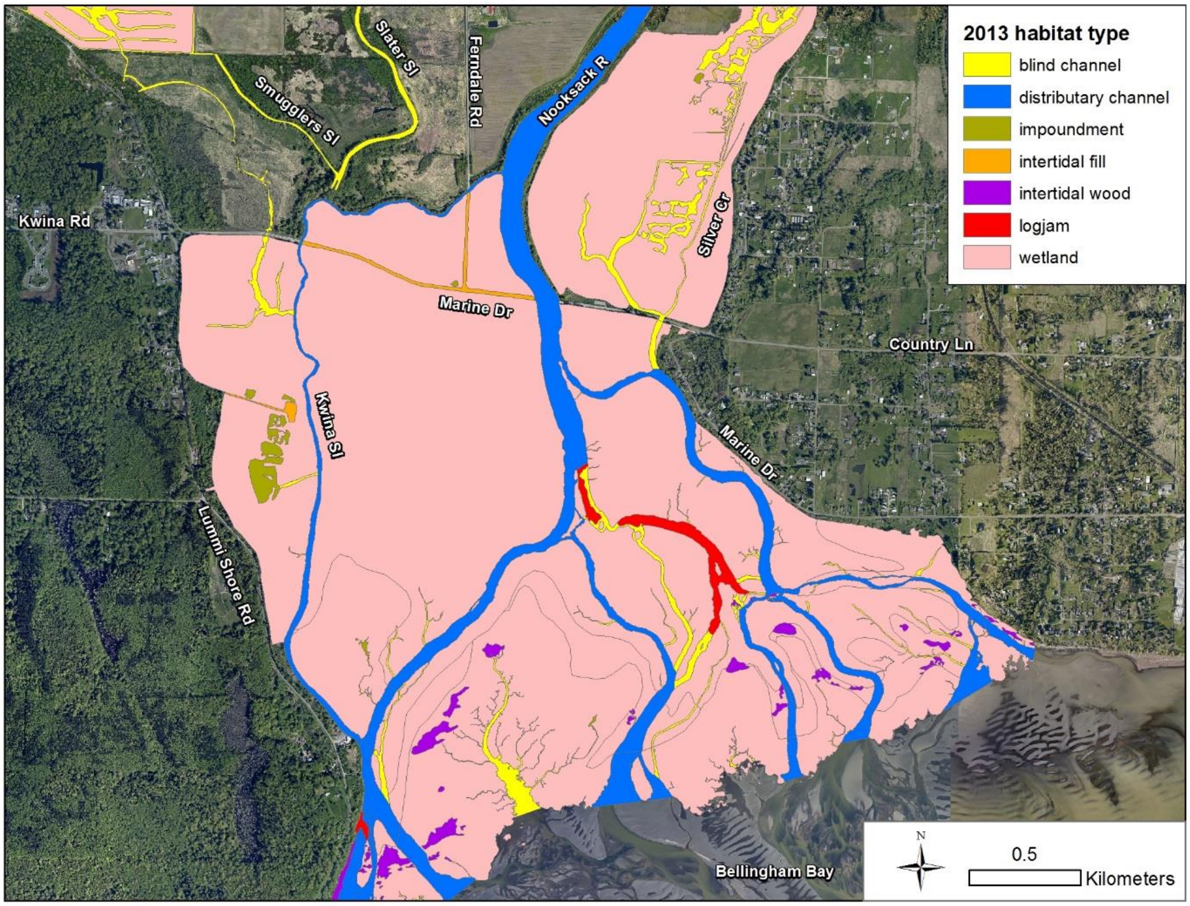

Figure 2.1.3. Example of digitizing detail in the lower Nooksack tidal delta in 2013 by habitat type.

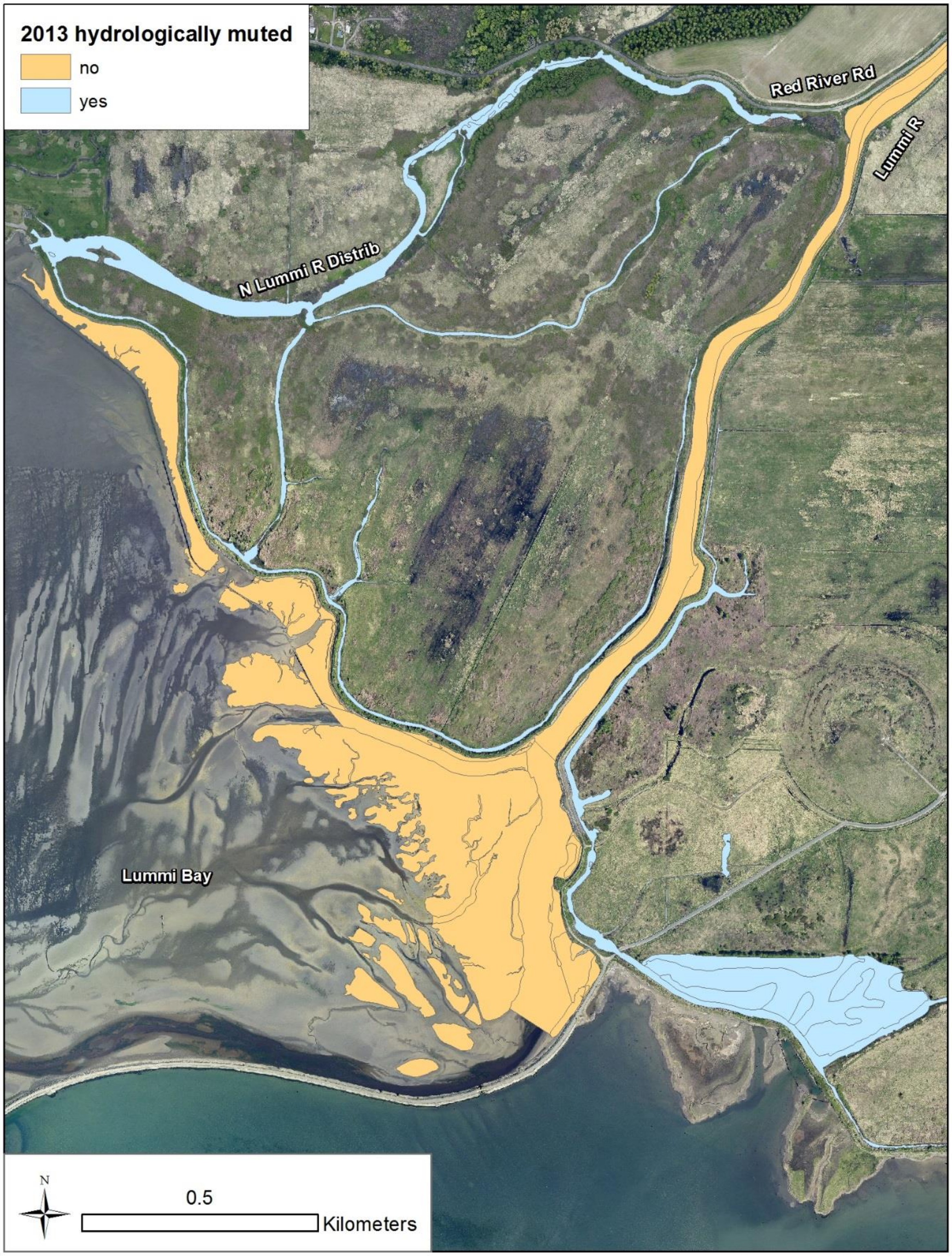

Figure 2.1.4. Example of tidally influenced areas of the vegetated Nooksack tidal delta in 2013 by hydrologically-muted and non-muted areas within Lummi River area.

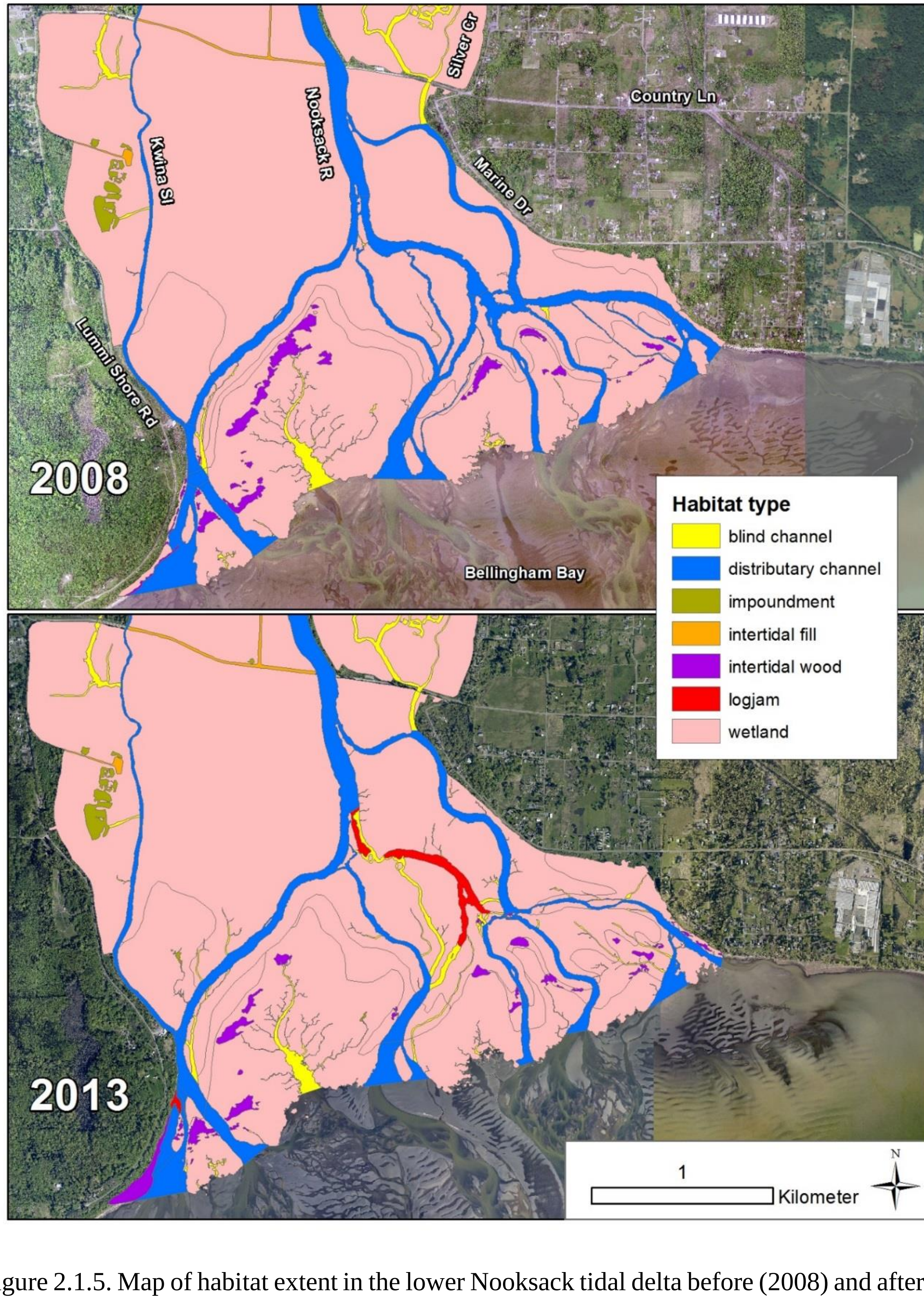

Figure 2.1.5. Map of habitat extent in the lower Nooksack tidal delta before (2008) and after (2013) the distributary-spanning logjam.

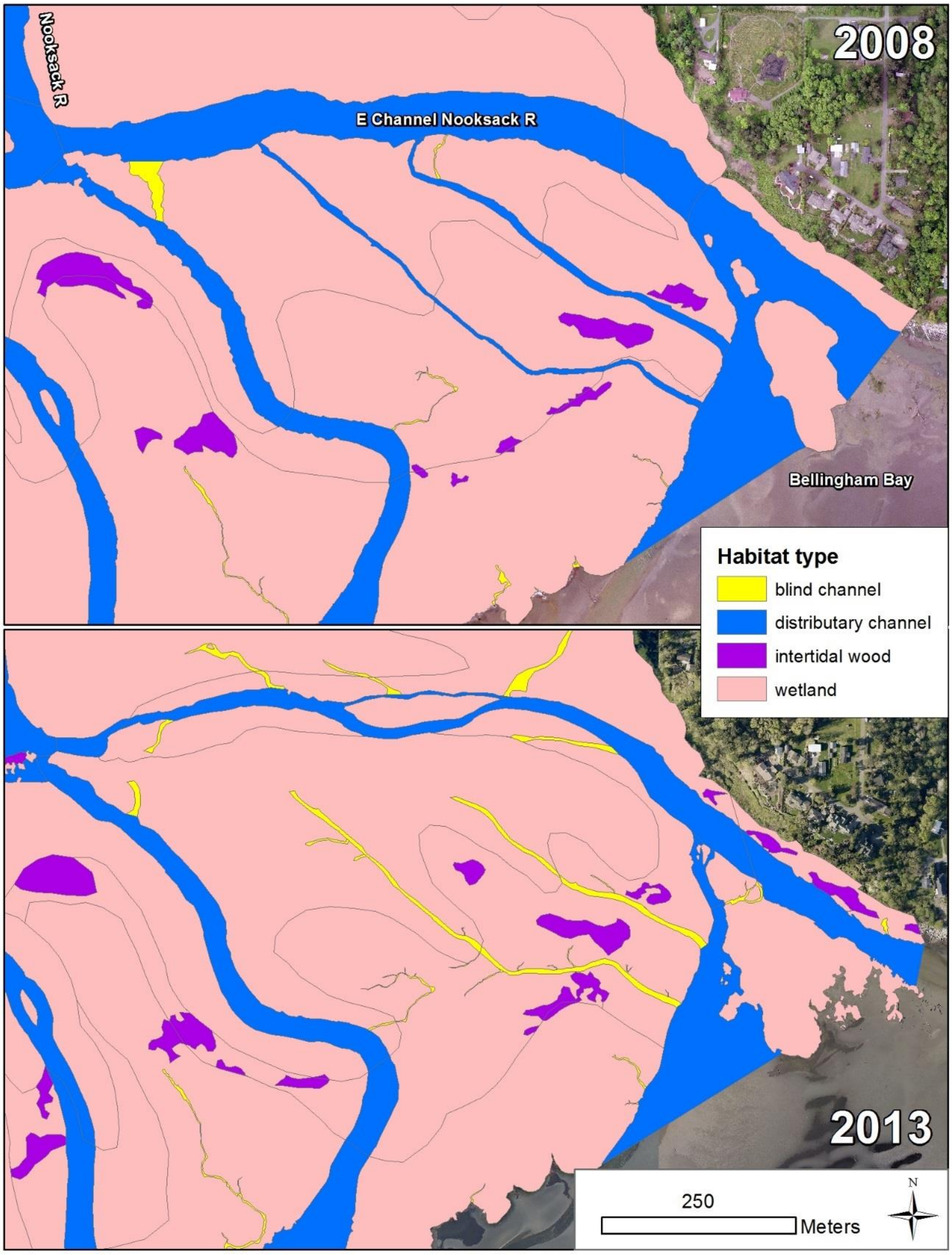

Figure 2.1.6. Detail showing habitat in the East Channel of the Nooksack River. Prior to the logjam, three distributary channels existed within the east fork branch of the delta. Post logjam, the two smaller distributaries have begun to act as blind channels while the larger distributary channel is less than a third of its original width.

2.2 Bellingham Bay nearshore

A GIS census of the Bellingham Bay nearshore habitat was not part of the scope of work for this study. However, we classified habitat type for all Bellingham Bay nearshore beach seine sites used in this study for the time period 2003 – 2015. Habitat classification variables and results for each site are presented in section 3.2 of this report.

2.3 Fish migration pathways - landscape connectivity

Within the tidal delta and nearshore ecosystems of the Skagit River, Beamer et al. (2005) used habitat connectivity as an attribute to help predict the use of specific habitats for Chinook salmon recovery planning. Landscape connectivity is defined as a function of both the length and the complexity of the pathway that juvenile Chinook salmon must follow to access certain types of habitat, like blind tidal channels in the tidal delta or pocket estuaries in adjacent nearshore areas. Habitat connectivity decreases as the complexity of the route fish must swim increases and as the distance the fish must swim increases.

Landscape connectivity measurements for habitat throughout an estuary can be useful to salmon recovery managers interested in planning and tracking implementation progress of restoration, as well as to researchers of juvenile salmon studies.

Methods

For this Nooksack/Bellingham Bay nearshore study we created a GIS layer of point data representing all the beach seine sites used in this report (see section 3.2 for beach seine site map). For each point, we calculated a landscape connectivity value according to the methods described in Beamer and Wolf (2011), utilizing a fish pathway arc layer (Figure 2.3.1). The GIS arc layer uses width measurements of distributary channels in the Nooksack tidal delta to calculate landscape connectivity for each beach seine site in this study.

The GIS arc layer reflects the pathways juvenile Chinook salmon are expected to move through the delta channel network and along the nearshore to find and colonize habitat represented by the beach seine sites. Per methods described in Appendix D.V, page 79 of Beamer et al. (2005), values for channel bifurcation order were assigned to each channel polygon. Landscape connectivity (LC) for each beach seine site is calculated:

$$LC = \frac{1}{\sum_{j=1}^{j_{end}} (O_j * D_j)}$$

where O_j = bifurcation order for distributary channel or nearshore segment j, D_j = distance along segment j of order O_j, j = count (1...j_{end}) of distributary channel or nearshore segments, and j_{end} = total number of distributary channel or nearshore segments at destination or sample point.

Measurements of channel width were made at each bifurcating (splitting) channel, and used to determine channel order per Table D.V.1. in Beamer et al. (2005). Rules followed for determining bifurcation order (and subsequent Bi values) are shown in Appendix 1. Arc pathway locations and directions outside of the Nooksack tidal delta were determined based on the Bellingham Bay circulation model (Wang et al. 2010), and low tide channel locations visible on orthophotos (also described in Appendix 1).

In some cases, multiple fish migration pathway routes were created in order to compare connectivity values. Values for channel length multiplied by the Bi value for each route arc were then summed for each beach seine site point and divided into the number 1 to calculate the landscape connectivity value. Table 2.3.1 shows attributes used for landscape connectivity calculations. Possible landscape connectivity values range from greater than 0 to less than 1, but never achieving 0 or 1. Higher values of landscape connectivity are more connected (i.e., have a shorter and/or less complex pathway) to the source of fish.

We created two GIS arc data layers, 2008 (pre-logjam) and 2013 (post-logjam), because of changes in distributary channel conditions caused by the channel spanning logjam (shown in Figure 2.1.5 and discussed in section 2.1 above). Changes in distributary channel characteristics result in some differences in bifurcation orders and channel lengths, or even channel location. These changes potentially result different landscape connectivity values to beach seine sites by time period (pre-post-logjam).

Results and discussion

Landscape connectivity values for beach seine sites within the study area varies by an order of magnitude (Table 2.3.2). For example, sites within the upper Nooksack tidal delta approximate values of 0.1 (e.g., Kwina Sl 1, Silver Cr 1) while more distant sites within Bellingham Bay (e.g., Post Point Lagoon, Marine Park, Padden Lagoon) approximate values of 0.01. Landscape connectivity calculations (pre and post logjam) and map figures depicting pathways to all beach seine sampling sites is found in Appendix 2.

Beach seine sites within the Lummi River portion of the Nooksack tidal delta have the lowest landscape connectivity values within the study area. Depending on the fish migration pathway taken, landscape connectivity values range from approximately 0.007 to 0.01 for the Lummi river and Red River 3 beach seine sites. For these two sites, the direct Lummi River route is not currently a realistic fish migration pathway. The more realistic pathway for fish to take to sites within Lummi bay is through the delta and around to Lummi Bay via Hale Passage. A possibly better fish migration pathway to Lummi Bay habitat could be via Smugglers Slater Slough complex if hydrologic connectivity for this area was improved. We did not calculate a fish migration pathway route via Smugglers Slough to Lummi Bay site for this study.

Overall, post-logjam conditions within the Nooksack tidal delta have a simpler distributary channel network than pre-logjam conditions. While eight distributary channels drain into Bellingham Bay for both pre and post-logjam time periods, the number of distinct distributary channels within the tidal delta is been reduced post-logjam (18 channels pre-logjam, 11 channels post-logjam) (Figure 2.3.2).

There has also been a shift in the location of dominant distributary channels pre and post-logjam within the delta (Figure 2.3.2). Larger width channels carry more water and have lower bifurcation orders, and are considered the more dominate pathways for migrating juvenile Chinook salmon than smaller channels with higher bifurcation orders. Pre-logjam conditions in the Nooksack tidal delta were more balanced throughout the delta (or slightly more dominant on the eastern side that the west side) than post-logjam conditions where the dominant western distributary channel is clearly much larger (bifurcation order of 1) than the eastern distributary channel (bifurcation of 5).

The physical changes in distributary conditions caused by logjam formation, in fact, do result in increases and decreases of landscape connectivity for beach seine sites depending on where the sites are positioned within the study area. For example, nearshore beach seine sites on the eastern Bellingham Bay shoreline were reduced in landscape connectivity by an average of 16% whereas sites on the western shoreline increased by an average of 28.0% after logjam formation (Table 2.3.2).

Conclusions and recommendations

1. Landscape connectivity varies within the study area: not all habitat within the study area has an equal opportunity to be utilized by rearing Chinook salmon. Based on differences in landscape connectivity values, we predict that Nooksack River juvenile Chinook migrants can best access upper Nooksack tidal delta habitat and least access Lummi Bay habitat (with access to all other habitat within the study area distributed somewhere in between, assuming no habitat type selectivity exists by the fish.
2. The channel-spanning logjam has changed landscape connectivity patterns within the Nooksack tidal delta and adjacent nearshore habitat. The changes in landscape connectivity occurred relatively rapidly (i.e., over a few years) and has changed the pathways fish must take to access habitat within the delta and adjacent nearshore areas.
    a. Habitat areas within the eastern tidal delta and Bellingham Bay nearshore east of the delta are less connected post-logjam compared to pre-logjam.
    b. Habitat areas within the western tidal delta and Bellingham Bay nearshore west of the delta are more connected post-logjam compared to pre-logjam.
    c. Habitat areas within the upper tidal delta have experienced minor changes in connectivity as a result of the logjam.
3. Based on differences in landscape connectivity values between pre- and post-logjam, we predict that Nooksack River juvenile Chinook migrants have better access to western Nooksack tidal delta and western Bellingham Bay nearshore habitat in the post-logjam period compared to the pre-logjam period. Conversely, we predict that Nooksack River juvenile Chinook migrants have poorer access to eastern Nooksack tidal delta and eastern Bellingham Bay nearshore habitat in the post-logjam period compared- to the pre-logjam period. In section 4.4 of this report we test whether juvenile Chinook density results vary systematically by pre- and post-logjam period.
4. Restoration of connectivity within the hydrologically muted areas of the Nooksack tidal delta should improve access to existing (future restored) habitat rearing options for tidal delta rearing fishes.
5. Because habitat connectivity can change within estuarine systems we recommend monitoring landscape connectivity if WRIA 1 salmon recovery strategies include restoration strategies for tidal delta and/or nearshore habitats.

Table 2.3.1. Attributes used to calculate landscape connectivity, and their descriptions.

Attribute	Description
Bi	Index bifurcation order of route arc
Length_km	Length of route arc in kilometers
Km_x_bi	“Length_km” multiplied by “Bi”
Sum	Sum of all “Km_x_bi” values for a specific fish migration pathway
Landscape Connectivity	1/Sum

Table 2.3.2. Landscape connective values for beach seine sites.

System	Position	Site Name	Connectivity value: pre-logjam	post-logjam	% change (from pre-logjam)	Which delta distributary pathway used?
Bellingham Bay	east of delta	Post Point Lagoon	0.0128	0.0115	-10.4%	east fork
		Marine Park	0.0130	0.0116	-10.4%	
		Padden Lagoon	0.0137	0.0122	-11.0%	
		Boulevard Park	0.0158	0.0139	-12.5%	
		Whatcom Cr Mouth	0.0173	0.0150	-13.5%	
		Cornwall St S	0.0181	0.0156	-14.0%	
		I & J Waterway	0.0200	0.0169	-15.2%	
		Squalicum Estuary	0.0265	0.0214	-19.2%	
		Little Squalicum Cr Beach	0.0324	0.0251	-22.6%	
		Whirlwind Beach	0.0465	0.0328	-29.5%	
				Average change	**-15.8%**	
	west of delta	Portage Is Marsh	0.0130	0.0155	19.2%	west fork
		Portage Is Marsh Beach	0.0130	0.0155	19.2%	
		Portage Is Cr	0.0134	0.0160	19.4%	
		Portage Is Cr Beach	0.0135	0.0162	20.0 %	
		Portage Island	0.0153	0.0189	23.4%	
		Portage Spit NW	0.0167	0.0211	26.1%	
		Portage Bay	0.0191	0.0249	30.9%	
		Lummi Shore Rd	0.0320	0.0531	65.7%	
				Average change	**28.0%**	
Nooksack tidal delta	eastern delta	Airport Cr Saltmarsh	0.0674	0.0516	-23.4%	only one route calculated in delta
		Silver Cr 3	0.0728	0.0570	-21.7%	
				Average change	**-22.6%**	
	Lummi Bay	Red River 3	0.0068	0.0075	9.4%	from the delta, west fork and through Hale Passage
		Lummi River	0.0077	0.0085	10.5%	
				Average change	**10.0%**	
		Lummi River	0.0126	0.0127	0.1%	Lummi River pathway
		Red River 3	0.0174	0.0175	0.4%	
				Average change	**0.3%**	
	upper delta	Silver Cr Upper	0.0686	0.0762	11.1%	only one route calculated in delta
		Kwina Sl 2	0.0694	0.0640	-7.8%	
		Silver Cr 1	0.0920	0.0997	8.4%	
		Kwina Sl 1	0.1145	0.1115	-2.6%	
				Average change	**2.3%**	
	western delta	Tidal Delta 2	0.0437	0.0744	70.4%	only one route calculated in delta
		Fish Pt	0.0652	0.0993	52.1%	
				Average change	**61.3%**	

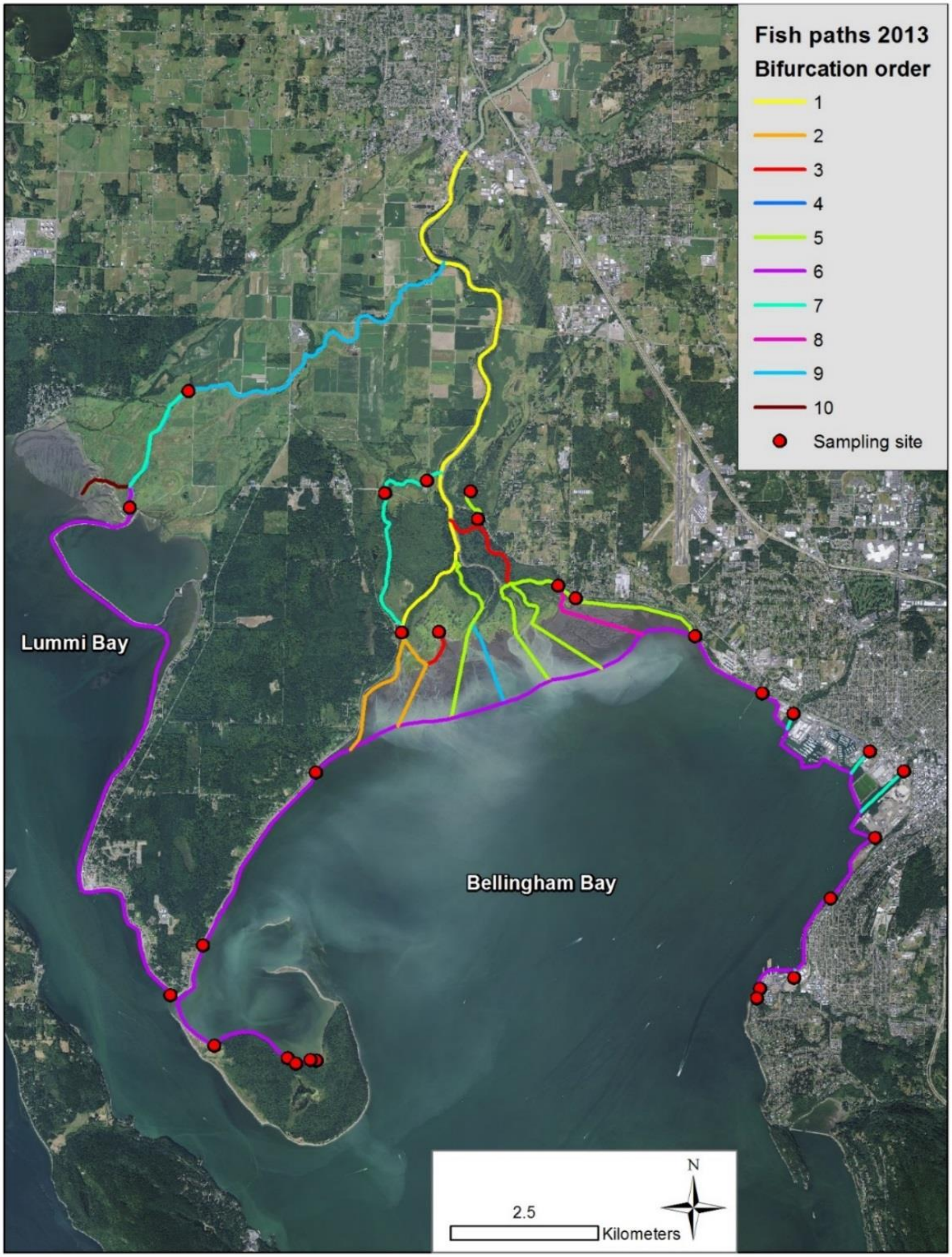

Figure 2.3.1. Fish path, or landscape connectivity, arcs for the Nooksack tidal delta and Bellingham Bay nearshore in 2013.

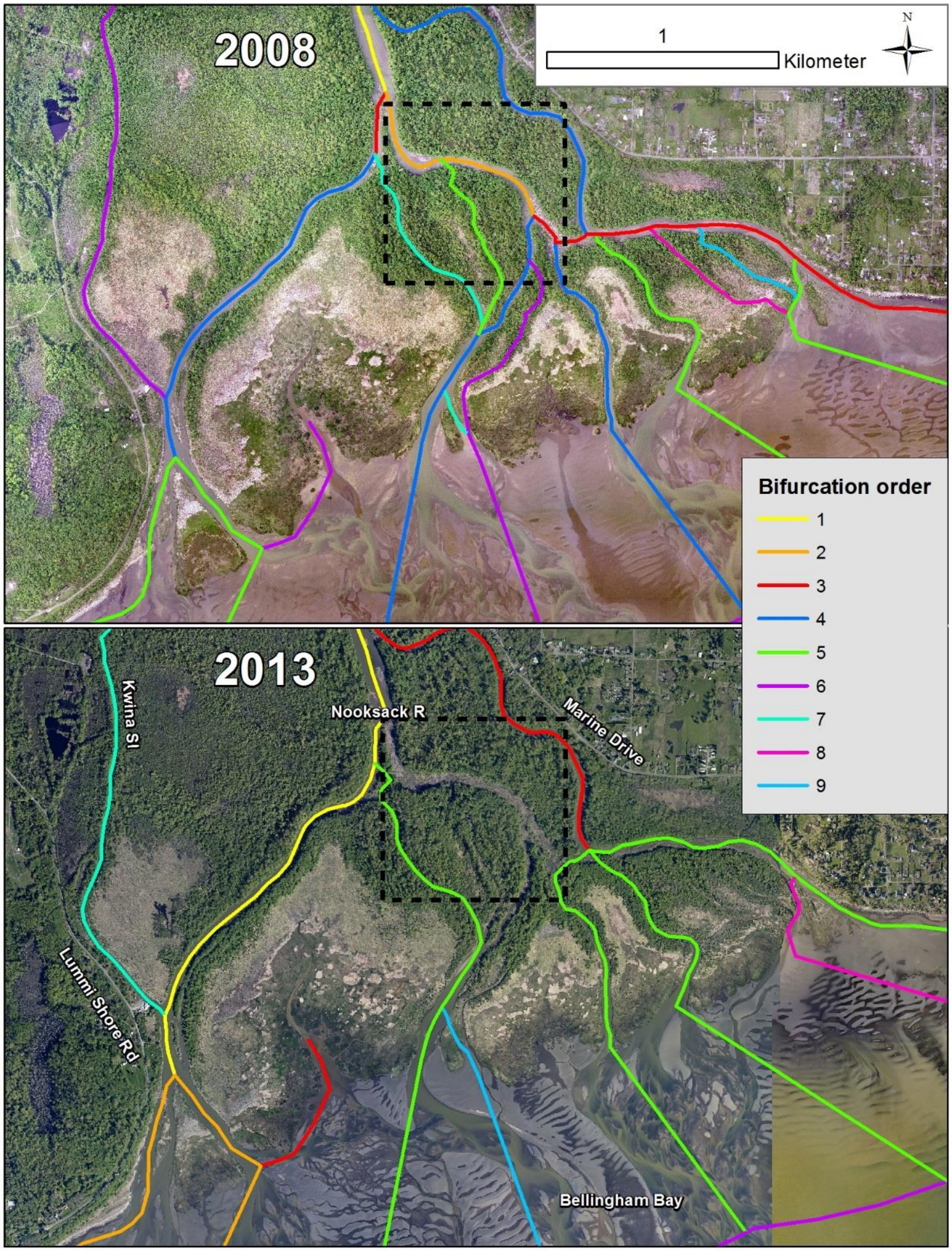

Figure 2.3.2. Pre-logjam fish pathways in 2008 (top panel) compared to post-logjam pathways in 2013 (bottom panel). Distributary channels are represented by lines color-coded by their bifurcation order. Dashed-line squares show vicinity of log jam that developed between 2008 and 2013.

2.4 Water properties, 2014 & 2015

Measurements of water properties were collected at fish sampling sites in 2014 and 2015 to help characterize study area habitat conditions (see section 3.2 for beach seine site map). In this section we describe annual, seasonal, and habitat type differences within the study area for three water properties: temperature, salinity, and dissolved oxygen (DO).

Methods

Water temperature, salinity, and DO measurements were taken during fish sampling using a YSI Pro Plus hand held meter. Measurements were taken at the top of the water column (0.15 to 0.25m below the water surface) within the area of each beach seine set. Measurements were taken at the bottom of the water column when water depth allowed, but are not reported here. Measurements were collected at every site for each sampling date during 2014 and 2015.

We used ANOVA methodology to determine factor and covariate influences on the three different dependent variables: 1) temperature, 2) salinity, and 3) DO. We conducted separate analyses for each dependent variable, using the same factors and covariates for each model. Factors included in each ANOVA were habitat type and year. Habitat types coincide with beach seine site classification (described in this report in section 3.2; see site classification and Table 3.2.1). To define habitat types for water property analysis we used the following habitat types:

- EEM tidal delta – estuarine emergent marsh zone within the Nooksack tidal delta
- ESS tidal delta – estuarine scrub shrub zone within the Nooksack tidal delta
- FRT tidal delta – forested riverine tidal zone within the Nooksack tidal delta
- Exposed nearshore – exposed nearshore areas within Bellingham Bay without direct local freshwater source
- Exposed nearshore w/FW – exposed nearshore areas within Bellingham Bay with direct local freshwater source
- Pocket estuary – true geomorphic and artificially formed pocket estuaries (see definition in section 3.2)

Covariates included in each ANOVA were month (seasonal effect) and other water property measurements (temperature, salinity, DO) if they were not auto correlated with the tested dependent variable. Results are shown graphically and as ANOVA summary tables and pairwise comparison tables for significant results (i.e., $p < 0.05$) of tested factors.

Results and discussion

Temperature

The final model uses 1,333 records of untransformed water surface temperature, has an r^2 of 0.61, retained month and salinity as the significant covariates, and found significant habitat type and year differences in water temperature (Table 2.4.1).

For the year effect, on average and accounting for habitat type and seasonal effects, 2014 was 1.5 degrees colder than 2015.

The model coefficient for Month = 1.9. This equates to 1.9°C increase in temperature per month over our sampling period. This is an expected seasonal increase in water temperature as winter turns to spring and summer (Figure 2.4.1) which was observed in both years; however, in 2014, when we sampled through October, we observed a decline in water temperature after August with the onset of autumn cooling. Monthly mean water surface temperature never exceeded the lethal limit for juvenile Chinook salmon of 24.8°C (McCullough 1999), but 15 of the 1,333 measurements of water temperature did. These observations occurred entirely at EEM tidal delta (Lummi River, Red River 3) and pocket estuary (Padden Lagoon, Portage Is Marsh) sites during late spring or summer months.

The model coefficient for the covariate salinity = -0.043, which means lower salinity water tended to be warmer water. This supports the idea that, throughout the study area and period, marine waters were a source of cool water. Analyses isolating specific months and habitat types would better tease out when and where marine cooling is most important.

There are significant differences in water temperature between habitat types (Table 2.4.2 and Figure 2.4.2). The main story is that EEM tidal delta and pocket estuary habitats are warmer than all other habitat types. Accounting for year and seasonal effects, EEM tidal delta and pocket estuary habitats are 1.4 to 3.4 °C warmer than the other habitat types (Table 2.4.2). The EEM tidal delta and pocket estuary habitats should be warmer than all other habitat types because they typically have emergent vegetation and shallow water which can heat up during spring and summer months. The ESS and FRT tidal habitats have significantly larger vegetation, including shrubs and trees with sufficient canopy to mediate effects of solar warming through shading. The exposed nearshore habitats have much more of an influence from nearby deeper and colder marine waters. The differences in water temperature by habitat type, season, and year can play a role in prey production and metabolic processes for juvenile salmon. We explore these topics in Chapter 6.

Table 2.4.1. ANOVA significance results for water surface temperature. *P*-values significant at the 0.05 level are bolded.

Variable Type	**Variable**	***P*-Value**
Factors	HABITAT TYPE	**0.000**
	YEAR	**0.000**
Interactions	HABITAT TYPE *YEAR	**0.000**
Covariates	MONTH	**0.000**
	SALINITY	**0.000**

Table 2.4.2. Pairwise results of water surface temperature by Habitat type using Tukey's Honestly Significant Difference Test. *P*-values significant at the 0.05 level are bolded.

Habitat Type (i)	**Habitat Type (j)**	**Difference**	***P*-Value**	**95% Confidence Interval**	
				Lower	**Upper**
EEM tidal delta	ESS tidal delta	2.722	**0.000**	1.664	3.780
EEM tidal delta	Exposed nearshore	1.369	**0.002**	0.576	2.162
EEM tidal delta	Exposed nearshore w/FW	1.486	**0.014**	0.362	2.610
EEM tidal delta	FRT tidal delta	3.394	**0.000**	2.480	4.309
EEM tidal delta	Pocket estuary	0.740	0.209	-0.044	1.525
ESS tidal delta	Exposed nearshore	-1.353	**0.014**	-2.317	-0.390
ESS tidal delta	Exposed nearshore w/FW	-1.236	0.130	-2.487	0.014
ESS tidal delta	FRT tidal delta	0.672	0.478	-0.394	1.738
ESS tidal delta	Pocket estuary	-1.982	**0.000**	-2.938	-1.025
Exposed nearshore	Exposed nearshore w/FW	0.117	1.000	-0.919	1.153
Exposed nearshore	FRT tidal delta	2.026	**0.000**	1.221	2.830
Exposed nearshore	Pocket estuary	-0.628	0.120	-1.281	0.024
Exposed nearshore w/FW	FRT tidal delta	1.908	**0.001**	0.776	3.040
Exposed nearshore w/FW	Pocket estuary	-0.746	0.389	-1.775	0.284
FRT tidal delta	Pocket estuary	-2.654	**0.000**	-3.449	-1.858

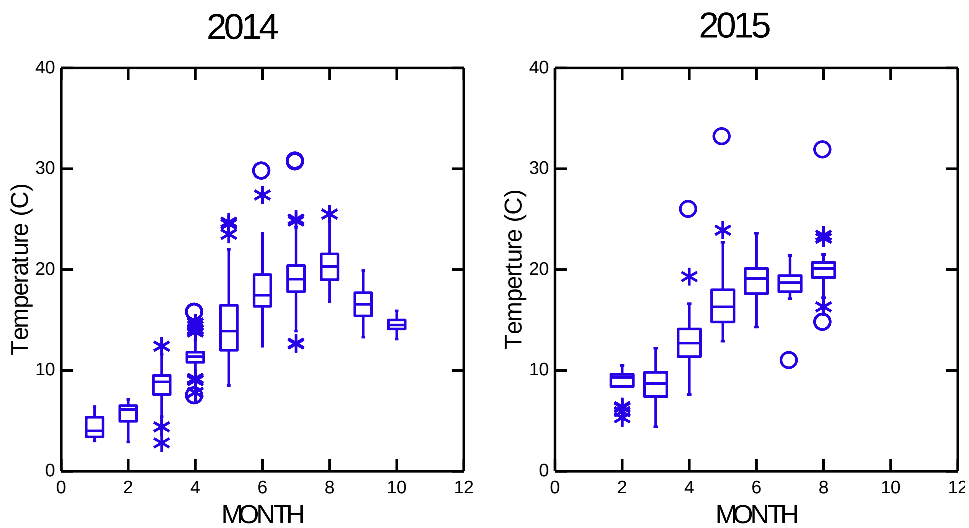

Figure 2.4.1. Boxplot of water surface temperature by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

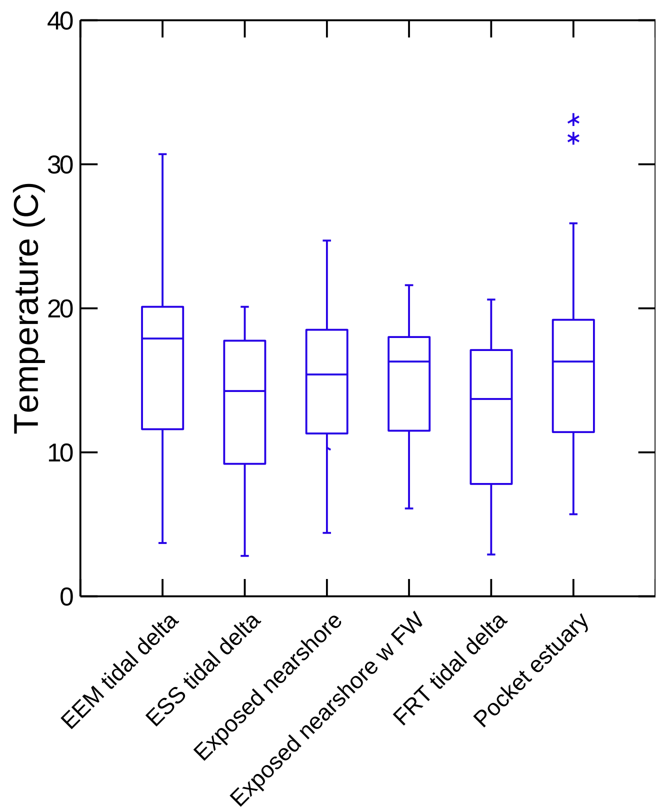

Figure 2.4.2. Boxplot of water surface temperature by habitat type. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Salinity

The final model uses 1,333 records of untransformed water surface salinity, has an r^2 of 0.54, retained month and temperature as significant covariates, and found significant year and habitat type influences on salinity (Table 2.4.3). For the year effect, on average and accounting for habitat type and seasonal effects, 2014 was 3.6 parts per thousand (ppt) lower in salinity than 2015.

The model coefficient for month is 1.25 which means, after correcting for factor (year, habitat type) and other covariate (salinity) differences, salinity increased 1.25 ppt per month over our sampling period which started in February and ended in late summer (Figure 2.4.3). The model coefficient for water temperature is -0.219 which means (after accounting for factor and covariate influences) that lower temperature water equates to higher salinity water.

