Appendix B:

A Synthesis of Changes in our Knowledge of Chinook Salmon Productivity and Habitat Uses in WRIA 9 (2004 – 2016)

ROGER TABOR

A synthesis of changes in our knowledge of Chinook salmon productivity and habitat uses in WRIA 9 (2004 – 2016)

Purpose:
This technical briefing synthesizes and evaluates available Chinook salmon habitat use and productivity literature that has become available since 2004, with an emphasis on WRIA 9 specific information. The information should pertain to possible updates the WRIA could make to amend programs, policies or project rankings as part of the Chinook salmon recovery effort that was documented in the 2005 Chinook salmon Habitat Plan.

The paper is organized into two primary sections, issues that cross subwatersheds, or 'watershed wide issues' and then issues focused on individual subwatersheds. Following the description of major topic area is a subsection summarizing the primary technical recommendations and implications for recovery actions. Three other technical briefings will cover climate change, chemical contaminants in the watershed, and water temperature issues. In sum, these briefings will be considered an addendum to the 2005 WRIA 9 Strategic Assessment Report-Scientific Foundation for Salmon Habitat Conservation, and provide the scientific foundation for updating the 2005 Salmon Habitat Plan.

Watershed Wide Issues

Viable Salmonid Population Parameters and Green River Chinook

In order for Puget Sound Chinook to be removed from the Endangered Species Act listing, two populations within the South Puget Sound geographic region (Nisqually, Puyallup, White, Duwamish/Green, and Lake Washington) will need to attain a low risk status of extinction. The watershed conditions for the remaining populations need to be improved compared to conditions at the time of listing. To be considered low risk of extinction, a population will need to meet the NOAA viability criteria for all Viable Salmonid Population (VSP) parameters (abundance, productivity, spatial structure, and diversity).

NOAA defines VSP as:

- Abundance is the number of individuals in the population at a given life stage or time;
- Productivity or population growth rate is the actual or expected ratio of abundance in the next generation to current abundance;
- Spatial structure refers to how the abundance at any life stage is distributed among available or potentially available habitats; and
- Diversity is the variety of life histories, sizes, and other characteristics expressed by individuals within a population.

VSP-Abundance
The number of natural origin Green River Chinook spawners is the primary life stage that is tracked for the abundance indicator. The overall trend in abundance has been steadily declining since before the first plan was adopted in 2005 (Figure 1 and Table 1). In 2009, the number of Natural Origin Spawners (NOS) was the lowest ever recorded, with less than 200 fish. For five of the past seven years (2010-2017), the number of NOS has been less than the lowest planning target range (1,000 NOS) for WRIA 9.

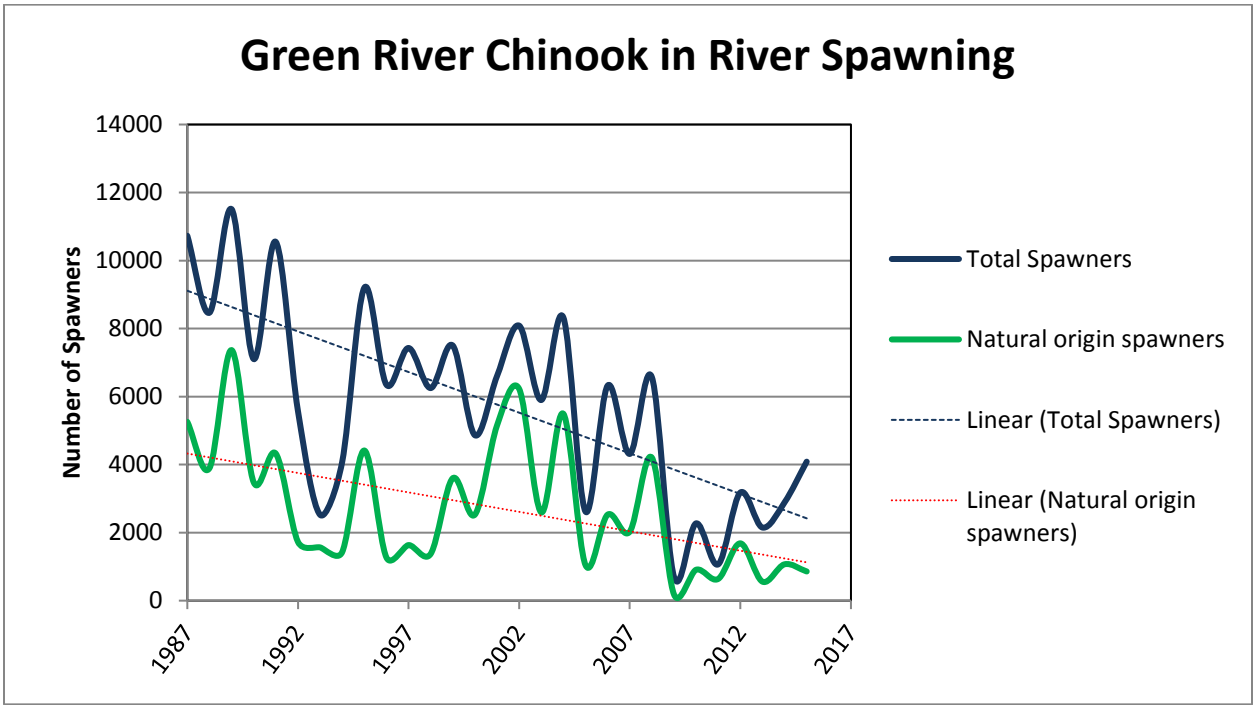

Figure 1. Trends in natural origin Chinook spawners and all spawners (hatchery origin plus natural origin). (*Data from NOAA Salmon Population Summary Database and WDFW Nathanael Overman)*

Table 1. Status of VSP metrics of the Green River Fall Chinook population from 2005 through 2015. *(Data from NOAA Salmon Population Summary Database and WDFW Nathanael Overman. 2005-2008 numbers from WRIA 9 ITC 2012)*

				From WRIA 9 ITC 2012				From NOAA SPSD and WDFW (Nathanael Overman)						
Population	**Indicators of change**	**Units**	**Target**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Productivity	Egg-to-Migrant Survival (RM 34-60)	% of eggs deposited	~8%	1.47	0.09	3.66	2.07	2.10%	5.70%	8.00%	6.02%	9.72%	11.39%	8.75%
Abundance	Natural origin spawners	#	1000-4200	1046	2535	2022	4227	182	909	640	1685	559	1069	864
Diversity	Hatchery-origin recruits spawning in river	% of total	<30%	60	60	53	35	74	60	40	47	74	63	79
Diversity	Relative abundance of parr	% parr	TBD	70	31	37	39	39	90	49	53	28	20	3
Diversity	Timing of peak outmigration	fry				3/11-3/16	3/30-4/5	3/30-4/5	3/29-4/4	3/7-3/13	2/20-2/26	3/11-3/17	3/3-3/9	2/2-2/8
Diversity	Timing of peak outmigration	parr				6/2-6/8	6/15-6/21	6/15-6/21	6/7-6/13	5/23-5/29	6/4-6/10	5/27-6/2	5/26-6/1	6/15-6/21
Diversity	Proportion 5 and 6 year old spawners	% of NOR returns	Increase	not evaluated				65%	1%	7%	2%	16%	17%	6%
Spatial Structure	Changes to spawning distribution		No data	not evaluated				not evaluated						

VSP-Productivity

The WRIA has tracked egg-to-migrant survival rates as a primary means of evaluating productivity (WRIA 9 ITC 2012). Egg-to-migrant survival rate is defined as the proportion of fertilized eggs that become juvenile migrants (fry or parr) into the Lower Green, as quantified by the WDFW smolt trap at river mile 34. Although, the average rate for wild Chinook populations is 10.4% (Quinn 2005), the WRIA has set a target of 8% because the Green River Chinook population has high rates of hatchery fish spawning with

wild fish (see diversity metric below). Between 2005 and 2015 the survival rate has ranged from 0.09% to 11%, with an average of 5.4% (Table 1). While the average over the last 11 years is below the WRIA's target, there has been an increase in the egg-to-migrant survival rate, with an average over the last 5 years (2011-2015) of 8.7%, compared to the previous 5 years (2006-2010) average of 2.9%.

VSP-Spatial Structure

The WRIA has not directly tracked a specific indicator or metric for spatial structure. However, natural origin adults predominately spawn in Newaukum Creek and the mainstem Green River. Due to genetic goals at the Soos Creek Hatchery, most of the adults passed above the hatchery to spawn naturally in Soos Creek are of hatchery origin. Furthermore, adults are still not being passed upstream of Howard Hanson Dam. For the spatial structure of the population to improve, natural origin spawners will need to be spawning in both of these areas that were part of their historic range.

VSP-Diversity

The fourth VSP parameter, diversity, refers to variation within a population which covers a wide range of characteristics, one of which is life history type. For example, within WRIA 9, juvenile life history types have been classified according to how long they reside in different parts of the Green River, with special emphasis on the Middle Green as well as the Duwamish. There are three broad life history types: fry migrants, parr migrants, and yearlings (Figure 2 and Table 1), however fry migrants can be broken down into three categories, making a total of 5 life history types.

1. The first fry life history type is early or marine direct fry migrants. These fry leave the Middle Green shortly after hatching and move quickly from the estuary into Puget Sound. Based on fish use sampling (Ruggerone et al. 2006, Nelson et al. 2012 and U.S. Army Corps of Engineers 2013, ICF International 2010) this life history type does not occur in large numbers, but appears to be present.
2. The second fry life history type leaves the Middle Green from Jan through March and rears for weeks to months in the Duwamish until they reach smolt size. This life history type is considered common and generally is the most abundant juvenile life history type (Ruggerone et al. 2006, Nelson et al. 2012, Topping and Anderson 2014), but recent data from 2015 and 2016 showed very few of this life history type survived to adulthood in 2015 (Personnel Communication Lance Campbell, WDFW 2017. See the otolith section below for more information).
3. The third fry life history type, Lower Green parr, are fish that leave the Middle Green as fry, but rear in the Lower Green until they are parr size and ready to smolt. The evidence for the prevalence of this life history type is incomplete due to limited fish use sampling and the constant immigration of new fish from the Middle Green River. Recent sampling shows some amount of preferential use of select habitats within the Lower Green, indicating that at least some fish are likely rearing in the Lower Green until reaching parr size (McCarthy et al. 2017 and Gregersen 2017). However, the Lower Green generally lacks adequate off channel habitat that would allow large numbers of fry to rear long enough to reach parr size (R2 Resource Consultants 2014).
4. The fourth life history type is the Middle Green parr that rear in the Middle Green River as fry and migrate out of this area from late March through June. They are considered relatively common, and are generally the second most abundant life history type (Topping and Anderson 2014, Anderson and Topping 2017).
5. The fifth life history type are yearlings, which are juveniles that spend an entire year in freshwater before immigrating out of the Green River. It is not clear where in the broader Green River they overwinter. The majority of yearlings captured in the past are from hatchery releases

of yearling fish that were purposefully held for a year in an attempt to residualize the fish to create year round fishing opportunities in Puget Sound. These fish are commonly referred to as being part of the 'blackmouth' fishery. The wild yearling life history type has been found in small numbers at the Washington Department of Fish and Wildlife (WDFW) smolt trap (Topping and Anderson 2014) and in the limited floodplain accessible habitats of the Lower Green (Lucchetti et al. 2014).

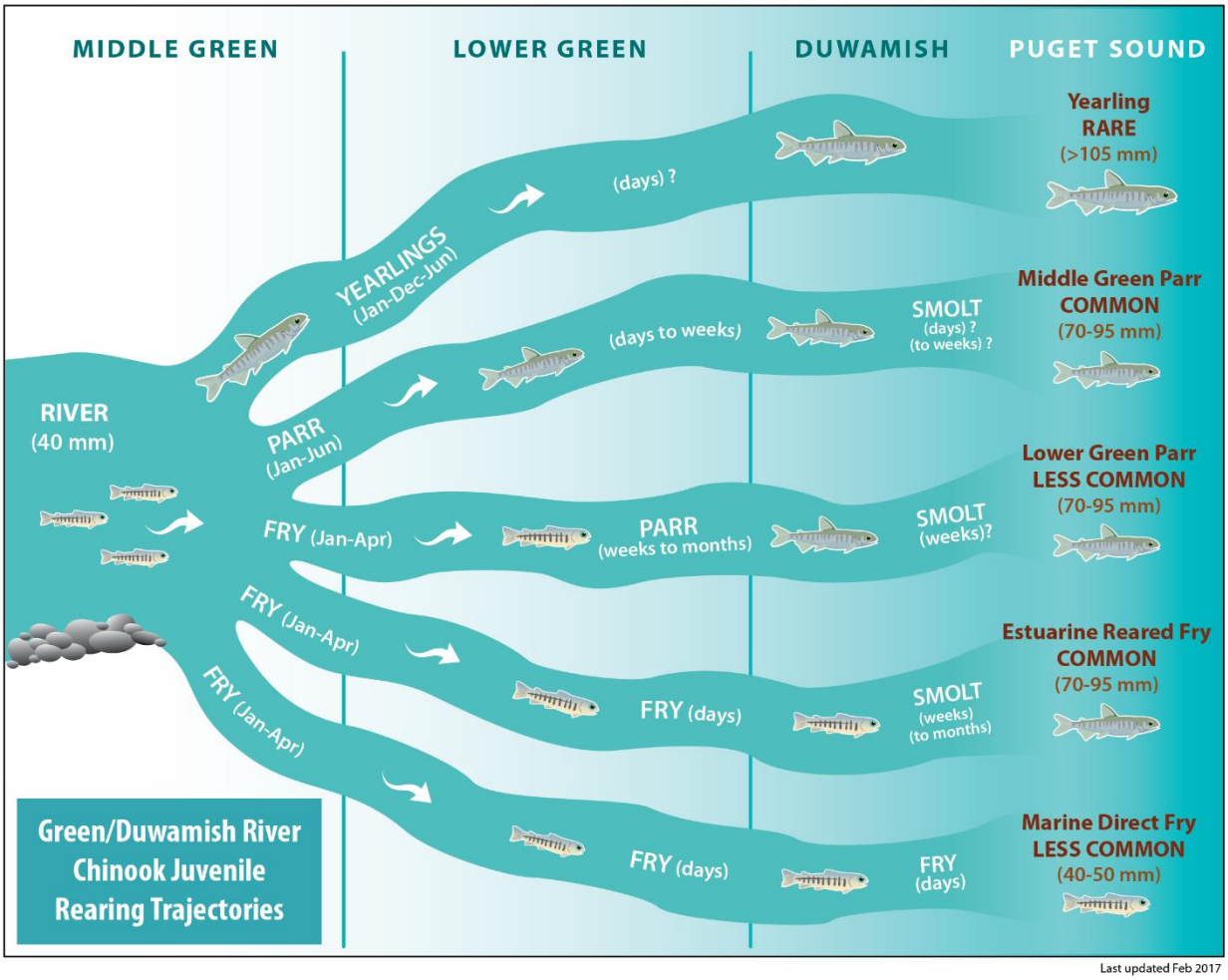

Figure 2. Primary Chinook salmon life history types in the Green River (updated and modified from Ruggerone and Weitkamp 2004).

WRIA 9 has used three metrics to measure diversity.

1. The first metric is the percentage of hatchery origin spawners spawning in the wild with natural origin Chinook. The target is for there to be less than 30% hatchery origin Chinook spawners. This has not been met in the last 10 years, during which time the proportion of hatchery fish on the spawning grounds has ranged from 35% to 75% (Figure 3 and Table 1).
2. The second metric is the percentage of juvenile Chinook that outmigrate as parr. Based on recent analyses by Anderson and Topping 2017 (described in more detail below in Middle Green subwatershed section), this indicator should no longer be used because the observed percentage relies heavily on basic habitat capacity, the number of natural origin spawners, and

the flow experienced during rearing. Tracking the percent of parr does not provide a reliable metric to compare trends given the number of factors that affect it.

3. The final metric is the proportion of natural origin adults that return as five and six-year old fish, with a simple target of an increasing percentage of older fish returning over time. In the last seven years there have been no six-year old fish, thus all the data discussed summarizes only five-year old Chinook. Excluding 2009, which was an outlier year with the lowest return of adults on record, the proportion of five-year olds has ranged from a high of 17% to a low of 1% (Table 1). The average percent return for the last 10 years, 14.4%, is similar to the average over the last 46 years of 15.4%.