However, the covariate influences on salinity pale in comparison to differences in salinity by habitat type (Figure 2.4.4). Most pairwise comparisons between habitat types are significantly different (Table 2.4.4). All habitat types within the tidal delta (EEM, ESS and FRT) are 9 to nearly 18 ppt lower in salinity than the exposed nearshore and pocket estuary habitat types. Interestingly, salinity in pocket estuary and exposed nearshore with FW habitat is similar and about 3 ppt lower than exposed nearshore with FW.

Overall, the salinity results within the study area are highly variable, which is expected for an estuarine system which encompass the mixing zone of riverine freshwater to the near full strength salinity seawater of northern Puget Sound. All habitat types within the study area had occurrences of very low salinities, caused by Nooksack River influence, which is likely conducive to allowing juvenile salmon lower physiological stress in their journey to access estuarine and nearshore rearing habitats as they adapt to seawater on their outmigration.

The differences in salinity by habitat type can play a role in vegetation formation and the invertebrates associated with differing vegetation communities. Invertebrates make up the majority of juvenile salmon diets, so salinity influences prey production and metabolic processes for juvenile salmon. We explore these topics in Chapter 6.

Table 2.4.3. ANOVA significance results for water surface salinity. *P*-values significant at the 0.05 level are bolded.

Variable Type	**Variable**	***P*-Value**
Factors	HABITAT TYPE	**0.000**
	YEAR	**0.000**
Interactions	HABITAT TYPE *YEAR	**0.000**
Covariates	MONTH	**0.000**
	TEMPERATURE	**0.000**

Table 2.4.4. Pairwise results of water surface salinity by habitat type using Tukey's Honestly Significant Difference Test. *P*-values significant at the 0.05 level are bolded.

Habitat Type (i)	**Habitat Type (j)**	**Difference**	***P*-Value**	**95% Confidence Interval**	
				Lower	**Upper**
EEM tidal delta	ESS tidal delta	5.709	**0.000**	3.317	8.101
EEM tidal delta	Exposed nearshore	-12.258	**0.000**	-14.052	-10.465
EEM tidal delta	Exposed nearshore w/FW	-9.498	**0.000**	-12.040	-6.956
EEM tidal delta	FRT tidal delta	6.824	**0.000**	4.755	8.892
EEM tidal delta	Pocket estuary	-9.356	**0.000**	-11.130	-7.582
ESS tidal delta	Exposed nearshore	-17.967	**0.000**	-20.146	-15.788
ESS tidal delta	Exposed nearshore w/FW	-15.206	**0.000**	-18.034	-12.379
ESS tidal delta	FRT tidal delta	1.115	0.782	-1.296	3.525
ESS tidal delta	Pocket estuary	-15.065	**0.000**	-17.228	-12.902
Exposed nearshore	Exposed nearshore w/FW	2.761	**0.028**	0.418	5.104
Exposed nearshore	FRT tidal delta	19.082	**0.000**	17.264	20.900
Exposed nearshore	Pocket estuary	2.902	**0.000**	1.428	4.377
Exposed nearshore w/FW	FRT tidal delta	16.321	**0.000**	13.762	18.881
Exposed nearshore w/FW	Pocket estuary	0.142	1.000	-2.186	2.470
FRT tidal delta	Pocket estuary	-16.180	**0.000**	-17.979	-14.381

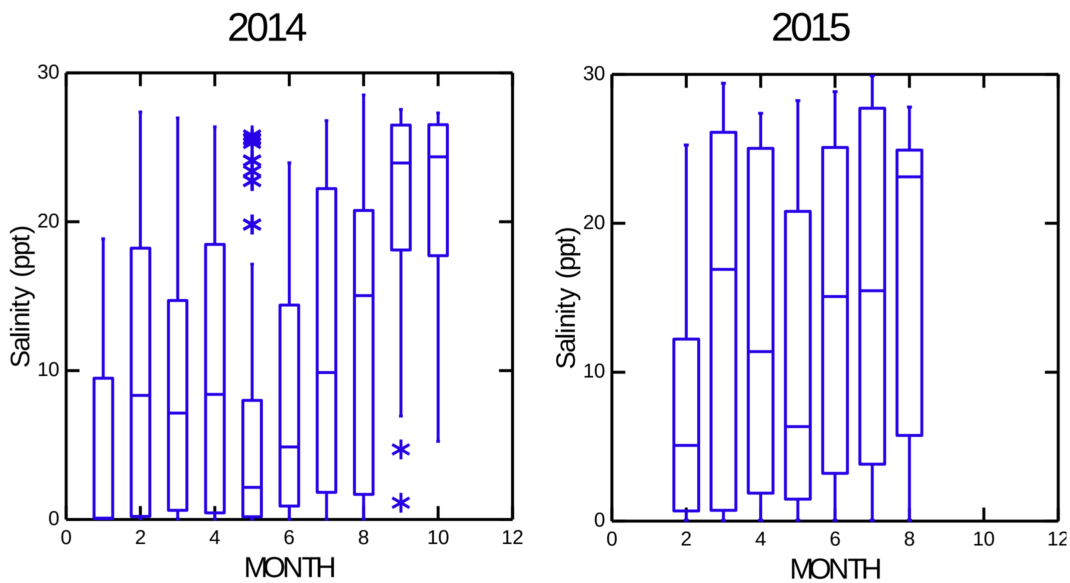

Figure 2.4.3. Boxplot of water surface salinity by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

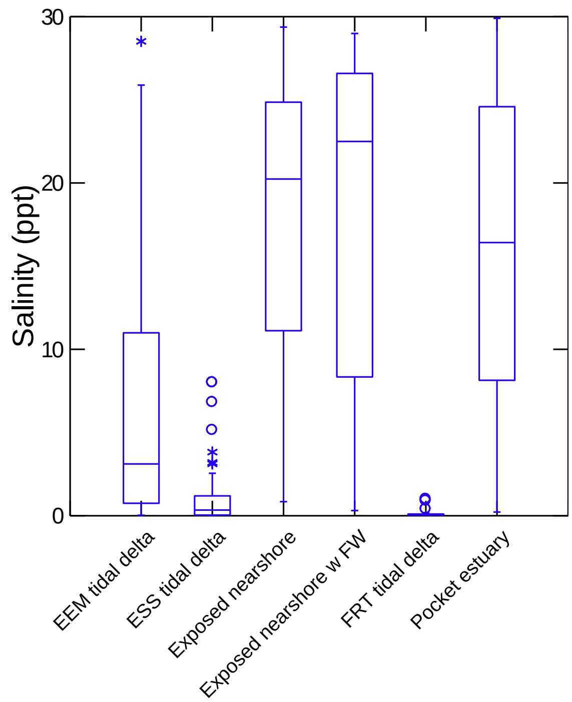

Figure 2.4.4. Boxplot of water surface salinity by habitat type. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Dissolved oxygen

The final model uses 1,333 records of untransformed water surface DO, has an r^2 of 0.26, retains Month and salinity as significant covariates, and found significant habitat type and year differences in DO levels (Table 2.4.5). For the year effect, on average and accounting for habitat type and seasonal effects, DO in 2014 was 0.72 mg/l (milligrams per liter) higher than in 2015.

The model coefficient for Month = - 0.44. The negative coefficient associated with month is expected. Lower DO levels occur in the summer of each year simply because the solubility of oxygen in water decreases as water temperature rises. Low DO levels may also occur in estuarine and nearshore habitats when aquatic plants or algae die. Bacteria and other decomposers reduce DO levels as they consume oxygen while breaking down organic matter as there is seasonal increase in water temperature. The decrease in DO averaged 0.44 mg/l per month over our sampling period (Figure 2.4.5)

There are significant differences in DO between habitat types although the relationships are complicated and hard to visualize or understand using simple boxplots (Figure 2.4.6) or a lengthy pairwise comparison list (Table 2.4.6). The main story is that exposed nearshore habitat had the highest DO while FRT tidal delta habitat had the lowest. This pattern was observed for both years and is driven by consistent results for the months April through July. The exposed nearshore site, Portage Bay NW, had the highest overall mean DO (12.5 mg/l) while the FRT tidal delta site, Silver Cr Upper, had the lowest overall mean DO (6.7 mg/l) (Figure 2.4.7).

Mean monthly DO was never less than Washington State's water quality criterion for salmonid rearing and migration (i.e., not less than 6.5 mg/l). However, 81 of 1,333 DO measurements (6%) were less than the 6.5 mg/l criterion. The low DO measurements occurred in all habitat types (including exposed nearshore) but the majority came from FRT and EEM tidal delta habitats in May, June, and July. Only three date/site combinations had extremely low DO observations (< 3.0 mg/l, a level that most fish cannot survive for even short periods of time). These observations occurred at Portage Is Marsh (5/29/15), Airport Cr Saltmarsh (7/7/14), and Silver Cr Upper (6/10/14).

Dissolved oxygen within the study area, while variable, is generally at levels sufficient to support salmonid rearing and migration. Across our entire sampling effort the DO distribution's lower 25th percentile was never less than 6.5 mg/l for any site (Figure 2.4.7). While Portage Is Marsh, Airport Cr Saltmarsh, and Silver Cr Upper all had very low DO observations, we raise the Silver Creek site as our only concern for low DO. This area has limited hydrologic flushing from river or tidal processes and may be receiving periodic poor DO from contributing tributaries. Portage Is Marsh and Airport Cr Saltmarsh are likely reflecting natural DO conditions for their habitat types. Portage Is Marsh is a very small and shallow pocket estuary that is naturally subject to high water temperature and low DO during summer months. Airport Cr Saltmarsh is a transitioning area due to the tidal delta's distributary-spanning logjam. The area's channels are resizing dramatically and the area is a sink for a large amount of decaying detritus, likely resulting low DO conditions at times.

Table 2.4.5. ANOVA significance results for water surface dissolved oxygen. *P*-values significant at the 0.05 level are bolded.

Variable Type	**Variable**	***P*-Value**
Factors	HABITAT TYPE	**0.000**
	YEAR	**0.000**
Interactions	HABITAT TYPE *YEAR	**0.025**
Covariates	MONTH	**0.000**
	SALINITY	**0.002**

Table 2.4.6. Pairwise results of water surface dissolved oxygen by habitat type using Tukey's Honestly Significant Difference Test. *P*-values significant at the 0.05 level are bolded.

Habitat Type (i)	**Habitat Type (j)**	**Difference**	***P*-Value**	**95% Confidence Interval**	
				Lower	**Upper**
EEM tidal delta	ESS tidal delta	-0.627	0.131	-1.293	0.040
EEM tidal delta	Exposed nearshore	-1.667	**0.000**	-2.167	-1.168
EEM tidal delta	Exposed nearshore w/FW	-0.536	0.422	-1.244	0.172
EEM tidal delta	FRT tidal delta	0.592	0.085	0.016	1.168
EEM tidal delta	Pocket estuary	-0.694	**0.010**	-1.188	-0.200
ESS tidal delta	Exposed nearshore	-1.041	**0.001**	-1.648	-0.434
ESS tidal delta	Exposed nearshore w/FW	0.091	1.000	-0.697	0.878
ESS tidal delta	FRT tidal delta	1.219	**0.000**	0.547	1.890
ESS tidal delta	Pocket estuary	-0.067	1.000	-0.670	0.535
Exposed nearshore	Exposed nearshore w/FW	1.131	**0.000**	0.479	1.784
Exposed nearshore	FRT tidal delta	2.260	**0.000**	1.753	2.766
Exposed nearshore	Pocket estuary	0.974	**0.000**	0.563	1.384
Exposed nearshore w/FW	FRT tidal delta	1.128	**0.002**	0.415	1.841
Exposed nearshore w/FW	Pocket estuary	-0.158	0.987	-0.806	0.491
FRT tidal delta	Pocket estuary	-1.286	**0.000**	-1.787	-0.785

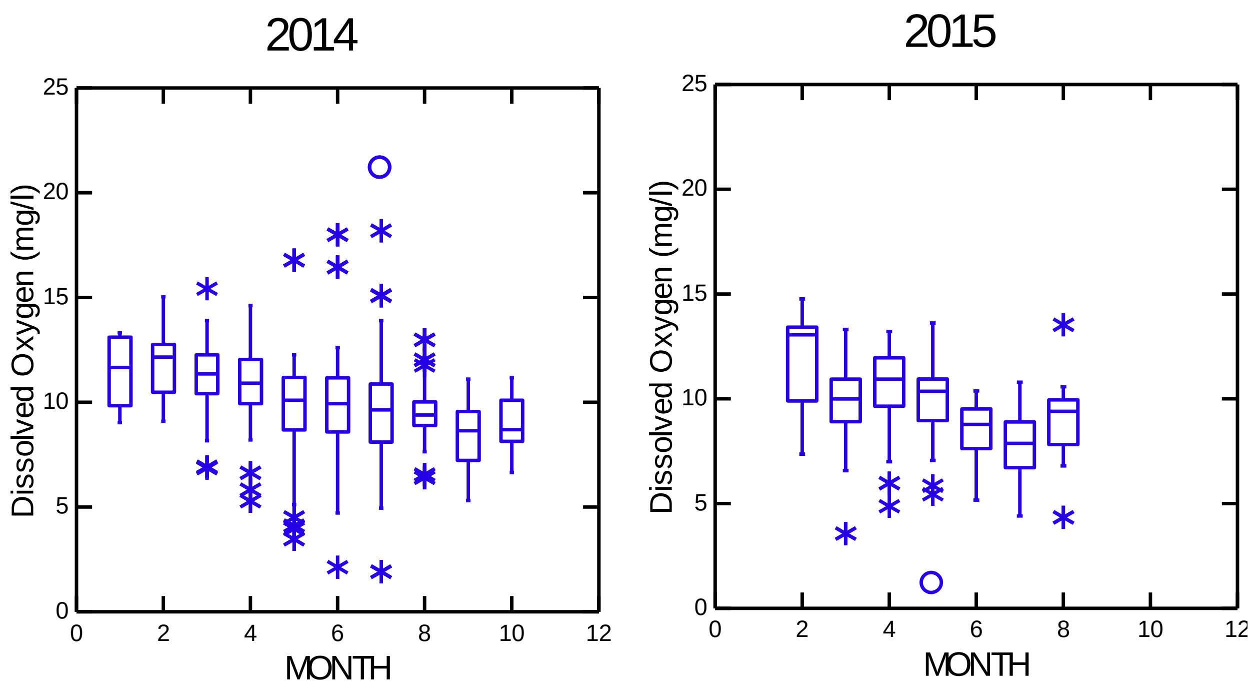

Figure 2.4.5. Boxplot of water surface dissolved oxygen by month and year. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

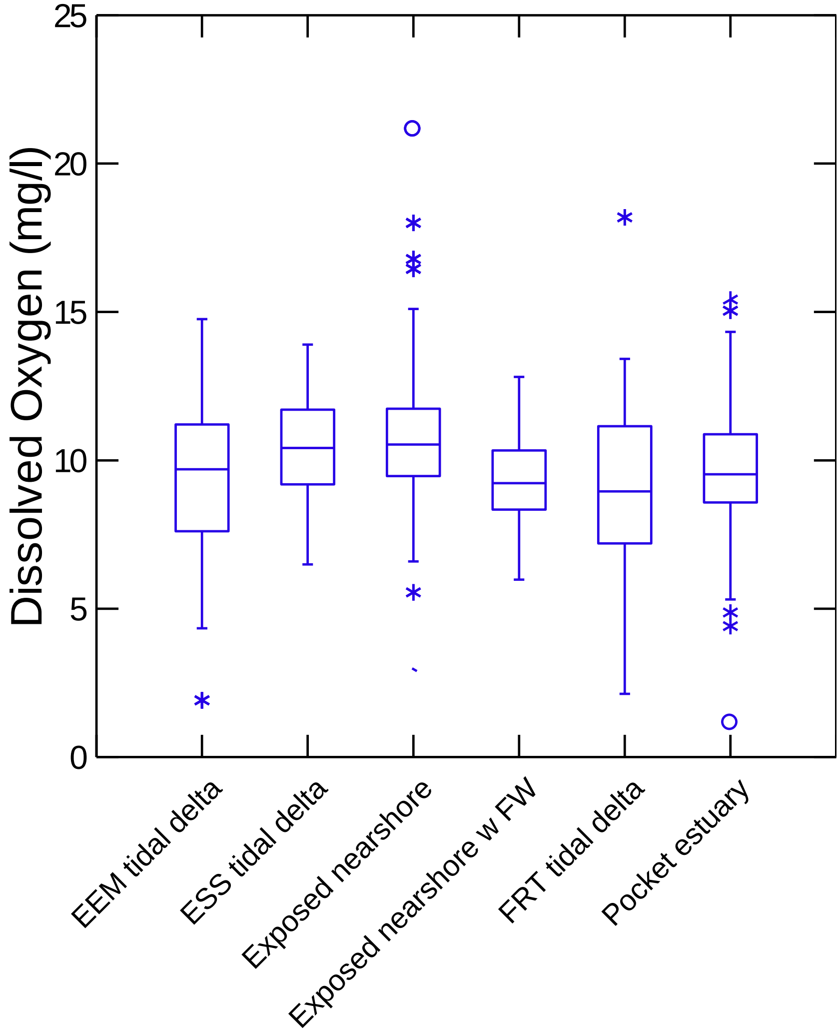

Figure 2.4.6. Boxplot of water surface dissolved oxygen by habitat type. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

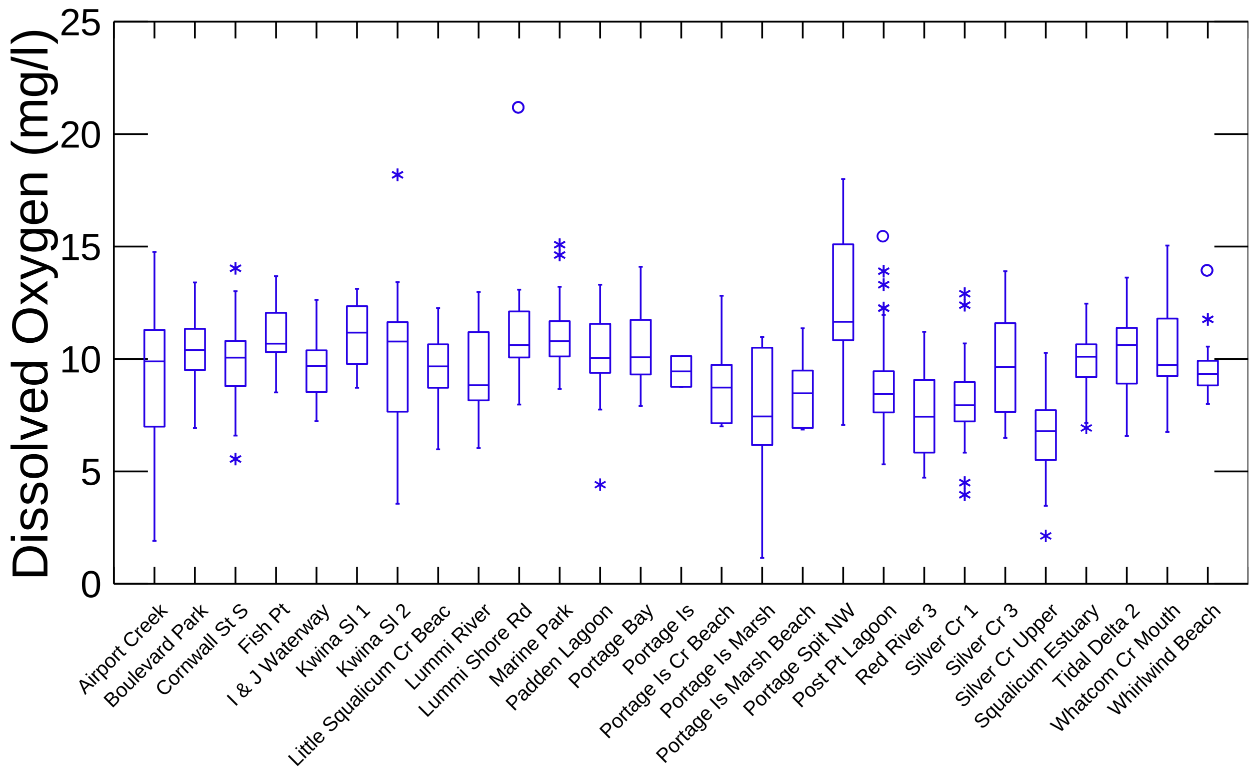

Figure 2.4.7. Boxplot of water surface dissolved oxygen by beach seine site. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentiles. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

Conclusions and recommendations

1. The water temperature, salinity, and dissolved oxygen results vary systematically by season and habitat type across the study area. These differences in water properties play a role in prey production and metabolic processes for juvenile salmon, which we explore in Chapter 6 of this report.
2. We found water properties within the study area to be generally consistent with habitat conditions suitable for juvenile salmon rearing and migration, with one exception: the area around our beach seine site at Silver Cr Upper. We recommend further analysis of this area to determine whether low DO conditions persist, and if present, whether they can be remedied.
3. Our analyses can help establish norms for each habitat type. Restoration and protection strategies could be developed to achieve water property norms where they are impaired. Site level strategies might include maintaining or restoring hydraulic connectivity and/or natural vegetation communities appropriate for each habitat type.

3.0 Site selection, fish data, and prey availability data

To complete analyses for this study we utilized existing data – possibly spanning the entire collection time period from 2003 to 2013 – and collected data in 2014 and 2015. This chapter describes the methods (including site selection rationale) we used to collect and/or process all (i.e., existing and collected this study) juvenile Chinook salmon and prey availability data used for analysis in this study.

The introduction chapter of this report (Chapter 1) presented a crosswalk of data used by analysis question (Table 1.1). The purpose of Table 1.1 is to give the reader an accounting of all data used for analyses in this study. Table 1.1 summarizes for each analysis in this study what data type(s) were used as well as the source and years of data. We do not repeat Table 1.1 in this chapter but remind the reader of each section of Chapter 3 the source and years of data being described.

3.1 Nooksack River juvenile Chinook outmigrants

Nooksack River juvenile Chinook outmigration data comes from an existing data collection program conducted by the Lummi Natural Resources Department (LNRD). For this study we used results from the 2005-2015 Nooksack River juvenile Chinook salmon outmigrations.

Site and gear

Lummi Natural Resources has operated a rotary-screw smolt trap (Trap) in the lower mainstem of the Nooksack River at Hovander Park near Ferndale since 1994 (LNRD 2013; MacKay 2000; Conrad and MacKay 2000). The Trap is located at a point in the river where there is a single channel and the migratory pathway is focused within the thalweg of this channel. The main objectives of the Trap sampling program include: 1) developing accurate estimates of the annual production of outmigrating wild-origin salmon fry and smolts; 2) providing a sampling platform for scales, otoliths, tissues for genetics, and others; and 3) providing numbers for regulatory compliance and monitoring (e.g., ESA listed species, Hatchery and Genetic Management Plans (HGMP), etc.). Although the emphasis of Trap operations is to quantify wild, listed Chinook fry, parr and yearlings, estimates of coho, pink, chum and steelhead are also produced.

A rotary-screw smolt trap is a barge-mounted sampling device that has a cone-shaped entrance that is lowered into the top of the water column with the opening facing upstream. The force of the flowing water continuously turns the cone, and internal vanes direct any fish that enter the trap into a screened holding area, known as the live box, from which they can be caught with dip nets to be processed by the attending field crew.

Rotary-screw traps only sample a small portion of the water column and the river's cross section, and it is therefore not possible to count every fish that passes the trap site. As a result, juvenile salmon outmigration estimates are produced by estimating the catch efficiency (CE), defined as the portion of fish sampled out of the total fish passing the trap site over a given time period. Expanded outmigration estimates are calculated by dividing the total catch by the CE for the time period over which the estimate is produced. Because a trap does not operate 24 hours a day, catches are extrapolated during non-operational periods by averaging catches before and after that period. The CE is affected by turbidity, flow, diurnal period, fish size and possibly varies by species (Volkhardt et al. 2007). Because of this variation, a weekly calibration trial will be conducted in most river systems, where a group of marked fish that best represents the species and fish sizes passing the trap during that period are released above the trap at a distance allowing the fish to adopt a normal migration pattern (e.g., Kinsel et al. 2008 for Skagit River; Topping and Anderson 2014 for Green River). The recovery rate of these marked fish passing the trap over a short time period (1-4 days) is the estimate of CE for that week of extrapolated catches. In a typical season, the CE is low before and after the peak migration during May and June, when the natural origin and hatchery parr exit the river system.

Abundance estimates

For the Nooksack River, the method to calculate the CE has varied over time. Calibration trials occurred from 1994 to 2001 (Conrad and MacKay 2000; MacKay 2000). Conrad and MacKay modeled impacts of river conditions on calibration CEs and found the best-fit model to be a single parameter, exponential model with turbidity as the predictor variable. Large weekly changes in flow and turbidity required weekly calibration estimates which were found to vary over these conditions by nearly an order in magnitude; this weekly variability was the basis for establishing weekly trials in the river systems cited above. Outmigration estimates can be impacted on a similar order of magnitude, since 1/CE is a direct multiplier, underscoring the need for weekly adjustments. Because natural origin Chinook exhibit fry, parr, and yearling life histories and because the fry and yearling life history types often exit the river during river conditions that tend to reduce the CE, undercounting of fry or yearling migrants is a high risk if a yearly mean or peak migration CE is used.

Despite these findings, calibration trials were eliminated entirely by 2002 at the Nooksack Trap as the marking rate for hatchery fish increased substantially. Reported outmigration estimates were produced from a Peterson Mark-Recapture (PMR) model method from 2003 to 2013 (annual reports found here: http://lnnr.lummi-nsn.gov/LummiWebsite/Website.php?PageID=1; click on available documents and search list).

The realization that wild Chinook might be undercounted led to a re-evaluation of trap estimation procedures in 2014. Although this project is still underway, a CE model was produced from an exhaustive analysis of river conditions, historic catches, historic calibration trial data, and new calibration trials re-initiated in 2015 after a 13-year hiatus. As an independent measure of outmigration that could be used to validate fish passage and adjust the CE model, beach seine efforts were initiated adjacent to the Trap site. A minimum of three to six sets are conducted per time period, which is defined as once a week, or more often if there is a 25% change in the river's flow or turbidity observed. In addition, juvenile Chinook salmon length frequency histograms of historic records revealed monthly length ranges associated with life history types and age; these ranges were used to automate aging and identification of fry versus parr for outmigration catch records. These length range protocols have been validated and adjusted with scales read from three of the ten years.

The CE model required establishing a relationship between the catch rate (number of fish caught per hour) and the CE (proportion of fish sampled) in the absence of a measured CE. Using only the calibration trial periods, catch rates during the trials were significantly correlated to the CE ($r = 0.88; P < 0.0001$). Catch rates immediately before and after the trial were significantly and positively correlated with catch rates during the trial ($r = 0.72; P < 0.0001$). The relationship between CE and turbidity, expressed as the inverse of the secchi depth (a standardized method for estimating turbidity), was confirmed to have a similar significant relationship ($r = 0.75; P < 0.0001$). There were also significant relationships or differences of mean catch rates with flow, day versus night, and fish length. However, flow, turbidity, and day versus night catches are correlated with one another and could not be used in the same model. Using all of these variables (raw, normalized or transformed), a series of two parameter models were compared using a generalized linear model (GLM). The best fit model (lowest AIC (Akaike information criterion) score) was a GLM with normal distributions and a log link function that included the inverse of the secchi depth reading. Although this model may be adjusted in the future with the inclusion of new calibration and validation catches, the model used to estimate outmigration included in this report is:

CE_t = 1.93(inverse secchi reading cm over time *t*) + 0.0088 (catch rate over time *t*) – 5.17

Where *t* is the period for which the expanded estimate is calculated; because of the scale of variability, a week is the minimum calculation period allowed. The weekly coefficient of variation (CV, or standard deviation around the predicted value over the mean predicted value) ranged from 8.6 to 20.5% with an overall model mean of 14.3%. The error range of annual estimates will vary with the range of catch rates and turbidity observed.

Using the revised CE model, Nooksack River NOR (natural origin recruit) juvenile Chinook outmigration estimates were re-calculated from 2005 to 2015 on weekly, monthly and annual time scales. Outmigration estimates were parsed by the three life history stages (fry, parr, and yearling) for NOR fish.

NOR juvenile Chinook genetics

Genetic results for NOR juvenile Chinook outmigrants were from fish sampled at the trap in 2013 between January and August; these were processed by WDFW using the WDFW Genetics Lab Baseline (Young and Shaklee 2002; Ken Warheit and Todd Seamons, WDFW Genetics, Olympia, pers. comm.).

3.2 Sampling sites and methods

Sites used

Lummi Natural Resource Department staff initiated beach seine sampling in the Nooksack tidal delta and Bellingham Bay nearshore in 2003 and continued through 2013. Data were summarized by MacKay (2014) and used for an initial report of juvenile Chinook utilization of Bellingham Bay (LNRD 2005). For our study we used data from MacKay (2014) for sites: a) with extensive annual and seasonal records; and b) that represented a diversity of habitat types and connectivity. We utilized data from 21 sites, including eight in the tidal delta, nine in exposed nearshore, and four in pocket estuaries (Table 3.2.1 and Figure 3.2.1). For beach seine efforts in 2014 and 2015 we balanced geographic representation of the sampling by adding seven additional sites, two each in pocket estuaries, tidal delta, and exposed nearshore, and one at a small stream (Figure 3.2.2). We also increased sampling frequency of each site to twice a month and the period of sampling from February-August for tidal delta sites and February-October for Bellingham Bay nearshore sites.

Site classification

We described each site using ten variables related to habitat type and the site's connectivity to juvenile salmon originating from the Nooksack River: The variables are:

1. System (Nooksack tidal delta, Bellingham Bay)
2. Adjacent landuse (natural, urban, agriculture, or rural residential)
3. Presence of intertidal armoring (yes, no)
4. Presence of a local freshwater input (yes, no)
5. Simple habitat (shoreline, blind channel, distributary channel)
6. Shore type (various geomorphic types) or estuary wetland zone (estuarine emergent marsh, estuarine scrub shrub, forested riverine tidal)
7. Combined habitat strata (a simplified combination of system, shoretype, and exposure)[3]
8. Exposed/Sheltered (determined by the enclosure calculation; Values > 1 are sheltered; values < 1 are exposed)
9. Enclosure (continuous numeric; enclosure = embayment opening width/embayment maximum length)
10. Pre/Post logjam (pre or post)
11. Landscape connectivity (continuous numeric variable calculated for each site, described in section 2.3)

Beach seine methods

Small net beach seine methods (Table 3.2.2) are used for sampling shallow intertidal shoreline areas of Bellingham Bay or distributary channel habitat in the Nooksack tidal delta. The areas seined are typically shallow and have relatively homogeneous habitat features such as water depth and velocity, substrate, and vegetation. The net is set by fixing one end of the net on the beach while the other end is deployed by wading the net 'upstream' against the water current using a floating tote, and then returning to the shoreline in a half-circle. If the water is too deep to wade, the tote is towed by boat. Both ends of the net are then retrieved, yielding a catch.

A 'smaller' net (LNRD BS 9x2) was used for sites at which access required hiking overland into the site. This net was deployed using a drag and haul method, where both ends of the net are pulled down the beach for a given distance and then pursed up, yielding a catch.

Open water round-haul sets are made offshore by bringing one end of the small beach seine net around to meet the other end.

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[3] One combined habitat stratum is called 'pocket estuary.' This category includes true geomorphic pocket estuaries and areas that resemble pocket estuaries even if they aren't true pocket estuaries. Many sites within the urban areas of Bellingham Bay are highly modified, including some true pocket estuaries like Padden Lagoon. In this highly modified environment, if a site is sheltered (i.e., enclosure calculation >1) and has a direct freshwater source, we define it as 'pocket estuary' regardless of the site's geomorphic type. Most often these sites are pocket beaches created by current land use (e.g., a beach surrounded by large areas of fill on either side).

A large net beach seine method was used for sampling the intertidal-subtidal fringe of Bellingham Bay. One end of the net is fixed on the beach while the other end is set by boat across the current at an approximate distance of 65% of the net's length. After a given amount of time, the boat end is brought to the shoreline edge and pulled in by hand.

The Puget Sound Protocol seine method deploys a net (either small beach seine or large beach seine) parallel to the beach 10-15 m offshore; both ends are then pulled to shore at the same time.

Set area calculation

Standard set area for the small net method when set in a half circle is 96 m^2. This is recorded as 100% set area. If the net was set so that the beach end of the net did not come to the shoreline edge, or not all of the net was deployed out of the tub, the area covered by the net was estimated and recorded as a percent of the standard set area.

When using the drag and haul net method, the length and width of the area covered during the set are recorded. This is converted to square meters and recorded as a percent of the standard set area covered by the small net beach seine method.

Standard set area for the large net method is 235 m^2. Variations in the area covered by the described sampling methods were minimal.

Electrofishing methods

Portage Is Cr was sampled using a Smith Root LR-24 electrofisher on the same days that beach seine sampling occurred in the adjacent nearshore sites on Portage Island in 2015 (see Figure 3.2.2 above). All electrofisher operators were certified as 'Qualified Individuals' and followed the criteria set forth in NOAA Fisheries Backpack Electrofishing Guidelines[4]. A single pass method was used when sampling at this site.

Catch processing

For each beach seine set and electrofishing catch, we identified and counted all fish by species, and measured individual fish lengths by species. When one set contained 20 individuals or less of one species, we measured all individual fish at each site/date combination. For sets with fish catches larger than 20 individuals of one species, we randomly selected 20 individuals for length samples. All Chinook, coho and steelhead were sampled to determine if the fish was natural or hatchery-origin. The presence of hatchery fish was determined if the fish had a clipped adipose fin or a coded wire tag (CWT) in its snout. If the fish had a CWT, it was sacrificed so that the hatchery release location could be determined. A tissue sample was taken on a selected subset of unmarked juvenile natural origin Chinook for DNA analysis. In collaboration with the Salish Sea Marine Survival Study (SSMSS), a subsample of unmarked and hatchery-origin juvenile Chinook were sacrificed to determine their diet.

[4] http://www.westcoast.fisheries.noaa.gov/publications/reference_documents/esa_refs/section4d/electro2000.pdf

Environmental data

Environmental data collected for each beach seine set includes:

- Time and date of set
- Tidal stage (ebb, flood, high tide slack, low tide slack)
- Water surface area seined (described above)
- Surface and bottom water temperature of area seined (YSI meter)
- Surface and bottom salinity of area seined (YSI meter)
- Maximum depth of area seined
- Average surface water velocity (Swoffer Model 2100 flow meter)
- Substrate of area seined
- Vegetation of area seined

Fish density estimates

For all fish sampled by beach seine, we calculated the density of fish by species for each set (the number of fish divided by set area). Set area is determined in the field for each beach seine set.

For Portage Island Creek electrofishing results we converted single pass electrofishing juvenile Chinook catch to total abundance estimates using a multiple regression equation after Kruse et al. (1998). Juvenile Chinook abundance was converted to density by dividing abundance by the area sampled during electrofishing in Portage Island Creek, which was 147 m^2. Other habitat characteristic of Portage Island Creek includes: average bankfull width of 2.2 m; average gradient of 2.8%; and pool spacing of 4.4 channel width per pool.

NOR juvenile Chinook genetics

A subset of unmarked juvenile natural origin Chinook was collected for DNA analysis to determine their population origin using Genetic Stock Identification (GSI) techniques on standardized microsatellite DNA loci. These GSI methods use a “baseline” genetic database to estimate the likely origin of juvenile Chinook salmon collected in our study. The baseline is the whole set of reference samples representing spawning aggregates in known geographic locations.

In years 2008 and 2009, fish were collected in the Nooksack tidal delta and Bellingham Bay nearshore by LNRD and analyzed by NOAA Fisheries Manchester Marine Research Station (David Teel and others) using a Washington and British Columbia baseline dataset extracted from the standardized coast-wide database developed by the multi-agency workgroup Genetic Analysis of Pacific Salmonids (GAPS) collaborators (Moran et al. 2005). In collaboration with the SSMSS, fish collected in the Nooksack tidal delta and Bellingham Bay nearshore during 2014 and 2015 were analyzed by WDFW (Ken Warheit and others) using a new single-nucleotide polymorphisms (SNPs) Chinook baseline (Warheit et al. 2014). Fish collected in the lower Nooksack River outmigrant trap by LNRD in 2013 from January through August and were analyzed by WDFW using the SNPs baseline.

NOR juvenile Chinook diets

In collaboration with the SSMSS, unmarked Chinook salmon diet samples were processed by the University of Washington (Dave Beauchamp's lab). Organisms within Chinook diet samples were identified to taxonomic order, counted and weighed.

Uses of juvenile Chinook data

We used data from 2014 and 2015 to describe juvenile Chinook habitat use within the Bellingham Bay nearshore in comparison with the Nooksack tidal delta because years 2014 and 2015 have extensive temporal and spatial sampling compared to prior years (see section 4.3). We also report juvenile Chinook origin results from fish caught in 2008, 2009, 2014, and 2015 (see Chapter 5). We utilized data from 2005 through 2015 within the Nooksack tidal delta to assess whether juvenile Chinook are experiencing density dependence (see section 6.1). For juvenile Chinook salmon bioenergetics analysis, we used diet data from 2014 and 2015 from Nooksack tidal delta and Bellingham Bay pocket estuary sites to compare estimated growth rates between these two habitat types known to have extended residence periods by individual Chinook salmon (see section 6.3).

Table 3.2.1. List of all sites sampled in this study with their habitat classification attributes.

Site name	System	Adjacent landuse (km scale)	Intertidal armoring	Local FW input	Simple habitat	Shore type / estuarine wetland zone	Exposure	Combined habitat strata
Airport Creek & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	distributary channel	tidal delta EEM	sheltered	Natal estuary
Boulevard Park & LNRD equiv.	Bellingham Bay	urban	yes	no	shoreline	pocket beach	exposed	Exposed nearshore
Cornwall St S & LNRD equiv.	Bellingham Bay	urban	yes	no	shoreline	pocket beach	exposed	Exposed nearshore
Fish Pt & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	distributary channel	tidal delta ESS	sheltered	Natal estuary
I & J Waterway & LNRD equiv.	Bellingham Bay	urban	yes	no	shoreline	pocket beach	sheltered	Pocket estuary
Kwina Sl 1	Nooksack Tidal Delta	natural	no	yes	distributary channel	tidal delta FRT	sheltered	Natal estuary
Kwina Sl 2 & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	distributary channel	tidal delta FRT	sheltered	Natal estuary
Little Squalicum Cr Beach & LNRD equiv.	Bellingham Bay	urban	no	yes	shoreline	depositional beach	exposed	Exposed nearshore w/FW
Lummi River & LNRD equiv.	Nooksack Tidal Delta	agriculture	no	yes	distributary channel	tidal delta EEM	sheltered	Natal estuary
Lummi Shore Rd	Bellingham Bay	rural residential	no	no	shoreline	bluff back beach/delta fringe	exposed	Exposed nearshore
Marine Park & LNRD equiv.	Bellingham Bay	urban	no	no	shoreline	pocket beach	exposed	Exposed nearshore
Padden Lagoon & LNRD equiv.	Bellingham Bay	urban	no	yes	shoreline	pocket estuary	sheltered	Pocket estuary
Portage Bay & LNRD equiv.	Bellingham Bay	rural residential	yes	no	shoreline	depositional beach	exposed	Exposed nearshore
Portage Is & LNRD equiv.	Bellingham Bay	natural	no	no	shoreline	depositional beach	exposed	Exposed nearshore
Portage Is Cr	Bellingham Bay	natural	no	yes	small stream	small stream	sheltered	Small stream
Portage Is Cr Beach & LNRD equiv.	Bellingham Bay	natural	no	yes	shoreline	depositional beach	exposed	Exposed nearshore w/FW
Portage Is Marsh	Bellingham Bay	natural	no	yes	shoreline	pocket estuary	sheltered	Pocket estuary
Portage Is Marsh Beach & LNRD equiv.	Bellingham Bay	natural	no	yes	shoreline	depositional beach	exposed	Exposed nearshore w/FW
Portage Spit NW & LNRD equiv.	Bellingham Bay	rural residential	no	no	shoreline	depositional beach	exposed	Exposed nearshore
Post Pt Lagoon & LNRD equiv.	Bellingham Bay	urban	yes	yes	shoreline	pocket estuary	sheltered	Pocket estuary

Site name	System	Adjacent landuse (km scale)	Intertidal armoring	Local FW input	Simple habitat	Shore type / estuarine wetland zone	Exposure	Combined habitat strata
Red River 3	Nooksack Tidal Delta	agriculture	no	yes	distributary channel	tidal delta EEM	sheltered	Natal estuary
Silver Cr 1 & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	blind channel	tidal delta FRT	sheltered	Natal estuary
Silver Cr 3 & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	distributary channel	tidal delta ESS	sheltered	Natal estuary
Silver Cr Upper & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	blind channel	tidal delta FRT	sheltered	Natal estuary
Squalicum Estuary	Bellingham Bay	urban	no	yes	shoreline	pocket estuary	sheltered	Pocket estuary
Tidal Delta 2 & LNRD equiv.	Nooksack Tidal Delta	natural	no	yes	blind channel	tidal delta EEM	sheltered	Natal estuary
Whatcom Cr Mouth & LNRD equiv.	Bellingham Bay	urban	yes	yes	shoreline	pocket estuary	sheltered	Pocket estuary
Whirlwind Beach	Bellingham Bay	rural residential	no	no	shoreline	bluff back beach/delta fringe	exposed	Exposed nearshore

Table 3.2.2. Nets used in this study. Table shows dimensions, set style and set area covered by the net during various sampling protocols.

Years used	Net description	Net dimensions	Set style	Standard set area (m^2)
2014 & 2015	SRSC small net beach seine	3 mm mesh, 1.8 m deep by 24.4 m long	small net beach seine method	96
			open water round-haul	125
			drag and haul	96-192
			Puget Sound Protocol	288
	SRSC large net beach seine	3 mm mesh, 3.7 m deep by 36.6 m long	large net beach seine method	235
			Puget Sound Protocol	229 or 345
2003-2015	LNRD BS 9x2	1.5 mm mesh, 2 m deep by 9 m long	small net beach seine method	26
			drag and haul	26-96
2003-2013	LNRD BS 40	3 mm mesh, 1.9 m deep by 11.3 m long	Described in MacKay (2014)	40
	LNRD BS 60	3 mm mesh, 3 m deep by 18.3 m long		103
	LNRD BS 80	3 mm mesh, 3 m deep by 24 m long		151

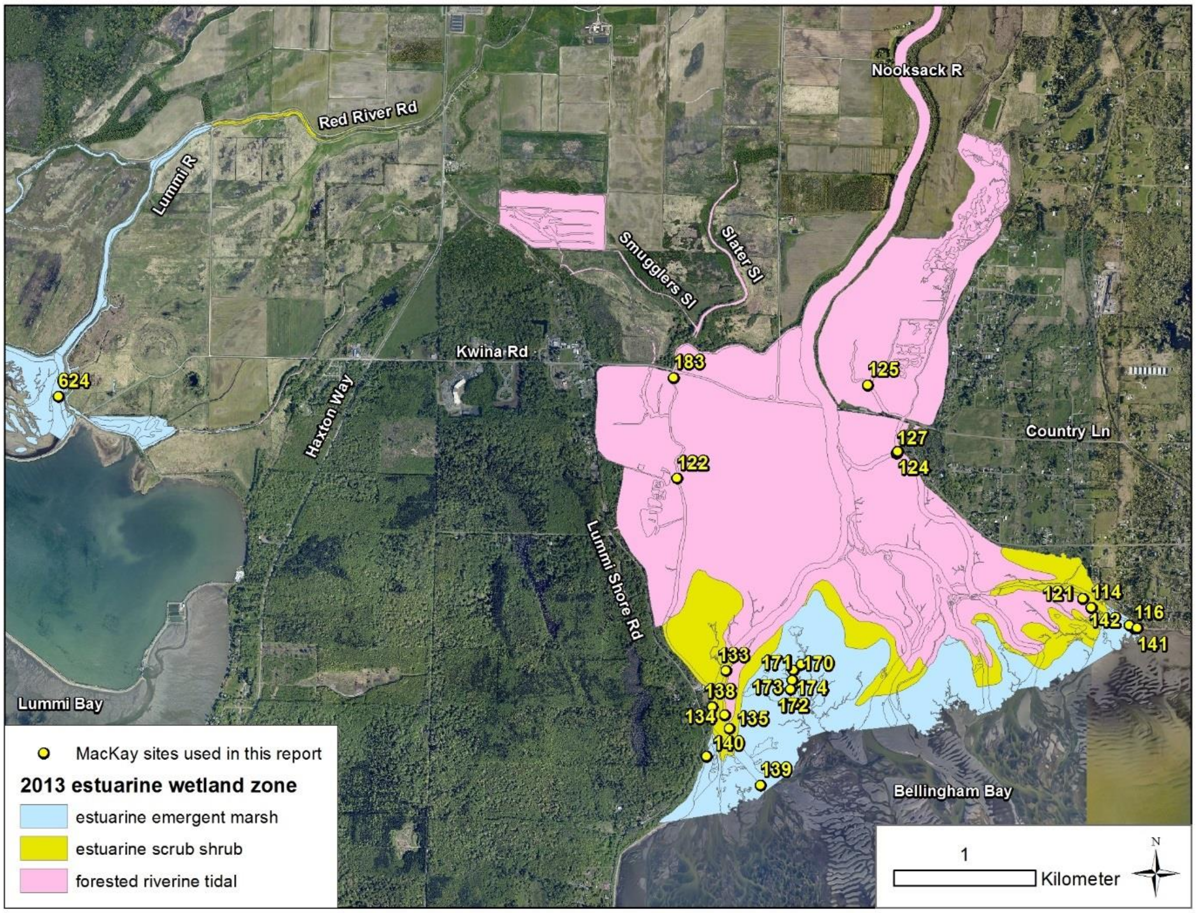


Figure 3.2.1. Map of Nooksack tidal delta sites from which this study used juvenile Chinook data spanning years 2003-2013. Site and fish data are from MacKay (2014).