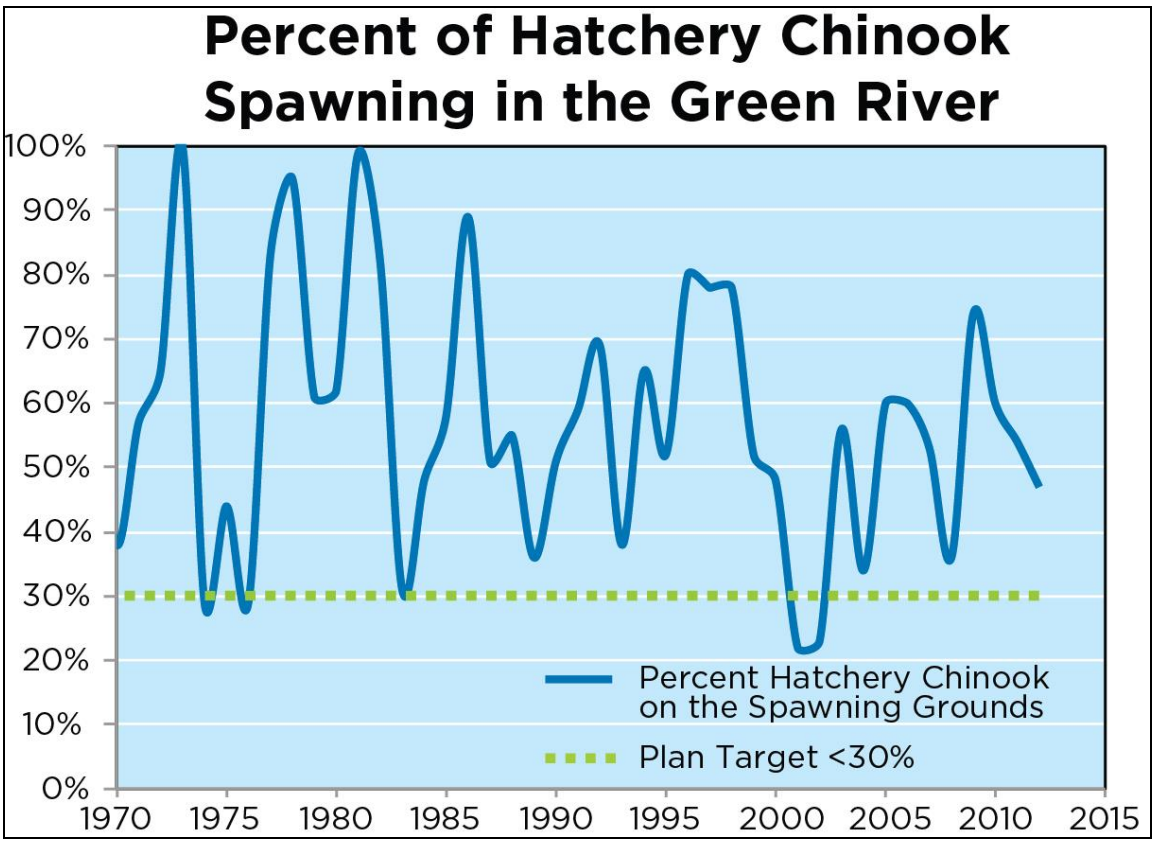

Figure 3. Percent of hatchery Chinook in the Green River spawning grounds compared to natural origin Chinook (*from the 2014 WRIA 9 Implementation Progress Report 2005-2014*)

Technical Recommendations and potential implications for recovery actions:

- The overall trend in wild Chinook salmon population abundance is still declining. The returns of wild fish to the Green River in 2009 were the lowest recorded in the last 30 years, with less than 200 wild fish spawning in the river (Figure 1). As noted above, a primary way to increase adult abundance is to create or get access to more rearing habitat. Improving and increasing rearing habitat in the Middle and Lower Green and providing access to the upper watershed are primary ways of achieving this goal.
- Productivity has improved in the last five years (2011-2015), compared to the previous 5 years when the WRIA last evaluated the egg-to-migrant survival rate. It is unclear why the rate has improved. Based on findings described in the diversity section above, the WRIA should likely

focus on evaluating the number of parr leaving the Middle Green versus the proportion of parr to fry as a better indicator of long term habitat capacity and productivity because the number of fry leaving the Middle Green is highly variable, which makes using the metric of the percentage of parr useless.

- Spatial structure is not being tracked. There is a suggestion in the Strategic Assessment that the WRIA create a method to track to what extent spawning habitat patches are utilized every year. The ITC also recommends creating a metric to evaluate Chinook parr distribution, possibly through minnow trapping as has been done in some Alaska watersheds (Bryant 2000). The WRIA should develop spatial structure metrics that can be cost efficiently tracked.
- Spatial Structure is still greatly limited compared to historic conditions. The lack of fish passage at Howard Hanson Dam (HHD) greatly impacts the WRIA's ability to meet this goal. The upstream fish passage facility is complete. However, the downstream fish passage facility at HHD (Project # UG-4) has not been built and it is unclear when it will be. Given the large quantity and high quality of spawning and rearing habitat above the dam in combination with the highly constrained built-out condition of the lower two thirds of the watershed, the lack of access to the habitat upstream of HHD is negatively affecting all VSP parameters. Providing fish passage at the dam is a critical need and this project should continue to be a high priority for the WRIA.
- Diversity metrics show there are still very high numbers of hatchery fish on the spawning grounds. Since plan adoption, the percent of hatchery spawners has not fallen within the target range set by the Hatchery Scientific Review Group (HSRG) for an integrated stock like the Green River. This points to a need for the 'H' integration process to be restarted and reinvigorated with the co-managers so that solutions for issues like the number of hatchery adults spawning with wild fish can be implemented.

Fish Passage

- The majority of known barriers are found higher up in most stream systems, limiting habitat access to primarily coho salmon and steelhead. A comprehensive fish passage barrier assessment has never been done within WRIA 9 and the list of known barriers comes from assessments of small geographic areas that underwent an assessment for one reason or another over many years. Given the built out nature of the lower two thirds of the watershed, there are many stream crossings that have never been assessed for passage. Furthermore, the ability of fish to pass a structure changes over time as stream conditions change. WDFW suggests that partial barriers and passable stream crossing be evaluated roughly every ten years (Price et al. 2010). With the recent establishment of the statewide Fish Barrier Removal Board, there has been renewed effort at the state level to fund and address known fish passage barriers. While there are many known barriers within WRIA 9, there are two barriers that are of higher importance than most others:
    - Howard Hanson Dam (HHD): In 2005 it was expected fish passage at the dam would be provided within five years. While the upstream passage facility was built, the downstream fish passage structure has not been built yet. There are differing estimates as to how much salmon habitat would be accessible above the dam. The range of fish habitat that would be opened up is from 78 miles to 165 miles (United States Army Corps of Engineers 1998 and WRIA 9 Salmon Plan 2005). The lack of downstream passage has had a huge impact on the trajectory of recovery for the population. The large amount of generally higher quality habitat above the dam that is still inaccessible, which affects all VSP parameters (WRIA 9 Strategic Assessment 2005).

- Black River pump station: New technical documents produced in 2015 as part of the Black River Needs Assessment and Capital Improvement Planning indicate that the pump station has a variety of fish passage issues related to how the facility is structured and managed. The description implies that velocities through parts of the structure would limit upstream passage of smaller juvenile salmonids. Passage equipment is run only during certain times of the year, greatly limiting both upstream and downstream passage. Some of the pump intakes lack fish exclusion screens to keep fish out of the intakes for the pumps; these unscreened pumps are each run an average of hours a year. The pump station is located near the mouth of the Black River, which limits access to over 50 miles of stream, including Springbrook Creek, Panther Lake Creek, Garrison Creek, and Mill Creek (Kent) (Figure 4). Habitat assessments done in the 1990s indicate that much of the physical habitat is not in ideal condition and there are a large variety of water quality problems (Harza 1995). While Chinook have been found in the system (Harza 1995 and Personal Communication Gordon Thomson, U.S. Army Corps of Engineers, 2011) the stream habitat is more typical for coho and steelhead.

Technical recommendations and potential implications for recovery actions:

- Implementation of the existing Salmon Plan Project UG-4 (Upper Green project #4), which would provide downstream fish passage at HHD, remains a critical gap to all VSP parameters - especial spatial structure.
- Work with King County to prioritize improvements in both the fish passage infrastructure as well as standard operating procedures at the Black River pump station.
- Invest in a fish passage program that would provide an ongoing comprehensive assessment of potential barriers, with an emphasis on areas within the typical range of Chinook salmon.
- Map and prioritize fish passage barriers in WRIA 9 according to the amount and quality of habitat upstream. Given issues described in the water quality temperature technical memo, an emphasis on cold water refugia and rearing habitat should also be considered in any passage program (Kubo 2017).

Spawning

- Chinook have been seen spawning in tributaries they were not previously documented in and we have more detailed data for where they spawn within Soos Creek (Figure 5).
    a. The Muckleshoot Indian Tribe (MIT) surveys in Soos Creek during the last five years have documented the primary spawning areas more definitively than past efforts. The vast majority of the spawning in the Soos Creek Watershed is occurring on the mainstem of Soos Creek from the mouth of Jenkins Creek downstream to the hatchery.
    b. Since plan adoption in 2005, Chinook have been seen spawning in: Bingamon Creek, tributary to Mullen Slough within the Agricultural Production District in 2010 (Personal Communication Don Finney King County, 2010), and by the ACOE in of Springbrook Creek in 2011 (Personal Communication Gordon Thomson, U.S. Army Corps of Engineers, 2011), Watercress Creek, a tributary to Newaukum Creek by KCDOT in 2007 (Personal Communication Stephen Conroy, King County, 2017), and Big Spring Creek in 2016 (Personal Communication Josh Latterell, King County, 2017).

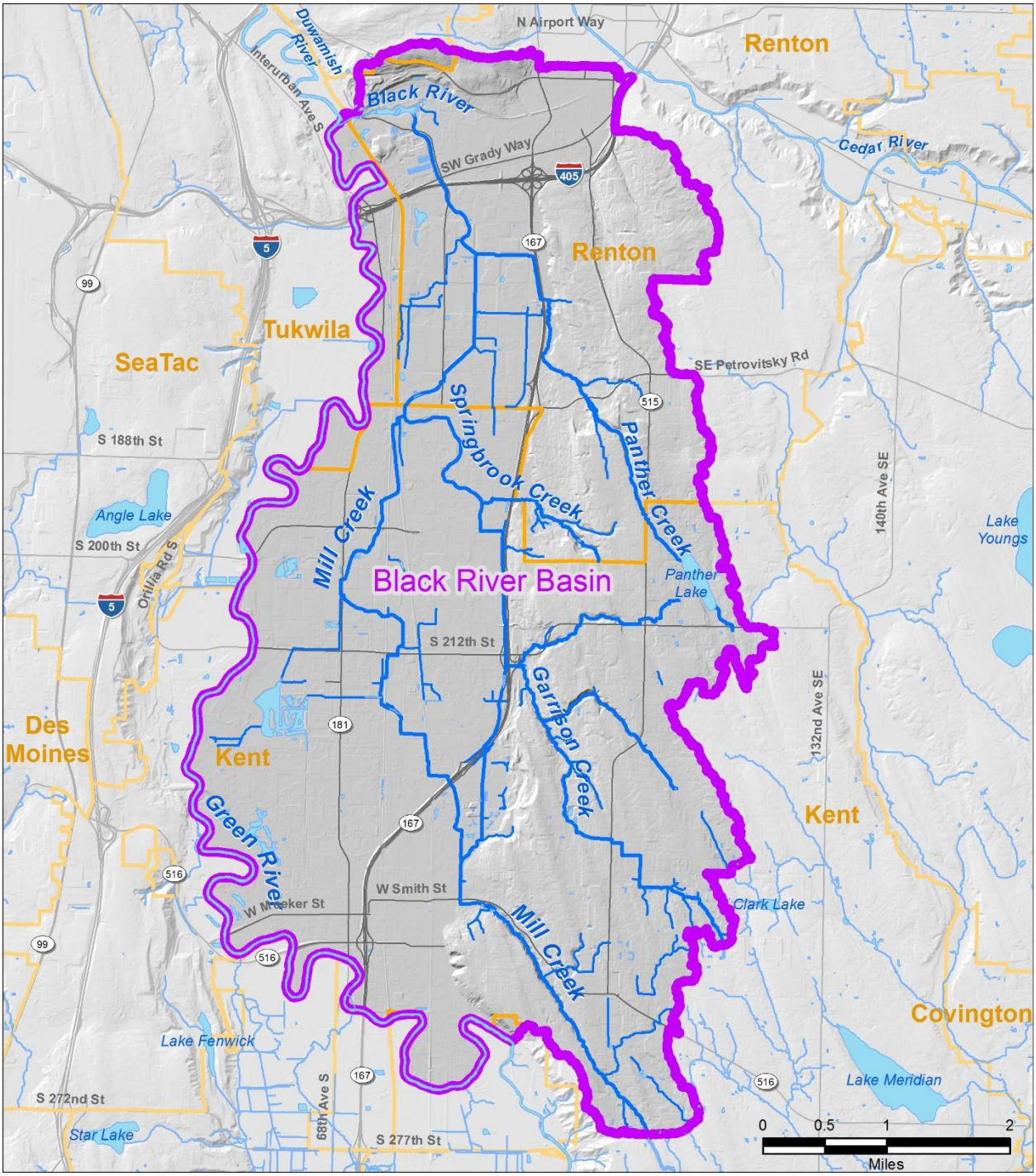

Figure 4. Map of the subwatershed that feeds into the historic Black River.

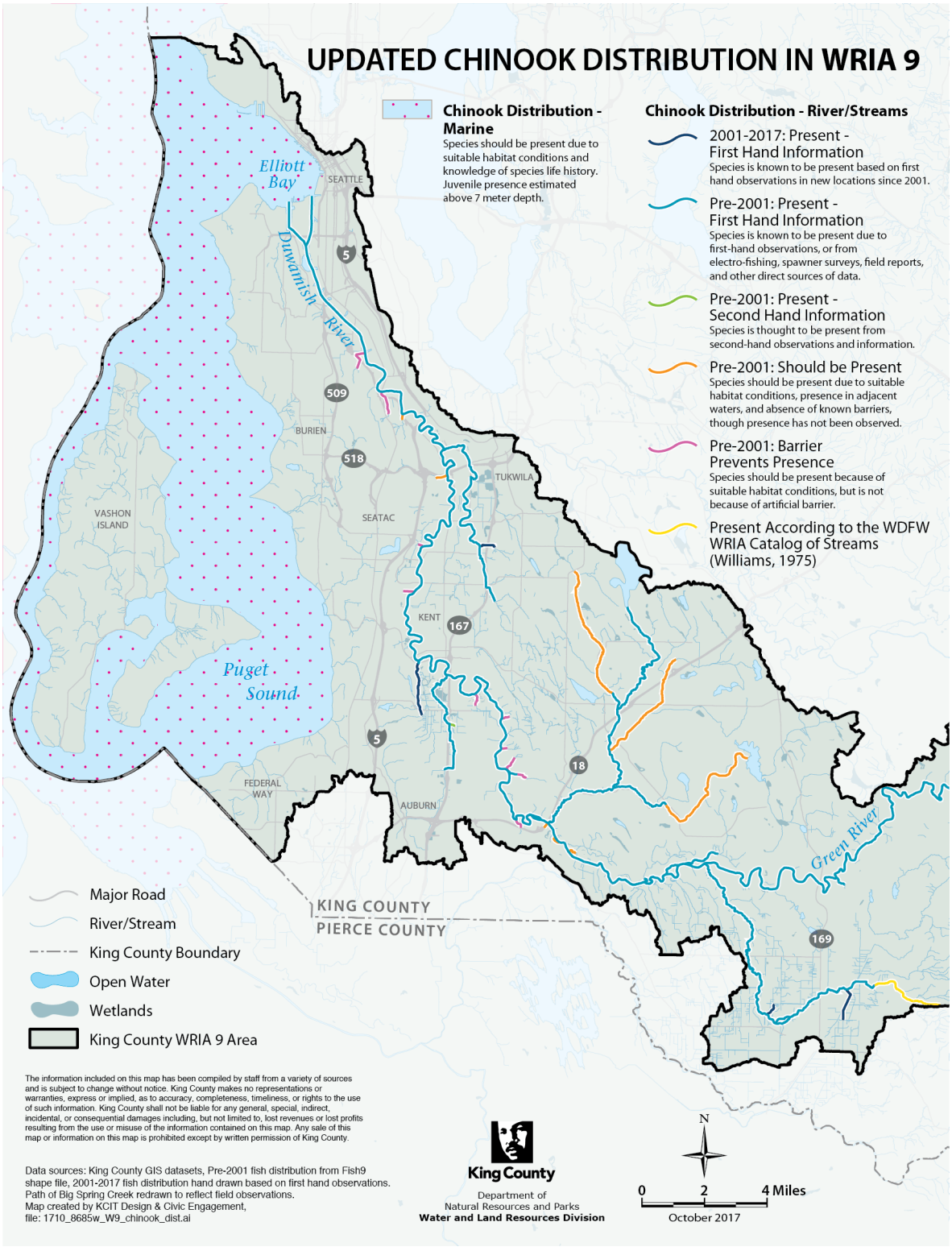

Figure 5. Locations of previously undocumented Chinook spawning areas. Adapted from the WRIA 9 Habitat Limiting Factors and Reconnaissance Assessment 2000.

- In the 2005 plan, a landslide located in the Middle Green near river mile 45.5 was singled out as a concern because of potential sedimentation of redds. However, a subsequent assessment indicated that there was no ongoing sedimentation impact from this slide (Booth 2012).
- The gravel supplementation program (Plan Program M-1) has been implemented for over ten years to supplement spawning gravel in the Middle Green to counteract the impacts of the HHD which had starved the Middle Green of spawning gravels. Concerns had been expressed about the high number of redds occurring in the immediate area supplemented with gravel and because of the potential for redds to be undermined by the mobility of recently placed substrate. In response to those concerns, the ACOE has modified how it places gravel and reduced the size uniformity of the gravel to make it less mobile so that the gravel more slowly gets incorporated into the river (Personal Communication Holly Coccoli, MIT, 2017).
- Since plan adoption, different methods to estimate spawner abundance have been used and explored by the co-managers. There are large differences in the escapement estimates created by redd counting versus genetic mark-recapture. More work is needed to understand the strengths and weaknesses of the different methods. This is predominately an issue to be worked between the Co-managers, but it affects the WRIA in because of how much the population abundance monitoring and tracking rely on the Co-managers' data.
- The MIT tagged and tracked adults shortly after entering the estuary in 2015, 2016, and, 2017, with tags that included temperature gauges. They undertook this study due to gain a greater understanding about the possible impacts of high water temperatures on adult Chinook migrating through the lower river. Temperature gauges on and in the fish provide a more accurate understanding about the conditions the fish experience while holding and migrating through the river and can provide insight into if fish are finding and utilizing any cold water refugia. Although the results of this research will not be available for this addendum to the Strategic Assessment (Personal Communication Holly Coccoli, MIT, 2017), the results should be tracked to see if different actions might be called for before the next 10 year update.
- Anderson and Topping's (2017) verified that spawning habitat in the Middle Green River is not currently limiting the productivity of the Chinook salmon population; rather the lack of juvenile rearing habitat is the primary limiting factor. No matter the number of spawners, a similar number of parr are leaving the Middle Green each year.