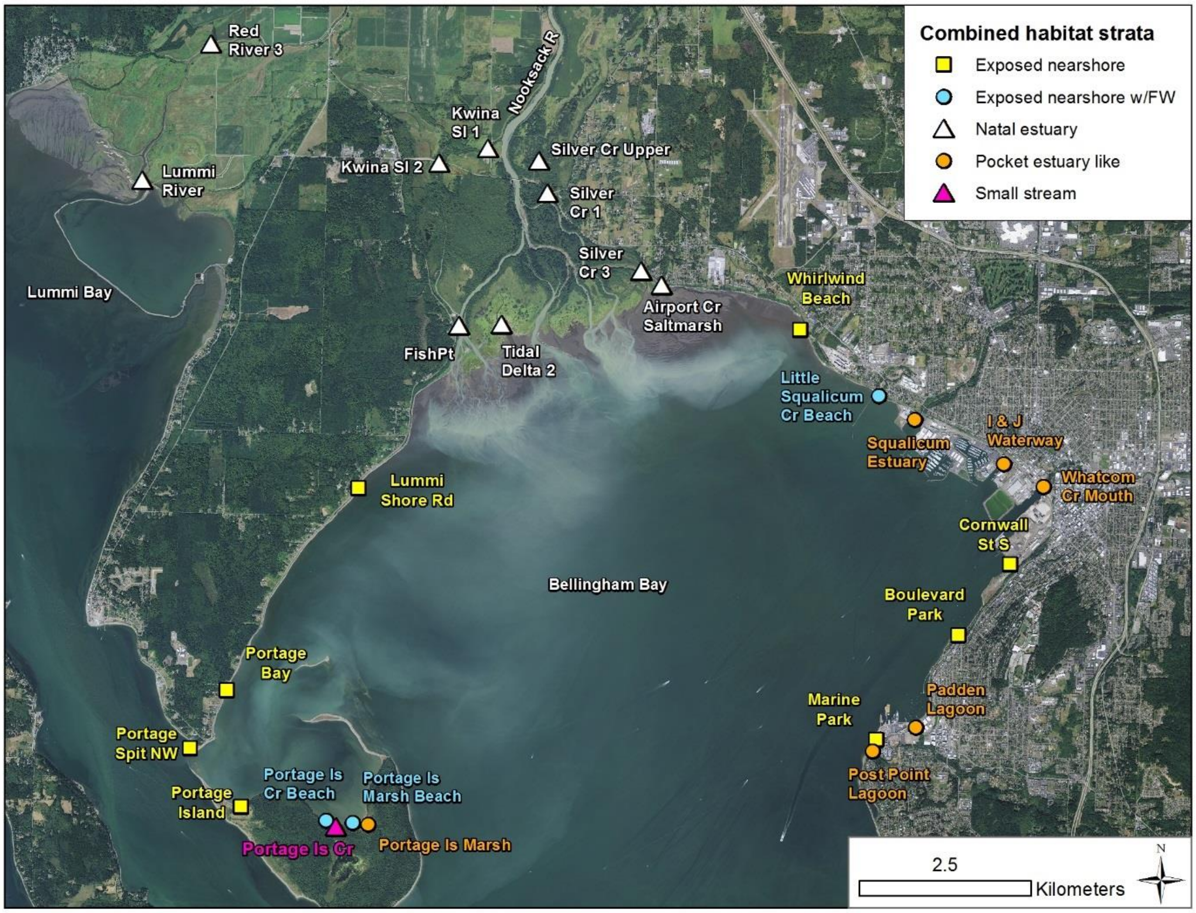


Figure 3.2.2. Map of sites beach seined for this study in 2014 and/or 2015, shown by combined habitat strata.

3.3 Salmonid prey availability

Sample collection methods

We collected a total of 74 neuston (surface) and epibenthic (bottom) samples of prey availability (32 in the Nooksack tidal delta, 42 in the Bellingham Bay nearshore) during April, May and June of 2014 to represent the time period when juvenile Chinook would be actively rearing within the tidal delta or pocket estuaries and shifting to more exposed nearshore habitat (Table 3.1.1). Samples were collected using either an 80- or 250-micron plankton net along the water's surface or just off the bottom.

The neuston method tows the net along just under the water surface in order to catch the organisms drifting on the surface as well as in the upper water column. The half-meter diameter net is towed so that the upper 10 to 12 cm of the net's frame is held above the surface of the water. The epibenthic method tows the net along the bottom of the water column, catching organisms living on and near the bottom. Care is taken to suspend the net just above the substrate so as to not stir up sediment. If water depth is too shallow to sample neuston separate from epibenthos, only one sample is collected. These samples are considered to sample the full water column.

The plankton net is towed against the water current (if present). It is attached it to a telescoping pole, adjustable in length from 2.4 m to 3.9 m (8 ft to 12 ft). If the water current is too strong to tow the net against it and sample plankton effectively, the sample is taken by holding the net stationary against the current for a measured period of time, usually 60 seconds. For each sample collection, the following data are recorded: net type (80- or 250-micron net), tow type (neuston, epibenthic, both), distance the net was towed, length of time the net was towed, water current velocity (measured with a Swoffer 2100 flow meter), and depth of the sample.

The net's contents are washed into a collection jar using a garden style pressure tank. The jar is rinsed three times with distilled or cleaned/filtered ambient water in the pressure tank. The material is transferred into a 16oz plastic jar. The samples are 'fixed' by adding 95% denatured ethanol alcohol in equal amounts to the volume of water used to rinse the collection jar. A label is affixed to each jar listing: site, collection date, collection area within the water column (neuston or epibenthic or both), distance the net was hauled, and time it took to haul the net.

Prey availability laboratory methods

The methods for the lab component of this study were to extract, concentrate and filter the contents of the sample jars by rinsing, decanting and concentrating samples through a series of increasingly fine filters, finally collecting the concentrated sample into a quartered Petri dish using both rinse and spray techniques, then examining the contents for potential prey species. Sample jars were emptied through a series of sieves starting at 600 micrometers and ending with 500 microns. The samples were first decanted and rinsed of gross contaminants (if needed), then, using the fine sieves, concentrated to no more than 50 mm. Using a combination of rinse or spray bottles the sample was extracted from the sieve and collected into a quartered Petri dish for examination. Using a Motic dissecting microscope and supplemental photographic software, we identified individuals to the finest taxonomical resolution practical, typically to family and sometimes to species (Table 3.3.2). We then allocated a representative count of those species based on direct observation or a sub-sampling protocol that was instituted in the event of numerous individuals within the sample. In this case we evenly distributed the sample across all four quarters of the Petri dish and counted those individuals within one quarter, then multiplied by four to represent the entire sample. Finally, the counts were entered into an Excel spreadsheet.

Table 3.3.1. Number of prey availability samples collected by site, combined habitat strata, and month in 2014. The location of each site is shown on Figure 3.2.2.

Combined habitat strata	Site	# of neuston and/or epibenthic samples collected		
		April	**May**	**June**
Exposed nearshore	Marine Park	2	2	2
	Portage Bay	2	1	2
	Whirlwind Beach	2	1	1
Exposed nearshore w/FW	Little Squalicum Cr Beach	2	1	2
Natal estuary - EEM	Airport Creek	1	1	1
	Lummi River	2	2	1
	Red River 3	1	1	1
	Tidal Delta 2	2	1	1
Natal estuary - ESS	Fish Pt	2	2	2
	Silver Cr 3	1	1	1
Natal estuary - FRT	Kwina Sl 2	2	1	1
	Silver Cr Upper	2	1	1
Pocket estuary	I & J Waterway	2	2	2
	Padden Lagoon	2	2	1
	Post Pt Lagoon	2	2	2
	Whatcom Cr Mouth	2	2	1
Grand Total		**29**	**23**	**22**

Table 3.3.2. List of 62 reported taxa present in the 74 prey availability samples by 33 grouped taxa (after Goertler et al.).

grouped taxa	**reported taxa**
aquatic arachnid	Water Mite
benthic polychaete	Polychaete Hobsonia Florida, Polychaete worm, Spionidae Polychaete Trochophore
benthic/epibenthic oligochaetes	Oligochaete worm
emergent diptera	Chironomid Adult
epibenthic/pelagic mysid	Mysid shrimp
epiben/planktonic Cladoceran	Cladocera Anomopoda Daphniidae, Cladocera Evadne, Cladoceran Podon
epibenthic amphipod	Amphipod Americocorphium
	Amphipod Eogammarus
epibenthic copepod	Harpacticoid copepod, Harpacticoid Copepod Gravid, Harpacticoid Ectinosomatidae Pseudobradia
epibenthic cumacea	Nippoleucon hinumensis
epibenthic diptera	Chironomid larvae, Tipulidae Fly Pupa
epibenthic ephemeroptera	Ephemeroptera Siphlonuridae
epibenthic hemiptera	Hemiptera Corixidae, Hemiptera Nymph
epibenthic odonata	Dragonfly nymph
epibenthic ostracod	Ostracod
epibenthic plecoptera	Plecoptera Perlodidae (Stone fly)
epibenthic decapoda	Paguridae (Juvenile hermit crab)
epibenthic snail	larval snail, Littorina scutulata Snail eggs
insecta other	Insect egg mass
other amphipod	Amphipod Tanidae Sinelobus
pelagic decapoda	Crab Larvae, Crab Megapolis
pelagic fish	Juvenile sculpin, Larval fish, stickleback fish
planktonic barnacle	Barnacle larvae, Barnacle Molt, Cyprid Barnacle Larvae, Nauplius Barnacle Larvae
planktonic copepod	Calanoid copepod, Calanoid Copepod gravid
terrestrial arachnid	Mite Acarina, Spider adult, Spider juvenile
terrestrial coleoptera	Lady Bug, Staphylinid Beetle
terrestrial diptera	Brachycera Fly, Dolichopodid fly (Metallic green), Ephydridae fly, Tephritidae fly
terrestrial hemiptera	Aphid, Delphacidae, Hemiptera Delphacid Adult, Hemiptera Terrestrial, Hemiptera adult
terrestrial hymenoptera	Braconid Wasp, Hymenoptera chalcidoidea
terrestrial isopod	Gnorimosphaeroma sp. isopod (pill bug)
terrestrial lepidoptera	Lepidoptera caterpillar
terrestrial springtail	Collembola Sand Flea, sminthuridae spring tail
terrestrial thysanoptera	Thysanoptera Thrip
unknown larvae	Unknown/undiscernible larvae

4.0 Population structure of juvenile Chinook salmon

This chapter describes the habitat associations, timing, and abundance of juvenile Chinook salmon using the Nooksack estuary and Bellingham Bay nearshore system. First, we identify the possible juvenile Chinook life history types that might be expressed in the Nooksack/Bellingham Bay nearshore system (section 4.1). Then we report on the natural and hatchery juvenile Chinook salmon that are, or could be, present in the Nooksack/Bellingham Bay system using Nooksack River rotary screw trap data and hatchery release records from 2005-2015 (section 4.2). In section 4.2 we also analyze spawner survey data from independent streams draining into Bellingham Bay to determine whether these streams are a source of Chinook salmon in the study area. We follow section 4.2 with a presentation of juvenile Chinook salmon use of Nooksack tidal delta and Bellingham Bay nearshore habitats, by studying beach seine data collected for this study in 2014 and 2015 (section 4.3). Lastly, we report on possible effects of habitat connectivity on patterns of juvenile Chinook abundance within the study area using existing beach seine data from MacKay (2014) and data collected for this study in 2014 and 2015 (section 4.4).

4.1 Conceptual model - life history types

Chinook salmon are described as the most estuarine-dependent of all the Pacific salmon and well-known for their life history variation (Reimers 1973, Healey 1980, Greene and Beechie 2004). Life history diversity can increase population resilience under variable environmental regimes (Miller et al. 2010). Life history types can be distinguished based on differences in body size and the seasonal timing during which fish transition from one habitat zone to another (Miller et al. 2010; Zimmerman et al. 2015).

Based on existing research and long-term monitoring in the Skagit River we conceptualize five life history types to comprise most of the juvenile life history variation of NOR Nooksack River/Bellingham Bay nearshore Chinook salmon (Figure 4.1.1). The distinct juvenile life history types occur based on branching by juvenile Chinook patterns (i.e., does the fish remain or migrate) within three main ecological zones (freshwater, natal estuary, and marine nearshore). Branching occurs in each zone, resulting in five distinct juvenile life history types. For the Nooksack River/Bellingham Bay nearshore system the ecological zones correspond to distinct geographic areas: 1) freshwater = Nooksack River and its tributaries; 2) natal estuary = Nooksack tidal delta; and 3) marine nearshore = Bellingham Bay.

Simply explained (see Figure 4.1.1), each year cohorts of Chinook salmon fry emerge from their gravel egg pockets in their natal river system during the winter and early spring months. Some fry migrate downstream without doing any appreciable rearing in the freshwater environment. Fry remaining in freshwater branch into two main life history types after an extended freshwater residence period. Some fish remain in freshwater for a few months and migrate downstream as parr, while others remain in the freshwater environment for over a year and migrate the following spring as yearlings. Of the fry that migrate downstream, some establish residence in their natal estuary (i.e., Nooksack tidal delta) for a period of time while others migrate into the more marine waters of Bellingham Bay. Of the fry that end up in Bellingham Bay, some establish residence in nearshore refuge habitats (e.g., non-natal pocket estuaries and creek mouths) while others do not.

In recent years (brood years 1993 – 2008), one million to over seven million wild juvenile Chinook salmon have migrated from the Skagit River each year (Zimmerman et al. 2015). In each migration all juvenile life history types were observed. Below is a description of the relationship of each life history type to the Skagit tidal delta. We expect natural origin Chinook salmon juveniles in the Nooksack River/Bellingham Bay nearshore system to have the potential to express any of these five life history types (Figure 4.1.1) along with similar size and timing characteristics (Table 4.1.1).

Fry migrants: Fry migrants move through their natal river estuary without rearing there. Once in the marine nearshore environment, some fry migrants exhibit extensive rearing in non-natal pocket estuaries (Beamer et al. 2003; Beamer et al. 2006) and creek mouths (Beamer et al. 2013). Thus, we characterize fry migrants in the nearshore as two different life history types: a) those that use nearshore refuge habitats, and b) those that do not use nearshore refuge habitats.

Tidal delta rearing migrants: Delta fry are by definition associated with their natal estuary, the tidal delta. Individuals rear in their natal tidal delta for a period of 0.5 –2 months (Larsen et al. 2009). The average tidal delta residence period for these Chinook salmon in 1995 and 1996 (combined) was 34.2 days (Beamer et al. 2000). Following the tidal delta rearing period, these fish migrate to marine nearshore areas, usually starting in late May or June. Beamer and Larsen (2004) further defined several life history sub-strategies for tidal delta rearing Chinook salmon based on movement patterns and overall residence period within the tidal delta.

Parr migrants: Parr migrants outmigrate their natal river in late spring though summer months after rearing in freshwater habitats on the order of weeks to months. Parr migrants do not extensively reside in tidal delta habitats, appearing to pass through relatively quickly (days) and on to nearshore areas. Parr migrants exhibit an extended freshwater rearing region and no tidal delta rearing region on their otolith (Beamer et al. 2000).

Yearlings: Yearlings outmigrate their natal river in late winter through spring after spending over one year in freshwater habitats. Yearlings do not extensively reside in tidal delta habitats, appearing to pass through relatively quickly (days) and on to nearshore areas. Yearlings are rarely found in shallow intertidal environments, but are most commonly detected in deeper subtidal or offshore habitats when sampled in the nearshore environment.

Why individual fish migrate, or not, can be influenced by genetic hardwiring, but for natural origin Puget Sound Chinook salmon populations, subyearling migration in freshwater, estuary, and into the nearshore environment can coincide with environmental events (e.g., floods that trigger migration or flush individual fish out of habitat areas), or can be due to competition between other individuals within the population (i.e., density dependence). We provide a conceptual diagram of juvenile Chinook salmon density dependence in sequence for the freshwater and estuary rearing life stage (Figure 4.1.2) to help interpret juvenile Chinook salmon data in following sections of this report.

Table 4.1.1. Size and timing of juvenile Chinook salmon migrants by life history type at the transition from freshwater to estuary and estuary to nearshore. “na” = not applicable (i.e., the condition does not occur). Table from Greene et al. 2015.

	Subyearlings				
Size characteristics	**Tidal delta rearing migrant**	**Fry migrant**	**Nearshore refuge rearing fry migrant**	**Parr migrant**	**Yearling**
Size at outmigration from freshwater to (or through) estuary (range in mm)	< 45	< 45	< 45	>45 - 90	80 - 150
Size at outmigration from estuary to nearshore (average and range in mm)	74 (46-124)	39 (30-46)	39 (30-46)	75 (57-92)	120 (92-154)
Size at outmigration from nearshore refuge habitat to open water (average and range in mm)	na	na	55 (45-66)	na	na
Timing characteristics					
Timing at outmigration from freshwater to (or through) estuary (months inclusive)	Jan-Apr	Jan-Apr	Jan-Apr	Apr-Aug	Mar-Apr
Timing at outmigration from estuary to nearshore (months inclusive)	Apr-Aug	Jan-Apr	Jan-Apr	Apr-Aug	Mar-Apr
Timing at outmigration from nearshore refuge habitat to open water (months inclusive)	na	na	Apr-Jul	na	na

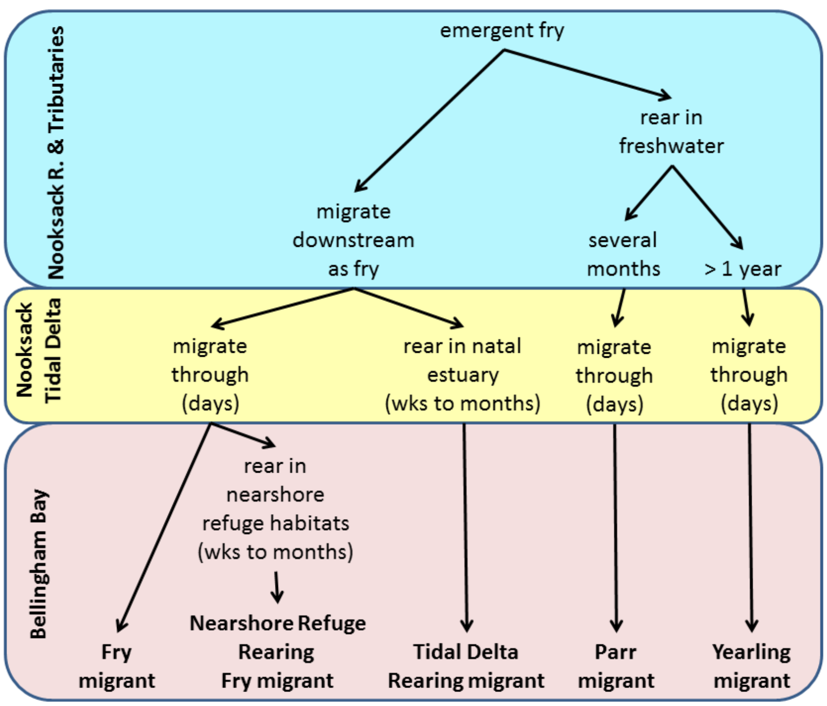


Figure 4.1.1. Phenotypic branching of juvenile Nooksack Chinook salmon by major ecological zones, resulting in five distinct juvenile life history types.

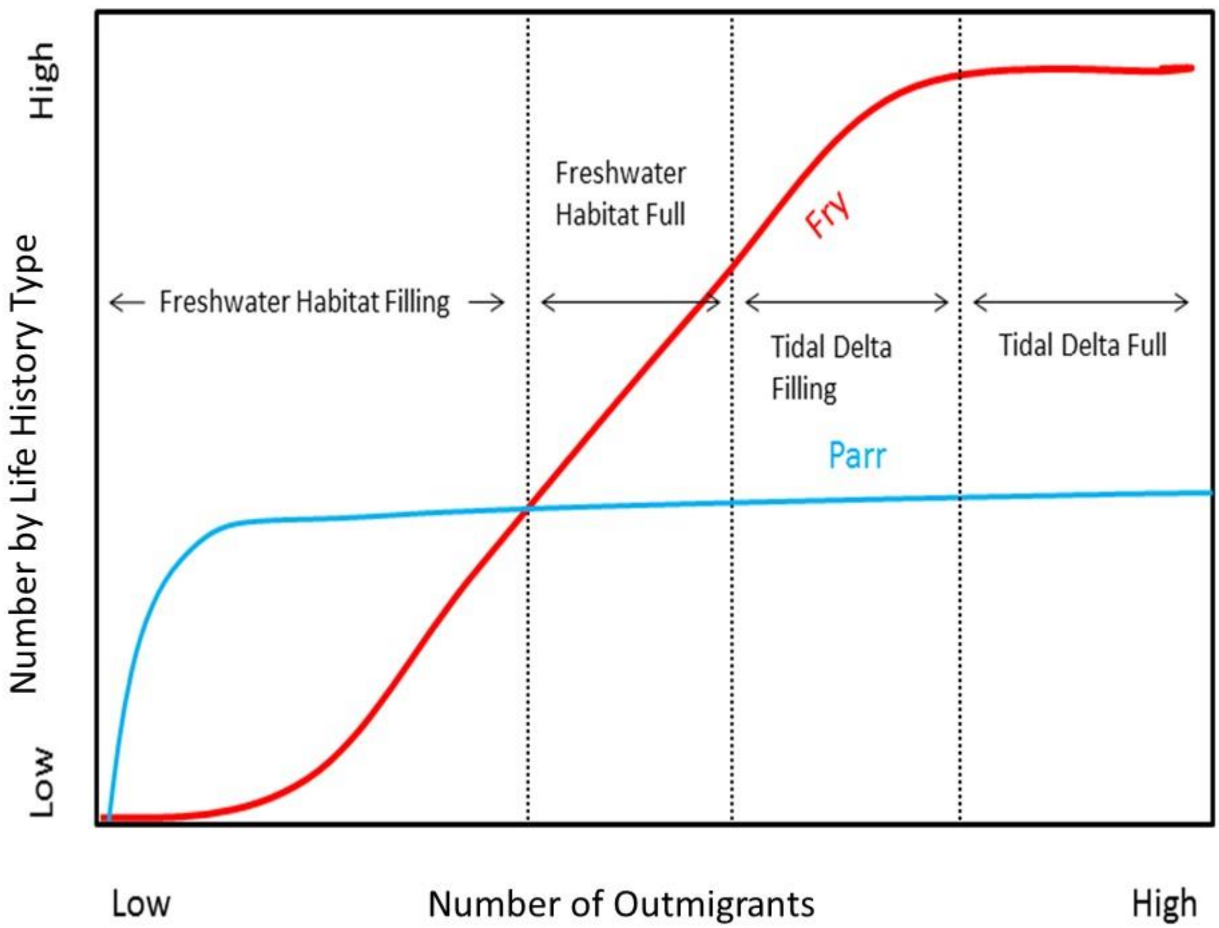


Figure 4.1.2. Conceptual diagram of juvenile Chinook salmon density dependence in sequence by life stage and habitats. As freshwater habitat fills with individuals, the number of fry migrants increase and the number of parr migrants level off. Fry migrant abundance continues to increase as tidal delta habitats fill, then levels off once that habitat is full. The distance between boundaries of full or filling habitat varies by the unique combination of habitat extent and quality and the number of migrants in the Chinook population.

4.2 Outmigrants

Juvenile Chinook salmon within our study area (Nooksack tidal delta, Bellingham Bay nearshore) could be from natural origin recruits (NOR) or hatchery origin recruits (HOR) from within the Nooksack River, tributaries within Bellingham Bay, or other nearby Chinook salmon bearing rivers (e.g., Samish River). In this section we present population estimates of NOR and HOR juvenile Chinook that are or could be in our study area.

NOR Chinook outmigrants from Nooksack River

Methods

We used existing Nooksack River NOR Chinook outmigration data from 2005-2015 to determine whether hypothesized juvenile life history types are present in the Nooksack River system. Through graphical and regression analysis, we determine the abundance, timing and size of the parr and fry life history types as they migrate through the lower Nooksack River. NOR juvenile Chinook catch data are from a rotary screw trap which is operated by LNRD near Ferndale. Trapping and population estimation methods are described in section 3.1 of this report.

Results and discussion

All three hypothesized juvenile life history types for freshwater are present in observed outmigrations of the Nooksack River NOR Chinook population (Table 4.2.1; Figure 4.2.1). Fry dominate the subyearling outmigration until late February or March when individual fish expressing the parr migrant life history type begin to move through the lower river (Figures 4.2.2 and 4.2.3). By March, a mixture of fry and parr make up the outmigration until late April. After April, fry have generally moved through the freshwater system. Parr continue to outmigrate until late August and usually peak in June. Yearlings have outmigrated the river by late April.

Numerically, the parr life history type dominates the total Nooksack River NOR Chinook outmigration. Fry migrants are a much smaller portion of the total (Table 4.2.1; Figure 4.2.4 top panel). There is a very strong linear function of parr migrants with total subyearling outmigrants ($r^2 = 0.99, P = 7.4 \times 10^{-11}$). Nooksack River fry migrants have a strong exponential relationship with total subyearling outmigrants ($r^2 = 0.77, P = 0.0004$). At the upper range of observed subyearling outmigrations (300,000/year) the rate of fry migrants to total outmigrants is visibly increased.

Relatively few fry are migrating out of the Nooksack River as a percentage of the total juvenile outmigration population compared to the Skagit River, which is known to have density dependence in sequence, starting in freshwater habitats (Zimmerman et al. 2015) and the estuary (Beamer et al. 2005, Greene et al. 2015). The two river systems exhibit opposite relationships for fry and parr expression by total outmigration size, but plotted together the trends combine for continuous functions for both parr and fry consistent with our conceptual model for density dependence of sequential life stages/habitats (see Figure 4.1.1 above). In this case, we observe freshwater production of juveniles in two different river systems. The Skagit typically experiences density dependence in freshwater and exports the excess fish as fry migrants while the Nooksack typically is not filling up its freshwater habitat, so proportionally few fish migrate as fry.

In contrast to the Skagit River, Nooksack River NOR Chinook outmigration results show the freshwater system is underseeded for parr migrants. The conclusion is based on Figure 4.2.4, which shows parr migrant abundance increasing as a very strong linear function of total outmigrants. There is no evidence, over the range of the dataset, of any leveling-off of parr migrant production. Parr migrants typically utilize freshwater rearing habitats for two to three months before migrating. It is during the freshwater rearing life stage of parr migrants that this habitat is underseeded. The causes of underseeded freshwater habitat should be addressed (or studied, if not known). The cause(s) could occur anywhere within the Chinook life cycle between spawners and dispersal of emergent fry into freshwater rearing habitat. It should not be automatically assumed the cause would be due to fishing resulting in too few spawners. In fact, the operating hypothesis for WRIA 1 is that Chinook salmon egg to fry survival is lower than expected (WRIA 1 Salmon Recovery Plan). If true, then improved habitat quality in the spawning and egg incubation areas will produce more emergent fry which will help fill vacant freshwater rearing habitat for parr migrants. An effective integrated hatchery program may also help offset poor egg to fry survival. If underseeding is solved, then at some point the Nooksack River system will begin to show signs of reaching freshwater rearing capacity for parr migrants. Spatial distribution of the Chinook populations within the Nooksack River system will complicate the carrying capacity detection of the various habitats within the river system. This could be figured out with good genetic monitoring of juveniles at the outmigrant trap and a good understanding of the spawning range for each population (as well as their escapement levels).

The HOR juvenile Chinook outmigration is synchronous in the lower Nooksack River with NOR parr migrants but not with NOR fry nor yearling migrants (Figure 4.2.2). The HOR migrants and NOR parr migrants are passing through the lower Nooksack River from mid-April though early July, peaking sharply in late May. Comingling of HOR and NOR fish can create negative ecological interactions, such as competition for available rearing habitat and food, increased predation, and introduction of disease and parasites on natural origin fish (Kostow 2009). However, as earlier stated, we found no evidence of density dependence occurring in the freshwater system for NOR parr migrants (Figure 4.2.4). The fact that comingling of HOR and NOR parr exists at outmigration does not necessarily mean there is adverse interaction response by NOR parr. It makes sense that HOR migrants would not have an opportunity to interact with NOR parr, except during outmigration (and later), because HOR fish are generally within the confines of their hatchery during the time that NOR fish are rearing within freshwater habitat before outmigrating as parr.

Conclusions and recommendations

1. The current Nooksack River NOR Chinook population is made up of individuals that can take advantage of habitat opportunities within the Nooksack River, Nooksack tidal delta, and Bellingham Bay nearshore as conceptualized in the life history type section of this report (see Figure 4.1.2 above).
2. The Nooksack NOR Chinook outmigration results, along with the comparison with Skagit, suggests the Nooksack River basin's freshwater system is not at carrying capacity for parr migrants, but possibly showing the beginning signs of density dependent pressure at the upper levels of observed total outmigration (300,000 fish/year, or higher).
3. Comingling of NOR and HOR juvenile Chinook within the lower Nooksack River occurs after most NOR fry and yearlings have outmigrated and is synchronous with the NOR parr outmigration.
4. The causes of the underseeded freshwater habitat for parr migrants should be addressed (or studied, if not known).

Table 4.2.1. Summary of NOR juvenile Chinook salmon outmigrating the lower Nooksack River near Ferndale by life history type.

Outmigration year	Fry	Parr	Yearling	Total
2005	5,926	233,797	11,383	**251,106**
2006	12,501	266,515	8,533	**287,549**
2007	2,518	46,628	5,156	**54,302**
2008	26,325	268,163	623	**295,111**
2009	4,097	114,564	23,520	**142,181**
2010	1,147	126,775	11,664	**139,586**
2011	9,951	284,752	3,734	**298,437**
2012	43,392	281,893	7,145	**332,430**
2013	7,602	130,202	12,056	**149,860**
2014	1,075	82,244	7,019	**90,338**
2015	293	32,832	1,701	**34,826**
11-year average	**10,439**	**169,851**	**8,412**	**188,702**
Percent of total	**5.5%**	**90.0%**	**4.5%**	

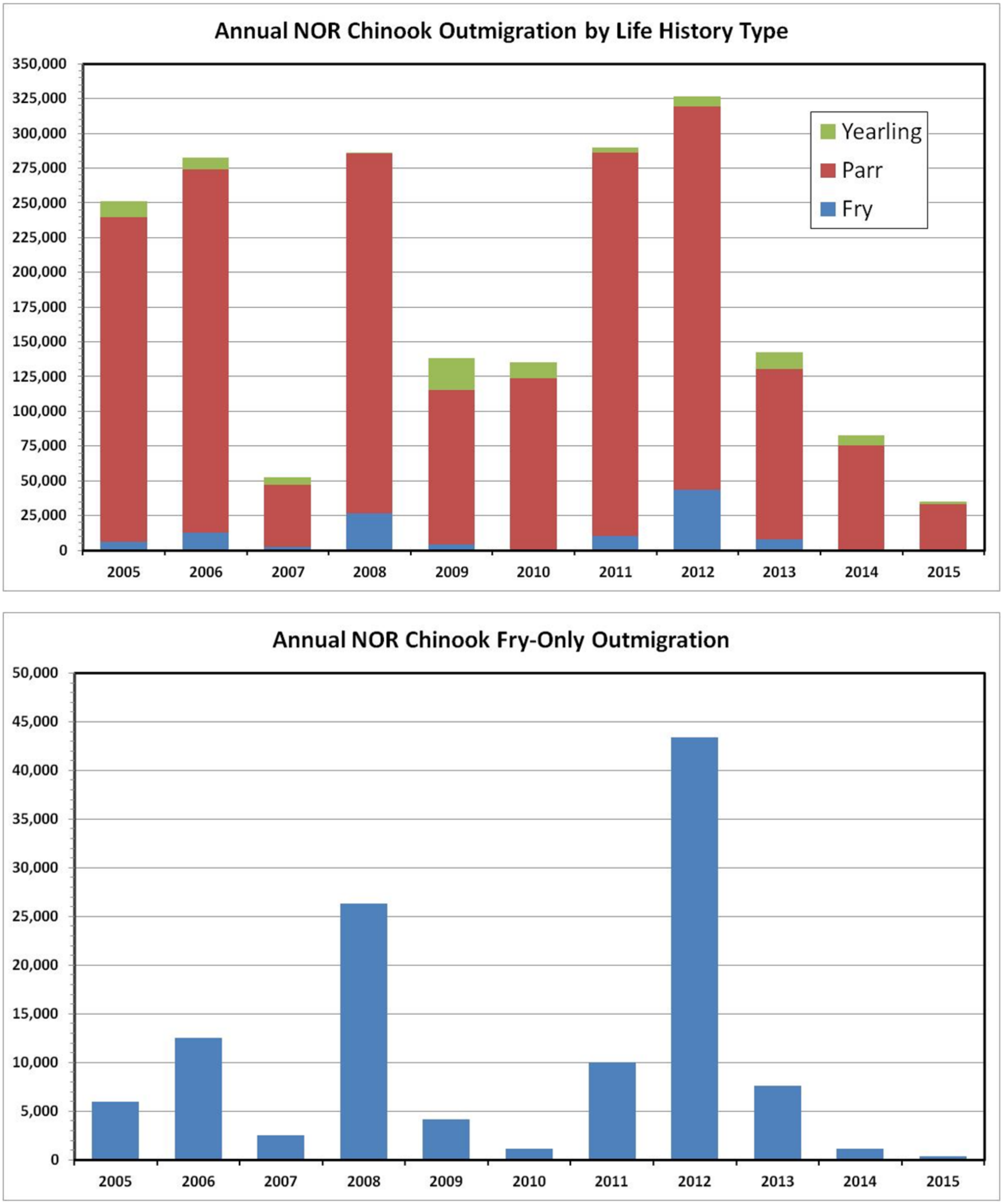


Figure 4.2.1. Annual population estimates of NOR juvenile Chinook outmigrating the Nooksack by all life history types (top panel) and fry only (bottom panel). Data from Lummi Natural Resources.

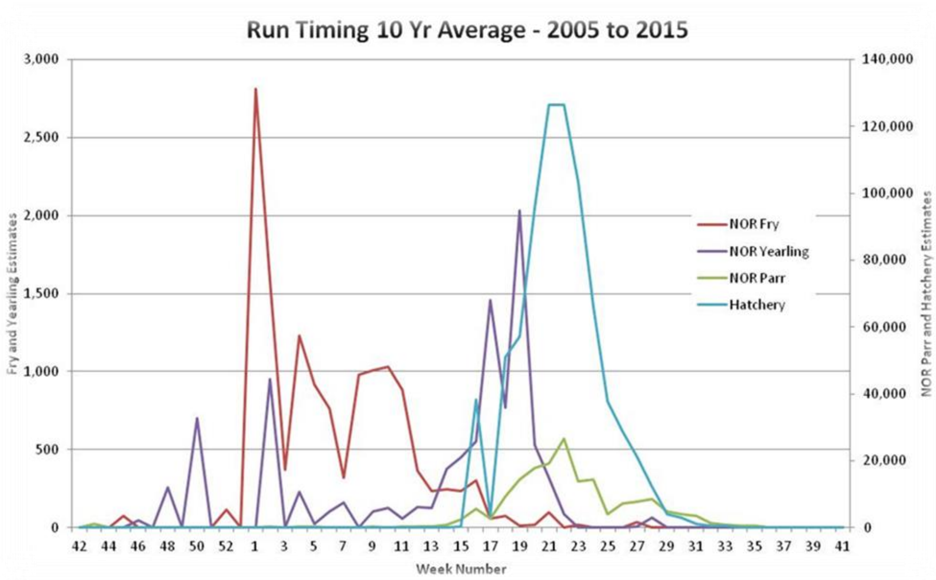


Figure 4.2.2. Ten-year average outmigration timing in the lower Nooksack River of NOR and HOR juvenile Chinook salmon. Data from Lummi Natural Resources.

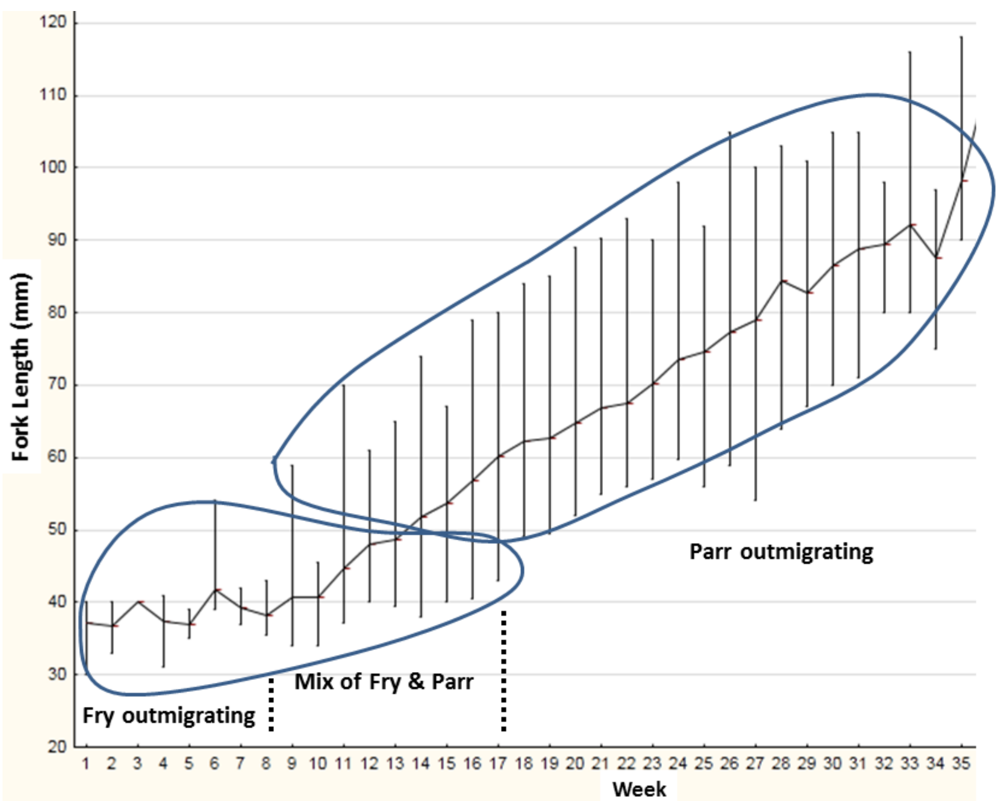
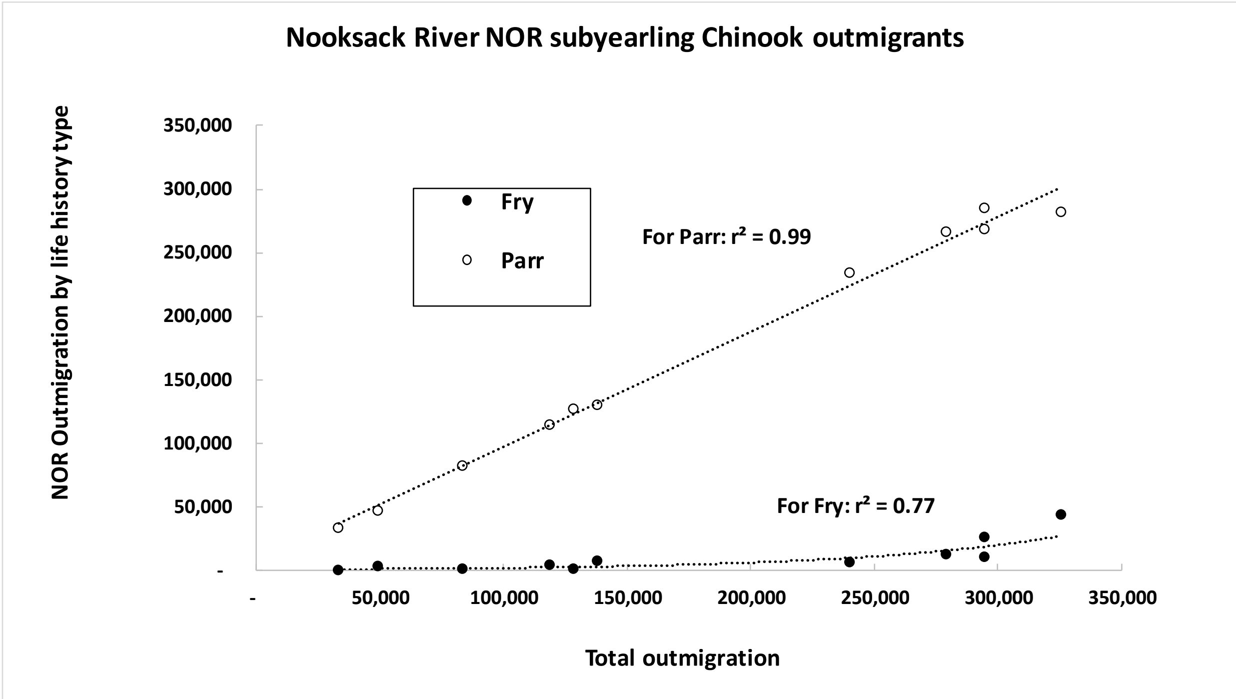


Figure 4.2.3. Example outmigration year showing the length (mean and range) of Nooksack River NOR subyearling Chinook over time during migration. Data from Lummi Natural Resources. The fry (< 50 mm fork length) and parr (>50 mm fork length) populations are circled.