Technical recommendations and potential implications for recovery actions:

- Management Strategy 1 (also known as Policy MS-1) guides differentially allocating funding to specific subbasins based on limiting factors and habitat needs, page 5-16 of the Salmon Plan. This policy should be reviewed for relevancy given all the information we now have. It is often difficult to determine how much an individual project improves spawning versus rearing habitat when restoring riverine processes. At a minimum, the stipulation related to spending one third of funding resources on spawning habitat restoration should be evaluated since spawning habitat does not appear to be limiting the population at this time.
- Devote resources to better understand the strengths and weaknesses of different methods of counting spawner returns, and encourage use of the most accurate methods.
- Continue to track the ACOE's gravel supplementation effectiveness monitoring and the MIT's adult archival tagging monitoring effort. Consider incorporating findings into a plan update prior to the next 10 year update if findings warrant it.

Floodplain Habitats

- The Salmon Plan does not generally describe the floodplain's value to salmonid rearing as much as it notes the large acreage loss of connected floodplain area and the conversion of land cover from forested floodplains to some form of developed land cover (industrial, residential and agricultural). The most intensive changes in land use and development patterns occurred along the banks of and within the floodplain of the Lower Green subwatershed (Strategic Assessment 2006).
- Since plan adoption, there have been many papers out of the Sacramento River area (Summers et al. 2001a and 2001b, 2004, 2005, Jeffres 2007, Feyrer et al. 2006, Moyle et al. 2007, Henry et al. 2010, and Katz et al. 2013), Columbia River system (Lestelle et al. 2005) and the Chehalis River (Henning 2004) showing that Chinook growth was greater for fish with access to the floodplain versus those rearing in mainstem habitats only. It is theorized that the increased growth rate is due to that they have access to a greater amount of food resources in the floodplain than in the main channel and that the risk of stranding is offset by the potential for increased growth rates. These papers describe how important floodplain habitats are to juvenile Chinook growth in general and aid in understanding how the magnitude of habitat loss in the Lower Green and to a lesser extent in the Middle Green have impacted juvenile Chinook production locally.
- The habitat area within the bank full width of mainstem channel in the Lower Green is approximately 282 acres (unpublished King County GIS data 2017). Historically, the Lower Green River had approximately 19,642 acres of connected floodplain (Collins and Sheikh 2004) and currently has only 3,518 acres of partially connected floodplain. The estimate of the current amount of connected floodplain was created by the WRIA 9 ITC in 2014 for the Lower Green SWIF based on analyses of existing FEMA 100 year floodplain data that excluded the majority of the right bank area within the City of Kent due to this area not really being connected in a meaningful way for fish and the City's efforts to bring all its levees in this area up to 100 year flood protection. This amounts to a complete loss of 82% of floodplain area. The remaining 18% of floodplain has very limited connectivity due a variety of factors (e.g. the White and Black Rivers being diverted, HHD).
- The timing of late winter and early spring flooding historically aligned with providing the early migrating fry life history type with substantial slow, shallow water habitat in the floodplain (WRIA 9 ITC 2012). Due to the loss of floodplain noted above (due to levees, HHD water management, etc.) fry are now more much more restricted in extent of potential rearing habitat, especially in the Lower Green.

Technical recommendations and potential implications for recovery actions:

- The new information on the importance of floodplain habitats to juvenile Chinook growth should be considered when prioritizing recovery actions.

Survival/Otolith Data:

Otoliths are ear bones in fish that look like a cross section of a tree, showing rings for each day of growth. The bones are made up of the minerals that were available to the fish in its specific environment. There are different levels of minerals, like strontium, in the marine and estuarine environments that create a mark on the ear bone that allows one to determine how old juvenile

salmon were when they left freshwater and began rearing in estuarine/marine waters. This also allows one to estimate what size they were when they entered salty water as well as look for patterns around which juvenile life history types are surviving to adulthood. This data will not allow us to compare the survival rate of all five life history types noted above. The format of the data lumps the five types into three groupings of juveniles: yearlings, Middle/Lower Green Parr and direct/estuarine fry.

- Ruggerone and Volk (2004) looked at juvenile Chinook in the Duwamish toward the end of the outmigration period. The results showed low surival of estuary reared Chinook, but these results should be treated carefully as they evaluaterd a very small portion of a single migratory period.
- Campbell and Claiborne (2017) indicated that the Duwamish estuarine rearing fry life history type's contribution to the adult return in 2015 was extremely low (<1%), based on a subsample of adult otoliths analyzed as part of the larger Puget Sound Marine Survival project. Juveniles that were smaller than 60mm in size when they began to rear in salt water were almost nonexistent in the adult returning Chinook. Whereas the Skagit and Nooksack's fry contribution was 36% and 24%, respectively. This indicates other watersheds estuarine rearing fry types are surviving to adulthood at much higher numbers than Green River's. WRIA 9 provided WDFW funding to collect adult otoliths from the 2016 and 2017 spawning seasons. Draft data for the 2016 adults found very similar results with less than 3% of the returning adults originating as estuarine rearing fry (Personal Communication Lance Campbell). Based on smolt trap data, an average of 60% of all juveniles migrate past the trap as fry. Some of these fry likely rear in the Lower Green and become the Lower Green parr life history type, but based on other data (Ruggerone et al. 2006, and Nelson et al. 2012) it is known that many of the fry rear in the Duwamish (Figure 6). If we apply the recent otolith findings to the previous research looking at size, abundance, and timing of fry using the estuary (Nelson et al. 2012, and Ruggerone et al. 2006) we see that fry in the Duwamish prior to early April did not survive to adulthood and many fry from early April to mid-May also did not survive to adulthood. While still tentative with only two years of similar data, the loss of almost all the fry that reared in the Duwamish is severely limiting fry productivity, overall population productivity, and abundance, as well as reducing overall life history diversity.
- If the outcomes of the 2017 data collection and analyses, are similar to 2015 and 2016, the ITC may need to reevaluate actions/recommendations made in specific subwatersheds, especially the Duwamish shortly after this plan update has occurred.
- There has been no new information on habitat use by yearling Chinook in the Green River. They have been found in the past in the Lower Green River floodplain within channels of the two larger streams that are accessible (Auburn Mill Creek and Mullen Slough). Limited data on fish use by yearlings in the Snoqualmie River have shown them to use similar small stream channels that are located within the floodplain of the Snoqualmie River. Draft work by Lance Campbell showed that wild yearlings made up a small portion (~5%) of the returning adults in 2015 based on a subsample of otoliths analyzed as part of the larger Puget Sound Marine Survival project (Personal Communication with Lance Campbell, WDFW, 2017). Interestingly, this number appears to be much larger than the percentage of yearlings outmigrating that have been captured by WDFW's smolt trap. There are several possible reasons for this. Fry and parr may migrate past the trap and choose to reside for a year in accessible habitats of the Lower Green, thus the trapping data would not record them as yearlings. It is known that the smolt trap has greater trapping efficiency with smaller fish than yearlings, thus there could be higher numbers of yearlings in the Middle Green, but they are able to avoid the trap when the outmigrate. And finally, it is possible the trap is accurately estimating the number of yearlings leaving the Middle Green. It is known that the larger fish are (like yearlings) when they outmigrate, the higher their

survival rate is to adulthood. This differential survival means that a very small number of juveniles of this life history type could make up a much larger proportion of adults.

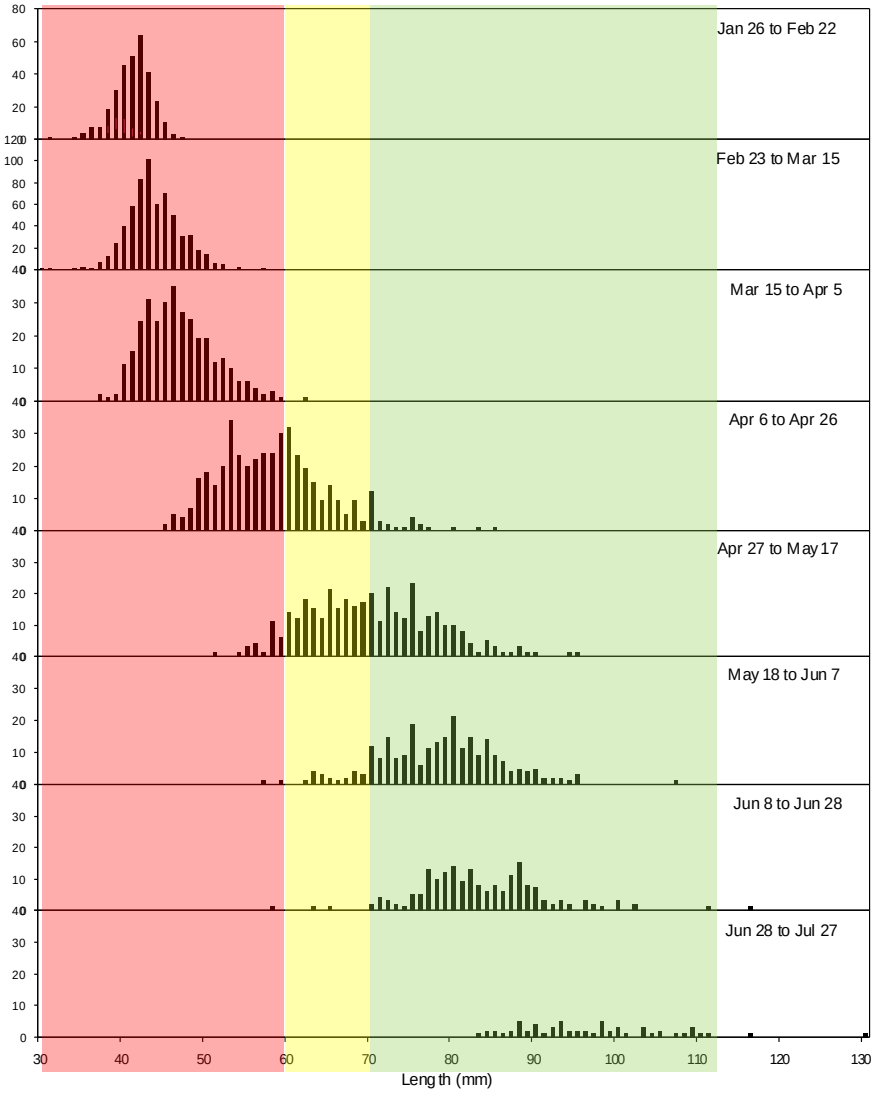

Figure 6. Shows juvenile Chinook timing from sampling that occurred in 2003, combined with highlighting to show survival to adulthood based on 2015 and 2016 otolith data. The red highlight shows timing and size of juveniles that would not survive to adulthood and the green highlight showing highest survival based on 2015 and 2016 data. Adapted from Nelson et al. 2012.