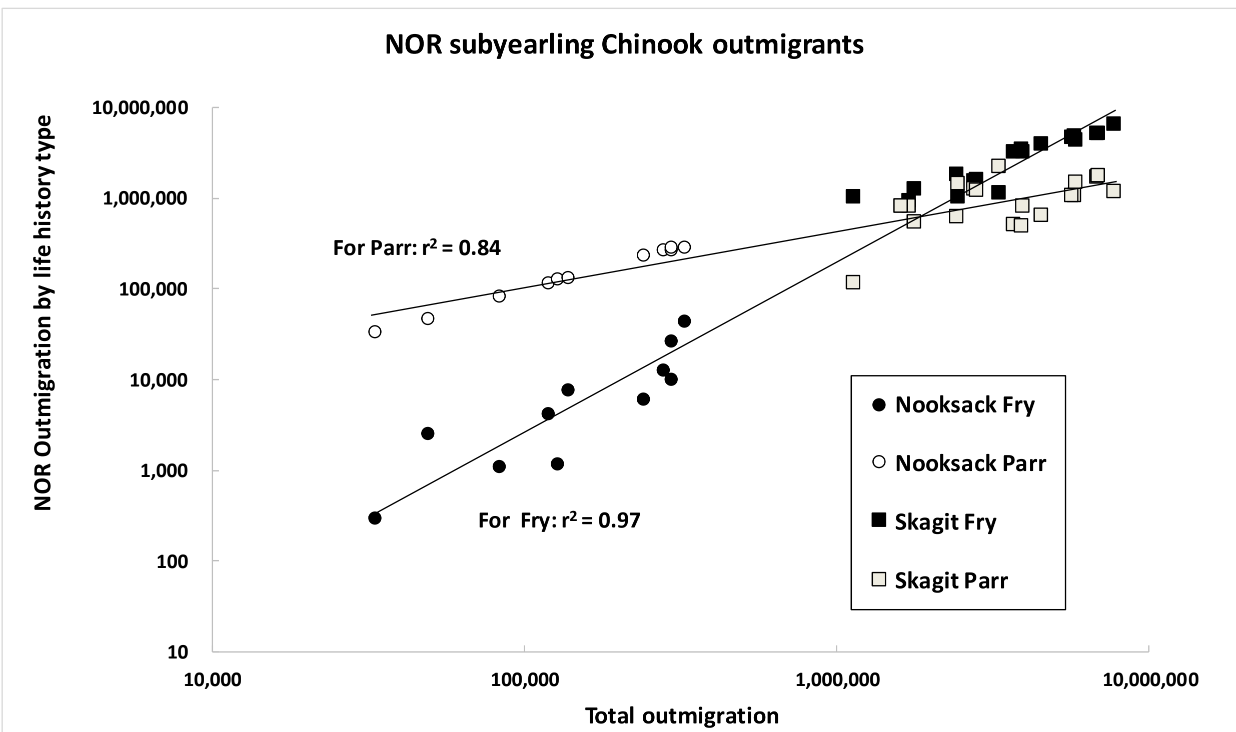


Figure 4.2.4. Expression of two NOR juvenile Chinook salmon life history strategies as a function of total subyearling outmigration size for the Nooksack River trapping years 2005 – 2015 (top panel) and Nooksack River and Skagit Rivers combined (bottom panel). Skagit data are for trapping years 1997 – 2015 (from Zimmerman et al. 2015 with additional years added courtesy J. Anderson and C. Kinsel of WDFW, pers. comm.).

NOR Chinook outmigrants from Bellingham Bay independent tributaries

We have accounted for NOR juvenile Chinook migrants entering the study area via the Nooksack River. In the next section of this chapter we account for HOR juvenile Chinook releases associated with the study area. However, there are several independent streams draining directly into Bellingham Bay that may be producing NOR Chinook migrants, and there are no estimates for migrants attributed to these streams. In lieu of sampling and counting juvenile migrants from these streams we analyzed existing spawner survey data from four independent streams draining into Bellingham Bay to determine whether these streams are a source of juvenile Chinook salmon in the study area, especially for the eastern side of the Bellingham Bay nearshore.

Methods

We examined existing spawner survey data from four independent watersheds (Whatcom Creek, Squalicum Creek, Padden Creek and Chuckanut Creek) to determine whether any stream had consistent presence of Chinook salmon spawners, and if so, whether we could estimate annual spawner abundance to pair with juvenile Chinook beach seine data. We used over 500 spawner surveys covering over 400 miles of index stream reaches collected in spawner years 2000-2014. The spawner survey years coincide with juvenile recruits that would have outmigrated 2001-2015 as subyearling fry or parr.

The spawner surveys were conducted by Washington Department Fish and Wildlife (WDFW), the Nooksack Salmon Enhancement Association (NSEA), and City of Bellingham (COB). These data are available through NSEA's website via reports (or spreadsheets by request). A summary of the spawner survey data used for this analysis is provided as Appendix 3.

The spawner survey effort was not designed to estimate Chinook salmon escapement for each stream so our first analysis step was to examine the survey period for each stream and year to determine whether surveys were conducted at the correct time of year to detect Chinook spawners. We did this by establishing a timing curve of Chinook spawner presence probability for the four streams based on the survey record (Figure 4.2.5). If Chinook spawning was present, the timing of spawning occurred as early as week 39 (i.e., end of September) and ran until week 48 (i.e., third week of November). We then only used surveys in our analysis that were done during the period when Chinook salmon would be expected so that we would not over-count observations of Chinook absence. Based on this analysis, we used spawner surveys that occurred from late September to mid-November each year to determine Chinook presence/absence and relative spawner abundance. We made the cutoff for using surveys mid-November to avoid erroneously including counts of coho salmon redds as an indication of Chinook spawning.

Having established which spawner survey records qualified as an indication of Chinook spawning, we calculated: 1) years of Chinook spawning presence/absence, 2) annual peak counts of live and dead Chinook spawners, and 3) total redds attributed to Chinook spawners for each stream. Cemetery Creek (a tributary to Whatcom Creek) is shown separately because of its extensive spawner survey. All other streams are shown as a single result even though some streams have multiple index spawner survey reaches.

Results

Results from the NSEA/COB spawner surveys reveal that only Whatcom Creek has regular spawning of Chinook salmon (Figure 4.2.6., top left panel). Thirteen of the 14 years surveyed at Whatcom Creek found Chinook spawning present whereas Chinook were consistently absent in the three other creek systems in most years.

Average annual peak live + dead counts and total redd counts of Chinook in Whatcom Creek were 12.1 fish and 21.6 redds, respectively (Figure 4.2.6, bottom left panel). In contrast, the three other creek systems average much less than one fish or redd per year.

Within Whatcom Creek index reaches, up to 99 peak live + dead Chinook salmon have been observed but recent peak live + dead counts have been much lower (Figure 4.2.6, top right panel). Total Chinook redds in index reaches of Whatcom Creek range from a low of zero to a high of 34 redds, which occurred in 2012 (Figure 4.2.6, bottom right panel).

Discussion

Whatcom Creek appears to be the only stream system of the four with strong evidence of annual Chinook spawning activity. Moreover, when Chinook spawning was present, Whatcom Creek had the highest estimates of relative Chinook spawner abundance, whether measured as Peak live + dead fish or redd counts. However, these conclusions must be considered in the context of the limitations of the spawner survey data. Data limitations may result in inaccurate Whatcom Creek Chinook spawner estimates and/or under-detection of Chinook spawners in the other watersheds. Limitations include the following:

1. We used surveys only from a time period when Chinook spawning was possible, by trimming the dataset outside the normal Chinook spawning period. This was primarily a means of not over-counting observations of Chinook absence occurring later in the year when other salmon species are spawning. However, the spawner survey dataset is likely biased against detecting Chinook spawning early in the season because the majority of spawner surveys each year started between late September and the middle of October. Only 15% of the surveys in the dataset started earlier than the middle of September, and anecdotal observations have observed Chinook spawning before late September in some years (Analiese Burns, personal communication). The lack of early spawner surveys means the dataset under-detects the number of Chinook spawners for the four stream systems if significant early Chinook spawning occurs.
2. A significant limitation in the spawner survey remains: the use of index reaches instead of a methodology that would result in a full watershed census of spawning areas. We did not evaluate whether the index reaches surveyed are representative of Chinook spawning within each watershed. If the index reaches represent the watersheds well, then our results for Chinook spawner presence and abundance between watersheds are likely correct. If the index reaches do not represent the watersheds well, then significant Chinook spawning activity within Squalicum, Padden, or Chuckanut Creeks may be undetected.
3. Additionally, Whatcom Creek spawner survey results may not be a good index of true Chinook spawner abundance each year because viewing conditions in Whatcom Creek are poor due to the drawing down of Lake Whatcom. Poor viewing conditions likely result in

missed fish and redds so our relative spawner or redd abundance estimates are likely biased low. Assuming total redds per year are correct and using average values for female Chinook per redd (1), female fecundity (4,947 from Zimmerman et al. 2015), and egg to migrant fry survival (4.5%, low from Zimmerman et al. 2015), the number of juvenile Chinook migrants contributing to Bellingham Bay nearshore habitat averaged 2,600 juveniles per year over the 2003-2015 period, the years of the Bellingham Bay nearshore beach seining record. Even though the 2,600 juveniles per year is a crude estimate of Whatcom Creek NOR Chinook outmigrants, the estimate does provide an order of magnitude idea of the number of fish originating from independent streams on the eastern side of Bellingham Bay to go along with Nooksack River NOR Chinook outmigrant estimates.

One additional line of evidence supports our findings of the low level and frequency of Chinook spawning in Squalicum Creek watershed. Squalicum Creek has been smolt trapped three different years, most recently in 2015, and no juvenile Chinook migrants have been observed (COB smolt trap data summary, found at: https://www.cob.org/Documents/pw/environment/restoration/2001-2015-squal-creek-smolt-trap-summary-final.pdf). However, the trapping methods utilized weir and trap box screens that Chinook fry would be able to swim through. That said, COB smolt trapping efforts using the same screen mesh size in Baker and Spring Creeks did detect the presence of juvenile salmonids as small as 50 mm in length which is within the size range of outmigrating subyearling juvenile Chinook salmon. While the smolt trapping results in Squalicum Creek are not designed for enumerating juvenile Chinook outmigrants, it is likely that juvenile Chinook would have been at least detected if many were present during the period and years of trapping.

We did not investigate whether the regular occurrence of spawning Chinook represents a NOR population or whether the spawners are a function of hatchery strays from the large Fall Chinook program within the Nooksack/Samish Management Unit. We were interested in whether streams directly entering the Bellingham Bay nearshore might be seeding nearshore or pocket estuary habitat with Chinook fry in addition to fish originating from the Nooksack River. Whatcom Creek most certainly is producing some Chinook fry each year. We included a covariate for spawner abundance in analyses exploring NOR juvenile Chinook density patterns in habitats of the Bellingham Bay nearshore (see section 4.4).

Conclusions and recommendations

1. Whatcom Creek has consistent annual presence of Chinook salmon spawners. Understanding the relative importance of Whatcom Creek requires additional study.
2. Up to several thousand NOR juvenile Chinook migrants are likely produced annually from spawners within Whatcom Creek.
3. We recommend spawner surveys be designed to better detect Chinook presence and abundance if WRIA 1 salmon recovery efforts want to account for NOR Chinook contributions from independent streams draining into Bellingham Bay.

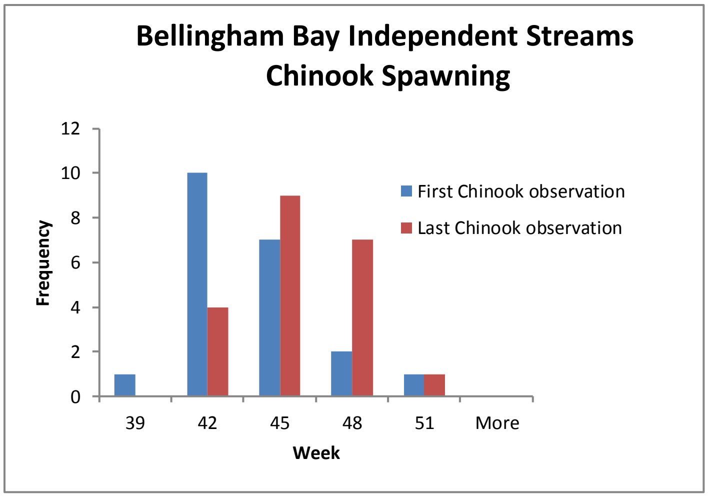


Figure 4.2.5. Frequency distribution by statistical week of first and last observations of spawning Chinook salmon (i.e. presence of live or dead fish, and/or redds) for combined years in four independent streams that drain into Bellingham Bay. Data are from 21 observations of Chinook presence (see Appendix 3 for summary of spawner survey dataset by stream and year). Week 39 coincides with late September. Week 48 coincides with the third week in November.

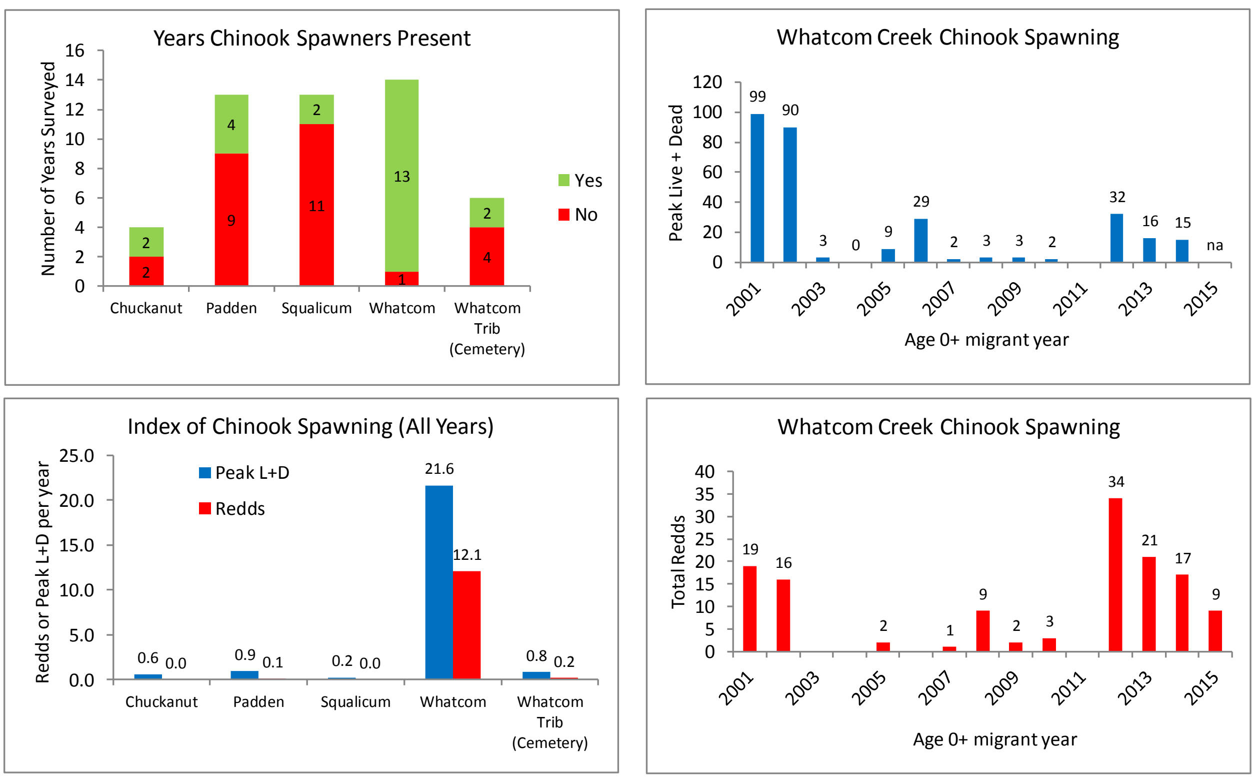


Figure 4.2.6. Results of spawner surveys in four independent streams draining into Bellingham Bay including: (top left) number of years Chinook spawning was present/absent for each stream; (bottom left) average annual peak live + dead counts of Chinook for each stream; (top right) annual peak live + dead count of Chinook; and (bottom right) total redds made by Chinook in Whatcom Creek surveyed reaches.

HOR Chinook releases into the Nooksack/Samish Management Unit

Hatchery origin (HOR) juvenile Chinook may be an important factor in estuary/nearshore habitat utilization depending on the numbers released and their size and timing of release. Unmarked hatchery releases would be confused with NOR juvenile Chinook salmon in our beach seine sampling, therefore it is important to know how many unmarked hatchery fish are in our study area each year. In this section we report HOR juvenile Chinook releases into or near the study area.

Methods

Hatchery Chinook salmon release data were downloaded from the Regional Mark Information System (RMIS) database (http://www.rmis.org/rmis_login.php?action=Login&system=cwt) for the Nooksack River and Bellingham, Samish and Lummi Bays. We selected this geographic area because of its proximity to our beach seine sampling sites. We checked the release data for accuracy with LNRD staff and made corrections as necessary, resulting in a table of hatchery releases of juvenile Chinook salmon summarized by four release areas (Lummi Bay, Nooksack River, Samish River, and Whatcom Creek) within the Nooksack/Samish Management Unit by year (2004-2015).

Results and discussion

On average 5.5 million HOR juvenile Chinook have been released into the Nooksack/Samish Management Unit each year from 2004 through 2015 (Table 4.2.2). The number of HOR fish released has remained relatively constant since 2008 (Figure 4.2.7, top panel). Two distinct periods exist for hatchery releases of juvenile Chinook with respect to marking practices (years before 2006; year 2006 and after) (Figure 4.2.7, bottom panel). In the two years prior to 2006 hundreds of thousands of unmarked hatchery Chinook were released (average of 644,000 fish/year for the entire area; average of 384,000 fish/year for the Nooksack River). In 2006 marking practices changed so that a greater percentage of fish that were released were marked. In 2006 to 2015 unmarked hatchery Chinook releases have averaged about 19,000 fish/year for the entire management area and <6,000 fish/year for the Nooksack River.

Depending on when unmarked HOR juveniles are released they would be confused as NOR fry or parr life history types. Hatchery releases in the Nooksack River occur at the time of year and fish size consistent with NOR parr size and outmigration timing (see Figure 4.2.2 above). Thus, unmarked HOR Chinook would be confused with NOR parr in the Nooksack River outmigration estimates or any beach seining effort located in the tidal delta or nearshore.

On average, there has been over seven times more HOR Chinook parr (marked and unmarked combined) than NOR Chinook parr originating within the Nooksack River system each year since 2006 (Table 4.2.3). However, there are on average over 28 times more NOR Chinook parr than unmarked HOR Chinook parr each year, which minimizes the effects of mistaking unmarked HOR as NOR juvenile Chinook.

Over five million HOR juvenile Chinook are released into, or near, the study area each year in contrast to up to several hundred thousand NOR juvenile Chinook outmigrating the Nooksack River. Thus, the juvenile Chinook population using the study area each year is dominated by HOR fish. How HOR fish utilize the study area (i.e., delay and rear in specific habitat areas) will dictate whether there is competition between HOR and NOR juvenile Chinook in any particular habitat area. Earlier in this report we showed outmigration timing of HOR migrants to be synchronous in the lower Nooksack River with NOR parr migrants but not NOR fry nor yearling migrants (see Figure 4.2.2 above) even though we found no evidence of density dependence occurring in the freshwater system for NOR parr migrants. In our Chinook life history conceptual model (section 4.1), we show parr migrants, whether of natural or hatchery origin, generally do not establish extended residence in natal estuary habitat or nearshore refuge habitat such as non-natal pocket estuaries or small independent streams. They are generally too large and arrive too late in the year to occupy the habitats that estuary and nearshore fry occupy earlier in the year. We explore how true these hypotheses are for the study area in section 4.3.

Conclusions and recommendations

1. The total juvenile Chinook population using the study area each year is dominated by releases of HOR fish from within or nearby the study area.
2. Although millions of HOR juvenile Chinook are released into the Nooksack/Samish Management Unit, fish marking practices are good so the effects of mistaking unmarked HOR juveniles with NOR juveniles are minimized.
3. Whether there is potential for adverse ecological interactions between HOR and NOR juvenile Chinook depends on the extent that HOR fish comingle with NOR fish. This topic may need future study if adverse ecological interactions are suspected between NOR and HOR fish.

Table 4.2.2. Summary of juvenile Chinook hatchery releases directly into the Nooksack/Samish Management Unit. Releases are summarized by year and release location at the river system level. Marked fish have either a coded wire tag or adipose fin clip (or both). Unmarked fish do not have coded wire tags or adipose fin clips.

Basin	Year	Marked	Unmarked
Lummi Bay	2004	510,492	0
	2005	435,915	0
	2006	331,758	2,992
	2007	655,971	9,584
	2008	465,516	10,766
	2009	601,098	1,282
	2010	268,773	2,715
	2011	450,000	0
	2012	256,720	0
	2013	375,210	3,790
	2014	323,400	0
	2015	543,510	6,355
Nooksack River	2004	948,873	407,627
	2005	763,640	499,385
	2006	735,266	5,164
	2007	611,461	2,110
	2008	1,367,202	9,278
	2009	1,134,758	3,742
	2010	1,268,825	4,553
	2011	1,226,233	8,760
	2012	1,243,815	5,924
	2013	1,290,747	7,260
	2014	1,933,523	7,951
	2015	1,468,936	5,167
Samish River	2004	3,483,332	160,815
	2005	3,473,365	196,546
	2006	2,602,264	4,169
	2007	2,819,511	0
	2008	4,086,003	0
	2009	3,435,649	18,039
	2010	4,954,151	17,588
	2011	4,004,261	6,065
	2012	3,974,915	27,375
	2013	4,001,031	7,393
	2014	3,996,638	7,337
	2015	3,921,895	6,519
Whatcom Creek	2004	0	0
	2005	0	24,099
	2006	0	0
	2007	0	0
	2008	0	0
	2009	89,715	285
	2010	0	0
	2011	0	0
	2012	36,000	0
	2013	0	0
	2014	0	0
	2015	0	0

Table 4.2.3. Summary of NOR juvenile Chinook outmigrants and HOR Chinook releases for the Nooksack River. NOR results are 11-year average outmigrations (from Table 4.2.1). HOR results are from Table 4.2.2.

Life stage (at migration or release)	NOR Chinook outmigrants	HOR Chinook Release		Ratios	
		Total (marked & unmarked)	Unmarked only	HOR/ NOR	NOR/ unmarked HOR
fry	10,439	0	0		
parr	169,851	1,234,068	5,991	7.3	28.4
yearling	8,412	0	0		

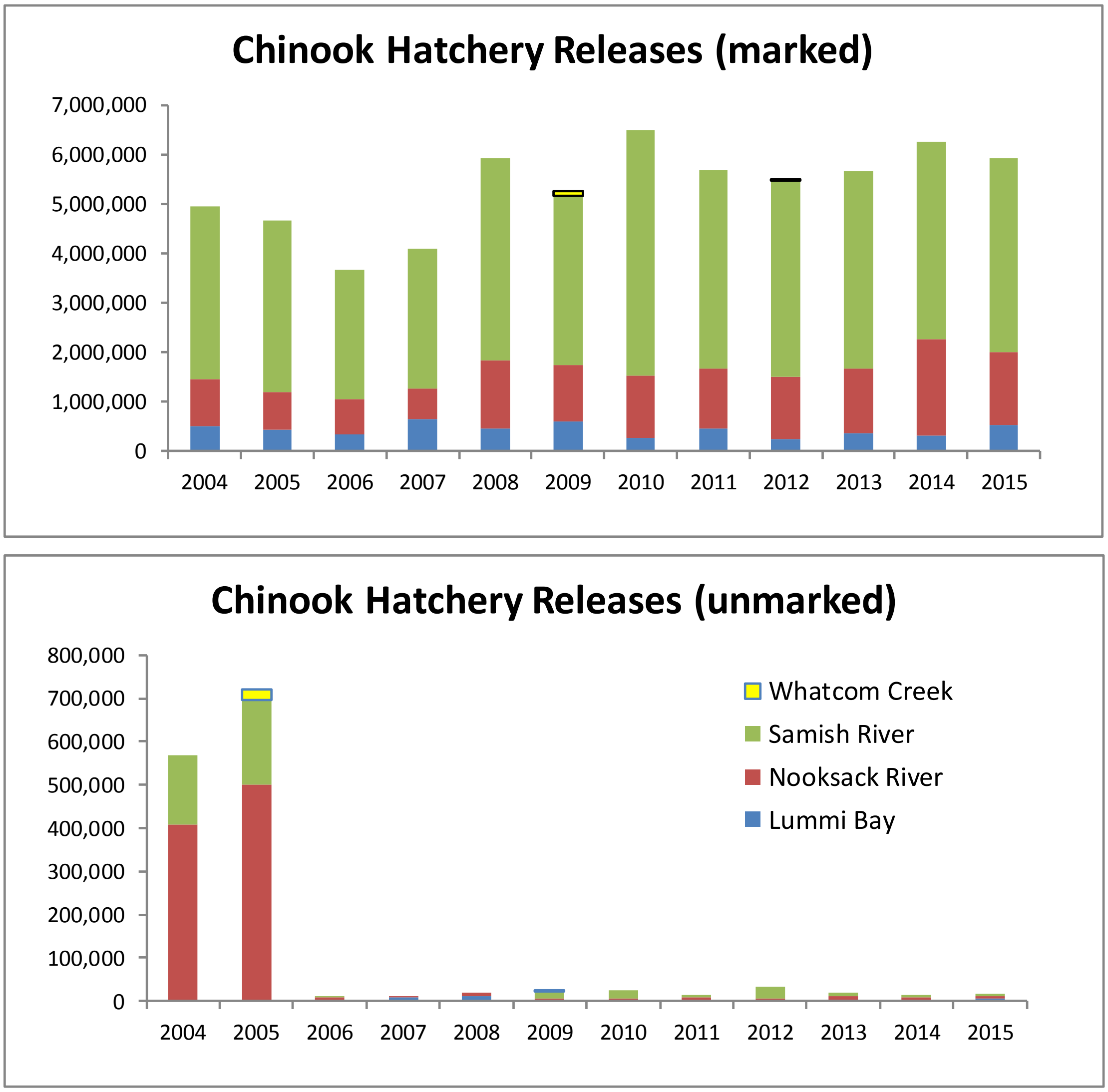


Figure 4.2.7. Summary of juvenile Chinook hatchery releases directly into the Nooksack/Samish Management Unit. Releases are summarized by year and release location at the river system level. Top panel is marked (CWT, adipose fin clip) fish; bottom panel is unmarked fish. Note difference in y-axis values.

4.3 Timing, relative abundance, size, and habitat associations of juvenile Chinook

This section presents patterns of NOR and HOR juvenile Chinook timing, relative abundance, and size in the Nooksack tidal delta and Bellingham Bay nearshore. We compare NOR and HOR juvenile Chinook patterns by simplified habitat types and pair NOR and HOR density results to NOR outmigration estimates and HOR juvenile Chinook release data from the Nooksack River to determine the likelihood of differential residence rates between NOR and HOR migrants by habitat type.

Methods

We only used juvenile Chinook density data from 2014 and 2015. These two years provide a more complete temporal and spatial sampling compared to all other years. Beach seine sampling occurred at each site twice per month with Nooksack tidal delta sites being sampled February through August (both years) and Bellingham Bay shoreline sites being sampled February through October in 2014 and February through August in 2015. Sample site locations and habitat types were shown in Figure 3.2.2 above. A detailed description of the methods used for beach seining, fish data processing, and fish density estimation is described in section 3.2 of this report.

We use graphical analysis to illustrate the timing, relative abundance, and size of NOR and HOR juvenile Chinook salmon by system (Nooksack tidal delta, Bellingham Bay nearshore) and combined habitat type for Bellingham Bay nearshore sites (exposed nearshore, pocket estuary). We included graphical results for one non-natal small stream sampled on Portage Island in 2015.

We used ANOVA methodology to determine differences in NOR juvenile Chinook density by three habitat types (tidal delta, exposed nearshore, and pocket estuary) and by two sampling periods (fry, parr). The fry period is from February through April and coincides with the bulk of the NOR fry migration from the Nooksack River. The parr period is from May through August and coincides with the bulk of the NOR parr migration from the Nooksack River. To reduce the effects of non-normal data distribution, zeros, and unequal variance, Chinook salmon densities were $\log_e$ transformed as: $\ln(x+1)$. Pair-wise testing (Tukey's Honestly Significant Difference Test) was used to compare fish density differences between habitat types and periods.

Results and discussion

Timing and abundance: Timing and abundance curves of NOR and HOR juvenile Chinook by system (Nooksack tidal delta, Bellingham Bay nearshore) and year is shown in Figure 4.3.1. The NOR juvenile Chinook were present in the Nooksack delta at low levels from February through April, peaking in May and then showing a steady decline in 2014. The pattern was somewhat different in 2015 when peak NOR juvenile Chinook abundance in the tidal delta occurred in March.

The NOR Chinook in Bellingham Bay were present along the shoreline at high levels in February through its peak in May, and then showed a dramatic decline in June, which continued through the end of sampling in 2014. In 2015, the early timing of NOR juvenile Chinook in Bellingham Bay nearshore was even more pronounced, peaking in February and declining through April and remaining at a low level through the remainder of sampling.

The vast majority of NOR juvenile Chinook captured in Bellingham Bay shoreline sites were in pocket estuary habitats (Figure 4.3.2). The pattern is consistent for both years. In fact, NOR juvenile Chinook densities in Bellingham Bay pocket estuary habitat were higher than NOR Chinook densities observed in the Nooksack tidal delta or exposed nearshore habitat for both the fry and parr time periods (Tables 4.31 and 4.3.2). The NOR juvenile Chinook residence in pocket estuary habitat occurred early in the season, February through May, consistent with findings of Chinook fry use of non-natal pocket estuaries within the Whidbey Basin (Beamer et al. 2003; Beamer et al. 2006). We have limited data for a non-natal stream being used as a nearshore refuge habitat, but the results from the one stream (Figure 4.3.2, lower right panel) is consistent with findings of Chinook fry use of small non-natal streams within the Whidbey Basin where juvenile Chinook are found in small streams early in the year (Beamer et al. 2013).

The Nooksack River NOR Chinook outmigration results show there were very few fry migrants in 2014 and 2015 (see Table 4.2.1 above), yet our largest catches of NOR juvenile Chinook (both years in Bellingham Bay nearshore; 2015 only for the tidal delta) were early in the year and were fry sized. In contrast, millions of HOR Chinook parr were released in the Nooksack River both years, yet our catches of HOR juvenile Chinook were relatively low compared to NOR juvenile Chinook over the entire study area over both years (Figure 4.3.1 and 4.3.2). These contrasting results may seem counter intuitive, but a likely explanation is that the relatively few NOR juveniles are actively residing in rearing habitats (i.e., remaining for weeks to months) whereas the abundant HOR juveniles are migrating quickly (i.e., days to weeks) through the tidal delta system and largely avoiding the nearshore refuge habitats such as pocket estuaries.

Fish size: The vast majority of all juvenile Chinook captured were subyearlings (Figure 4.3.3; Figure 4.3.4). Natural origin juvenile Chinook in Nooksack tidal delta and Bellingham Bay nearshore consisted of fry size individuals in February and March, with some individuals beginning to be parr sized in April. Before April, NOR juvenile Chinook increased in fork length by approximately 5 mm/month in both years. Starting in April NOR juvenile Chinook fork length increased by approximately 12-13 mm/month. Hatchery origin juvenile Chinook exhibited a similar pattern of increasing size per month with one exception: in both years, HOR fish were larger than NOR fish in April, but after April HOR and NOR juvenile Chinook lengths were similar and exhibited the same rate of size increase per month. There was no difference in fork length patterns of NOR juvenile Chinook between exposed nearshore and pocket estuary habitat for either year (Figure 4.3.5; Figure 4.3.6).

One yearling HOR Chinook was caught in 2014 (I&J Waterway on March 11) but none in 2015. The HOR yearling was not tagged so we were unable to determine its origin. Two yearling NOR Chinook were caught in 2014 (Squalicum Estuary on March 11, Fish Pt on April 24) but none in 2015.

Importance of habitat quality: In tidal delta and nearshore refuge habitats (pocket estuaries, small independent streams) the good (e.g., nutritional prey) and bad (e.g., toxins) inputs to existing habitats and potential restoration sites should be considered along with restoration of the physical footprint that fish access and rear within. Because NOR Chinook are keying in on these tidal delta and nearshore refuge habitats, it is important to understand the level of toxins and their effect on salmonids. This would help inform if and to what degree these habitats are an attractive nuisance. It is becoming more obvious that the toxic contamination problem needs attention in the context of juvenile salmon estuarine and nearshore exposure, especially in urban embayments. A recent study (O'Neill et al. 2015) found a significant portion of Puget Sound Chinook salmon are at risk for some type of health impairment due to contaminant exposure. Approximately one third of the juvenile Chinook salmon sampled from Puget Sound, regardless of the degree of nearby land development, had contaminant concentrations associated with adverse effects including mortality, impaired growth and reproduction, increased disease susceptibility, immune dysfunction, hormone alterations, and enzyme inductions. Additional study is needed to understand these relationships for WRIA 1 because the O'Neill study did not provide a connection between specific land use and contaminant exposure at a local scale. Toxic inputs to specific Nooksack tidal delta areas and Bellingham nearshore refuge habitats are currently unknown with respect to the health of juvenile Chinook salmon. We recommend conducting a study of toxins in juvenile Chinook salmon designed to identify spatial differences in toxin loading within WRIA 1 habitats. Answers from such a study would remove speculation as to whether watershed input remediation is necessary and provide restoration planners with information useful for sequencing specific restoration actions.

Conclusions and recommendations

1. There is consistent use of Nooksack tidal delta habitat by NOR juvenile Chinook but juvenile Chinook density results are lower than in Bellingham Bay nearshore habitats.
2. There is consistent use of nearshore refuge habitat (i.e., pocket estuary habitats and small streams) by NOR juvenile Chinook within Bellingham Bay.
3. NOR and HOR juvenile Chinook did not co-mingle in tidal delta habitat or pocket estuaries during the early rearing period; they did not co-mingle until the parr migration period in May (or later) when the bulk of the NOR Chinook had left (or were leaving) tidal delta or pocket estuary habitat. This suggests hatchery/wild interaction would not be possible for the NOR Chinook life history types that extensively rear in the tidal delta or pocket estuary habitats early in the year.
4. Significant co-mingling by NOR and HOR Chinook occurred in the Nooksack tidal delta and exposed nearshore habitats after April. This suggests hatchery/wild interaction would be possible for the NOR Chinook parr life history type that outmigrate the lower river and tidal delta with HOR Chinook and all NOR Chinook life history types once they reach exposed nearshore habitats during summer.
5. A strong inference from the NOR Chinook density results for the Nooksack tidal delta and Bellingham Bay nearshore along with HOR Chinook release results suggest the relatively few NOR juveniles are actively residing in rearing habitats (i.e., remaining for weeks to months) while the abundant HOR juveniles are migrating quickly (i.e., days to weeks) through the tidal delta system and largely avoiding the nearshore refuge habitats such as pocket estuaries.
6. We recommend conducting a study of toxins in juvenile Chinook salmon designed to identify spatial differences in toxin loading within WRIA 1 habitats.

Table 4.3.1. ANOVA significance results for transformed NOR juvenile Chinook density. *P*-values significant at the 0.05 level are bolded.

Variable Type	Variable	*P*-Value
Factor	HABITAT (Tidal delta, Pocket estuary, Exposed nearshore	**0.000**
	PERIOD (fry, parr)	**0.010**
	YEAR (2014, 2015)	**0.003**
Interaction	HABITAT*PERIOD	**0.036**
	HABITAT*YEAR	0.338
	PERIOD*YEAR	**0.035**
	HABITAT*PERIOD*YEAR	0.132

Table 4.3.2. Pairwise results of NOR juvenile Chinook density by the interaction term: Habitat*Period using Tukey's Honestly Significant Difference Test. *P*-values significant at the 0.05 level are bolded.

Habitat type(i) *Period(i)	Habitat type(j) *Period(j)	Difference	*P*-Value	95% Confidence Interval	
				Lower	Upper
Exposed nearshore*fry	Exposed nearshore*parr	-0.119	0.999	-0.983	0.745
Exposed nearshore*fry	Pocket estuary*fry	-2.214	**0.000**	-3.273	-1.154
Exposed nearshore*fry	Tidal Delta*fry	-0.644	0.374	-1.583	0.296
Exposed nearshore*parr	Pocket estuary*parr	-0.967	**0.021**	-1.841	-0.093
Exposed nearshore*parr	Tidal Delta*parr	-0.057	1.000	-0.840	0.726
Pocket estuary *fry	Pocket estuary *parr	1.128	**0.032**	0.060	2.195
Pocket estuary *fry	Tidal Delta*fry	1.570	**0.000**	0.508	2.632
Pocket estuary *parr	Tidal Delta*parr	0.910	**0.035**	0.037	1.783
Tidal Delta*fry	Tidal Delta*parr	0.467	0.640	-0.398	1.333

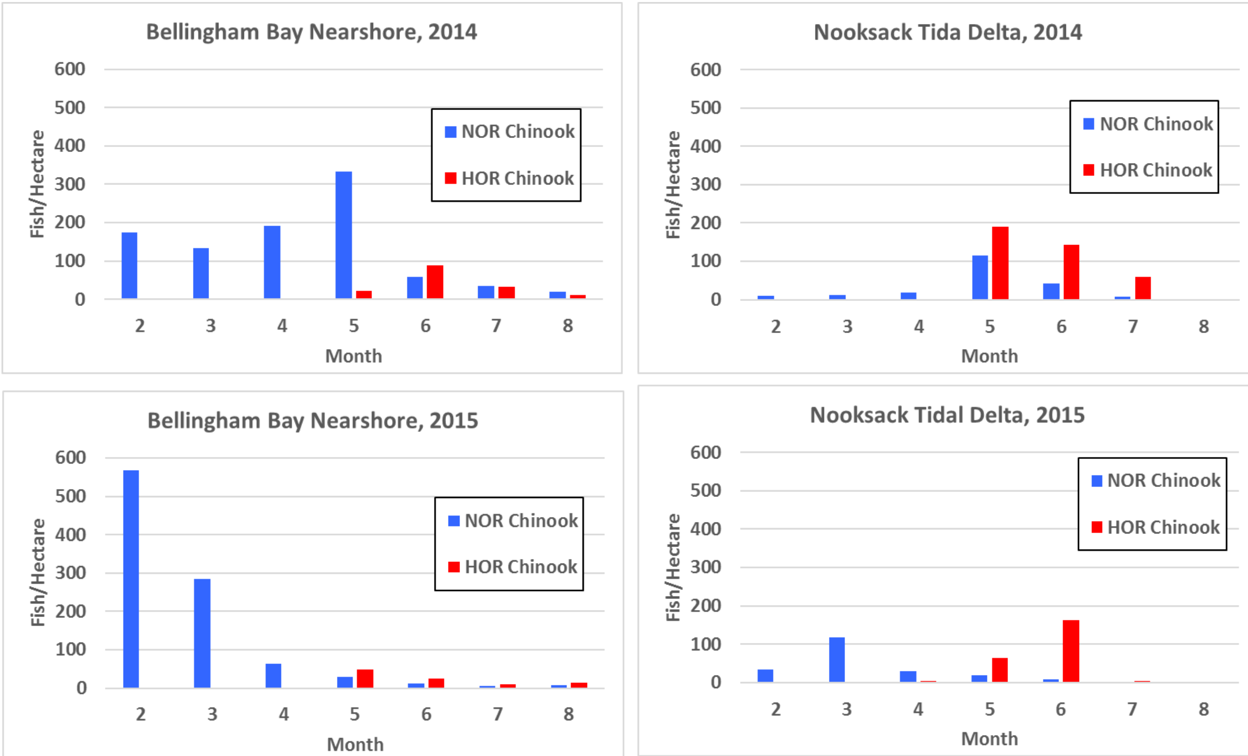


Figure 4.3.1. Average juvenile Chinook salmon density along the Bellingham Bay shoreline (left panels) and within the Nooksack tidal delta (right panels) in 2014 (top panels) and 2015 (bottom panels).

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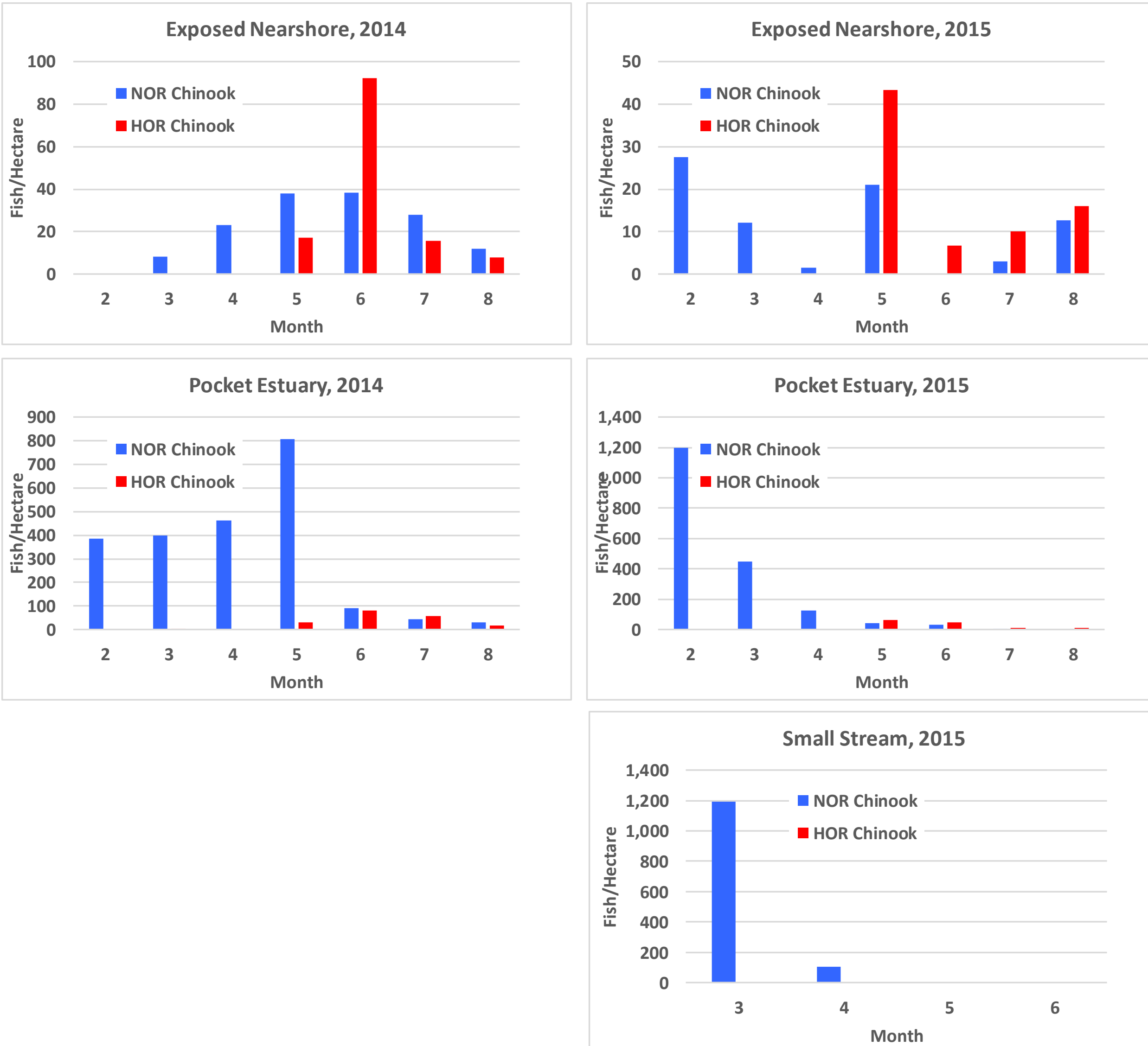

Figure 4.3.2. Average juvenile Chinook salmon density by habitat type for Bellingham Bay nearshore for 2014 and 2015. No small stream habitat was sampled in 2014. Note the varying y-axis scales. Pocket estuary and small stream graphs have a y-axis of 1 to 2 orders of magnitude higher than the exposed nearshore graphs.