Technical recommendations and potential implications for recovery actions:

- See Duwamish subsection below for related recommendations.
- Update strategies based on new findings after more years of otolith work are completed.
- Conduct research to determine where yearling Chinook are currently rearing/overwintering, so that these areas can be identified for protection and restoration. Begin by looking in small stream channels along the mainstem Green River.

- Combined with the floodplain subsection above, it provides more context to the value of accessible floodplain habitats to provide habitat for fry, which do not appear to be surviving to adulthood in large numbers.

Relevant Co-Manager Topics

- As part of a recent update to the Hatchery Genetic Management Plan, the Co-managers changed hatchery practices and began a new program to create unclipped 'highly integrated' hatchery juveniles. These hatchery juveniles are managed separately from the primary Soos Creek hatchery fish and are reared and released farther upstream at the Pautzke ponds. Given that these hatchery fish are not externally marked, it will be difficult to tell them apart from naturally spawned fish. This is a concern because it will affect current monitoring protocols, and affect WRIA 9's monitoring approaches, assumptions, and recovery goals around the number of natural origin adult returners as well as that more juvenile fish are being released and how that higher number of hatchery fish may impact juvenile productivity.
- The Research Framework noted that the historic run timing of Chinook returning to the Soos Creek hatchery has been shifted three weeks earlier due to older (pre-1960s) hatchery practices. Given that the Green River system has been managed as an integrated stock and that there has been a higher proportion of hatchery fish on the spawning grounds than recommended in the HSRG, it is assumed that the wild population's timing was also shifted earlier. Bowerman et al. 2016 noted that spring and summer Chinook, which enter fresh water earlier than fall Chinook, are more susceptible to energetic depletion and environmental stressors like high water temperatures. The Green River Chinook population timing being shifted earlier likely has negative impacts on abundance and productivity due to lower water levels and higher temperatures, early emergence of fry before prey is available. Expected environmental and habitat changes associated with climate change will only exacerbate those negative impacts. *NOTE: This issue may be best addressed via a recommendation for a future H-integration effort to evaluate the broader issue.*

Technical recommendations and potential implications for recovery actions:

- Addressing climate change impacts on Chinook may require changing hatchery and harvest practices, which are not within the WRIAs purview to directly affect or change. The WRIA should work with the co-managers to lay out a process or framework where these technical and policy issues can be discussed.
- An 'H' integration process needs to be restarted and reinvigorated so that issues like the number of hatchery adults spawning with wild fish and how the 'highly integrated' returning adult fish effect HSRG goals related to managing integrated stocks, productivity of wild fish, as well as monitoring and assessment efforts.

Subwatershed Specific Issues

Upper Green River

- Program Upper Green 1 (U-1) is the development of planning effort focused on a long term comprehensive restoration and planning approach for the upper watershed. It did not occur prior to this Salmon Plan update.
- The 2015 Mt. Baker-Snoqualmie National Forest: Forest-Wide Sustainable Roads Report was recently completed. The Mount Baker-Snoqualmie Forest includes much of the Upper Green River basin. It lays out the USFS recommendations for which forest roads to maintain and abandon.
- Since 2001, Tacoma Water has implemented several fisheries-related habitat conservation measures projects under its habitat conservation plan. Briefly they include:
    - Construction and operation of an adult fish trap and haul facility and downstream juvenile bypass system at the Tacoma Water Municipal Intake (RM 61)
    - Replacement of impassable culverts on twenty-five streams within the Upper Green River
    - In cooperation with the USACE, installation of individual LWD and ELJs within approximately thirteen miles of the mainstem Upper Green River and approximately six total miles of tributary stream
    - Provided approximately 70 pieces of LWD annually from the Upper Green River for release into the Middle Green River below the Tacoma Water Headworks
- As part of the Additional Water Storage Project (AWSP), baseline habitat surveys were conducted in 2005 and 2006 by R2 Resource Consultants, Inc. (R2) (2007). The first post-AWSP survey was conducted by Tacoma Water in 2012 and 2013 (in review). The second post-AWSP survey is scheduled to be conducted by Tacoma Water in 2017 and 2018. While habitat surveys done by different crews or in different years can result in habitat changes that are not 'real' but an artifact of surveyor bias, it is believed the statistical differences between years noted below are real (Personal Communication Tyler Patterson, Tacoma Water, 2017).
- The post ASWP in 2012 and 2013 habitat monitoring surveys were conducted on Tacoma Water-owned portions of the mainstem river (RM 68-85) and several tributary streams, including the Sunday Creek (RM 0-3.5), Smay Creek (RM 0-1.8), and the North Fork Green River (RM 0-2) and compared against baseline surveys from six years prior by R2. Results indicated:
    - Pool frequency (pools per channel width) and total pool area (feet^2) improved throughout the mainstem between surveys, while residual pool depth (feet) remained about the same.
    - Pool frequency increased substantially in the major tributaries of the Upper Green River (i.e. Sunday Creek, Smay Creek and the NF Green River) between surveys. Total pool area increased in Smay Creek and the NF Green River, but decreased slightly in Sunday Creek. The decrease in Sunday Creek total pool area was due to a substantial decrease in mean pool area. Like the mainstem, residual pool depths and canopy cover remained relatively constant between surveys in these tributaries.
    - Canopy cover did not change significantly between surveys, moving from a mean of 20% in the baseline to 23% post-AWSP. The adjacent riparian areas along the mainstem and major tributaries are within Tacoma's "Natural" Forest Management Zone. This zone is managed "to preserve health and vigor of the vegetative cover to reduce erosion and provide habitat for fish and wildlife". Substantial portions of the riparian areas within

this zone are still composed of young alder and black cottonwood with mature alder and black cottonwood interspersed. Conifers are present but are mostly subdominant in these areas. These immature canopy areas are adjacent to channel banks and appear to the result of channel migration over time versus any active management measures. The six year time span between surveys is not likely long enough to see significant improvement in canopy-related shading overall.

- The frequency of Large Wood Debris (LWD) increased from 140 pieces mile to 208 pieces per mile between surveys and jam frequency increased from 4 jams per mile to 8 jams per mile. In comparison, the LWD and jam frequencies in the Middle Green River in 2012 were 141 pieces mile and 4 jams per mile, respectively. Median bed surface grain size (D50) decreased throughout the mainstem likely indicating increased sediment storage capacity behind jams and sediment supply rates out pacing the system's ability to transport it. This is likely the result of that there has been an increase in total LWD frequency from both engineered projects and natural bank input. Two substantial high flow events (2006 and 2009) occurred between the baseline and first post-AWSP surveys which likely increased natural LWD input, sediment supply (e.g. bank erosion), and sediment storage.
- The frequency of LWD also increased substantially in all three tributaries, while the frequency of log jams increased in Sunday Creek and remained about the same in Smay Creek and the NF Green River (Table 2). A similar trend in sediment grain size seen in the mainstem was observed in the three major tributaries with greatly reduced D50 between surveys.

Table 2. LWD and wood jam frequency comparisons between baseline and post-AWSP surveys for major tributaries in the Upper Green River.

Major Tributaries	LWD/mile		Jams/mile	
	Baseline	Post-AWSP	Baseline	Post-AWSP
Sunday Creek	238	317	7	12
Smay Creek	491	663	22	23
NF Green River	420	547	19	18

Technical recommendations and potential implications for recovery actions:

- The habitat in the Upper Green is generally of higher quality than the Middle and Lower Green River, but it is still inaccessible to anadromous fish. Given the continuing decline of Chinook abundance, there is a strong and urgent need to provide access to this habitat.
- Development of Program U-1 should be a high priority because a more in depth planning process would help set priorities for remaining habitat issues in the Upper Green. WRIA 9 should seek funding to do this work over the next three years. This process should be tracked, and depending on the outcomes, another plan amendment should be considered at that time.