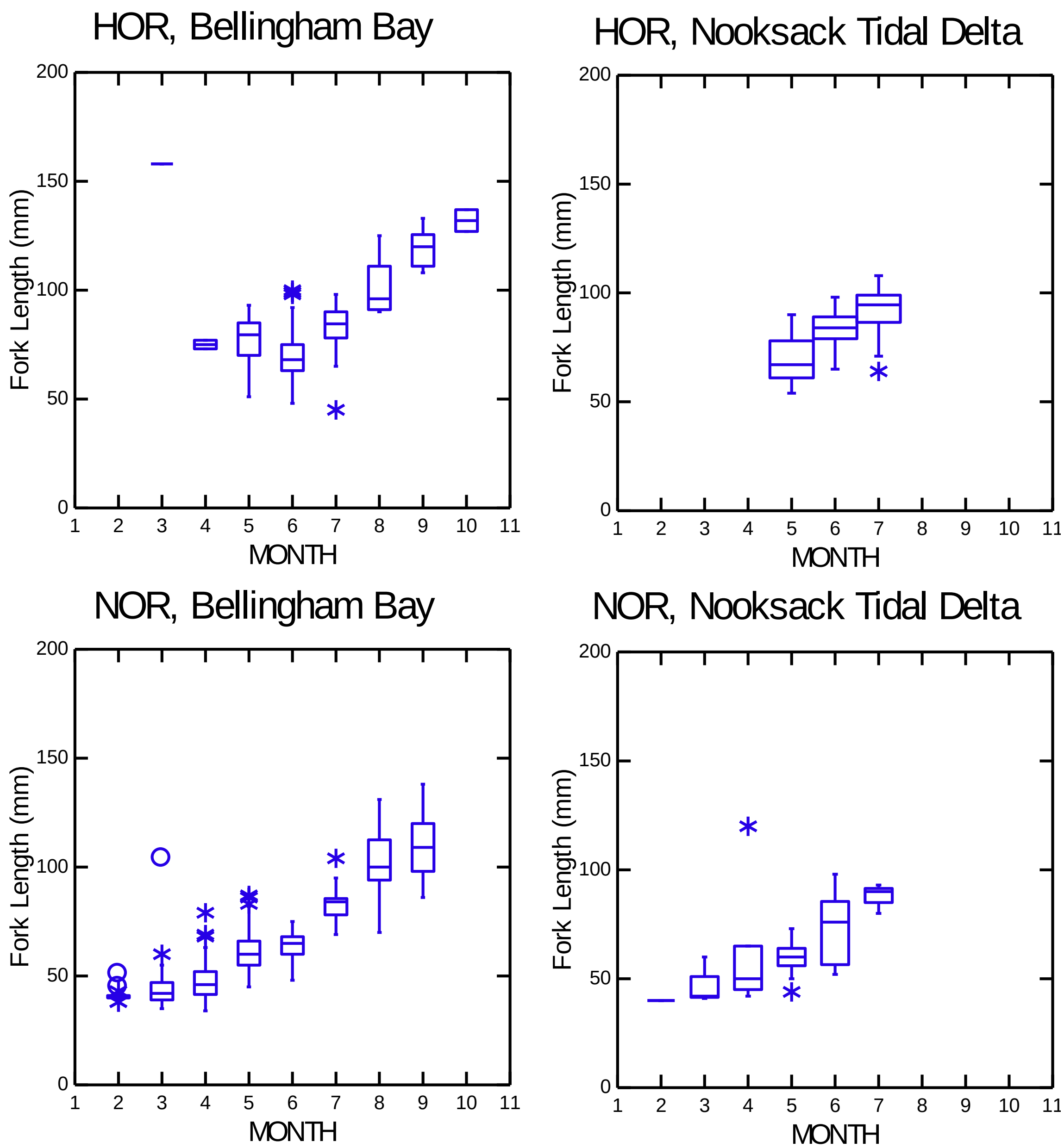

Figure 4.3.3. Box plots of NOR and HOR juvenile Chinook salmon fork length within the Nooksack tidal delta and along the Bellingham Bay shoreline in 2014. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

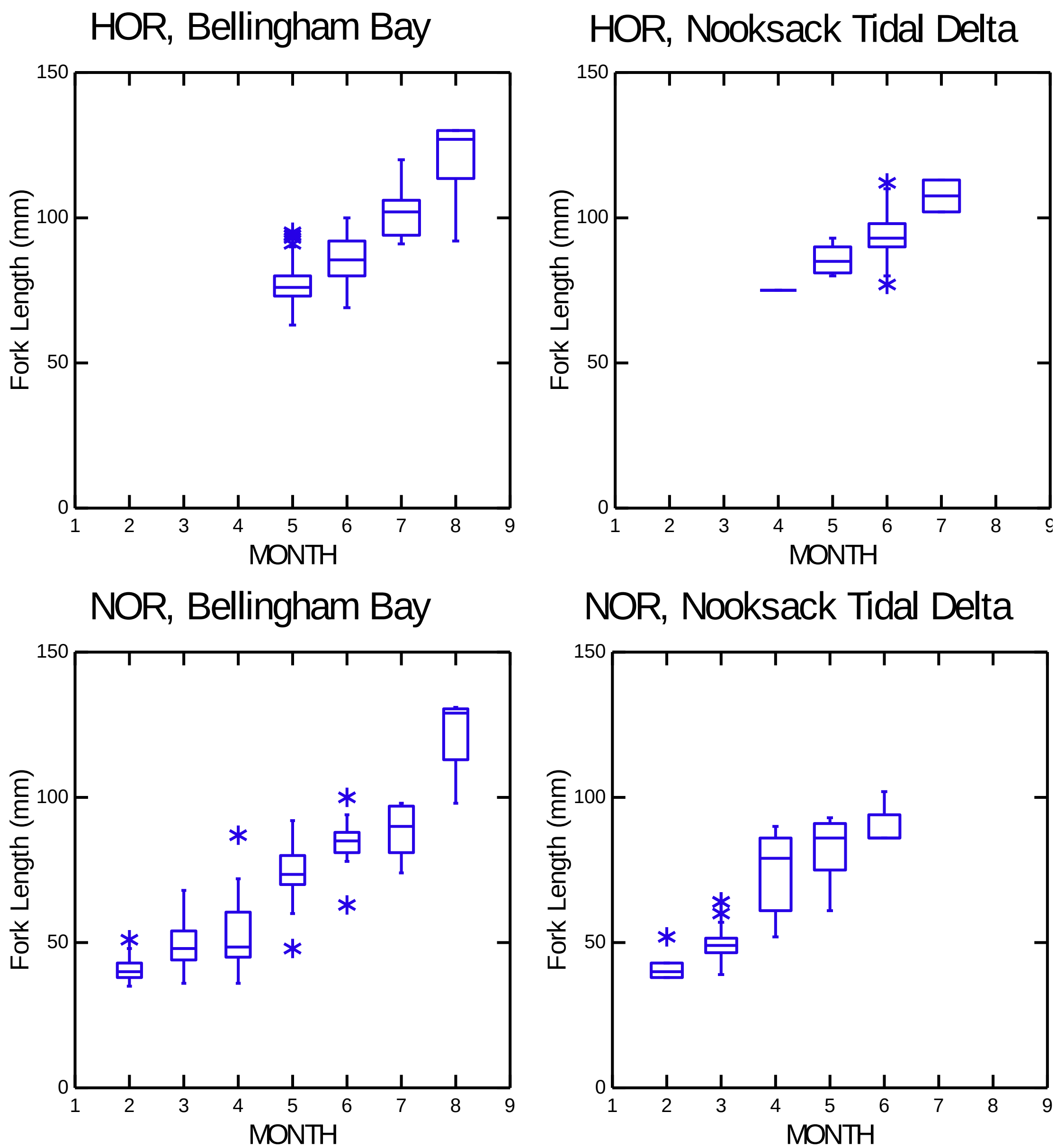

Figure 4.3.4. Box plots of NOR and HOR juvenile Chinook salmon fork length within the Nooksack tidal delta and along the Bellingham Bay shoreline in 2015. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

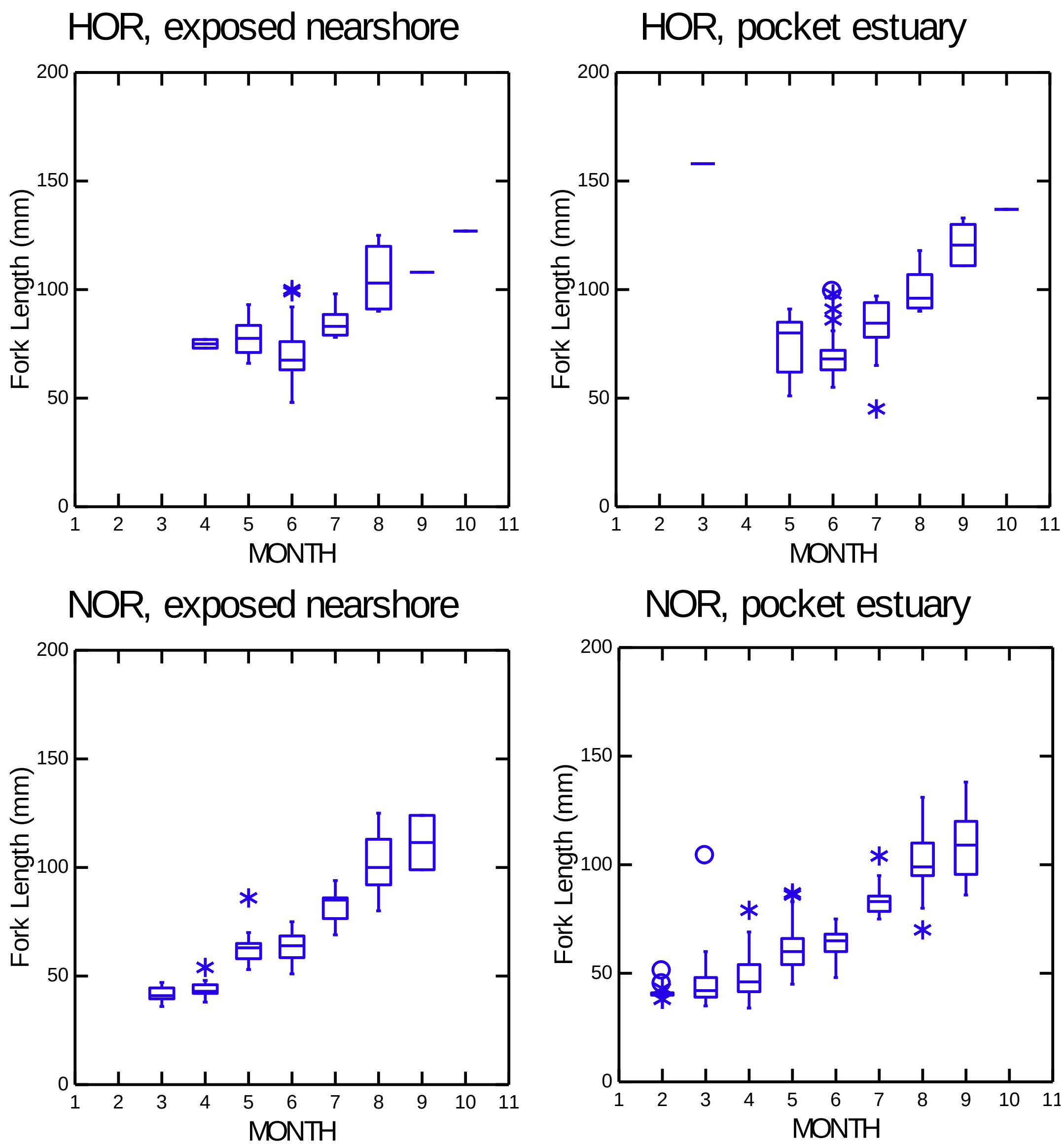

Figure 4.3.5. Box plots of NOR and HOR juvenile Chinook salmon fork length within habitat along the Bellingham Bay shoreline in 2014. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

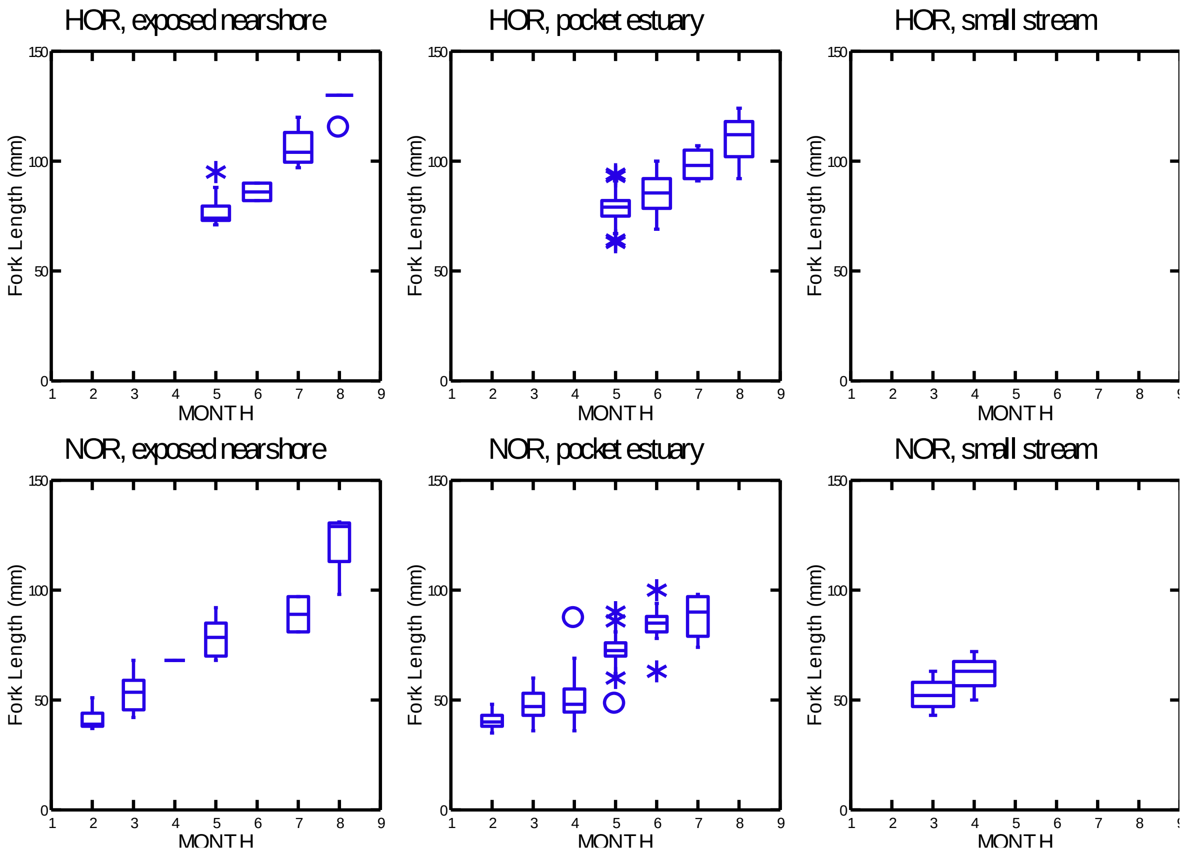

Figure 4.3.6. Box plots of NOR and HOR juvenile Chinook salmon fork length within habitat along the Bellingham Bay shoreline in 2015. Boxes show median, 25th and 75th percentiles. Whiskers show the 5th and 95th percentile. Stars are observations that are still within the full distribution. Circles (if present) are outliers, i.e., observations outside the statistical distribution.

4.4 Influence of habitat connectivity on NOR juvenile Chinook density

In this section we examine the influence of connectivity on NOR juvenile Chinook salmon densities at sites within the Nooksack tidal delta and Bellingham Bay nearshore. Mostly we are concerned about differences in habitat connectivity within the Nooksack tidal delta and how they might affect the fish coming from the Nooksack River. However, in section 4.2 we concluded that NOR juvenile Chinook from Whatcom Creek might be seeding Bellingham Bay nearshore habitats along with Nooksack origin fish. In this case, sites within Bellingham Bay might have signals in their NOR Chinook density results from multiple populations (i.e., connectivity to different sources). Thus, in this section of the report we test for statistical evidence of a Whatcom Creek spawner effect on NOR juvenile Chinook densities at Whatcom Creek mouth, a nearby Bellingham Bay nearshore site.

Chinook spawners in Whatcom Creek

Methods

Natural origin juvenile Chinook migrants are likely produced annually from spawners within Whatcom Creek (see section 4.2). We tested whether annual Chinook redd counts in Whatcom Creek had any influence on catches of NOR juvenile Chinook salmon at the regularly sampled site Whatcom Cr Mouth.

We used multiple regression analysis to test the hypothesis: NOR Chinook densities at Whatcom Creek mouth are influenced by the number of Chinook redds in Whatcom Creek and the number of NOR fry outmigrating the Nooksack River. We used beach seine data from Whatcom Cr Mouth for the fry rearing period in pocket estuaries (February through May) from years 2005-2010 and 2012-2015.

Results and discussion

Overall, we found log transformed NOR Chinook density to be significantly influenced by Whatcom Creek Chinook redds and Nooksack River NOR fry outmigrants ($r^2 = 0.31, P = 0.002$). The effect of Whatcom Creek Chinook redds was positive (more redds predicted higher NOR Chinook densities at Whatcom Cr Mouth) and highly significant ($P=0.0005$).

The predictive power of this model is not strong (r^2 of only 0.31) and may be caused by our use of total redds as a surrogate for an indication of the true Chinook escapement to Whatcom Creek, as well as by us not accounting for any variability that occurs within the life cycle of Chinook between spawning and migrating fry.

During this report's review process hatchery Chinook escapees were suggested as another possible explanation of juvenile Chinook salmon found at the Whatcom Creek Mouth beach seine site. We followed up this idea with Rayan Vasak of the Whatcom Creek Hatchery facility and learned the following:

- Young of the year Fall Chinook salmon are reared at the Whatcom Creek facility for a period of time and then transferred to other facilities within the Nooksack/Samish management area and ultimately released at Lummi Sea Ponds and/or Bertrand Creek, a lowland tributary to the Nooksack River downstream of Lynden.
- This program has been running since 2008 with approximately 250,000 (but not more than 500,000) juvenile Chinook released annually.
- Fish come to the Whatcom Creek Hatchery Facility as eyed eggs that have been otolith thermal marked.
- At the time of ponding (usually in February) some unknown number of Chinook fry escape due their very small size (~35 mm) and the size of the screens (1/8th inch mesh) needed to maintain adequate water flow in the rearing ponds.
- The Chinook fry at the time of ponding are not yet externally marked with adipose fin clips (because they are too small for fin clipping) but they are 100% otolith thermal marked and could be identified as hatchery origin fish through otolith analysis.

- Escaped fish would travel over 0.7 km inside culverts and enter the Whatcom Creek waterway via the C Street storm drain which outlets approximately 0.5 km away from the Whatcom Creek Mouth beach seine site.

The issue of hatchery escapees did not come up until after field data collection for this study was completed. Thus, we did not directly measure whether hatchery escapees from the Whatcom Creek facility made up part of our juvenile Chinook catches. Otolith analysis on a sample of unmarked juvenile Chinook (i.e., no adipose fin clip and no CWT) could be completed to determine what portion of the Bellingham Bay nearshore unmarked juvenile Chinook population is made up of Whatcom Creek Hatchery escapees.

If hatchery escapees are a significant component of the juvenile Chinook population, we would expect to see a large increase in juvenile Chinook catches after the program began compared to before. We examined yearly patterns of unmarked juvenile Chinook density at Whatcom Cr Mouth and found no conclusive evidence that the density of juvenile Chinook salmon increased at Whatcom Creek Mouth after the Whatcom Creek facility was used to rear juvenile Chinook salmon. In contrast, the significant positive relationship between Whatcom Creek Chinook redds and Whatcom Cr Mouth NOR Chinook density is strong evidence that Chinook spawners in Whatcom Creek are producing juveniles that are rearing in nearby Bellingham Bay nearshore areas.

Sub-delta areas within the Nooksack tidal delta

Methods

In section 2.1 we showed a classification of the Nooksack tidal delta as four sub-delta areas based on gross differences in hypothesized fish migration pathways. We analyzed data from years 2003 through 2015 to determine the habitat use by NORs in the sub-delta regions.

Results and discussion

Utilizing all years of data (2003-2015) we found the vast majority of NOR juvenile Chinook caught in the Nooksack tidal delta were within the sub-delta area identified as 'connected Nooksack tidal delta' (Figure 4.4.1).

The results for the Smugglers Slough area are not included in Figure 4.4.1. According to data from MacKay (2014), 16 beach seine sets were made over five different years in Smugglers Slough, but no juvenile Chinook were caught. Also, there is a spotty temporal record for the Silver Creek sub-delta area. The most extensive sampling years are 2014 and 2015 where over 40 beach seine sets were made each year consistently from February through August. No juvenile Chinook salmon were caught in 2014 and only four were caught in 2015. There is a much better temporal record of sampling in the Lummi/Red River sub-delta area (187 beach seine sets over 11 different years and 41 different months), but out of all sets combined, juvenile NOR Chinook were present in only one month (March 2012) with a catch of one fish.

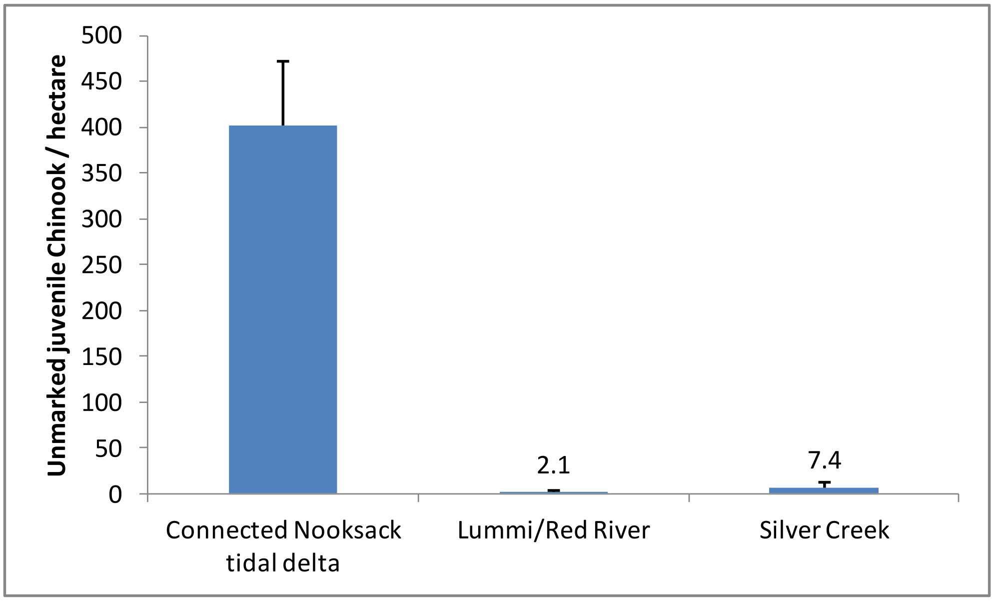

Figure 4.4.1. Overall average of natural origin juvenile Chinook density by sub-delta polygon. Error bars are standard error. Average values for Lummi/Red River and Silver Creek are shown above bars.

Pre and post logjam at Airport Creek

Methods

In section 2.1 we showed a distributary channel spanning logjam in the Nooksack tidal delta formed during the time period of our overall fish dataset (2003-2015). The logjam influenced habitat conditions within the tidal delta in terms of extent by habitat type (Tables 2.1.2 and 2.1.3 above) and fish migration pathways through the delta (section 2.3). Airport Creek is a long-term fish sampling site that changed dramatically because of the logjam deflecting river flow away from the east channel. We used ANOVA analysis for all years of data at Airport Creek to test whether NOR Chinook densities differed for the periods before and after logjam formation.

Results and discussion

ANOVA analysis for all years of data at Airport Creek found NOR Chinook density differed between time periods before and after logjam formation ($P = 0.02$). We included tests using covariates (seasonal effects – month; the number of Nooksack River NOR outmigrants) but they were not statistically significant and did not improve the model. The logjam has reduced NOR Chinook density at Airport Creek (Figure 4.4.2) and likely reduced the number of fish taking the east channel pathway to the Bellingham Bay nearshore habitats on the east side of the tidal delta.

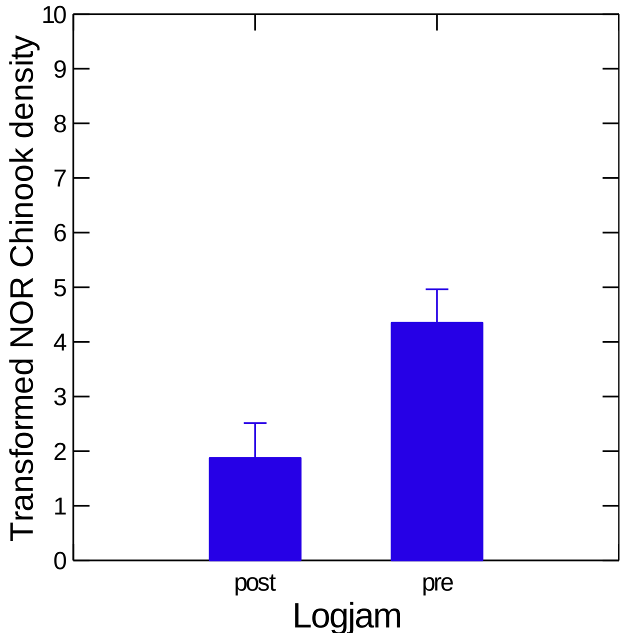

Figure 4.4.2. Airport Creek area after (post) and before (pre) logjam. Transformed NOR juvenile Chinook densities (February-July, all years combined).

Influence of landscape connectivity on all Nooksack tidal delta sites

Methods

Landscape connectivity is defined and quantified for each site in section 2.3. The purpose of the landscape connectivity variable is to determine what effect distance and complexity of pathways has on migrating juvenile Chinook salmon finding habitat. We used regression analysis to test the influence of landscape connectivity on NOR Chinook density for individual years (2014 and 2015) with high temporal and spatial (i.e., # of sites) sampling and for multiple years at sites within the Nooksack tidal delta only because of the influence Whatcom Creek Chinook spawners potentially have on Bellingham Bay nearshore sites.

Results and discussion

Regression analysis for individual years gives mixed results (Figure 4.4.3). For example, 2014 is significant ($P = 0.0006$) whereas 2015 is not ($P = 0.3$). The result in 2015 has a narrow range in landscape connectivity values compared to 2014 and has the fewest number of outmigrating fish, which may limit our ability to statistically detect a response. To increase degrees of freedom in the analysis we included data from all years. However, a multi-year analysis needs to account for variability caused by differing numbers of outmigrating fish each year. Multiple regression revealed that the number of outmigrants ($P = 0.025$) and landscape connectivity ($P = 0.025$) are important in explaining NOR Chinook density in the Nooksack tidal delta, but the model is not highly predictive ($r^2 = 0.21$).

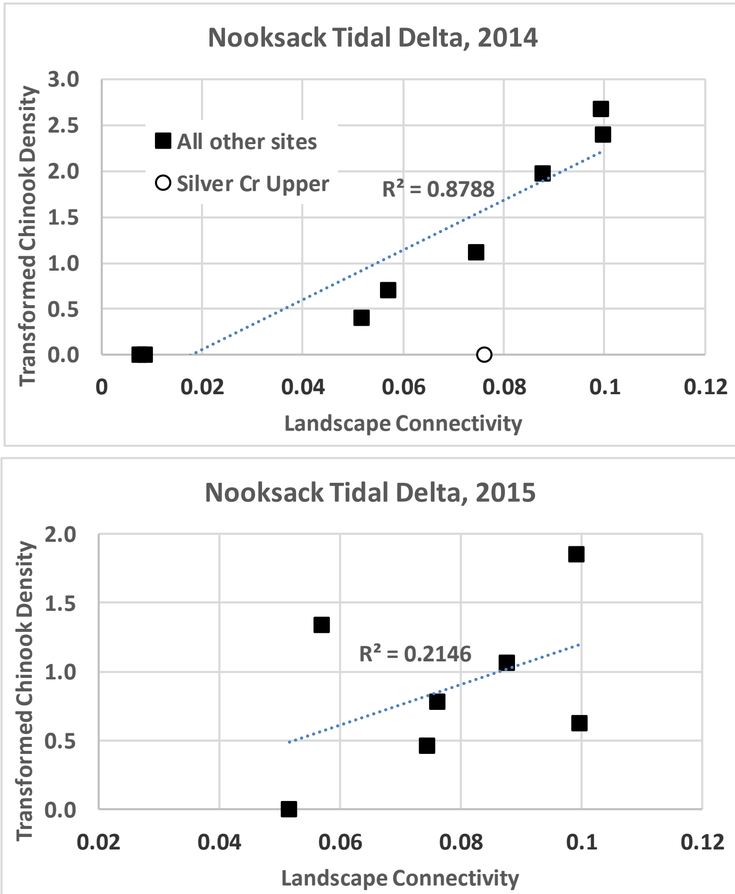

Figure 4.4.3. Example years (2014 and 2015 chosen for this example) of the influence of landscape connectivity on NOR juvenile Chinook salmon density within the Nooksack tidal delta. The Silver Creek upper site is an outlier in the 2014 relationship (top panel), likely due to low dissolved oxygen levels at that site. Only low DO tolerant fish were caught.

Conclusions and recommendations

1. Habitat connectivity within the Nooksack tidal delta is important to explaining differences of NOR Chinook salmon density within the tidal delta.
2. The portion of the Nooksack tidal delta mostly utilized by natural origin juvenile Chinook salmon is the 'connected Nooksack tidal delta'.
3. The distributary-spanning logjam within the Nooksack tidal delta has reduced NOR Chinook density at Airport Creek and likely reduced the number of fish taking the east channel pathway to the Bellingham Bay nearshore habitats on the east side of the tidal delta.
4. Chinook spawners in Whatcom Creek are producing juveniles that are rearing in nearby Bellingham Bay nearshore areas. Detecting landscape connectivity signals of Nooksack origin Chinook at east side Bellingham Bay nearshore sites is likely confounded by fish coming from Whatcom Creek.
5. Using landscape connectivity as a covariate in juvenile salmon use analysis for the Nooksack tidal delta can help elucidate treatment effects on restoration effectiveness.

5.0 Origins of juvenile Chinook salmon

It is important to know the geographic scope of hatchery origin fish and out-of-system natural origin fish using the available habitat within the Nooksack tidal delta and Bellingham Bay nearshore in order to understand juvenile Chinook population dynamics acting within the study area. In this chapter we look at evidence from coded wire tagged juvenile HOR Chinook salmon and DNA analysis from juvenile NOR Chinook salmon caught at the Nooksack River outmigration trap, Nooksack tidal delta, and Bellingham Bay nearshore to determine the origin of juvenile Chinook utilizing the study area.

5.1 CWT results from juvenile Chinook salmon

Methods

All juvenile Chinook salmon caught by beach seine and electrofishing in the Nooksack tidal delta and Bellingham Bay nearshore in 2014 and 2015 were identified as natural or hatchery-origin (see Chapter 3.2). A hatchery fish had a clipped adipose fin or CWT in its snout. If the fish was found to have a CWT, it was sacrificed so the hatchery release location could be determined by reading the code on its CWT. We examined CWTs of 104 and 42 fish caught in beach seine samples in 2014 and 2015, respectively.

Results and discussion

Only Nooksack River-released hatchery juvenile Chinook salmon were caught in the Nooksack tidal delta, whereas a mixture of Nooksack, Skagit, and Samish River-released fish were caught in Bellingham Bay nearshore in both years (Figure 5.1.1). All CWT Chinook in the Nooksack tidal delta were from Nooksack River hatchery releases, suggesting out-of-basin HOR juvenile Chinook do not swim up into the Nooksack tidal delta. In contrast, Skagit River origin HOR Chinook were caught in Bellingham Bay nearshore in both years, demonstrating out-of-basin HOR Chinook from the Whidbey Basin utilize Bellingham Bay nearshore habitat. It is noteworthy that no CWT Chinook were recovered from any other nearby, or regionally close, basin, including British Columbia, Central Puget Sound, South Puget Sound, or Hood Canal HOR Chinook releases, yet hundreds of thousands of CWT HOR Chinook are released each year from these basins.

The HOR juvenile Chinook in the three basins represented by the observed CWT recoveries (i.e., Nooksack, Samish, and Skagit Rivers) are released as parr-sized fish in late April or May. We previously showed Nooksack HOR juvenile Chinook move through the tidal delta area fairly quickly (see sections 4.1 and 4.2). Hatchery origin fish with CWTs were found in the Nooksack tidal delta approximately three weeks after the first release date in 2014 and one month after the first release date in 2015. In the Bellingham Bay nearshore HOR fish were found from April through the end of sampling in October 2014 and from May through the end of sampling in August 2015.

The CWT results reported in this section show which HOR Chinook populations are comingling significantly with NOR Chinook in the study area. We previously concluded (see section 4.3) that hatchery/wild interaction would be possible for (a) the NOR Chinook parr life history type that outmigrates the Nooksack River and Nooksack tidal delta with HOR Chinook, and (b) all NOR Chinook life history types once they reach Bellingham Bay exposed nearshore habitats during summer. Based on the CWT results, Nooksack tidal delta comingling of NOR and HOR fish is limited to Nooksack River fish only. Bellingham Bay nearshore comingling of NOR and HOR fish is limited to Samish and Skagit River fish.

Conclusions and recommendations

1. All CWT HOR juvenile Chinook in the Nooksack tidal delta were from Nooksack River hatchery releases, while CWT HOR Chinook in the Bellingham Bay nearshore were from a combination of release sites in Nooksack, Samish, and Skagit River basins.
2. No CWT HOR juvenile Chinook were recovered from any other nearby, or regionally close, basin, including British Columbia, Central Puget Sound, South Puget Sound, or Hood Canal hatchery releases.
3. If juvenile Chinook hatchery/wild interactions are suspected, then the CWT results could be used as a basis to understand which Chinook populations are potentially interacting.

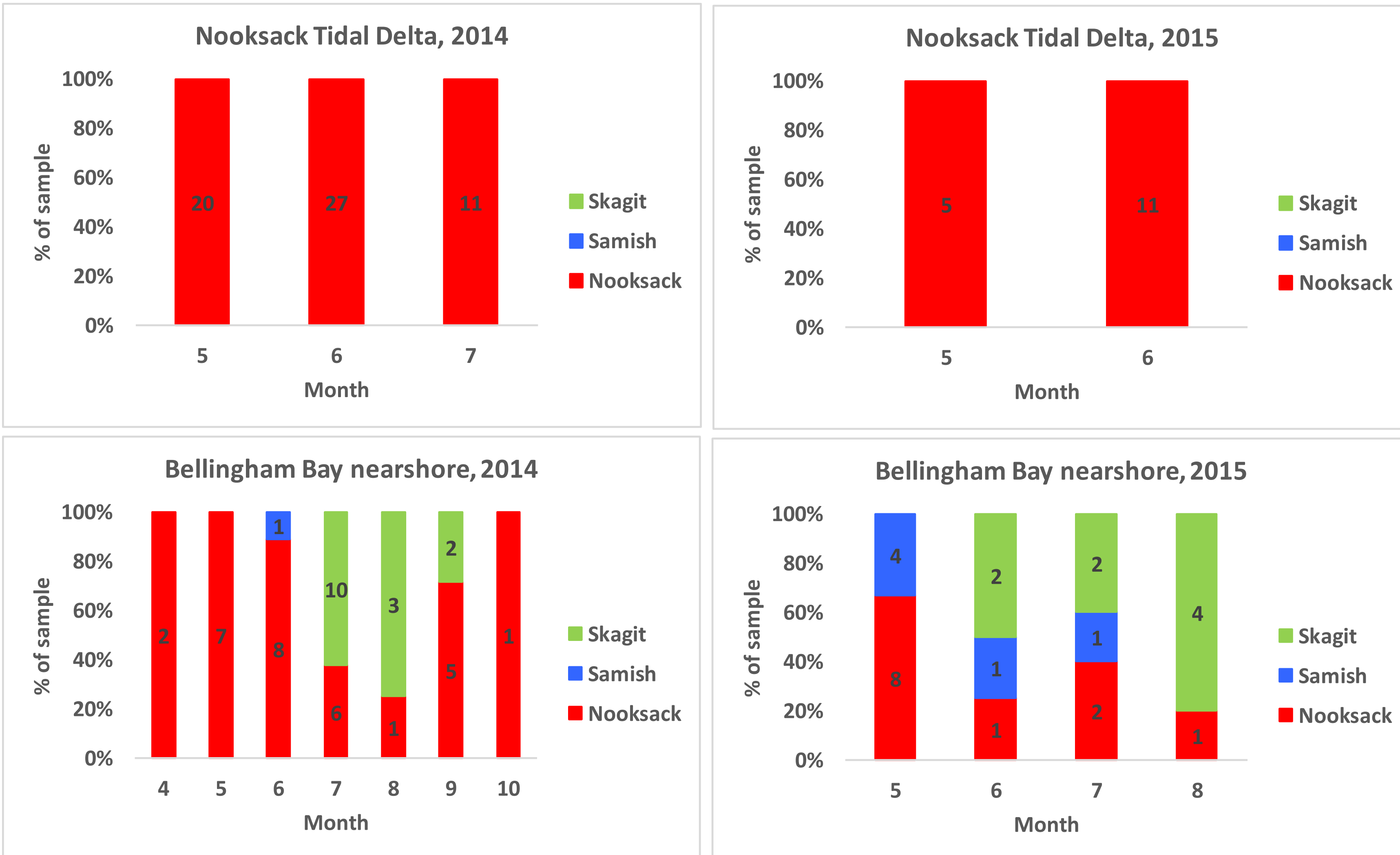

Figure 5.1.1. Origin of HOR juvenile Chinook caught in the Nooksack tidal delta (top panels) and Bellingham Bay nearshore (bottom panels) in 2014 (left panels) and 2015 (right panels). Origin is defined as river basin of the release site. Months shown on the x-axes indicate times when CWTs were found (not the entire sampling period for each year). The number of fish in each month / coded wire tag grouping is shown within each graph bar.

5.2 Genetic assignment of juvenile Chinook salmon

Methods

Tissue samples from NOR juvenile Chinook were collected in specific years in the lower Nooksack River, Nooksack tidal delta, and Bellingham Bay nearshore for the purpose of determining the origin of individual fish based on genetic analysis using DNA (see Section 3.2 above). Chinook origin analyses use genotypic data to assign a sample of unknown origin to baseline samples of known origin. In this study, we used two different baselines depending on the year of sample collection.

In years 2008 and 2009, fish were collected by LNRD in the Nooksack tidal delta and Bellingham Bay nearshore. These samples were analyzed by NOAA Fisheries Manchester Marine Research Station (David Teel and others) using a Washington and British Columbia baseline dataset extracted from a standardized coast-wide database developed by the multi-agency workgroup Genetic Analysis of Pacific Salmonids ('GAPS baseline' for the purpose of this report). In collaboration with the SSMSS, fish collected in the Nooksack tidal delta and Bellingham Bay nearshore in 2014 and 2015 were analyzed by WDFW using a new single-nucleotide polymorphisms Chinook baseline ('SNPs baseline' for the purpose of this report). Fish collected in the lower Nooksack River outmigrant trap by LNRD in 2013 from January through August were analyzed by WDFW using the SNPs baseline.

The GAPS and SNPs baselines use their own terminology to report genetic results consistent with the known origins of their baseline samples. Within both the GAPS and SNPs baselines, there are Chinook population aggregation levels ranging from a source Chinook population to an aggregation of source populations within a basin (e.g., Fall Chinook) or regional aggregations of basins (e.g., all Chinook populations in British Columbia). We report results at the lowest aggregation level, where Chinook origin results have a probability of assignment to the baseline of 0.8 or better. We present genetic results for each baseline using their specific language for Chinook origin, and we interpret the specific language into the 'likely Chinook population' relevant to WRIA 1 salmon recovery (Tables 5.2.1 through 5.2.3).

An apparent disagreement between genetic assignment and 'likely Chinook population' must be highlighted for NOR Fall Chinook throughout Puget Sound. In the GAPS baseline, NOR Fall Chinook originating from within the Nooksack and Samish Rivers as well as Bellingham Bay tributaries are assigned as SSF/HC (South Sound Fall/Hood Canal). The fish are genetically the same with respect to what the GAPs baseline can detect. This was likely caused by the long history of planting hatchery Fall Chinook from the Green River throughout Puget Sound, which homogenized Puget Sound Fall Chinook genetics. The SNPs baseline has a similar, but somewhat less difficult, time determining NOR Fall Chinook originating within the Nooksack/Samish Management Unit, albeit not as poorly as the GAPS baseline. We assume, based on the lack of CWT evidence (i.e., no South Puget Sound, Central Puget Sound, or Hood Canal CWT recoveries – See section 5.1), that NOR juvenile Chinook assigned as SSF/HC (GAPS baseline) and Fall_Aggregate, GreenR, NooksackFall(Samish) (from SNPs baseline) are all NOR Chinook originating from either the Nooksack or Samish Rivers, or Bellingham Bay tributaries.

We also note that origin assignments of the British Columbia Chinook populations detected in this study may include unmarked HOR juvenile Chinook because hatchery fish marking practices in British Columbia are not as complete as they currently are in Puget Sound. Large numbers (millions) of non-adipose fin clipped fish without CWT were released from Fraser River, Thompson River, and East Vancouver Island hatcheries during 2008, 2009, 2014, and 2015 (RMIS database).

Table 5.2.1. Origin results for 120 NOR juvenile Chinook salmon collected in the Nooksack tidal delta in 2008 and Bellingham Bay nearshore in 2008 & 2009 using the GAPS baseline.

Genetic levels within GAPS baseline		**Number of fish in sample**	**Graphed in figures**	**Likely Chinook population**
Population aggregate	**Identified level**			
British Columbia	Lower Fraser	1	Lower Fraser	NOR or unmarked HOR Chinook from the Lower Fraser River
	East Vancouver Is.	1	East Vancouver Is.	NOR or unmarked HOR Chinook from rivers on the eastern side of Vancouver Island
Fall aggregate	SSF/HC	63	SSF/HC (Nooksack, late run)	NOR fall Chinook from the Nooksack River, Samish River., and/or Bellingham Bay tributaries
Nooksack, early run	Nooksack, early run	29	Nooksack, early run	NOR Chinook from the Nooksack River. No assignment given to South Fork or North Fork/Middle Fork Nooksack populations
Whidbey Basin	Whidbey Basin	26	Whidbey Basin	NOR Chinook from Whidbey Basin rivers. No assignment given of a specific river within the Whidbey Basin.

Table 5.2.2. Origin results for 151 NOR juvenile Chinook salmon collected in the Nooksack tidal delta and Bellingham Bay nearshore in 2014. Aggregation levels are based on Warheit (2015).

Genetic levels within SNPs baseline		**Number of fish in sample**	**Graphed in figures**	**Likely Chinook population**
Population aggregate	**Identified level**			
British Columbia	FraserR_Late	1	British Columbia	NOR or unmarked HOR Chinook from British Columbia rivers, including the Fraser and South Thompson Rivers and smaller rivers entering the lower Strait of Georgia.
	LStraitGeorgia	3		
	SouthThompson_Early	1		
Fall aggregate	Fall_Aggregate	20	Fall aggregate	NOR fall Chinook from the Nooksack River, Samish River., and/or Bellingham Bay tributaries
	GreenR	6	Green R	
	NooksackFall(Samish)	72	Nooksack Fall (Samish)	
Nooksack, early run	NFMFNooksackSp	33	Nooksack, early run	NOR Spring Chinook from the Nooksack River. Assignments are given to the two source populations.
	NooksackSp	2		
	SFNooksackSp	1		
Whidbey Basin	LSkagitFa	2	Whidbey Basin	NOR Chinook from Whidbey Basin rivers. Assignments are given for 3 of 6 Skagit source populations, an aggregate of all Skagit populations, and an aggregate of all Whidbey Basin populations
	Skagit	1		
	Skagit_MarblemountSpH	1		
	UpperSkagitSu	5		
	WhidbeyBasin	3		

Table 5.2.3. Origin results for 170 NOR juvenile Chinook salmon collected in the Nooksack tidal delta and Bellingham Bay nearshore in 2015. Aggregation levels are based on Warheit (2015).