Middle Green River

- Fish productivity associated with existing habitat conditions within the Middle Green River is discussed in detail in Anderson and Topping (2017); their findings, likely apply in the Lower

Green River channel as well because that portion of the river provides the same rearing functions as the Middle Green. Many of their findings reinforce background technical information or assumptions in the Salmon Plan and Strategic Assessment, and provide greater certainty that a lack of rearing habitat is the primary limiting factor. Some of their primary findings are:

- There is limited rearing habitat capacity (off channel habitats like side channels and backwaters) for fry in the Middle Green, and this is likely one of the main factors contributing to the early downstream migration of fry in large numbers. There is not enough habitat for large numbers of fry to grow into parr. Thus, the limited habitat capacity expresses itself by limiting the number of parr that can be produced, while the number of fry produced does not get limited. Since it is assumed that parr survive to adulthood at much higher rates than fry, the habitat limitation reduces our ability to meet abundance, productivity, and diversity Viable Salmonid Population goals.
- High flows (between 8,000 to 10,000 cfs*) from November through mid-January appear to scour eggs in gravel, sharply reducing the overall productivity of the number of juveniles per spawner.
- High flows (between 6,000 to 8,000 cfs*) during typical fry outmigration period (mid-January through the end of March) reduced the number of parr produced, likely because fish were flushed into habitats downstream of the trap.
- More days with spring flows (April through June) above 1,200 cfs* appears to increase the number of parr produced. This is likely due to increased connectivity to off-channel habitats, like side channels. A separate study (R2 2010) showed that as flows drop below 1,200 cfs, side channel habitats become less connected to the mainstem Green.

**flow ranges are tentative and should be refined over time as more data is collected.*

- A combination of reports from R2 and Tacoma Water looked at habitat availability and juvenile salmonid use in the Middle Green River over the last 15 years. The intent of the reports was to be able to compare changes in habitat and fish use over time. However, due to agency priorities and variations in annual weather/flow patterns, the results are not completely comparable. The findings of each effort are synthesized here.
    - The 2006 R2 report on fish use of lateral habitats showed high usage of mainstem slow velocity habitats by juvenile Chinook between 1998 and 2002. However, the observed use of these habitats may merely be a function of higher mean daily flow levels and outmigration timing with more fish being flushed out of the system early. The sampling design was not set up to evaluate habitat usage for different flow regimes, thus the recommend that future studies be designed to incorporate different flow regimes. A follow on study to evaluate the distribution of what habitats were available at different flows (R2 2013) showed that 500 cfs flows produced the most slow water habitats overall. However, most of the habitat was adjacent to unvegetated banks, was not complex, and occurred after most juvenile Chinook have left the Middle Green River making the amount of habitat available at 500 cfs less important. The transition point for complex vegetated mainstem edge habitat and side channel habitats appeared to be that as flows decreased below 1,200 cfs, wetted habitats begin to pull away from complex vegetated banks and that the more heavily armored lower reaches of the Middle Green had less slow velocity habitat available at all flows.

  - Overall the R2 2013 report found that as flows increased more slow velocity *lateral* (off channel) habitat became available, but slow velocity *mainstem* habitat decreased. However, as flows decreased, more *mainstem* slow velocity habitats were available while the amount of low velocity *lateral* habitats decreased.
  - Juvenile use surveys of lateral habitat in 2011 were unable to sample sufficiently across the four flow targets established by R2 in 2010 to find patterns of use related to flow (Patterson et al. 2015). Most sampling occurred at relatively higher flows, with very limited sampling in the 500 and 800 cfs range. Unlike the R2 2006 study, the 2011 juvenile salmonid use study (Patterson et al. 2015) found higher use of off channel habitats than mainstem habitats. This higher use may be driven by the flow to habitat relationship noted in the previous year's habitat study, i.e., at higher flows there are more slow velocity lateral habitats available than similar velocity mainstem habitats.
- Since 2001 there has been a slow increase in pool frequency in two reaches of the Middle Green, while the amount in the other three reaches was variable over time (R2 2012).
- The amount of individual pieces of wood per mile has fluctuated, with the most recent data (2012) showing 32.3 pieces per mile, with a high of 47.8 pieces per mile in 2009 and with a low of 15 pieces per mile in 2001. However, while the number of jams has fluctuated between years, there appears to have been a relatively steady increase in the number of jams per mile (2001 0.8 jams/mile to 2012 4.2 jams/mile) (R2 2012).
- Channel Dynamics Middle Green
  - The extent and duration of higher flows are controlled by operations of the HHD. Stream flow greater than 8,829 cfs (250 cms) as measured at the Auburn USGS gauge is needed to force lateral bank migration, which in turn creates new off channel habitats necessary for juvenile Chinook rearing (Konrad et al. 2011). For the purpose of relating flow discharge to habitat, this report will refer to flow discharge in excess of 8,800 cfs as "habitat forming flows".
  - Flow management at HHD prolongs the duration of moderate flows (>5,900cfs) by 39% compared to historic conditions (Kerwin and Nelson 2000).
  - Scour of redds begins between 5,000 and 8,000 cfs (R2 2014 Zone 1 nourishment gravel stability). Thus, this report will refer to flow discharge in the range of 5,000-8,000 cfs as "redd scouring flows" to differentiate these high flows from higher ones that can have positive habitat benefits.
  - Combining the findings above, flow management appears to be increasing the number of days with redd scouring flows (directly reducing egg and fry survival) while at the same time reducing the number of years that attain habitat forming flows (indirectly leading to lower productivity through less off channel habitats created). Follow up analyses should look at whether there has been a continued increase in the number of days of "redd scouring flows" noted by Kerwin and Nelson (2000) and WRIA 9 ITC (2012). Future Status and Trends reports should quantify this metric as well as number of days of habitat forming flows (above 8,800 cfs).
- MIT Draft smolt trapping data from Soos and Newaukum creeks (~2013-2016) indicate lower survival rates in these streams than previously calculated previously by WDFW based on several

years of trapping. MIT data indicate that the primary Chinook life history type leaving the creeks is fry, with very few fish rearing to parr size/age. *(*Personal Communication Holly Coccoli, MIT, 2017).

Technical recommendations and potential implications for recovery actions:

- As supported by the numerous studies conducted in the Middle-Green subwatershed, there is a need to increase off channel habitat availability, especially in the Middle Green (and Lower Green River), in order to increase the abundance of habitat that can support more fry rearing to parr sized juveniles, which have the highest likelihood of surviving to adulthood.
  Given our improved understanding and certainty that a lack of fry habitat is a primary limiting factor in overall abundance and productivity of the Chinook population, greater emphasis should be placed on creating more rearing habitats in the Middle Green or more specifically, removing infrastructure (levees and revetments) that limits of creation of and access to off channel habitat. The Middle Green has undergone several project identification efforts in the past. The projects that are most likely to create the type of necessary rearing habitat unfortunately overlap with both the County's 'Upper Green Agricultural Production District as well as many Farmland Protection Program easements. County agricultural policies and programs create regulatory and implementation hurdles to implementing the aforementioned high priority restoration projects in the Middle Green. With the ongoing downward trend in Chinook abundance and the urgent need for more fry habitat, the Forum should engage the County to facilitate implementation of high priority salmon projects.
- Evaluate the raw data from the earliest R2 study in the Middle Green against flows during the sampling periods to try to better understand the relationships between different flows and habitat use seen in later reports.
- The WRIA should work with Tacoma Water, the ACOE, and the MIT to look at how river flows are managed to see if there is a way to limit the amount of "redd scouring flows" that occur between 5,000 and 8,800 cfs that likely scour redds and/or flush fry out of the Middle Green, but aren't high enough to cause lateral channel migration, which is necessary for high quality off channel rearing habitat creation.
- Continued funding for the smolt trap is imperative. As can be seen above, the smolt trap has been in the river enough years that we are able to undertake analyses that show trends related to high and low flows and Chinook productivity. Some of the relationships are still tentative and more data will allow us to have greater confidence in the relationships that have been seen, as well as explore more relationships over time. These data are essential to Chinook recovery.

Lower Green River

- The draft Retrospective, the Reddington Monitoring Report, the draft 2014 Juvenile Salmonid Use of Aquatic Habitats in the Lower Green River study, and the 2013-2014 MIT/R2 Lower Green Fish Use Report all describe differential use of some habitats by juvenile salmon use in the Lower Green River. This indicates it can function as rearing habitat when conditions are appropriate (e.g. off channel habitat exists).
    - Statistically significant higher catch per unit of effort (CPUE) of wild Chinook along banks with LWD (R2 2014a), though this finding was not replicated by the Retrospective work (KC 2016).