Genetic levels within SNPs baseline		Number of fish in sample	Graphed in figures	Likely Chinook population
Population aggregate	**Identified level**			
British Columbia	BigQualicumHat	3	British Columbia	NOR or unmarked HOR Chinook from British Columbia rivers, including the South Thompson River and Big Qualicum River
	SouthThompson_Early	3		
Fall aggregate	Fall_Aggregate	23	Fall Aggregate	NOR fall Chinook from the Nooksack River, Samish River., and/or Bellingham Bay tributaries
	SkokomishFa	2		
	SamishFa	71	Nooksack Fall (Samish)	
Nooksack, early run	NFMFNooksackSp	51	Nooksack, early run	NOR Spring Chinook from the Nooksack River. Assignments are given to the two source populations.
	SFNooksackSp	1		
Whidbey Basin	LSkagitFa	5	Whidbey Basin	NOR Chinook from Whidbey Basin rivers. Assignments are given for 4 of 6 Skagit source populations, 1 of 3 Snohomish source populations, and an aggregate of all Whidbey Basin populations.
	SFStillaguamishFa	1		
	Skagit_MarblemountSpH	1		
	SkykomishSu	2		
	SuiattleSp	3		
	UpperSkagitSu	3		
	WhidbeyBasin	1		

Nooksack River outmigrant trap

Results and discussion

There were outmigration timing differences in Nooksack Chinook populations in 2013 (Figure 5.2.1). For subyearlings, the South Fork Nooksack Spring and Nooksack Fall Chinook populations exhibit similar outmigration timing through the lower river, outmigrating mostly as parr sized fish and showing up in the lower river by late April through early May, increasing in their percent of the total outmigration through August. The North Fork Nooksack Spring population dominated the outmigration early in the year (January through March), migrating as fry, and then later contributed to the mixture of parr outmigrating from each of the three populations. Yearlings were present in the outmigration, observed as a small fraction of the largest fish outmigrating January through May from the Nooksack Fall and North Fork Nooksack Spring populations. No South Fork Nooksack Spring yearlings were detected in the 2013 outmigration, likely due to their low proportion of the total Nooksack River juvenile Chinook outmigration population and a low probability of detection at the outmigrant trap.

In examining juvenile Chinook salmon use of the Nooksack tidal delta and Bellingham Bay nearshore, we are most concerned about subyearling Chinook outmigrants because they are the juveniles that may remain in the estuary and nearshore for extended rearing rather than migrating quickly through. The genetic-base origin results from the lower river outmigrant trap in 2013 suggest all Nooksack NOR Chinook populations produce fish of the life history types capable of estuary or nearshore rearing. Based on their early timing through the lower river, of the three Nooksack NOR Chinook populations, individuals from the North Fork Nooksack Spring population would have most likely reared in the Nooksack tidal delta or Bellingham Bay nearshore in 2013.

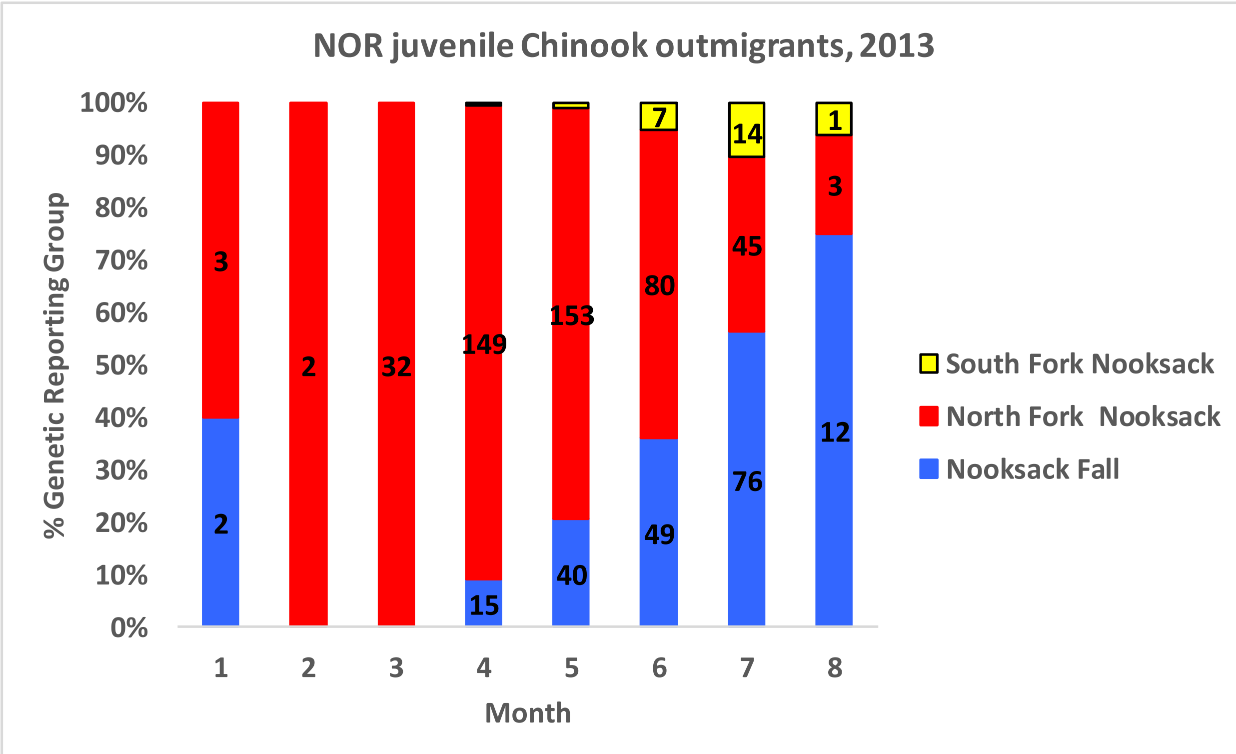

Figure 5.2.1. SNPs baseline genetic assignment of 686 juvenile Chinook salmon outmigrating from the Nooksack River in 2013. The number of fish in each month /genetic assignment group is shown within each graph bar. Note: not visible in the figure, 1 fish in April and 2 fish in May were assigned South Fork Nooksack origin.

Nooksack tidal delta

Results and discussion

The NOR juvenile Chinook salmon origin was examined by genetic analysis over three separate years: 2008, 2014, and 2015, from fish caught in the Nooksack tidal delta (Figure 5.2.2). In all years Nooksack early run fish dominated catches in the Nooksack tidal delta during the early fry migrating period (February through April). During the parr migration period (May and later) Nooksack early and fall run fish made up the catches. In 2008 and 2015 non-natal Chinook juveniles were detected later in the season. Whidbey Basin origin Chinook made up a small portion of the total seasonal catch in the Nooksack tidal delta and were present only during June and July.

The Chinook populations detected in the Nooksack tidal delta differed between NOR and HOR juveniles. We found all HOR juveniles in the tidal delta were from Nooksack River hatchery releases and that out-of-basin HOR fish did not swim up into the tidal delta (see Section 5.1 above). In contrast, NOR juvenile Chinook from the Whidbey Basin were detected in the Nooksack tidal delta in two of three years, although their overall abundance each year was very small (Figure 5.2.2). The difference between HOR and NOR Chinook populations detected in the Nooksack tidal delta may reflect the difference between NOR and HOR juvenile Chinook life history diversity. The NOR Chinook are expressing multiple life history types and therefore may be seeking more extensive habitat opportunities than HOR Chinook, which are most similar to the parr life history type in terms of timing through their natal river and estuary and entrance into the nearshore. The HOR juvenile Chinook may be less likely to colonize out-of-system estuarine habitats.

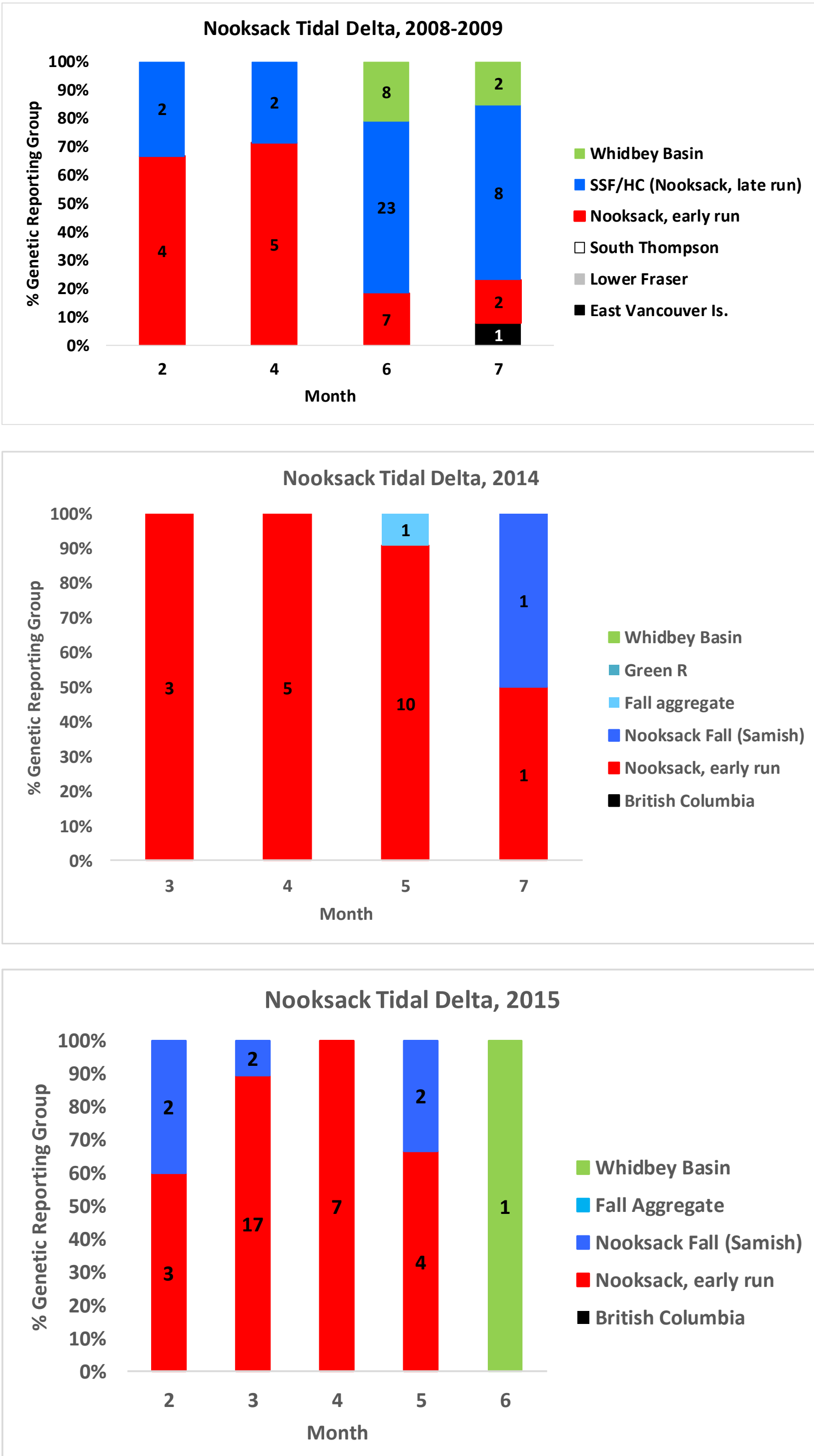

Figure 5.2.2. Genetic assignment of juvenile Chinook from the Nooksack tidal delta. Top panel: 64 fish caught in 2008 using the GAPS baseline; middle panel: 21 fish caught in 2014 using the SNPs baseline; bottom panel: 38 fish caught in 2015 using the SNPs baseline. Only fish with a "best stock" estimate probability of 0.8 or greater compared to the baseline are shown. The number of fish in each month/genetic assignment group is shown within each graph bar.

Bellingham Bay nearshore

Results and discussion

The NOR juvenile Chinook salmon origin was examined by genetic analysis over three separate periods (2008/2009, 2014, and 2015) from fish caught in Bellingham Bay nearshore habitat (Figures 5.2.3 – 5.2.5). Nooksack early run and late run fish were present in pocket estuary habitat (top right panel, Figures 5.2.3 – 5.2.5), but fall run fish contributed proportionally more in all years. This demonstrates that Nooksack origin Chinook are utilizing pocket estuary habitat.

Whidbey Basin origin Chinook were present in Bellingham Bay nearshore habitats as early as March (in 2015) but were not a major percentage of the monthly juvenile Chinook population until summer months (Figures 5.2.3 – 5.2.5). Whidbey Basin origin Chinook were detected utilizing Bellingham Bay pocket estuary habitat all three years, but not typically during the early rearing period from February through April when competition for habitat and resources might be expected. British Columbia origin Chinook were present in Bellingham Bay nearshore by June or July of each year, but were a minor part of the nearshore juvenile Chinook population. They did not dominate any month/year/nearshore habitat strata, except for east side Bellingham Bay nearshore areas in August of 2015, when only one fish was sampled (bottom right panel, Figure 5.2.5).

After the distributary channel-spanning logjam formed in the Nooksack tidal delta circa 2009, proportionately more Nooksack early run fish made up catches at nearshore sites west of the tidal delta than east of the tidal delta (bottom panels, Figures 5.2.3 – 5.2.5). This suggests the logjam in the tidal delta is influencing where fish go within the Bellingham Bay nearshore and not just within the tidal delta.

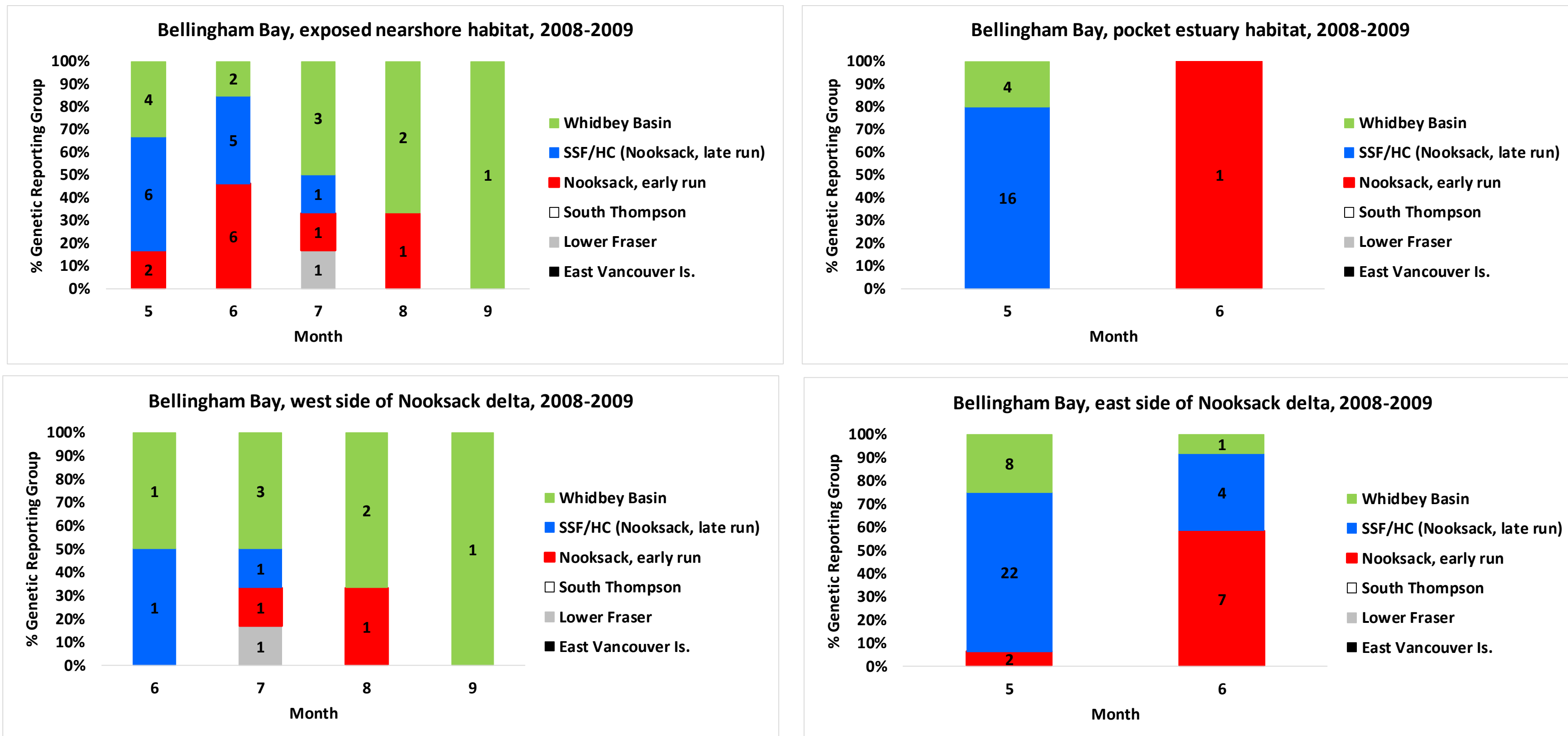

Figure 5.2.3. GAPS baseline genetic assignment of 56 juvenile Chinook salmon caught in the Bellingham Bay nearshore in 2008 and 2009. Only fish with a “best stock” estimate probability of 0.8 or greater compared to the baseline are shown. The number of fish in each month/genetic assignment group is shown within each graph bar. The 56 samples were graphed in two ways: by habitat type (top panels) and by proximity to the Nooksack delta (bottom panels).

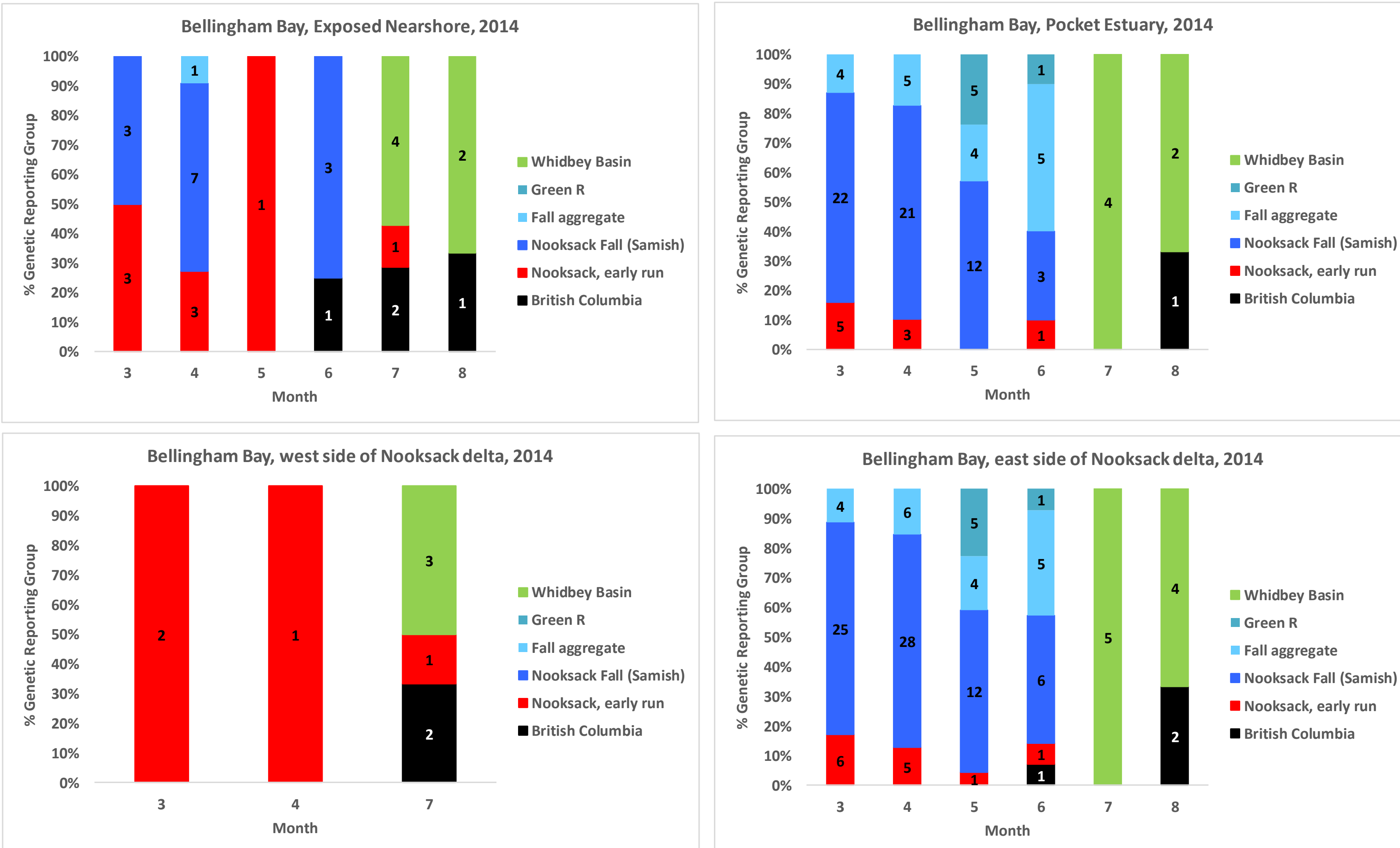

Figure 5.2.4. SNPs baseline genetic assignment of 130 juvenile Chinook salmon caught in the Bellingham Bay nearshore in 2014. Only fish with a “best stock” estimate probability of 0.8 or greater compared to the baseline are shown. The number of fish in each month/genetic assignment group is shown within each graph bar. The 130 samples were graphed in two ways: by habitat type (top panels) and by proximity to the Nooksack delta (bottom panels).

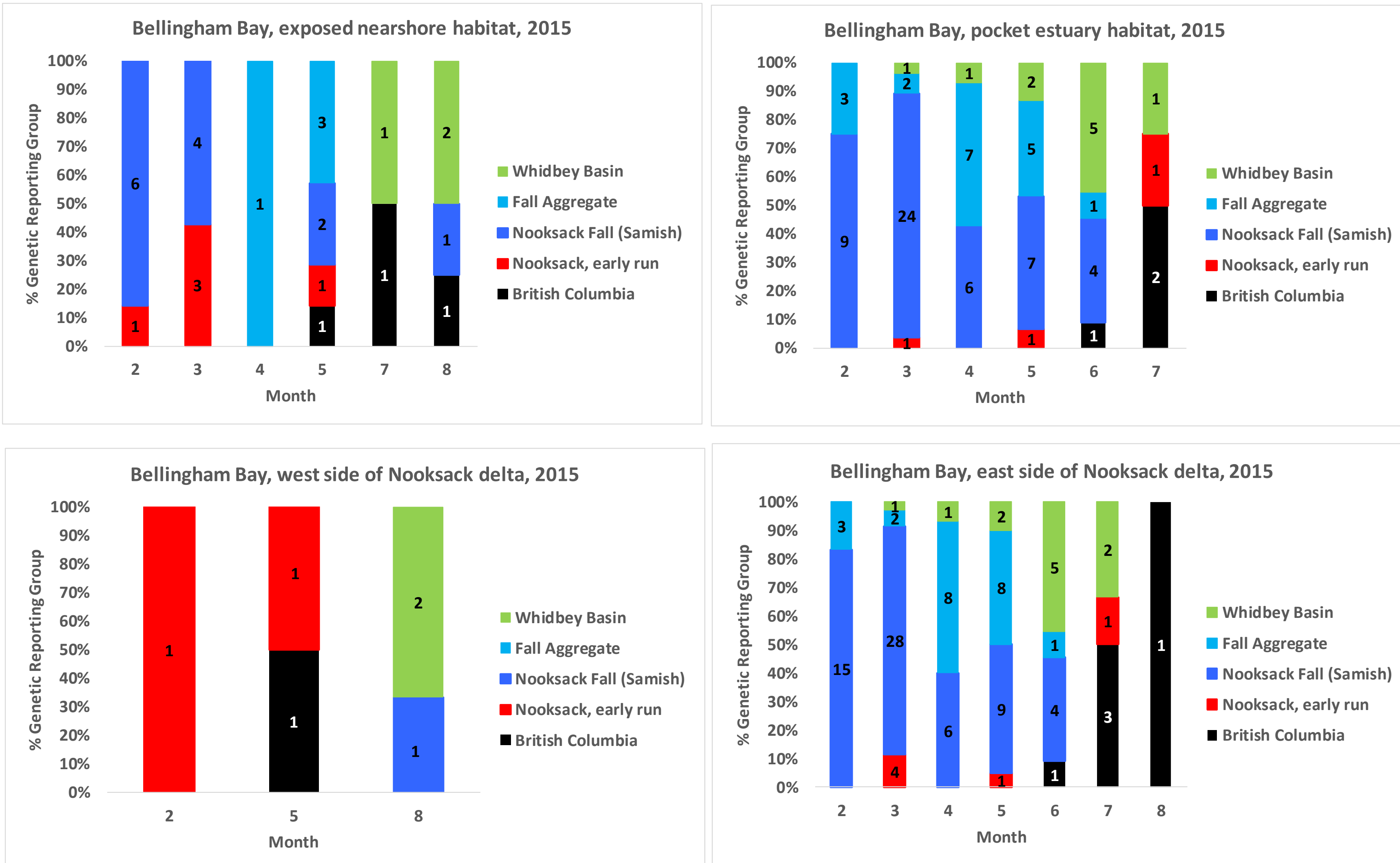

Figure 5.2.5. SNPs baseline genetic assignment of 112 juvenile Chinook salmon caught in the Bellingham Bay nearshore in 2015. Only fish with a "best stock" estimate probability of 0.8 or greater compared to the baseline are shown. The number of fish in each month/genetic assignment group is shown within each graph bar. The 112 samples were graphed in two ways: by habitat type (top panels) and by proximity to the Nooksack delta (bottom panels).

Portage Island Creek

Results and discussion

Portage Island Creek was sampled only in 2015. The NOR juvenile Chinook from Portage Island Creek were comprised mainly of Nooksack early run fish in March and a mix of Whidbey basin and Nooksack Fall Chinook in April (Figure 5.2.6).

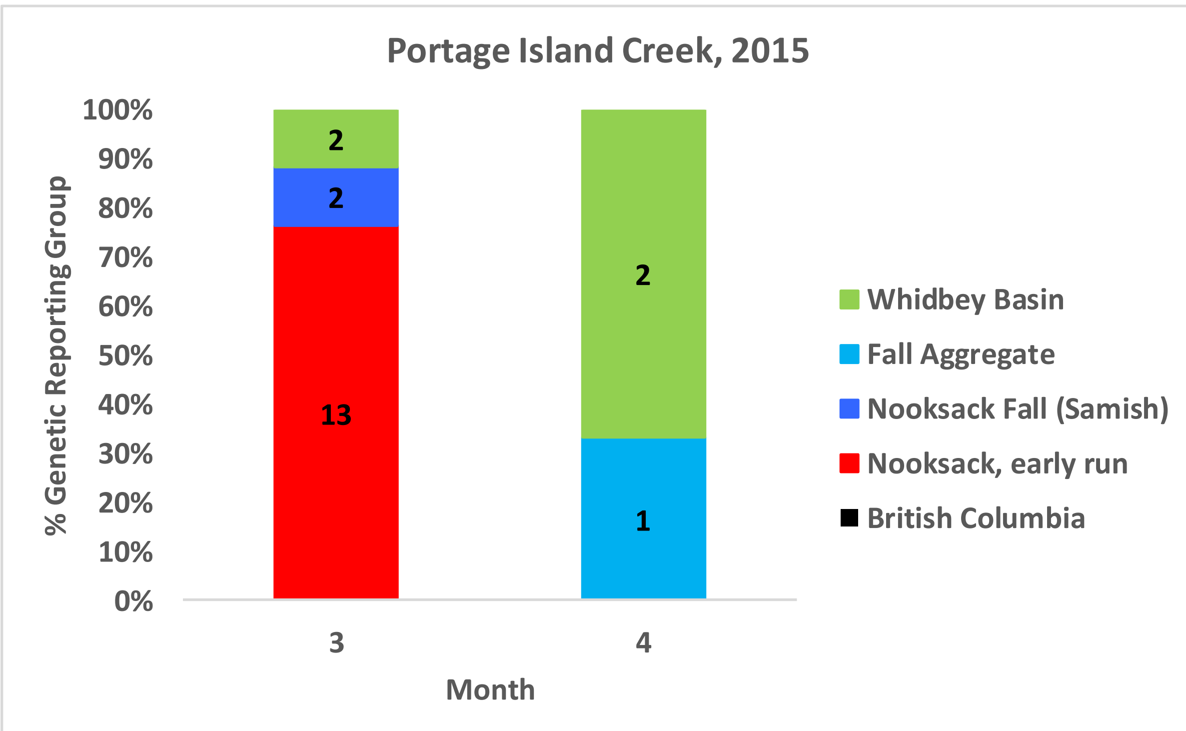

Figure 5.2.6. SNPs baseline genetic assignment of 20 juvenile Chinook salmon caught in Portage Island Creek in 2015. Only fish with a "best stock" estimate probability of 0.8 or greater compared to the baseline are shown. The number of fish in each month/genetic assignment group is shown within each graph bar

Conclusions and recommendations

1. Nooksack River NOR Chinook spring and fall populations produce juveniles capable of expressing the life history types that rear extensively within their natal estuary or nearshore refuge habitat such as pocket estuaries.
2. NOR juvenile Chinook in the Nooksack tidal delta were predominately Nooksack origin fish comprised of early run fish in the fry migration period followed by a combination of early and fall run fish in the parr outmigration period.
3. Bellingham Bay nearshore and pocket estuary habitats were mostly comprised of Nooksack origin NOR juvenile Chinook, especially early in the season.
4. Out-of-system NOR juvenile Chinook in Bellingham Bay nearshore habitats were primarily from the Whidbey basin and were generally not present before summer months. However, consistent presence of Whidbey Basin fish along with intermittent presence of some British Columbia stocks show the Bellingham Bay nearshore environment is an important rearing area for fish in the Salish Sea.
5. The distributary channel-spanning logjam in the Nooksack tidal delta may be influencing where juvenile Chinook outmigrating from the Nooksack River go within the Bellingham Bay nearshore and not just within the tidal delta.

6.0 Juvenile Chinook salmon performance

To assess performance of juvenile Chinook salmon using the Nooksack tidal delta and Bellingham Bay nearshore refuge habitats we tested for evidence of density dependence in the Nooksack tidal delta, and used a bioenergetics approach to examine how competition for prey in different habitat types influences growth and residency, and by extension, habitat capacity in the Nooksack tidal delta and Bellingham Bay pocket estuary habitats for NOR juvenile Chinook salmon. This chapter addresses the following questions for juvenile Chinook salmon using the Nooksack estuary and Bellingham Bay nearshore refuge habitats:

1. Is there evidence of system level density dependence in the Nooksack estuary?
2. What is available to eat and what are fish eating?
3. Are there bioenergetic influences on the fish at certain times, habitat types, or local density levels?

6.1 System level density dependence

The idea that competition among individuals structures dynamic changes in a population's abundance and other attributes has a long history in the field of ecology. More recently, there has been a resurgence in interest in population dynamics at low abundances, where competitive interactions may be minimal and benefits to survival and growth by living together (so-called Allee effects after Warder Clyde Allee, an early proponent, Greene 2008) can predominate. Competitive interactions and Allee effects are predicted to have important population consequences: while competitive interactions result in population regulation (a tendency for the population to equilibrate at a moderate abundance level in the absence of environmental variation), Allee effects result in unstable dynamics, creating situations in which the population can decline toward extinction (sometimes called depensation). Evidence for both types of density-dependent dynamics exist in salmon and other fish species. Competitive dynamics come in many forms, such as reduction in growth, body size, dispersal, and migration at high densities. Likewise, evidence exists that populations at low densities may be slow to return to high abundances. Studies examining population dynamics across species suggest that while competitive interactions predominate across broad ranges in abundance (Myers et al. 1995), depensation at low abundance levels is difficult to rule out (Liermann and Hilborn 2001).

These concepts underpin views of management strategies to restore and protect habitat. Habitat may sometimes be considered 'underseeded', implying either lack of competitive interactions or invoking the existence of Allee effects, in which case strategies that serve to boost population size or to concentrate individuals in time or space (e.g., high quality and easily accessible sites that attract fish) may have population benefits. Alternately, if the population is considered to be nearing capacity, habitat restoration strategies that allow populations to spread out in space or time (e.g., restoring connectivity to disconnected areas, restoring large areas of habitat) are likely to improve productivity.

Because of a long history of habitat modifications in the Pacific Northwest, the reality is that much suitable habitat has been lost (Simenstad et al. 2011), thereby potentially shifting the baseline for competitive interactions to lower levels of abundance. While this reality may argue for rapid broad-scale restoration of all habitat types, the possibility that some habitats may offer higher productivity than others could facilitate prioritization solutions that could address both ends of the density-dependence spectrum.

Here we determine whether there is support for juvenile Chinook salmon density dependence or density independence in the Nooksack estuary. We do this by examining whether estuarine rearing habitats for juvenile Chinook salmon in the Nooksack River exhibit similar patterns of fish density across various outmigration population sizes. We utilize 13 years of data collected at the Nooksack River smolt trap and within the Nooksack estuary and the shoreline of Bellingham Bay. Habitats were differentiated based on differences in tidal and freshwater influence. We compare data from the Nooksack River to those obtained in the Skagit River, a system which exhibits evidence for strong density dependence at both high and low densities (Beamer et al. 2005).

Methods

Fish data

Data collected from the trapping in the lower Nooksack River were converted into annual summaries of outmigrant fry, the portion of the cohort that benefits from estuary rearing. Likewise, fish sampling in three habitats of the Nooksack River estuary (forested riverine tidal, estuarine scrub shrub, and estuarine emergent marsh) were summarized as annual average density.

Statistical analysis

We asked whether annual habitat-specific density estimates followed density-dependent dynamics typical of stock-recruit relationships (Figure 6.1.1). Annual estimates of outmigrant fry is summarized in Chapter 4 (section 4.2). Annual estimates of habitat-specific density were based on the geometric mean of multiple samplings of density (converted to fish/ha) in estuary habitats. Data for these habitats in the connected Nooksack tidal delta were collected as early as 2003, although life history-specific (fry, parr) data for NOR Chinook salmon outmigrants in the Nooksack River starts in 2005. Furthermore, sampling was sometimes missing in particular habitats, so we interpolated three data points for a missing annual habitat-specific density when the other two systems were sampled. This provided nine years of data for the Nooksack system with paired observations of habitat-specific densities and outmigrant estimates.

As shown in Figure 6.1.2, geometric mean density of juvenile Chinook salmon rearing in the estuary can be thought of as recruits and outmigrant fry as the “stock”. Following methods similar to Zimmerman et al. (2015), we evaluated three models of density dependence (Table 6.1.1). The first model is density- independent, i.e., density in the estuary relative to outmigrant fry is constant. The second model is a Ricker function of density dependence, while the third is a Ricker function that includes an Allee effect. Models were tested using nonlinear regression and compared using AICc (Burnham and Anderson 2002), which adjusts for small sample size.

Results and discussion

Annual estimates of both average juvenile NOR Chinook salmon density within habitats of the Nooksack tidal delta and numbers of outmigrant fry were relatively low for the nine-year period of record analyzed. This is exemplified by comparison to habitat-specific estimates from the Skagit River (Figure 6.1.2 above), illustrating that Nooksack values were a small fraction of both outmigrant fry numbers and densities in the estuary. These patterns indicate that in the Nooksack River, outmigrants reared within the Nooksack estuary at densities far below levels normally observed in different habitats in the Skagit River, a system that exhibits strong patterns of density dependence (Beamer et al. 2005, Greene et al. 2005, Zimmerman et al. 2015). In both systems, juvenile Chinook tended to rear at higher densities in ESS and EEM habitats compared to FRT, especially at higher outmigration sizes.

All stock-recruit analyses suggested that density-independent interpretations were the most parsimonious model of the relationships between density in the estuary and outmigrant fry (Table 6.1.2). Because only nine years of data existed, we first pooled all habitat-specific observations to provide the strongest power to detect a density-dependent relationship. While the density-dependent parameter (b) in the Ricker model was significantly greater than zero ($P < 0.05$), the best model as determined by AIC (Akaike information criterion) was the density-independent model. Of the three models compared, this model received a probability weight of 0.78. Hence, while some evidence existed for density dependence following a Ricker relationship, model comparison suggested that this relationship was poorly supported. Of the three models examined, the Ricker model with an Allee effect exhibited very poor support, and the parameter estimate was not a biologically realistic value.

Habitat-specific relationships followed the same patterns as the system-wide analysis. For all estuary habitats, the density-independent model had very strong support (probability weight > 0.9 in all cases), and the density-dependent parameter in the Ricker model was significantly different from 0 in only one model (FRT). This effect would probably have been eliminated had one anomalous year (2009) with low sampling effort and which produced the highest density estimate for FRT in the Nooksack (see Figure 6.1.2 above) been included in the analysis. The Ricker models with an Allee effect produced a biologically realistic value in only one habitat (EEM), and this model generally received poor support.

Taken together, these results suggest that estuary habitats of the Nooksack are generally being utilized by juvenile NOR Chinook salmon at very low densities, especially compared to the habitat-specific levels witnessed in the Skagit River. These two systems have very different outmigration sizes and different amounts of habitat in the estuary, so direct comparisons of data should be made with care. Nevertheless, the fact that Skagit habitats normally support over 100x the densities observed in the Nooksack (Figure 6.1.2 above) strongly suggests habitat utilization levels are nowhere near levels that would trigger strongly competitive interactions. Although there were some indications of limited system-wide density dependence in the Nooksack, the most strongly supported models were density-independent. Models with an Allee effect were very poorly supported, in part possibly due to low sample sizes that would tend to hamper robust statistical approximation. Hence, while estuary habitats might be considered ‘underseeded’ in that they are not utilized at high densities, depensatory effects of habitat use at very low densities do not appear to strongly impact juvenile fish.

Long-term monitoring from the Skagit River (Beamer et al. 2005) suggests that habitat limitations in the Skagit estuary result in fry migrating into nearshore habitats in a density-dependent manner. These results are suggested from abundance patterns in river, estuary, and nearshore as well as annual differences in size of fish rearing within the estuary. The results also suggest that parr migrants, which rear for an extended period of time upriver instead of in the estuary, do not greatly influence density dependence within the estuary. Parr migrants correspond to fingerling hatchery releases, and both hatchery and wild-origin parr migrants appear to move very rapidly through the estuary. Given the low current densities of fry as well as the timing of hatchery releases and their behavior when migrating downstream, our findings suggest that migrant hatchery fish have a minimal effect on density dependence in the Nooksack estuary. It remains possible that density-dependent interactions, including interactions between wild and hatchery fish, could occur in riverine habitats. These issues were examined earlier in this report (Chapter 4.2) with the finding of no evidence a NOR parr migrant carrying capacity limitation exists in freshwater habitat. Furthermore, as different populations commingle in Bellingham Bay and the Salish Sea, it remains possible that density-dependent interactions exist in marine waters.

Conclusions and recommendations

1. There is consistent use of Nooksack tidal delta habitat by NOR juvenile Chinook but juvenile Chinook density data does not exhibit a density dependence relationship over the current range of NOR juvenile outmigrations. The Nooksack tidal delta is underseeded by NOR juvenile Chinook salmon.
2. Ongoing efforts by the authors to better understand the range of potential density-dependent interactions of Chinook salmon in estuaries will be improved by additional comparisons among estuary systems. The Nooksack and Skagit may represent two endpoints of a spectrum of salmon populations – one with a small current population size utilizing a relatively small estuary that has undergone moderate habitat modification (Simenstad et al. 2011), and the other with the largest population size for Puget Sound, the largest extant estuary system, but also high amounts of habitat lost to agriculture and urbanization. Correcting for amounts of existing habitat may help facilitate comparison of the Nooksack to the Skagit and other estuaries like those of the Nisqually and Snohomish Rivers. These comparisons may help shed better light on the ranges of outmigration population size that may result in density dependence in existing habitat, the possible existence of depensation, the potential habitat-specific differences in productivity, and possible interactions of wild and hatchery fish in the estuary during outmigrations.

Table 6.1.1. Three models used to examine possible stock-recruit relationships in the three habitats of the Nooksack delta. In each equation, D = habitat-specific density, F = outmigrant fry, *e* = error, and a, b, and c = parameters estimated in nonlinear regression.

Model	**Nonlinear regression equation**
Density independence (DI)	$\log_e(D) = \log_e(a) + \log_e(F) + e$
Density dependence (DD)	$\log_e(D) = \log_e(a) + \log_e(F) – b*F + e$
Density dependence (DD w/Allee)	$\log_e(D) = \log_e(a) + \log_e(F^2) – b*F – \log_e(c + F) + e$

Table 6.1.2. Summary of model selection for density dependence in Nooksack estuary habitats. Number of parameters estimated (K) includes a single parameter for error estimation. ΔAICc is the basis for model selection (lower is best) and is calculated using mean-square error (MSE) of the model, K, and number of annual estimates (N). ΔAICc values were used to estimate probability weights of different models. Italicized parameter estimates are significantly different from 0 (based on 95% confidence intervals).

Habitat	**Model**	**Parameter estimate**			**MSE**	**K**	**N**	**ΔAICc**	**Probability**
		a	**b**	**c**					**weight**
System	DI	*-8.35*			1.163	2	27	0	0.784
	DD	*-7.74*	**0.00005**		0.916	3	27	3.021	0.173
	DD w/Allee	*-7.91*	**0.00005**	-140.95	0.915	4	27	5.797	0.043
Forested Riverine Tidal	DI	*-8.13*			1.451	2	9	0	0.931
	DD	*-7.35*	**0.00007**		1.143	3	9	5.277	0.067
	DD w/Allee	*-7.52*	0.00006	-130.00	1.216	4	9	12.354	0.002
Estuarine Scrub Shrub	DI	*-8.30*			1.139	2	9	0	0.948
	DD	*-7.56*	0.00007		0.695	3	9	5.787	0.052
	DD w/Allee							Failed to converge	
Estuarine Emergent Marsh	DI	*-8.62*			0.922	2	9	0	0.917
	DD	*-8.31*	0.00003		0.893	3	9	4.864	0.081
	DD w/Allee	*-8.08*	0.00003	299.27	0.940	4	9	11.962	0.002

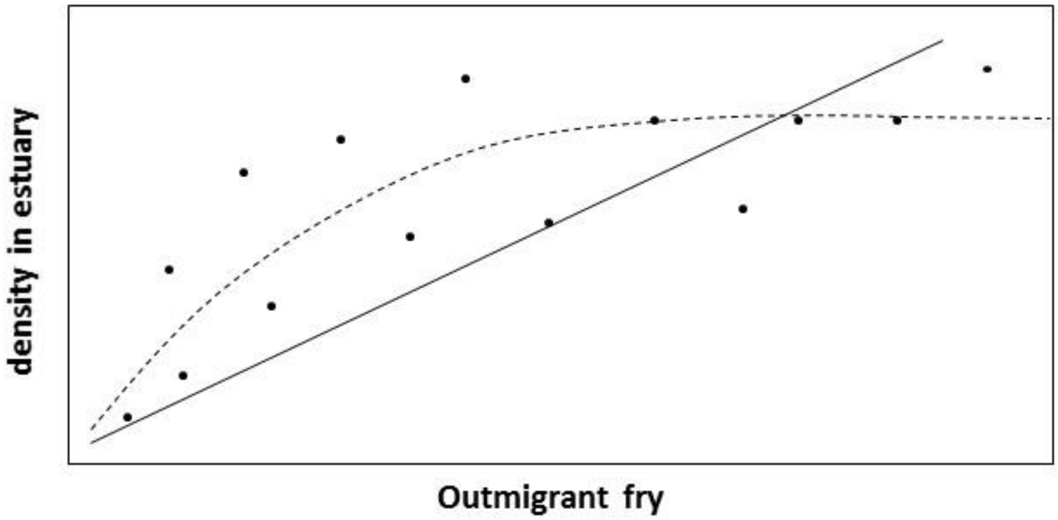

Figure 6.1.1. Hypothetical density-dependent (dashed line) vs density-independent (solid line) relationships between annually measured outmigrant fry measured in-river and fish rearing in the tidal delta.

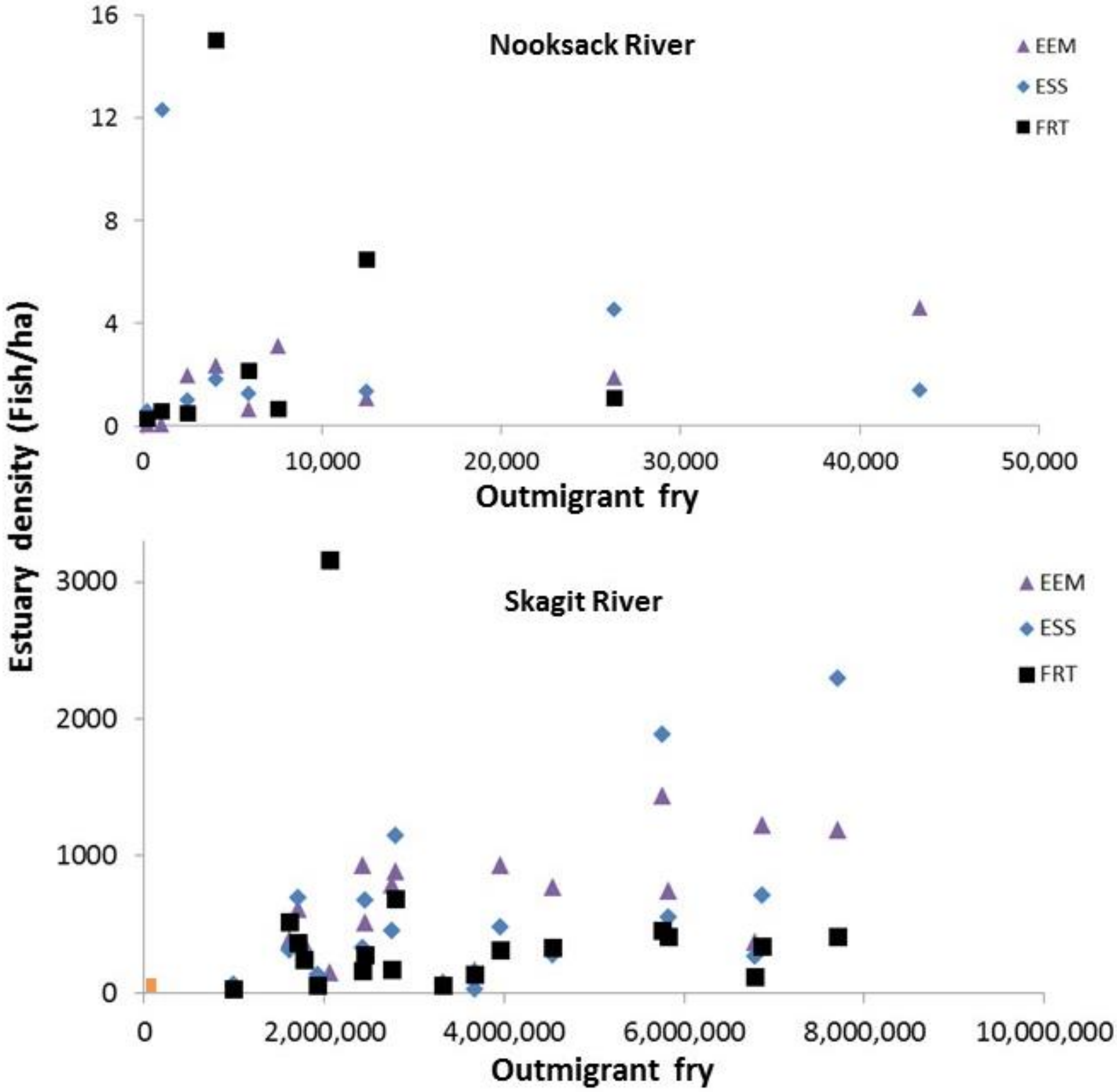

Figure 6.1.2. Geometric mean NOR Chinook salmon fry density in forested riverine tidal (FRT), estuarine scrub shrub (ESS), and estuarine emergent marsh (EEM) as a function of outmigrant fry in the Nooksack River (top panel) and the Skagit River (bottom panel). In the bottom panel, the orange box near the origin represents the range of data from the Nooksack.

6.2 Prey availability and juvenile Chinook salmon diet assessment, 2014 and 2015

This study component examined potential juvenile salmon prey that is available in the Nooksack tidal delta and compared it to what was eaten by juvenile Chinook salmon in the same habitats at the same time of year. Results from this study component help us know whether certain habitat types (or times of the year) are providing food for juvenile Chinook salmon and whether the fish are taking advantage of it.

Methods

Because no existing data for potential prey of juvenile Chinook salmon are available for the Nooksack tidal delta or Bellingham Bay nearshore, we collected prey availability and juvenile Chinook salmon diet data in 2014 at same time and sites as the fish sampling occurred. Prey sampling focused on neuston[5] and epibenthos[6] which are known to make up the majority of juvenile Chinook salmon diets. Unmarked (wild) juvenile Chinook salmon diet samples were analyzed as part of the SSMSS by the University of Washington (D. Beauchamp lab).

We explored the following questions with these data using nonparametric statistics in PRIMER. To statistically compare overall prey or Chinook diet assemblage composition among the factors (i.e., month, combined habitat type), we used ANOSIM (analysis of similarity) and SIMPER (similarity percentages) tests to determine which taxa contributed most to assemblage similarity.

1. Are there differences in the prey assemblage by month and combined habitat type?
2. What are the prey availability taxa by month and combined habitat type?
3. Are there differences in juvenile Chinook salmon diets by month and combined habitat type?
4. What are the juvenile Chinook salmon diet taxa by month and combined habitat type?
5. Is there evidence of prey selectivity by juvenile Chinook salmon by month and combined habitat type?

We combined neuston and epibenthic prey availability samples for each site/date combination into one result to represent prey availability for the entire water column. Count of prey by grouped taxa were divided by the amount of water sieved by the plankton net during sample collection to standardize the prey availability result into density (# of individuals/m^3 of water) by each taxon. We matched juvenile Chinook diet samples collected at the same sites by month in 2014. A summary of samples is shown in Table 6.2.1.

Taxa within prey availability and juvenile Chinook salmon diet were identified to various levels including to genus/species. To organize taxa for PRIMER analysis all taxa were summarized into 44 possible taxa groupings based on: 1) where the organism likely originated (i.e., aquatic, benthic, epibenthic, planktonic, pelagic, terrestrial) and 2) a common taxonomic level (order, if possible). The 44 possible taxa, and other variables used in PRIMER analysis, are shown in Table 6.2.2.

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[5] Neuston is the collective term for the organisms that float on the top of water (epineuston) or live right under the surface (hyponeuston).

[6] Epibenthos is the community of organisms which live on or near the seabed.

The sample distribution is unbalanced and spotty for matches across prey and diet samples (Table 6.2.1). The samples are complete temporally for prey availability, but are spotty in replication (i.e., sites) by combined habitat type. These limitations reduced our ability to detect differences for habitat and temporal (month) strata.

For separate analysis of prey availability and juvenile Chinook salmon diet we used a 4^{th} root transformation to maximize the differences across all records (site/date combinations). To compare prey availability to juvenile Chinook diet, we excluded one combined habitat strata (exposed nearshore) and two months (March and June) due to patchy samples across both sample types. We did a presence absence transformation on the data because one dataset is a count based on weight while the other is a count based on the number of organisms per volume of water. We also dropped one taxon (unID digested) because it is not a possible taxon for prey availability samples.

Results and discussion

Prey availability

A non-metric multidimensional scaling (NMDS) plot of prey availability assemblage (Figure 6.2.1) and two way crossed ANOSIM (combined habitat strata by month) found significant differences for both variables. The combined habitat strata effect has a *r*-statistic of 0.246 (*P = .003*). The combined month effect has a *r*-statistic of 0.276 (*P = 0.002*). For the month effect on prey availability, April is significantly different than both May and June, reflecting a seasonal shift in taxa available. For the combined habitat strata effect, pocket estuary habitats are different than all natal estuary types (FRT, EEM, and ESS) (Table 6.2.3). Table 6.2.4 shows the percentage of taxonomic similarity contributed by taxa grouping for prey availability by combined habitat strata across all month groups in 2014. The exposed nearshore w/FW group is not represented because there were no groups with at least two samples.

Wild juvenile Chinook salmon diet

A NMDS plot of wild juvenile Chinook salmon diet assemblage (Figure 6.2.2) and two way crossed (combined habitat strata by month) ANOSIM found significant differences for both variables, but the month effect was stronger than combined habitat strata. The combined habitat strata effect has a *r*-statistic value of 0.159 (*P = .025*). The combined month effect has a *r*-statistic value of 0.237 (*P = 0.001*). Many month pairings are significantly different reflecting a seasonal shift in diet (Table 6.2.5), whereas the only different combined habitat strata pairing is: pocket estuary and natal estuary ESS *(r = 0.408, P = 0.002*). Table 6.2.6. shows percentage of taxonomic similarity contributed by taxa grouping for wild juvenile Chinook salmon by combined habitat strata across all month groups in 2014. Table 6.2.7. shows percentage of taxonomic similarity contributed by taxa grouping for wild juvenile Chinook salmon by month across all combined habitat strata in 2014.

Comparing prey availability and juvenile Chinook salmon diet

Two way crossed (sample type by month) ANOSIM found significant differences for both variables. Sample type (wild juvenile Chinook diet, prey availability) has a *r*-statistic value of 0.758 (*P = .001*). Month (April, May) has a *r*-statistic value of 0.113 (*P = 0.005*). There is a strong difference between prey available compared to what is actually eaten by wild juvenile Chinook salmon (Figure 6.2.3). Table 6.2.8 shows percentage of taxonomic similarity contributed by taxa grouping for prey availability and juvenile Chinook diet across April and May in 2014.

Conclusions and recommendations

1. All Nooksack tidal delta and pocket estuary habitats sampled produced food for NOR juvenile Chinook salmon.
2. Potential juvenile salmon prey taxa were caught at all estuarine emergent marsh, estuarine scrub shrub, and forested riverine tidal sites within the Nooksack tidal delta and Bellingham Bay pocket estuaries.
3. Habitat type had a stronger effect than season on prey assemblage.
4. NOR juvenile Chinook salmon consumed prey in all habitats, but our study shows evidence of selectivity between prey taxa consumed and prey taxa numerically available.
5. Season was more important than habitat type with respect to prey taxa consumed by juvenile Chinook salmon.

Table 6.2.1. Summary of juvenile Chinook diet and prey availability samples analyzed in PRIMER by site, combined habitat strata, and month in 2014. Neuston and epibenthic prey availability samples were combined to represent one result for the entire water column.

Combined habitat strata	**Site**	**Unmarked Chinook subyearling diet samples**				**Prey availability samples**		
		March	**April**	**May**	**June**	**April**	**May**	**June**
Exposed nearshore	Marine Park					1	1	1
	Portage Bay					1	1	1
	Whirlwind Beach					1	1	1
Exposed nearshore w/FW	Little Squalicum Cr Beach	1	2	1		1	1	1
Natal estuary - EEM	Airport Creek			2		1	1	1
	Lummi River					1	1	1
	Red River 3					1	1	1
	Tidal Delta 2	1		3		1	1	1
Natal estuary - ESS	Fish Pt	1	1	4	1	1	1	1
	Silver Cr 3		1			1	1	1
Natal estuary - FRT	Kwina Sl 2	2	3	3		1	1	1
	Silver Cr Upper					1	1	1
Pocket estuary	I & J Waterway	3		9	8	1	1	1
	Padden Lagoon	14	12	3		1	1	1
	Post Pt Lagoon	6	6			1	1	1
	Whatcom Cr Mouth	10	16	9		1	1	1
	Grand Total	**38**	**41**	**34**	**9**	**16**	**16**	**16**

Table 6.2.2. List of 44 possible prey availability or juvenile Chinook salmon diet taxa and variables used in PRIMER analysis.

Variable name	Description (data type)
SiteName	Spatial factor (text)
Combined habitat strata	Habitat factor (text)
Collection date	Temporal variable (numeric)
Month	
Sample type	'Chinook diet' or 'prey availability'
SampleUnits	Chinook diet = weight (grams) Prey availability = density (count of organisms/m^3)
Average water temperature (degrees C)	Environmental covariate (numeric)
Maximum salinity (ppt)	
Minimum salinity (ppt)	
Minimum dissolved oxygen (mg/l)	
Water depth (m)	Environmental covariate (numeric), only applies to prey availability samples
• aquatic arachnid • benthic barnacles, benthic polychaete, benthic/epi oligochaetes, benthic ribbon worm, • emergent diptera • epibenthic/pelagic mysid, epibenthic/planktonic Cladoceran, • epibenthic amphipod, epibenthic copepod, epibenthic cumacea, epibenthic diptera, epibenthic ephemeroptera, epibenthic hemipteran, epibenthic isopod, epibenthic odonata, epibenthic ostracod, epibenthic plecoptera, epibenthic decapoda, epibenthic snail • insect – digested, insecta other • unID amphipod • parasitic copepod • pelagic decapoda, pelagic fish • planktonic amphipod, planktonic barnacle, planktonic copepod • plant material • terrestrial arachnid, terrestrial coleoptera, terrestrial diptera, terrestrial hemiptera, terrestrial hymenoptera, terrestrial isopod, terrestrial lepidoptera, terrestrial psocoptera, terrestrial springtail, terrestrial thysanoptera, terrestrial trichoptera • unknown larvae, unID Worm	Potential taxa of prey availability and Chinook diet samples (numeric)
• unID digested	Potential taxa of prey availability and Chinook diet samples (numeric) only possible in Chinook diet samples

Table 6.2.3. ANOSIM results of prey availability assemblage differences for combined habitat strata pairings. The *r*-values range from near zero (no difference) to 1 (most different). The *r*-values are more informative of similarity/dissimilarity than *P*-values which are strongly influenced by sample size.

Groups		***r*-Statistic**	**Significance Level %**
Natal estuary - EEM	Natal estuary - ESS	0.119	26.4
	Pocket estuary	0.191	2.5
	Natal estuary - FRT	0.292	5.6
	Exposed nearshore w/FW	-0.167	64.8
	Exposed nearshore	0.136	12.2
Natal estuary - ESS	Pocket estuary	0.833	0.1
	Natal estuary - FRT	0.083	37.0
	Exposed nearshore w/FW	0.333	37.0
	Exposed nearshore	0.444	5.6
Pocket estuary	Natal estuary - FRT	0.702	0.1
	Exposed nearshore w/FW	0.194	20.8
	Exposed nearshore	0.049	33.7
Natal estuary - FRT	Exposed nearshore w/FW	-0.667	96.3
	Exposed nearshore	0.250	12.7
Exposed nearshore w/FW	Exposed nearshore	-0.481	95.3

Table 6.2.4 (A-E). Percentage of taxonomic similarity contributed by taxa grouping for prey availability by combined habitat strata (SIMPER test; top 90% of contributions) across all month groups in 2014.

A. Group Natal Estuary – EEM. Average similarity: 39.08.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
epibenthic amphipod	1.87	8.78	1.44	22.47	22.47
epibenthic copepod	2.03	7.44	1.09	19.04	41.51
planktonic barnacle	1.27	5.02	0.72	12.84	54.35
epibenthic ostracod	1.48	3.70	0.65	9.45	63.80
planktonic copepod	0.96	2.88	0.65	7.38	71.18
epibenthic cumacea	0.89	2.71	0.65	6.94	78.12
epiben/plank cladoceran	0.84	2.08	0.43	5.33	83.45
aquatic arachnid	0.46	1.25	0.41	3.21	86.66
benthic/epi oligochaetes	0.33	0.73	0.24	1.86	88.52
benthic polychaete	0.63	0.72	0.24	1.84	90.36

B. Group Natal Estuary – ESS. Average similarity: 35.72

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
epibenthic copepod	1.85	14.63	2.28	40.95	40.95
epibenthic amphipod	1.22	6.27	1.02	17.55	58.50
aquatic arachnid	0.57	4.60	0.58	12.88	71.38
terrestrial springtail	0.49	3.54	0.58	9.91	81.28
epibenthic ostracod	1.15	3.45	0.58	9.66	90.95

C. Group Pocket estuary. Average similarity: 63.03

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
epiben/plank cladoceran	2.80	12.72	4.59	20.19	20.19
epibenthic copepod	2.01	10.57	6.30	16.77	36.96
planktonic barnacle	1.81	7.58	0.99	12.02	48.98
planktonic copepod	1.92	7.12	1.41	11.29	60.27
benthic polychaete	1.44	6.75	1.38	10.71	70.98
epibenthic ostracod	1.02	4.88	0.96	7.75	78.73
epibenthic amphipod	0.95	4.24	1.04	6.72	85.45
pelagic decapoda	1.17	2.35	0.51	3.72	89.18
benthic/epi oligochaetes	0.57	1.62	0.68	2.56	91.74

D. Group Natal Estuary – FRT. Average similarity: 15.78.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
epibenthic ostracod	2.09	2.79	0.58	17.71	17.71
planktonic copepod	1.81	2.70	0.58	17.13	34.83
aquatic arachnid	1.07	1.98	0.58	12.52	47.35
benthic/epi oligochaetes	0.51	1.66	0.58	10.53	57.88
epiben/plank cladoceran	0.64	1.66	0.58	10.53	68.41
epibenthic amphipod	0.98	1.66	0.58	10.53	78.94
epibenthic diptera	0.78	1.66	0.58	10.53	89.47
terrestrial hymenoptera	0.36	1.66	0.58	10.53	100.00

E. Group Exposed nearshore. Average similarity: 44.80.

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum.%
planktonic barnacle	2.71	10.73	1.35	23.96	23.96
epiben/plank cladoceran	2.13	7.68	1.47	17.15	41.11
planktonic copepod	1.73	5.62	1.04	12.54	53.65
epibenthic copepod	1.18	4.99	0.76	11.14	64.79
epibenthic ostracod	1.07	4.94	0.75	11.02	75.82
benthic polychaete	1.38	4.30	0.69	9.60	85.41
epibenthic amphipod	0.78	3.87	0.74	8.64	94.05

Table 6.2.5. ANOSIM results of juvenile Chinook salmon diet differences for month pairs. The *r*-values range from near zero (no difference) to 1 (most different). The *r*-values are more informative of similarity/dissimilarity than *P*-values which are strongly influenced by sample size.

Groups	***r*-Statistic**	Significance Level %
3, 4	0.060	1.1
5, 3	0.163	0.4
3, 6	0.625	0.1
5, 4	0.258	0.1
4, 6	0.753	0.1
5, 6	0.083	14.9

Table 6.2.6 (A-B). Percentage of taxonomic similarity contributed by taxa grouping for wild juvenile Chinook salmon by combined habitat strata (SIMPER test; top 90% of contributions) across all month groups in 2014.

A. Group Natal Estuary – ESS. Average similarity: 25.49.

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
insect - digested	0.17	12.25	0.79	48.06	48.06
plant material	0.13	6.51	0.67	25.55	73.61
epibenthic diptera	0.08	2.66	0.38	10.45	84.05
terrestrial diptera	0.05	1.68	0.38	6.60	90.66

B. Group Pocket estuary. Average similarity: 29.78

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
unID digested	0.16	17.99	1.00	60.42	60.42
epibenthic copepod	0.04	2.18	0.30	7.30	67.72
unID amphipod	0.08	1.95	0.35	6.55	74.27
epibenthic diptera	0.05	1.63	0.32	5.48	79.74
pelagic decapoda	0.08	1.43	0.20	4.80	84.54
epibenthic amphipod	0.04	1.30	0.20	4.38	88.92
epiben/plank cladoceran	0.04	0.86	0.21	2.88	91.80

Table 6.2.7 (A-D). Percentage of taxonomic similarity contributed by taxa grouping for wild juvenile Chinook salmon diets by month (SIMPER test; top 90% of contributions) across all combined habitat strata groups in 2014.

A. May. Average similarity: 18.96.

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
unID digested	0.10	7.48	0.55	39.46	39.46
pelagic decapoda	0.08	2.92	0.35	15.41	54.87
unID amphipod	0.07	1.89	0.40	9.98	64.85
insect - digested	0.09	1.45	0.24	7.65	72.50
epiben/plank cladoceran	0.05	1.43	0.24	7.57	80.06
emergent diptera	0.06	1.41	0.30	7.43	87.49
terrestrial diptera	0.05	1.09	0.24	5.74	93.23

B. March. Average similarity: 28.15

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
unID digested	0.18	16.81	0.89	59.73	59.73
epibenthic copepod	0.07	4.67	0.45	16.60	76.33
insecta other	0.06	1.83	0.24	6.49	82.82
unID amphipod	0.06	1.79	0.30	6.38	89.20
epibenthic diptera	0.04	0.84	0.20	2.99	92.19

C. April. Average similarity: 34.04.

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
unID digested	0.21	23.67	1.43	69.54	69.54
epibenthic diptera	0.07	3.04	0.47	8.93	78.17
epibenthic amphipod	0.08	2.62	0.29	7.68	86.15
unID amphipod	0.07	2.07	0.37	6.08	92.23

D. June. Average similarity: 55.38.

Species	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
pelagic decapoda	0.41	39.26	3.29	70.90	70.90
emergent diptera	0.16	6.29	0.73	11.36	82.26
insect - digested	0.19	4.34	0.51	7.83	90.09

Table 6.2.8. Percentage of taxonomic similarity contributed by taxa grouping for prey availability and juvenile Chinook diet (SIMPER test; top 90% of contributions) across April and May in 2014.

Prey availability					
Taxa group	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
epibenthic copepod	11.28	6.52	1.20	17.19	17.19
planktonic copepod	8.52	5.18	0.97	13.65	30.83
epibenthic amphipod	8.91	4.73	0.91	12.46	43.29
planktonic barnacle	6.93	3.77	0.70	9.92	53.22
epiben/plank cladoceran	6.42	3.22	0.66	8.49	61.71
epibenthic ostracod	5.38	2.70	0.62	7.11	68.82
benthic/epi oligochaetes	7.31	2.45	0.51	6.46	75.28
aquatic arachnid	6.72	2.34	0.53	6.15	81.43
benthic polychaete	6.03	2.25	0.50	5.93	87.36
epibenthic diptera	4.10	0.98	0.33	2.59	89.95
terrestrial springtail	4.12	0.73	0.23	1.93	91.88
Juvenile Chinook salmon diet					
Taxa group	**Av.Abund**	**Av.Sim**	**Sim/SD**	**Contrib%**	**Cum.%**
epibenthic diptera	11.36	7.26	0.69	42.31	42.31
unID amphipod	8.99	2.00	0.41	11.63	53.95
terrestrial diptera	4.44	1.59	0.40	9.25	63.20
epibenthic ephemeroptera	6.72	1.13	0.29	6.61	69.81
epiben/plank cladoceran	4.40	1.13	0.24	6.59	76.40
planktonic amphipod	2.54	0.62	0.23	3.62	80.02
epibenthic amphipod	2.36	0.59	0.22	3.43	83.45
epibenthic copepod	2.48	0.53	0.23	3.10	86.55
insecta other	6.86	0.50	0.28	2.90	89.46
plant material	2.59	0.44	0.14	2.55	92.01

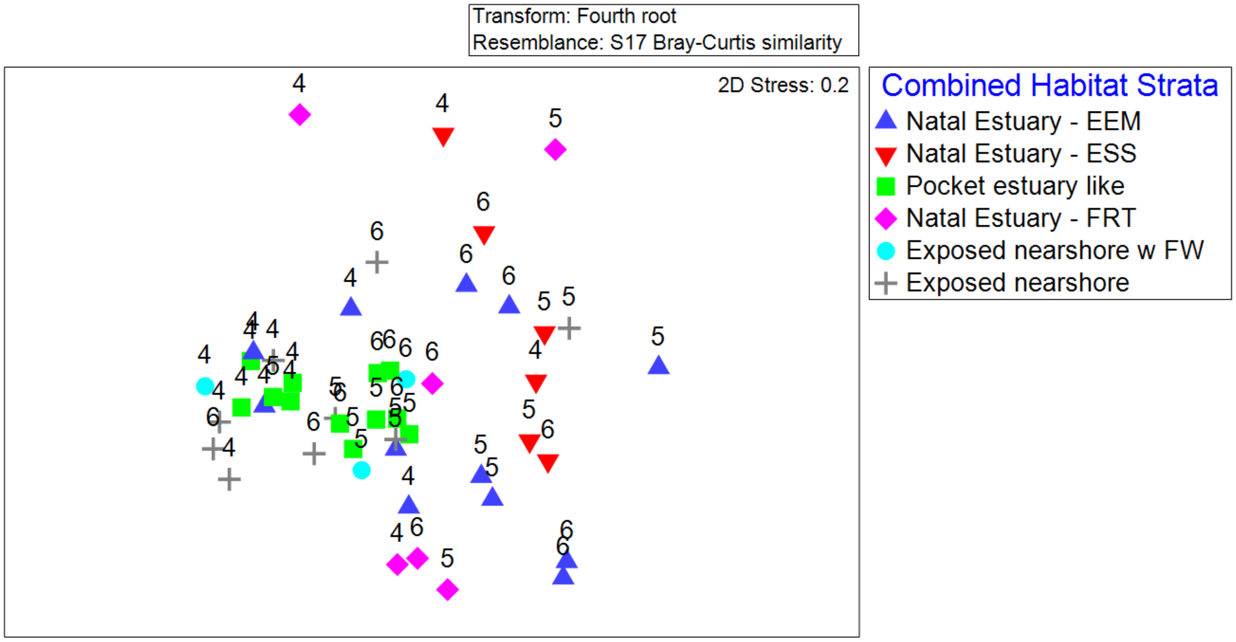

Figure 6.2.1. NMDS plot for prey availability by combined habitat strata. Numbers next to symbols indicate month of sample.

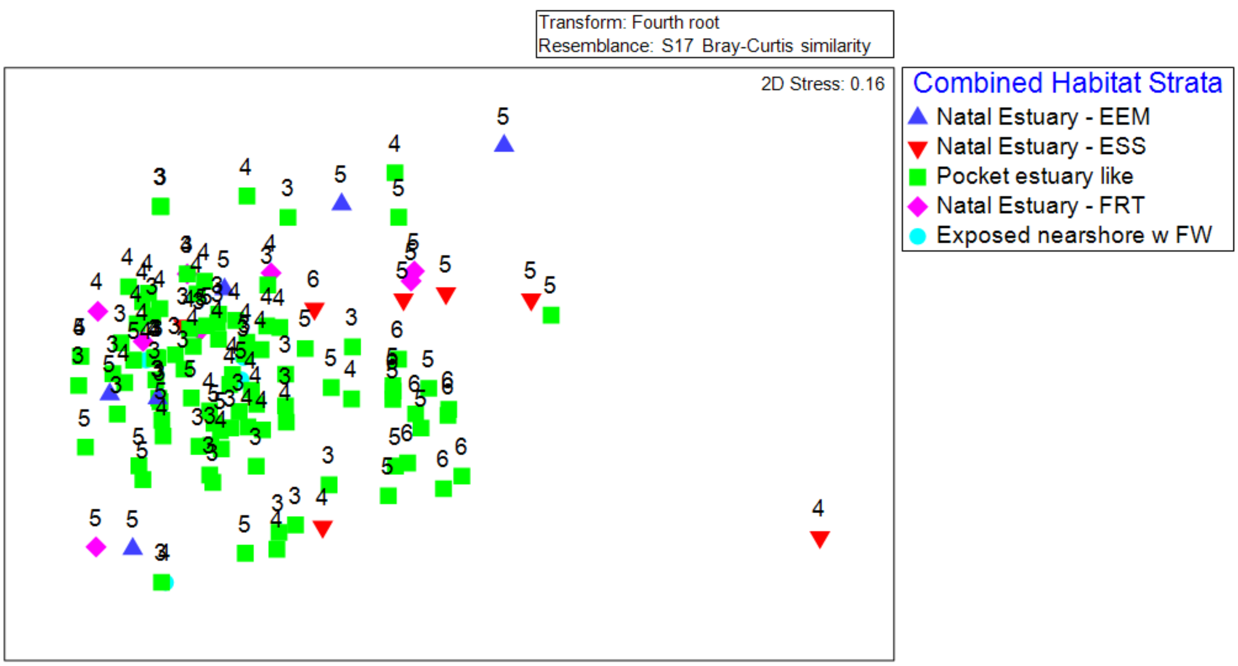

Figure 6.2.2. NMDS plot for wild juvenile Chinook salmon diet by combined habitat strata. Numbers next to symbols indicate month of sample.

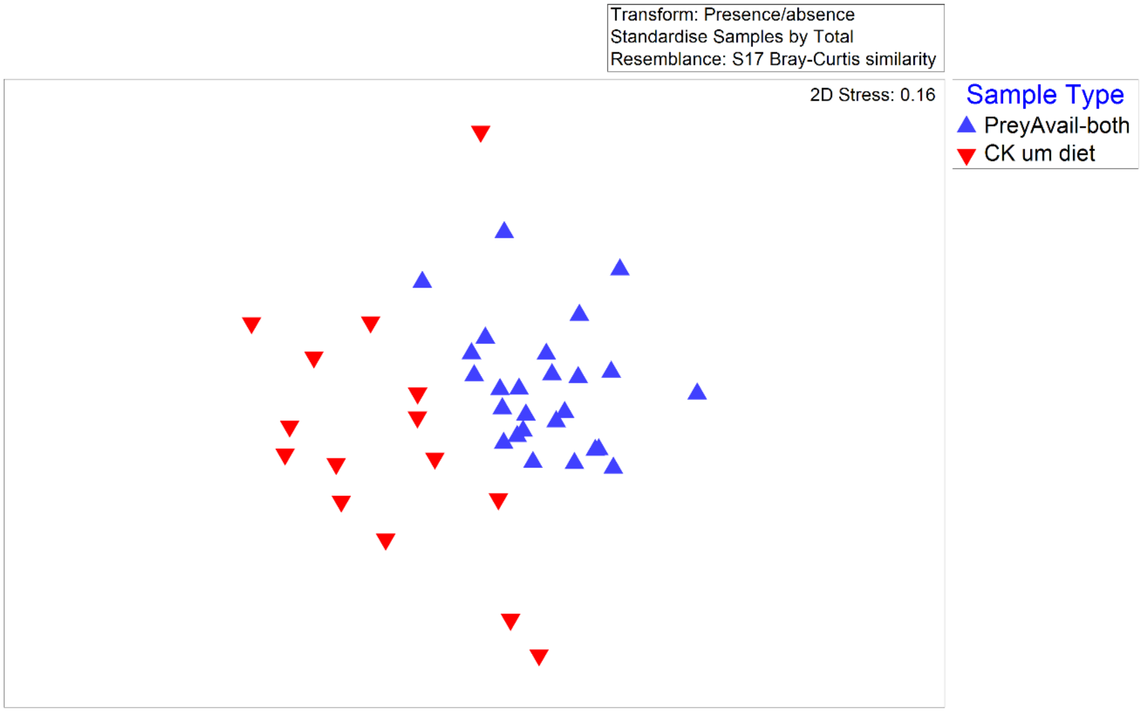

Figure 6.2.3. NMDS plot for wild juvenile Chinook salmon diet and prey availability assemblages.

6.3 Bioenergetics approaches to examine habitat-specific productivity

Growth has often been considered a primary currency by which species alter behavior. Bioenergetics theory predicts that habitats that consistently produce more food, produce food with higher energy density, or allow for more rapid assimilation of food should be utilized by animals for longer periods of time (Goldberg and Novoplansky 1997, Brown et al. 2004).

Anadromous fish present an interesting case because of their migratory habits and ability to temporarily reside in different habitats to feed and rear. Historically, a variety of habitats including riverine environments, floodplains, estuarine systems, and marine shoreline habitats existed that could offer rearing to migratory juveniles. This habitat diversity has provided mechanisms to spread juvenile fish over time and space, reducing the potential for competition over prey. However, over the past 150 years, these habitats have been modified by people, resulting in a shifting baseline of habitat capacity for populations (David et al. 2015). Managers tasked with restoring habitat generally assume different areas are of equivalent value to different species; understanding potential bioenergetic differences among habitat types could therefore provide additional context to decisions regarding how and where to better prioritize restoration efforts.

We sought to address the question of whether certain estuarine habitats might be bioenergetically more productive for juvenile Chinook salmon. Bioenergetic habitat differences might arise for several reasons. First, the types or abundance of prey might differ by habitat types. Secondly, because metabolic processes in most fish depend upon ambient temperature, systematic temperature differences between habitats could offer different growth opportunities independent of prey abundance or energetic density. We therefore collected diet and temperature data from several estuary habitat types to evaluate habitat-specific growth potential using standard bioenergetics models.

Methods

Model framework

We used the Wisconsin Bioenergetics Model (WBM) (Hanson et al. 1997) to predict differences in growth in different habitats across the period of estuarine residence. We focused our analysis on the three estuary habitats (FRT, ESS, and EEM) as well as on pocket estuary (POC) sites in Bellingham Bay, and our sample collections enabled us to produce model runs for two years.

Bioenergetic models are based on a simple equation describing energy balance in an organism:

Consumption = Metabolism + Waste + Growth

Metabolism combines respiration at rest, active metabolism, and digestion, and waste combines egestion and excretion (Hanson et al. 1997). Habitat-specific differences in growth could arise due to differences in the types of prey consumed, as well as from temperature-dependent metabolic processes. The WBM uses a set of equations to estimate consumption and growth based on temperature patterns over time, diets of individuals across time, energy density of prey, and assumptions concerning start and ending biomass and duration of residency. To model potential habitat-specific bioenergetic differences, we monitored temperature in the four habitats from February through July, using temperature loggers, and sampled fish diets in specific habitat types across the period of residency.

Temperature data

Temperature data were collected at ten sites representing different habitat types, primarily using iButton temperature loggers that were sealed in PVC canisters and attached to the substrate using existing large woody debris or rebar stakes. Loggers provided readings every 15 minutes and were periodically replaced to ensure they did not exceed memory storage capabilities. In 2014, loggers were deployed on March 10 (Julian day 69). In 2015, loggers were deployed during the week of March 16 (Julian day 75-80). Data were quality controlled to remove time periods in which loggers were either not submerged (and recorded air temperatures) or became buried in sediment (and recorded hyporheic temperatures). Spot temperature readings during fish sampling were used to supplement temperature logger data prior to the earliest dates of deployment.

NOR juvenile Chinook salmon diets

Diet collections from different habitats were grouped into ranges of days so that potential diet changes in different habitat types could be tracked over time (Table 6.3.1). In order to insure no single diet sample unduly affected results, we grouped time ranges so that a minimum of six individuals were represented in each time range. Due to a low number of sites, proximity of sampling locations, and a relatively low number of captured fish, ESS and EEM individuals were combined for the purposes of tracking diet changes over time.

Prey energy density

A key input of bioenergetic models is the amount of energy that individual prey items provide. We derived estimates of energy density of prey (joules/g wet weight) for all taxa identified based on previous studies of Chinook salmon diets by Gray (2005) and David et al. (2014).

Residency considerations

We constructed the period of residency to reflect some of the broader aspects of fish abundance and size in the Nooksack and Skagit estuaries. In 2014 and 2015, fish were captured in four habitat types (FRT, ESS, EEM, and POC) from February through July. In the bioenergetics models, fish were assumed to enter estuarine habitats early in the season as fry (40-45 mm fork length or 0.5 g), remain in one habitat type, and migrate on the day they achieve a parr size (70-75 mm fork length or approximately 5.0 g). These are the sizes observed in the Skagit early in the season as fry migrate into the estuary, and the sizes at which fish appear to leave tidal delta or pocket estuary habitats (summarized in Table 4.1.1 above). In order to let the model determine the time course to reach emigration size, we specified the end of the rearing period in July (Julian day 190) and observed the rate at which fish attained a migrant body size. In reality, juveniles spend considerably less time within the tidal delta. Otolith microstructure analyses from the Skagit suggest that juveniles reside in estuary habitats a maximum of about ten weeks, and the vast majority of juveniles reside in estuary habitats for less than eight weeks (Figure 6.3.1). In the three years that the otolith study was conducted, shorter estuary residence occurred in the year with the largest outmigration. Given the Nooksack's low patterns of abundance in estuary habitats, one might assume that estuary residency patterns in the Nooksack are skewed toward the higher range of residence time (>42 days). Hence, for our bioenergetics model runs, the initial month and a half of growth likely provides the most biologically realistic differences among habitat types. Following results of system density dependence, we assumed that diet and growth was not affected by competition.

Results

Habitat-specific temperature patterns

In the Nooksack estuary, temperatures strongly varied each year of the study and in the different habitat types (Figure 6.3.2). In 2014, temperatures in FRT habitats were initially colder than the marine waters of POC, and ESS and EEM were intermediate. By mid-March, this pattern switched so that FRT sites were warmer than more marine-influenced areas, and ESS and EEM habitats were virtually identical in temperature. By May, all estuarine environments displayed similar temperature patterns, and thereafter, POCs became warmer than other estuarine habitats.

In 2015, coastal atmospheric warming from the “warm blob” (Bond et al. 2015) resulted in about a 4-degree elevation in all habitat types across the season. Early in the season, temperatures exhibited the same differences across habitats as in 2014, but for most of the season, FRT and POC habitats had similar patterns (perhaps due to freshwater influence in both habitat types), and exhibited smaller temperature spikes than ESS and EEM habitats. Starting in early June, temperatures of some habitats surpassed levels considered stressful for juvenile Chinook salmon (>20°C, Richter and Kolmes 2005), and ESS/EEM habitats exhibited particularly inhospitable temperature spikes.

Habitat-specific diets

Nooksack NOR juvenile Chinook salmon diets, expressed as energy density and wet weight, did not greatly vary by habitat type, but did show evidence for different patterns in the two years (Figure 6.3.3). In 2014, summed energy density of entire diets tended to remain fairly constant among habitat types across the year until after June (Julian day 150), when diets tended to diverge among habitat types, primarily due to the presence of insect taxa in diets. Energy density tended to increase in 2015, when some differences emerged between diets in estuary compared to pocket estuary habitats. These differences were primarily due to relative abundance differences of insect and crustacean taxa in the diets. The rank order of energy density in both years tended to follow FRT > ESS/EEM > POC, although substantial variation existed in this pattern over time.

Diets exhibited even less habitat-specific variation with respect to average wet weight. Very few differences were observed among habitat types or years, except following June 1 (Julian day 150), when the main difference occurred in pocket estuary habitats in 2014 compared to 2015. This large change in wet weight was due primarily to an influx of terrestrial hymenopterans in 2015.

Habitat-specific growth

Predictions from the bioenergetics models revealed strong differences in growth of juvenile Chinook salmon over time in different habitat types, but habitats switched in growth potential in the two years (Figure 6.3.4). In 2014, the model predicted much stronger growth in POC habitats than in FRT environments, with ESS and EEM habitats intermediate. These differences emerged early in the season and were magnified as time continued, at least through the initial 100 days of the simulation (i.e., at Julian day 150). At this point, juveniles that had continued to reside in the FRT would have been 50 days behind in growth compared to fish that had continually resided in POC habitats. In 2015 differences among habitats emerged more slowly. Growth in POC habitats lagged behind other estuarine habitats, and growth in ESS and EEM surpassed that in FRT by late April (Julian day 110). By Julian day 150, fish continually residing in POC habitats would have been 35-45 days behind fish in other habitats.

Discussion

Our main finding from the bioenergetics model is that habitat-specific differences in predicted juvenile Chinook salmon growth can be substantial. These differences were largely an outcome of temperature differences among habitats (Figure 6.3.2) and not due to prey quality or quantity aspects (Figure 6.3.3), particularly during the early time periods (before Julian day 140) when fish are most abundant and differences in growth are most important for future survival. However, because temperature patterns by habitat type varied by year, no single habitat type examined systematically offered better growth benefits. These findings suggest that habitat diversity is important to provide optimal rearing temperatures across the rearing season in order to buffer impacts from particularly cold or (increasingly likely) warm time periods.

The strong temperature influence on fish growth does not mean we categorically conclude prey quality and quantity within Nooksack tidal delta and Bellingham Bay are optimal for juvenile Chinook salmon. We only know prey quality and quantity were adequate to support juvenile Chinook growth in all habitats for both years of study in the Nooksack. A comparative study of Chinook diets and prey availability across multiple estuaries would elucidate where the Nooksack system ranks among other Chinook salmon estuaries. Such a study is underway as part of the Estuary and Salmon Restoration Program Learning Objective Project: Chinook Density Dependence. Project #13-1508P.

Some elements of the model deserve greater complexity to match the ecology of juvenile Chinook salmon. The model examined individuals with a fixed entry time and size and exit biomass using one habitat type. In reality, juveniles migrate downstream over multiple weeks, resulting in overlapping groups of residents that are at different sizes and growth trajectories. Furthermore, actual residency based on otolith microstructure indicates that individual residence time is normally less than seven weeks (Larsen et al. 2009), indicating that actual growth rates are likely higher than reported.

The bioenergetics model assumed density independence. Findings from the Skagit River system suggest that growth is density-dependent (Figure 6.3.1., bottom panel) and may have habitat-specific aspects as well. Juvenile Chinook salmon collected in Skagit tidal delta EEM habitats had approximately three times the growth rates of other Skagit tidal delta habitats and pocket estuaries within the Whidbey Basin (Beamer et al. 2000; Beamer et al. 2013). While the system-wide analysis certainly suggested that fish in the Nooksack tidal delta currently rear at fairly low densities and that the system is unlikely near carry capacity (see section 6.1), it is still possible that competition might occur during certain time periods when a large number of fish (e.g., wild parr migrants and hatchery fingerlings) are migrating downstream. One way to examine these possibilities would be to model habitat-specific consumptive demand (Juncos et al. 2013) with multiple subgroups of fish indexed by time of arrival, residence time, their size at entry, and the resultant changes in habitat-specific density. Outputs of the model could identify time periods or habitats where consumptive demand is particularly high or low, and these patterns could be compared with data on prey availability to determine whether demand is likely to be met at that time and place. As this research is part of an ongoing study of bioenergetics patterns across natal Chinook salmon estuaries in Puget Sound, we will be pursuing these more complex models as a basis for examining habitat-specific differences in the broader study.

Of course, a larger reality is that all fish naturally use a mix of habitat types during outmigration. In this context, the model results point to some time-specific differences in growth opportunity. Fish rearing in the estuary will likely use different habitats by 1) moving dynamically based on tidal current and river flow dynamics that may be partially out of their control, and 2) making choices between staying in a particular habitat with its growth opportunities and moving when those growth opportunities decline to a particular level. Based on the sizes of fish during the rearing period, the first response is likely more important during early phases of immigration, when fish are small and cannot overcome certain current dynamics, while the second response is likely to occur after individuals have grown for several weeks within the estuary. Both responses will likely involve habitat switching to varying degrees, further emphasizing that restoration plans in estuary environments should prioritize a diversity of connected habitats.

Concurrent work, through the SSMSP, evaluated growth of juvenile Chinook in the nearshore and offshore habitats adjacent to the Nooksack tidal delta in 2014 and showed results similar to our study (Gamble 2016). Temperature had the strongest effect on juvenile Chinook growth rates among fish rearing in the different nearshore and offshore habitats, while the effects of prey energy density was minimal. Temperature in the offshore habitats was less variable and remained within the optimal range for growth the entire season. In contrast, nearshore surface temperatures increased considerably from late June through the end of the summer, resulting in a decrease in growth rates. Absolute growth rates for juvenile Chinook in the nearshore and offshore habitats were higher than those we found in the Nooksack tidal delta or pocket estuaries; however, when growth rates were standardized by fish size within each habitat, the difference was considerably less. Although results still showed a higher mean standardized growth rate for fish that transition from nearshore to offshore habitats, growth rates within each habitat type varied considerably, which may reflect temporal variability among conditions (temperature, prey availability/quality) that influence growth rates. Conditions may be optimal, or sub-optimal, in a given habitat at a given time and thus the timing of transitions among habitats is the most important aspect for fish growth rather than the absolute benefit of a certain habitat. This is especially important for natural origin Chinook which have more extensive habitat use patterns given their complex life history diversity compared to hatchery reared fish.

Conclusions and recommendations

1. Functional habitat conditions exist for juvenile Chinook in all estuarine wetland zones of the Nooksack tidal delta and in nearshore refuge habitat (pocket estuaries) based on modeled growth of juvenile Chinook utilizing those habitat types over two different (and contrasting) years.
2. Predicted habitat-specific differences in juvenile Chinook salmon growth were substantial in the Nooksack tidal delta and Bellingham Bay pocket estuaries. Growth differences were largely an outcome of temperature differences between habitat types and were not due to prey quality or abundance differences between habitats.
3. Because temperature patterns by habitat type varied by year, no single habitat type examined systematically offered better juvenile Chinook growth benefits. These findings suggest that habitat diversity is important to provide optimal temperatures across the rearing season in order to buffer impacts from particularly cold or warm time periods.
4. Juvenile Chinook salmon are expected to naturally use a mix of habitat types during outmigration where habitat- and season-specific differences in growth opportunity exist. Because of this, restoration plans in estuary environments should seek a diversity of connected habitats.

Table 6.3.1. Processed juvenile Chinook salmon diet samples used in bioenergetics model. First and last sampling day denotes the Julian day that samples were grouped for analysis over time in order to provide a minimum of six diet samples for analysis in any given time range. Average wet weight is the average wet biomass of stomach contents for that sample of fish.

Nooksack tidal delta or Bellingham Bay habitat type	1st sampling day	Last sampling day	Number of samples	Average wet weight (g)
2014				
Forested Riverine Tidal	86	113	6	0.02
	133	133	16	0.04
	141	148	9	0.03
	161	191	12	0.12
Estuarine Scrub Shrub/ Estuarine Emergent Marsh	71	127	10	0.03
	139	143	12	0.04
	160	160	13	0.03
	174	174	10	0.04
	190	202	12	0.01
Pocket Estuary	69	70	12	0.03
	83	84	23	0.01
	97	98	17	0.01
	111	115	18	0.02
	126	129	16	0.03
	140	140	13	0.04
	157	157	11	0.05
	199	216	9	0.02
2015				
Forested Riverine Tidal	49	76	9	0.01
	103	120	7	0.04
Estuarine Scrub Shrub/ Estuarine Emergent Marsh	48	84	18	0.02
	119	173	9	0.03
Pocket Estuary	50	51	12	0.00
	63	64	15	0.01
	83	84	13	0.01
	106	118	18	0.01
	133	134	11	0.03
	147	161	10	0.09
	175	190	12	0.29

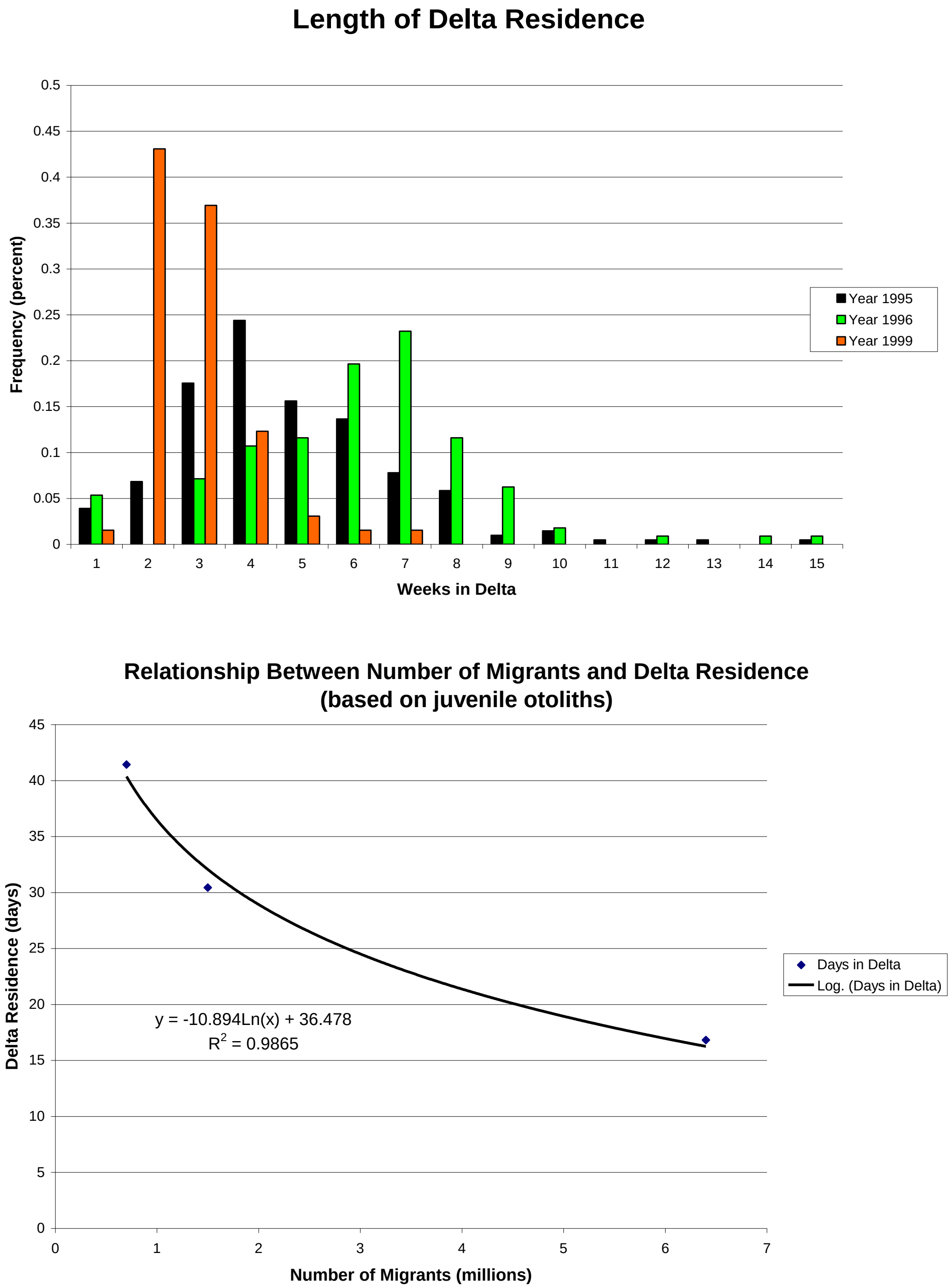

Figure 6.3.1. Otolith based estimates of wild Chinook salmon residence in the Skagit tidal delta which vary by year (top panel) and are negatively correlated with outmigration population size (bottom panel). Figures are from Larsen et al. (2009).

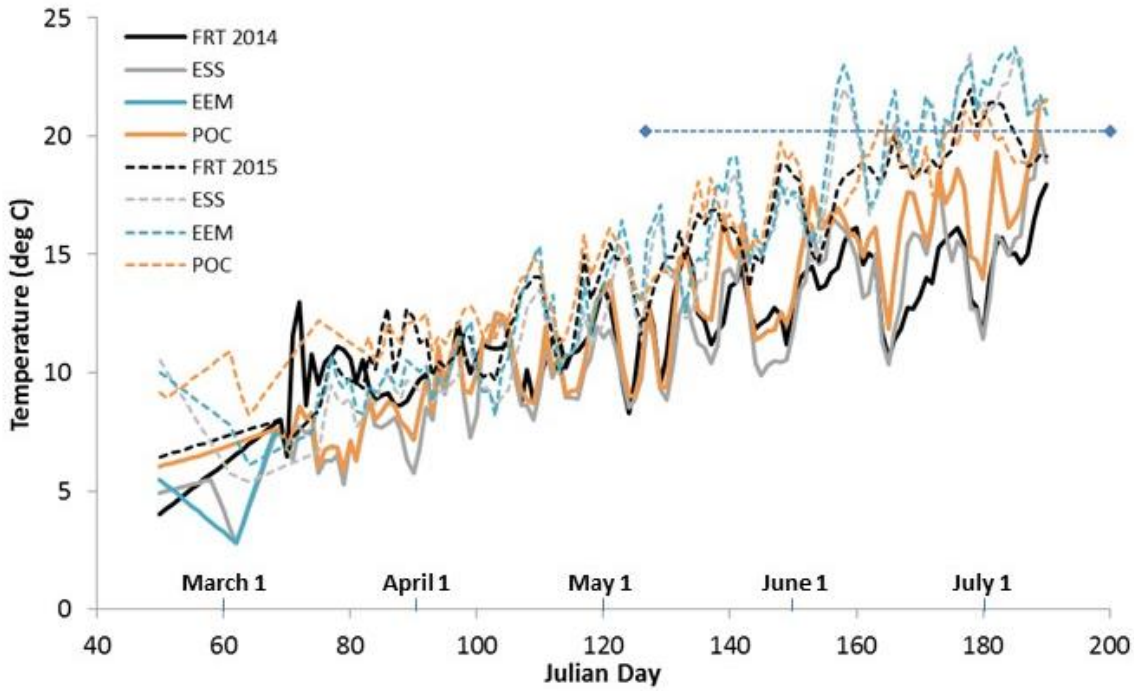

Figure 6.3.2. Seasonal temperature patterns in four habitat types across the rearing period in the Nooksack estuary in 2014 (solid lines) and 2015 (dashed lines). Horizontal line indicates stressful conditions for juvenile Chinook salmon.

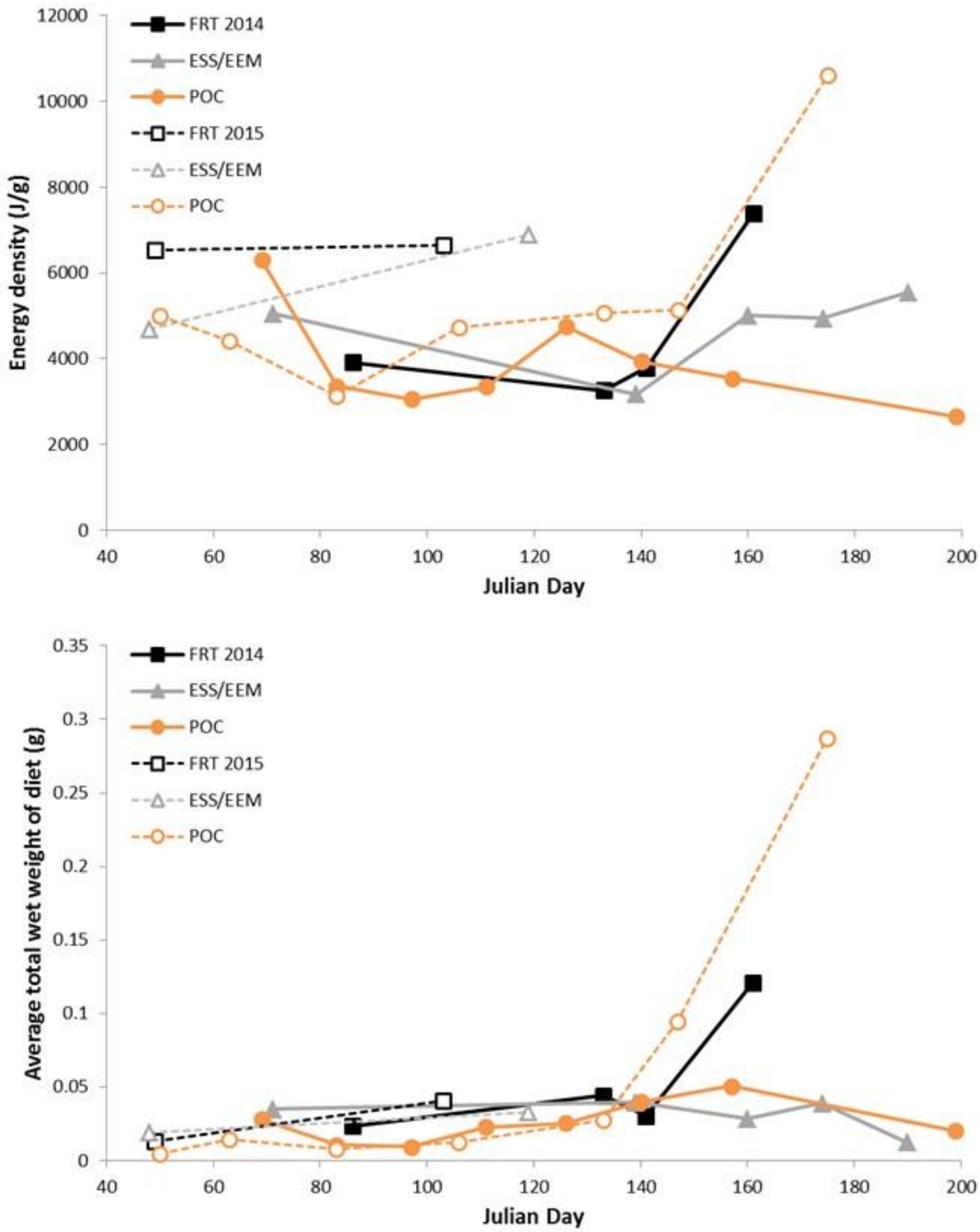

Figure 6.3.3. Average total energy density (joules/g wet weight) of diet and average total wet weight (g) of fish collected in four habitat types in 2014 (solid lines) and 2015 (dashed lines) across the rearing period in the Nooksack estuary.

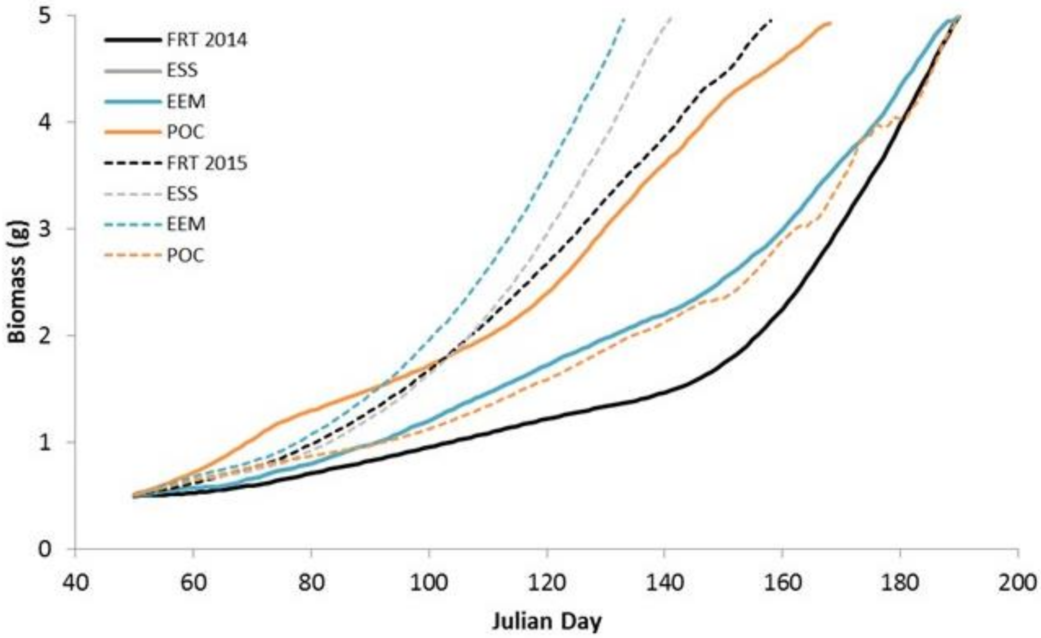

Figure 6.3.4. Bioenergetics model output predicting biomass (g) of fry inhabiting each habitat type until attaining a biomass of 5 g, in 2014 (solid lines) and 2015 (dashed lines). This is the average biomass at which juvenile Chinook salmon leave estuary habitats.

7.0 Summary of conclusions and recommendations

In this chapter we repeat all conclusions and recommendations stated throughout the report. Here they are organized according to the four general and fourteen specific topics shown in Table 1.1.

Note that there are no conclusions or recommendations for the following: Chapter 1 (Introduction); Section 2.2 (no results given as it is outside our scope of work); Chapter 3 (description of methods); and Section 4.1 (introduction of life history conceptual model).

Habitat and connectivity conditions

Habitat extent of the Nooksack tidal delta

The following conclusions and recommendation are from Section 2.1.

<u>Conclusions</u>:

1. Natural (logjam) and anthropogenic (restoration) causes have changed habitat conditions within the Nooksack tidal delta within a relatively short and recent time period.
2. Changes in tidal delta habitat extent influence juvenile Chinook carrying capacity.
3. Changes in tidal delta distributary channels affect opportunities for migrating fish to find habitat within the tidal delta and to move though the delta to nearshore habitat.
4. The GIS habitat results from this study add two new time periods (2008, 2013) to results for earlier time periods (e.g., Brown et al. 2005) and are useful for monitoring status and trends of estuarine habitat, including common indicators for Puget Sound Recovery (Beamer et al. 2015; Fore et al. 2015).

<u>Recommendation</u>:

1. We recommend continued status and trends monitoring of Nooksack tidal delta habitat conditions if WRIA 1 salmon recovery efforts have actions meant to improve: a) juvenile Chinook tidal delta rearing habitat capacity, and/or b) connectivity to existing tidal delta habitat and adjacent nearshore habitat. Habitat status and trends monitoring results are necessary to determine the effect of implemented restoration and habitat protection strategies on the entire tidal delta system as well as to document the influence of natural changes to the tidal delta.

Fish migration pathways within the Nooksack tidal delta

The following conclusions and recommendation are from Section 2.3.

<u>Conclusions</u>:

1. Landscape connectivity varies within the study area: not all habitat within the study area has an equal opportunity to be utilized by rearing Chinook salmon. Based on differences in landscape connectivity values, we predict that Nooksack River juvenile Chinook migrants can best access upper Nooksack tidal delta habitat and least access Lummi Bay habitat (with access to all other habitat within the study area distributed somewhere in between, assuming no habitat type selectivity exists by the fish).
2. The channel-spanning logjam has changed landscape connectivity patterns within the Nooksack tidal delta and adjacent nearshore habitat. The changes in landscape connectivity

occurred relatively rapidly (i.e., over a few years) and has changed the pathways fish must take to access habitat within the delta and adjacent nearshore areas.

   a. Habitat areas within the eastern tidal delta and Bellingham Bay nearshore east of the delta are less connected post-logjam compared to pre-logjam.
   b. Habitat areas within the western tidal delta and Bellingham Bay nearshore west of the delta are more connected post-logjam compared to pre-logjam.
   c. Habitat areas within the upper tidal delta have experienced minor changes in connectivity as a result of the logjam.

3. Based on differences in landscape connectivity values between pre- and post-logjam, we predict that Nooksack River juvenile Chinook migrants have better access to western Nooksack tidal delta and western Bellingham Bay nearshore habitat in the post-logjam period compared to the pre-logjam period. Conversely, we predict that Nooksack River juvenile Chinook migrants have poorer access to eastern Nooksack tidal delta and eastern Bellingham Bay nearshore habitat in the post-logjam period compared to the pre-logjam period.
4. Restoration of connectivity within the hydrologically muted areas of the Nooksack tidal delta should improve access to existing (future restored) habitat rearing options for tidal delta rearing.

<u>Recommendation</u>:

1. Because habitat connectivity can change within estuarine systems we recommend monitoring landscape connectivity if WRIA 1 salmon recovery strategies include restoration strategies for tidal delta and/or nearshore habitats.

Water properties, 2014 & 2015

The following conclusions and recommendations are from Section 2.4.

<u>Conclusions</u>:

1. The water temperature, salinity, and dissolved oxygen results vary systematically by season and habitat type across the study area. These differences in water properties play a role in prey production and metabolic processes for juvenile salmon.
2. The water properties within the study area were found to be generally consistent with habitat conditions suitable for juvenile salmon rearing and migration, with one exception: the area around our beach seine site at Silver Cr Upper.

<u>Recommendations</u>:

1. We recommend further analysis of Silver Cr Upper area to determine whether low DO conditions persist, and if present, whether they can be remedied.
2. Our analyses can help establish norms for each habitat type. Restoration and protection strategies could be developed to achieve water property norms where they are impaired. Site level strategies might include maintaining or restoring hydraulic connectivity and/or natural vegetation communities appropriate for each habitat type.

Population structure of juvenile Chinook salmon

Nooksack River NOR juvenile Chinook outmigrants

The following conclusions and recommendation are from Section 4.2.

Conclusions:

1. The current Nooksack River NOR Chinook population is made up of individuals that can take advantage of habitat opportunities within the Nooksack River, Nooksack tidal delta, and Bellingham Bay nearshore as conceptualized in the life history type section of this report.
2. The Nooksack NOR Chinook outmigration results, along with the comparison with Skagit, suggests the Nooksack River basin's freshwater system is not at carrying capacity for parr migrants, but possibly showing the beginning signs of density dependent pressure at the upper levels of observed total outmigration (300,000 fish/year, or higher).
3. Comingling of NOR and HOR juvenile Chinook within the lower Nooksack River occurs after most NOR fry and yearlings have outmigrated and is synchronous with the NOR parr outmigration.

Recommendation:

1. The causes of underseeded freshwater habitat for parr migrants should be addressed (or studied, if not known).

NOR juvenile Chinook outmigrants from Bellingham Bay independent tributaries

The following conclusions and recommendation are from Section 4.2.

Conclusions:

1. Whatcom Creek has consistent annual presence of Chinook salmon spawners. Understanding the relative importance of Whatcom Creek requires additional study.
2. Up to several thousand NOR juvenile Chinook migrants are likely produced annually from spawners within Whatcom Creek.

Recommendation:

1. We recommend spawner surveys be designed to better detect Chinook presence and abundance if WRIA 1 salmon recovery efforts want to account for NOR Chinook contributions from independent streams draining into Bellingham Bay.

HOR juvenile Chinook releases into the Nooksack/Samish Management Unit

The following conclusions and recommendation are from Section 4.2.

Conclusions:

1. The total juvenile Chinook population using the study area each year is dominated by releases of HOR fish from within or nearby the study area.
2. Although millions of HOR juvenile Chinook are released into the Nooksack/Samish Management Unit, fish marking practices are good so the effects of mistaking unmarked HOR juveniles with NOR juveniles are minimized.

Recommendation:

1. Whether there is potential for adverse ecological interactions between HOR and NOR juvenile Chinook depends on the extent that HOR fish comingle with NOR fish. This topic may need future study if adverse ecological interactions are suspected between NOR and HOR fish.

NOR and HOR juvenile Chinook by habitat type

The following conclusions are from Section 4.3.

Conclusions:

1. There is consistent use of Nooksack tidal delta habitat by NOR juvenile Chinook but juvenile Chinook density results are lower than in Bellingham Bay nearshore habitats.
2. There is consistent use of nearshore refuge habitat (i.e., pocket estuary habitats and small streams) by NOR juvenile Chinook within Bellingham Bay.
3. NOR and HOR juvenile Chinook did not co-mingle in tidal delta habitat or pocket estuaries during the early rearing period; they did not co-mingle until the parr migration period in May (or later) when the bulk of the NOR Chinook had left (or were leaving) tidal delta or pocket estuary habitat. This suggests hatchery/wild interaction would not be possible for the NOR Chinook life history types that extensively rear in the tidal delta or pocket estuary habitats early in the year.
4. Significant co-mingling by NOR and HOR Chinook occurred in the Nooksack tidal delta and exposed nearshore habitats after April. This suggests hatchery/wild interaction could be possible for the NOR Chinook parr life history type that outmigrate the lower river and tidal delta with HOR Chinook and all NOR Chinook life history types once they reach exposed nearshore habitats during summer.
5. A strong inference from the NOR Chinook density results for the Nooksack tidal delta and Bellingham Bay nearshore along with HOR Chinook release results suggest the relatively few NOR juveniles are actively residing in rearing habitats (i.e., remaining for weeks to months) while the abundant HOR juveniles are migrating quickly (i.e., days to weeks) through the tidal delta system and largely avoiding the nearshore refuge habitats such as pocket estuaries.

Recommendations:

1. We recommend conducting a study of toxins in juvenile Chinook salmon designed to identify spatial differences in toxin loading within WRIA 1 habitats.

Influence of habitat connectivity on NOR juvenile Chinook density

The following conclusions are from Section 4.4.

Conclusions:

1. Habitat connectivity within the Nooksack tidal delta is important to explaining differences of NOR Chinook salmon density within the tidal delta.
2. The portion of the Nooksack tidal delta mostly utilized by natural origin juvenile Chinook salmon is the 'connected Nooksack tidal delta'.
3. The distributary-spanning logjam within the Nooksack tidal delta has reduced NOR Chinook density at Airport Creek and likely reduced the number of fish taking the east channel pathway to the Bellingham Bay nearshore habitats on the east side of the tidal delta.
4. Chinook spawners in Whatcom Creek are producing juveniles that are rearing in nearby Bellingham Bay nearshore areas. Detecting landscape connectivity signals of Nooksack origin Chinook at east side Bellingham Bay nearshore sites is likely confounded by fish coming from Whatcom Creek.
5. Using landscape connectivity as a covariate in juvenile salmon use analysis for the Nooksack tidal delta can help elucidate treatment effects on restoration effectiveness.

Recommendations:

None.

Origins of juvenile Chinook salmon

HOR juvenile Chinook

The following conclusions and recommendation are from Section 5.1.

Conclusions:

1. All CWT HOR juvenile Chinook in the Nooksack tidal delta were from Nooksack River hatchery releases, while CWT HOR Chinook in the Bellingham Bay nearshore were from a combination of release sites in Nooksack, Samish, and Skagit River basins.
2. No CWT HOR juvenile Chinook were recovered from any other nearby, or regionally close, basin, including British Columbia, Central Puget Sound, South Puget Sound, or Hood Canal hatchery releases.

Recommendation:

1. If juvenile Chinook hatchery/wild interactions are suspected, then the CWT results could be used as a basis to understand which Chinook populations are potentially interacting.

Genetic assignment of NOR juvenile Chinook salmon

The following conclusions are from Section 5.2.

<u>Conclusions</u>:

1. Nooksack River NOR Chinook spring and fall populations produce juveniles capable of expressing the life history types that rear extensively within their natal estuary or nearshore refuge habitat such as pocket estuaries.
2. NOR juvenile Chinook in the Nooksack tidal delta were predominately Nooksack origin fish comprised of early run fish in the fry migration period followed by a combination of early and fall run fish in the parr outmigration period.
3. Bellingham Bay nearshore and pocket estuary habitats were mostly comprised of Nooksack origin NOR juvenile Chinook, especially early in the season.
4. Out-of-system NOR juvenile Chinook in Bellingham Bay nearshore habitats were primarily from the Whidbey basin and were generally not present before summer months. However, consistent presence of Whidbey Basin fish along with intermittent presence of some British Columbia stocks show the Bellingham Bay nearshore environment is an important rearing area for fish in the Salish Sea.
5. The distributary channel-spanning logjam in the Nooksack tidal delta may be influencing where juvenile Chinook outmigrating from the Nooksack River go within the Bellingham Bay nearshore and not just within the tidal delta.

<u>Recommendations</u>:

None.

Juvenile Chinook salmon performance

Juvenile Chinook salmon density dependence in the Nooksack tidal delta

The following conclusion and recommendation are from Section 6.1.

Conclusion:

1. There is consistent use of Nooksack tidal delta habitat by NOR juvenile Chinook but juvenile Chinook density data does not exhibit a density dependence relationship over the current range of NOR juvenile outmigrations. The Nooksack tidal delta is underseeded by NOR juvenile Chinook salmon.

Recommendation:

1. Ongoing efforts by the authors to better understand the range of potential density-dependent interactions of Chinook salmon in large river estuaries will be improved by additional comparisons among estuary systems. The Nooksack and Skagit may represent two endpoints of a spectrum of salmon populations. Correcting for amounts of existing habitat may help facilitate comparison of the Nooksack to the Skagit and other estuaries like those of the Nisqually and Snohomish Rivers. These comparisons may help shed better light on the ranges of outmigration population size that may result in density dependence in existing habitat, the possible existence of depensation, the potential habitat-specific differences in productivity, and possible interactions of wild and hatchery fish in the estuary during outmigrations.

NOR juvenile Chinook diet and prey availability within the study area

The following conclusions are from Section 6.2.

Conclusions:

1. All Nooksack tidal delta and pocket estuary habitats sampled produced food for NOR juvenile Chinook salmon.
2. Potential juvenile salmon prey taxa were caught at all estuarine emergent marsh, estuarine scrub shrub, and forested riverine tidal sites within the Nooksack tidal delta and Bellingham Bay pocket estuaries.
3. Habitat type had a stronger effect than season on prey assemblage.
4. NOR juvenile Chinook salmon consumed prey in all habitats, but our study shows evidence of selectivity between prey taxa consumed and prey taxa numerically available.
5. Season was more important than habitat type with respect to prey taxa consumed by juvenile Chinook salmon.

Recommendations:

None.

Bioenergetics of juvenile Chinook

The following conclusions are from Section 6.3.

Conclusions:

1. Functional habitat conditions exist for juvenile Chinook in all estuarine wetland zones of the Nooksack tidal delta and in nearshore refuge habitat (pocket estuaries) based on modeled growth of juvenile Chinook utilizing those habitat types over two different (and contrasting) years.
2. Predicted habitat-specific differences in juvenile Chinook salmon growth were substantial in the Nooksack tidal delta and Bellingham Bay pocket estuaries. Growth differences were largely an outcome of temperature differences between habitat types and were not due to prey quality or abundance differences between habitats.
3. Because temperature patterns by habitat type varied by year, no single habitat type examined systematically offered better juvenile Chinook growth benefits. These findings suggest that habitat diversity is important to provide optimal temperatures across the rearing season in order to buffer impacts from particularly cold or warm time periods.
4. Juvenile Chinook salmon are expected to naturally use a mix of habitat types during outmigration where habitat- and season-specific differences in growth opportunity exist. Because of this, restoration plans in estuary environments should seek a diversity of connected habitats.

Recommendations:

None.

Suggested WRIA 1 Chinook salmon recovery strategies

Several conclusions cross the boundaries of the individual chapters of this report and highlight the importance of implementing a Chinook salmon recovery strategy that accounts for a) population resilience and b) precautionary goal setting for desired future conditions of habitat.

To support a Chinook population resilient recovery strategy:

Nooksack tidal delta and Bellingham Bay nearshore refuge habitats (pocket estuaries, small independent streams) are utilized by NOR Chinook even at the current (underseeded) outmigration levels. The juvenile life history types exist in the overall system to capitalize on tidal delta and nearshore habitat opportunities. Restoration and protection of these habitats would benefit the comparatively few fish currently expressing these life history types and support resilience in the Nooksack NOR Chinook populations as they move toward recovery.

To support precautionary goal setting for desired future conditions of habitat:

Use of Nooksack tidal delta habitats by NOR Chinook is concentrated in only one area. Restoration of connectivity to the sub-delta areas of Silver Creek, Smugglers/Slater Slough, and Lummi Bay would vastly increase the use and carrying capacity for Nooksack NOR juvenile Chinook salmon. It is also true the restored capacity of the Nooksack tidal delta will not be realized (much) at the current NOR juvenile outmigration levels. Prioritization and sequencing of restoration of Nooksack tidal delta and Bellingham Bay nearshore habitats should be considered not only through our findings derived under low NOR outmigrant population levels, but also should be determined by considering the habitat extent, connectivity, and quality needed for the desired future Nooksack Chinook populations.

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Appendix 1. GIS for landscape connectivity calculations

Bifurcation order determination rules for Nooksack tidal delta fish path arcs

Method for determining Bi value is:

1) Measure each bifurcating (splitting) channel at head (hdwideft) and just upstream of bifurcation (uplkwidft).

2) Divide 'hdwideft' by 'uplkwidft' and multiply by 100 to get the percentage of head width to upper width (PCT_value).

3) Use 'PCT_value' to ascertain 'PlusBi' value from Table D.V.1. ("Assignment of distributary channel order for channels that split into unequal widths") from the Chinook Plan (SRSC and WDFW 2005).

4) Assign 'uplkbi' value for each arc that already has a Bi value assigned to the arc upstream (this process is repeated many times as you work your way downstream assigning Bi values).

5) Compute 'Bi' for each arc by adding 'uplkbi' and 'PlusBi' (this is the other part of the cycle that repeats with step 4).

6) Arcs that are separate from their upstream arc for some reason other than bifurcating (such as stopping at a fish sampling site) are assigned the same Bi as the upstream arc.

7) If two (or more) streams flow into an arc at its head, the Bi assigned to that arc is equal to the lower Bi number of the incoming streams (5,8=5). If all incoming streams have the same Bi number, the arc is assigned a Bi of 1 number less (5,5=4).

8) Arcs that have a stream flowing into one side will keep the same Bi as its upstream Bi, unless the stream flowing in is of a higher order (lower Bi number).

Fish path arcs extending beyond the edges of the Nooksack tidal delta

Method for creating arcs outside the Nooksack tidal delta (i.e. extending into Bellingham Bay):

1) Arcs were drawn along the bayfront based on orthos and LiDAR. Arcs running along the shoreline to sampling sites were drawn near the shore over orthophotos at a scale of 1:5000.

2) Bi values along the bayfront were computed by averaging the sum of the Bi value of each arc (channel) entering the bayfront from the delta and adding 1 (2008: 5+5+4+6+4+5+5+3=37/8=5+1=6); (2013: 2+2+5+9+5+5+8+5=41/8=5+1=6). These arcs retained the same Bi value alongshore to the ends of the study area.

3) Unless the shoreline arc landed directly on a sampling site, short arcs were added from shoreline arcs to each sampling site. These arcs were given a Bi value of the nearby arc plus 1.

Appendix 1 Reference

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Appendix 2. Figures of landscape connectivity calculations

Appendix 2 is too large to be included in this paper and is its own separate document.

Appendix 3. Spawner survey records for streams draining into Bellingham Bay, 2000-2014

Spawn-er Year	Age0+ migrant year	stream	first survey date	last survey date	first date Chinook observed	last date Chinook observed	# of sur-veys	total miles sur-veyed	Peak Chi-nook count (L+D)	Redd Chi-nook Spawn-er Index	total new Chinook redds count	total new "un-known" redds before mid-Nov	Surv-eys during Chi-nook spawn-ing period?	Chi-nook Present ?	Source of data
2000	2001	Whatcom	10/11/2000	10/31/2000	10/11/2000	10/31/2000	4	4.00	99	19	19	0	yes	yes	Spread-sheet
2001	2002	Whatcom	10/11/2001	3/28/2002	10/11/2001	11/9/2001	11	11.00	90	16	9	7	yes	yes	Spread-sheet
2002	2003	Whatcom	9/25/2002	1/6/2003	10/30/2002	11/13/2002	9	not report ed	3		not counted	not counted	yes	yes	Spread-sheet
2003	2004	Whatcom	8/27/2003	11/17/2003	no Chinook	no Chinook	6	5.40	0		not counted	not counted	yes	no	Spread-sheet
2004	2005	Whatcom	9/21/2004	12/14/2004	9/21/2004	10/15/2004	10	9.00	9	2	2	0	yes	yes	Spread-sheet
2005	2006	Whatcom	na	na	na	na	na	na	29		na	na	yes	yes	Table 3, NSEA report for 2005
2006	2007	Whatcom	10/5/2006	12/27/2006	10/5/2006	10/5/2006	11	6.90	2	1	1	0	yes	yes	Spread-sheet
2007	2008	Whatcom	8/22/2007	1/9/2008	10/8/2007	11/28/2007	29	29.80	3	9	5	4	yes	yes	Spread-sheet
2008	2009	Whatcom	9/17/2008	3/26/2009	10/24/2008	10/24/2008	25	19.10	3	2	2	0	yes	yes	Spread-sheet
2009	2010	Whatcom	9/29/2009	12/14/2009	10/6/2009	10/15/2009	8	not report ed	2	3	0	3	yes	yes	Spread-sheet
2010	2011	Whatcom	na	na	na	na	na	na			na	na			Not surveyed this year
2011	2012	Whatcom	10/12/2011	12/30/2011	10/13/2011	11/4/2011	24	8.50	32	34	22	12	yes	yes	Spread-sheet
2012	2013	Whatcom	10/4/2012	1/4/2013	10/4/2012	11/2/2012	28	18.30	16	21	9	12	yes	yes	Spread-sheet
2013	2014	Whatcom	10/18/2013	12/20/2013	10/18/2013	11/8/2013	29	17.10	15	17	4	13	yes	yes	Spread-sheet
2014	2015	Whatcom	10/20/2014	2/11/2015	na	na	17	22.10	na	14	9	5	yes	yes	NSEA report for 2014

Spawn -er Year	Age0+ migrant year	stream	first survey date	last survey date	first date Chinook observed	last date Chinook observed	# of sur-veys	total miles sur-veyed	Peak Chi-nook count (L+D)	Redd Chi-nook Spawn -er Index	total new Chinook redds count	total new "un-known" redds before mid-Nov	Surv-eys during Chi-nook spawn-ing period?	Chi-nook Present ?	Source of data
2007	2008	Whatcom Trib (Cemetery Cr)	10/4/2007	12/26/2007	11/1/2007	11/1/2007	12	6.00	1	0	0	0	yes	yes	Spread-sheet
2008	2009	Whatcom Trib (Cemetery Cr)	9/8/2008	12/15/2008	no Chinook	no Chinook	11	5.50	0	0	0	0	yes	no	Spread-sheet
2009	2010	Whatcom Trib (Cemetery CR)	na	na	na	na	na	na			na	na			Not surveyed this year
2010	2011	Whatcom Trib (Cemetery Cr)	9/9/2010	12/30/2010	10/14/2010	11/6/2010	17	8.50	4	1	0	1	yes	yes	Spread-sheet
2011	2012	Whatcom Trib (Cemetery Cr)	9/7/2011	12/28/2011	no Chinook	no Chinook	18	9.00	0	0	0	0	yes	no	Spread-sheet
2012	2013	Whatcom Trib (Cemetery Cr)	9/4/2012	12/27/2012	no Chinook	no Chinook	17	8.50	0	0	0	0	yes	no	Spread-sheet
2013	2014	Whatcom Trib (Cemetery Cr)	9/4/2013	12/31/2013	no Chinook	no Chinook	18	9.00	0	0	0	0	yes	no	Spread-sheet
2000	2001	Padden	11/6/2000	11/11/2000	no Chinook	no Chinook	8	10.10	0	0	0	0	yes	no	Spread-sheet
2001	2002	Padden	10/29/2001	11/13/2001	no Chinook	no Chinook	4	4.50	0	0	0	0	yes	no	Spread-sheet
2002	2003	Padden	9/29/2002	12/28/2002	11/12/2002	11/12/2002	18	16.20	1	0	0	0	yes	yes	Spread-sheet
2003	2004	Padden	10/29/2003	12/16/2003	10/29/2003	11/12/2003	6	5.40	3	1	1	0	yes	yes	Spread-sheet
2004	2005	Padden	9/22/2004	12/29/2004	10/15/2004	10/15/2004	14	12.60	3	0	0	0	yes	yes	Spread-sheet
2005	2006	Padden	11/11/2005	12/19/2005	no Chinook	no Chinook	5	4.50	0	0	0	0	yes	no	Spread-sheet
2006	2007	Padden											no		Spread-sheet

Spawn-er Year	Age0+ migrant year	stream	first survey date	last survey date	first date Chinook observed	last date Chinook observed	# of sur-veys	total miles sur-veyed	Peak Chi-nook count (L+D)	Redd Chi-nook Spawn-er Index	total new Chinook redds count	total new "un-known" redds before mid-Nov	Surv-eys during Chi-nook spawn-ing period?	Chi-nook Present ?	Source of data
2007	2008	Padden	9/12/2007	12/26/2007	no Chinook	no Chinook	12	7.20	0	0	0	0	yes	no	Spread-sheet
2008	2009	Padden	na	na	na	na	na	na			na	na			Not surveyed this year
2009	2010	Padden	10/21/2009	1/6/2010	no Chinook	no Chinook	7	5.60	0	0	0	0	yes	no	Spread-sheet
2010	2011	Padden	9/15/2010	1/26/2011	10/12/2010	10/26/2010	12	9.60	4	0	0	0	yes	yes	Spread-sheet
2011	2012	Padden	10/13/2011	12/30/2011	no Chinook	no Chinook	9	7.20	0	0	0	0	yes	no	Spread-sheet
2012	2013	Padden	10/4/2012	1/6/2013	no Chinook	no Chinook	13	10.40	0	0	0	0	yes	no	Spread-sheet
2013	2014	Padden	10/18/2013	1/23/2014	no Chinook	no Chinook	15	12.00	0	0	0	0	yes	no	Spread-sheet
2000	2001	Squalicum	11/1/2000	12/12/2000	11/10/2000	11/10/2000	7	22.30	1	0	0	0	yes	yes	Spread-sheet
2001	2002	Squalicum	10/9/2001	12/19/2001	no Chinook	no Chinook	7	11.50	0	0	0	0	yes	no	Spread-sheet
2002	2003	Squalicum	9/30/2002	12/31/2002	no Chinook	no Chinook	8	not report ed	0	0	0	0	yes	no	Spread-sheet
2003	2004	Squalicum	10/7/2003	12/11/2003	no Chinook	no Chinook	3	5.40	0	0	0	0	yes	no	Spread-sheet
2004	2005	Squalicum	9/22/2004	12/22/2004	no Chinook	no Chinook	13	23.40	0	0	0	0	yes	no	Spread-sheet
2005	2006	Squalicum	11/14/2005	12/16/2005	no Chinook	no Chinook	3	5.40	0	0	0	0	no		Spread-sheet
2006	2007	Squalicum	10/9/2006	12/19/2006	no Chinook	no Chinook	10	5.00	0	0	0	0	yes	no	Spread-sheet
2007	2008	Squalicum	9/12/2007	12/26/2007	no Chinook	no Chinook	12	6.00	0	0	0	0	yes	no	Spreads-heet
2008	2009	Squalicum													not surveyed this year
2009	2010	Squalicum	9/29/2009	12/14/2009	no Chinook	no Chinook	7	not report ed	0	0	0	0	yes	no	Spread-sheet
2010	2011	Squalicum	9/15/2010	12/6/2010	no Chinook	no Chinook	8	4.00	0	0	0	0	yes	no	Spread-sheet

Spawn -er Year	Age0+ migrant year	stream	first survey date	last survey date	first date Chinook observed	last date Chinook observed	# of sur-veys	total miles sur-veyed	Peak Chi-nook count (L+D)	Redd Chi-nook Spawn -er Index	total new Chinook redds count	total new "un-known" redds before mid-Nov	Surv-eys during Chi-nook spawn-ing period?	Chi-nook Present ?	Source of data
2011	2012	Squalicum	10/12/2011	12/30/2011	no Chinook	no Chinook	10	5.00	0	0	0	0	yes	no	Spread-sheet
2012	2013	Squalicum	10/4/2012	1/3/2013	no Chinook	no Chinook	13	6.50	0	0	0	0	yes	no	Spread-sheet
2013	2014	Squalicum	10/25/2013	12/27/2013	12/13/2013	12/13/2013	10	not report ed	2	0	0	0	yes	yes	Spread-sheet
2001	2002	Chuckanut	10/23/2001	12/27/2001	no Chinook	no Chinook	7	6.40	0	0	0	0	yes	no	Spread-sheet
2002	2003	Chuckanut	11/15/2002	12/27/2002	no Chinook	no Chinook	6	13.20	0	0	0	0	no		Spread-sheet
2003	2004	Chuckanut	11/5/2003	12/16/2003	no Chinook	no Chinook	5	11.00	0	0	0	0	yes	no	Spread-sheet
2004	2005	Chuckanut	10/4/2004	12/15/2004	10/20/2004	10/20/2004	8	8.00	2	0	0	0	yes	yes	Spread-sheet
2005	2006	Chuckanut	10/26/2005	12/8/2005	10/26/2005	10/26/2005	3	4.30	1	0	0	0	yes	yes	Spread-sheet