  - Shallow or gradually sloped banks with modest levels of LWD had greater CPUE of juvenile salmonids than steep banks with high amounts of complex LWD. (R2 2014a).
  - Created shallow/slow water habitats at Reddington and Riverview had higher CPUE of juvenile Chinook than nearby vegetated and unvegetated steeper banks. The Retrospective study (2016) also showed higher Chinook CPUE with gradual banks than with slow water.
  - Most of the studies did not focus on the depth of the sample areas as much as velocity over a range of flows.
  - The data on overhanging cover and CPUE of Chinook showed a statistically significant decline in CPUE with increasing overhanging vegetation. However, areas with overhanging vegetation are notorious difficult to sample and generally cannot be sampled as efficiently as areas without overhanging vegetation. The likely catch biases from the sampling approach used were not accounted for in any of the studies. Therefore, the results should be treated carefully.
  - None of the studies attempted to directly assess whether juvenile Chinook are residing in the Lower Green or just passing through. Some of the data indicates juveniles are keying in on some habitats, using them in higher numbers. This preferential use implies fish are residing. More directed mark and recapture studies would help improve our understanding of how long juvenile Chinook reside in Lower Green Habitats.
  - In March of 2017, the recently restored Leber Homestead site on Mill Creek (Auburn) was sampled twice, once during lower flow conditions (~1,300 cfs, about mean flow during the January –June outmigration period) and once during high flow conditions (~7,000 cfs, about an annual flood) (Gregersen 2017). A small area near the outlet was being used by Chinook fry during lower flow conditions. During high flow conditions three weeks later, Chinook fry were found throughout the larger restored area. Interestingly, the fish that were present under low flow were roughly 5mm longer than the fish that used the site during high flow three weeks later. One explanation of this observation is that the earlier and larger fish at the restoration site migrated downstream volitionally and were residing in productive habitat, whereas the smaller juveniles three weeks later were likely unvolitionally flushed out of the Middle Green and used the Leber site as flood refuge.
- Recent surveys of juvenile salmon habitat conditions in the Lower Green show that conditions are still very degraded (R2 2014b)
- Initial analyses related to sediment loads of the river for the Lower Russell Road Project indicate that there is a large amount of coarse and fine sand moving through the confined river channel. There is concern that this large sediment load might quickly fill in restored/created off channel habitats as the wider channel area will likely create depositional areas. The Salmon Plan acknowledged that off-channel creation projects in the Lower Green would not be as sustainable as true restoration projects and that maintenance would be needed occasionally for those projects to function as fish habitat. The current concerns are focused around how often maintenance would be needed and if the maintenance interval is financially sustainable.

Technical recommendations and potential implications for recovery actions:

- A greater understanding is needed of where fry go when they leave the Middle Green River, and if freshwater and estuarine rearing conditions downstream are conducive to fry rearing to parr size and surviving to adulthood.

- River bank stabilization/modification projects should strive to provide gradual slopes that inundate over a large range of flows, with large woody cover instead of constructing projects with steep slopes or benches that provide habitat at a very narrow range of flows.
- In order to increase the number of fry that can grow into parr before entering the Duwamish, off channel habitat availability should be increased, especially in the Middle Green and Lower Green River.
- Any major levee/bank set back project should consider how the project will be affected by sediment movement and deposition, and how this will affect sediment conditions downstream.
- Detailed monitoring is needed of existing setback projects like Riverview, Leber, and Reddington to better understand potential maintenance intervals and risks associated with sedimentation.
- Future juvenile salmonid use studies should attempt to:
    - Sample different habitat types (side channels, backwaters, bars, etc.) versus different bank types and with several methods (e.g. minnow traps, and electrofishing).
    - Explore CPUE effort and depth of habitat.
    - Focus on differences CPUE and overhanging vegetation to better inform project design
    - Undertake a mark and recapture study to help improve our understanding of how long juvenile Chinook reside in Lower Green Habitats.
- Given the relatively low use of the broader Leber Homestead project site during lower flow conditions, more directed fish use and water quality monitoring should be undertaken to try to understand why more of the site is not being used by Chinook during lower flows.

Duwamish River

A significant research and planning effort, the Duwamish Blueprint, was completed in 2014 as part of the WRIA 9 planning effort to help understand how juveniles use the estuary, and to identify restoration opportunities. The first four bullets below are described in more detail in in the Duwamish Blueprint (2014):

- Ruggerone et al. 2006 found that the entire estuary, not just RM 4-6, was used by juvenile Chinook, but by different life history types at different times of the rearing season. The lowest, saltier area of the estuary was more heavily used by early fry migrants, while the later, larger Chinook migrants (parr) had higher use of the area above RM 6. The Middle portion of the estuary appeared to be more heavily used by the large pulse of later fry migrants during late March, April and May.
- Bigger inlets are likely better than smaller inlets for increased use of juvenile Chinook, (Ruggerone et al. 2006, Cordell et al. 2010, and Toft and Cordell 2017)
- The findings from Ruggerone et al. 2006, combined with data from other reports (Ruggerone and 2004, Nelson et al. 2011, Oxborrow et al. 2016), and expected climate change impacts on habitat area within the Duwamish, indicate we need bigger restoration sites with more habitat heterogeneity (e.g. deeper water that would not drain out at low tide and available shallow water habitat throughout the full tidal range).
- Brackish waters appear to have higher growth potential based on prey availability than more saline areas (Cordell et al. 2010).

Other recent findings not included with in the Duwamish Blueprint include:

- David et al. 2016 found that variation in abundance of different species of arthropods (prey for juvenile Chinook salmon) in estuaries across the west coast was driven predominately by types of

vegetation versus broad categories of land cover (e.g. developed, undeveloped, agricultural). Arthropod abundance was highest in freshwater emergent and mixohaline wetland vegetation, compared to scrub shrub wetlands and forested wetlands. Other physical environment factors that are not readily modifiable by humans, like temperature and precipitation, were also found to influence arthropod abundance. They also found that arthropod abundance in restored wetlands rapidly achieved levels found in reference wetlands. They did find that while abundance was similar in both newer and older restored sites, older sites had different arthropod assemblages, including having more energy rich trichopterans than recently restored sites.

- Recent sampling from Toft and Cordell 2017 found similar results to the previous sampling efforts. Primarily, they found that the interior areas of restoration sites like Codiga and North Winds Weir are being used at a higher rates/densities than nearby non restored habitats, though the differences were not statistically different. Finding differences that are statistically significantly different can be difficult with this type of sampling, especially when there is so little habitat available. Similarly, the Herrings House restoration site continued to have relatively low use by juvenile salmonids.
- Recent sampling by WDFW (O'Neill et al. 2015) and others showed that juvenile Chinook caught in the lower part of the Duwamish River had levels of persistent organic pollutants (POPs), including PCBs, and PAHs that may have adverse effects on fish health and growth rates, thus would be expected to decrease overall productivity. However, based on the limited spatial sampling, it is not clear if the POPs originated in the Duwamish or upstream in other parts of the watershed.
- Work by Meador (2014) indicated that hatchery Chinook migrating through contaminated estuaries, like the Duwamish, had a 45% lower marine survival rate than hatchery Chinook that migrated through uncontaminated Puget Sound estuaries. He evaluated these findings against the total amount of estuary habitat, length of freshwater habitat between each hatchery and estuary, as well as growth rates and did not find these other factors to be explanatory of the lower survival rates seen. He also cited work by Varanasi et al. 1993 that showed Chinook from the Soos Creek hatchery and the Duwamish held in lab conditions for 40 days survived at a rate of 86% and 56%, respectively. The experiment was repeated for a second year with similar results. It is important to note that this specific evaluation looked strictly at hatchery Chinook and given their size at release they are not as reliant on the estuary as wild Green River Chinook fry and parr would be. Thus the effects seen on wild Chinook, that are more reliant on the estuary, would likely be more extreme.

Technical recommendations and potential implications for recovery actions:

- The information from various previous Duwamish fish studies should be compared and combined with the contaminant findings in the Water Quality white paper to see if there are specific overlaps in timing and location that might be more problematic for certain life history types/times of year.
- An adaptive management plan or feasibility study should be completed to evaluate options to improve the habitat use by salmonids at the Herrings House restoration site. At a minimum, it has been suggested by Toft and Cordell 2017 that the inlet/outlet of the channel leading to the restoration area is too narrow and should be widened and shortened to allow for greater connectivity with the river. The site is generally dewatered during lower tides, thus it has also been suggested it could be deepened to increase the amount of habitat available and the duration of availability.
- Results by David et al. 2016 show that restoring estuarine wetlands, especially freshwater emergent and mixohaline wetlands, can increase arthropod prey species that juvenile Chinook rely on fairly rapidly. This finding suggests that wetland restoration actions in the Duwamish

could have fairly quick benefits by providing both space to rear and food and that food resource quality will improve over time.

- The combination of recent sampling showing that juvenile Chinook from the Duwamish have levels of contamination that may negatively affect survival as well as the 2015 and 2016 data from Chinook otoliths showing few of the returning adults being from fry that reared in the Duwamish from Jan through April is concerning. Unfortunately, both studies covered only a short period of time and limited area, which means the level of certainty about the broader applicability of the results is lower than what would generally be recommended for taking a dramatically different course of action. In the near term, more studies are recommended to create a better spatial understanding of Chinook contamination levels in the Lower Green and Duwamish. This data would help to better understand contaminant patterns in juvenile Chinook in comparison to known sediment contamination. In addition, it is recommended that more years of otolith data on survival to adulthood of different life history types be collected.
- The Lower Duwamish Waterway Superfund Site (RM 0 to 5) is currently in pre-design study phase. The next phase will include signing of responsible parties to a Consent Decree to perform the work as well as the detailed design of the sediment cleanup; both of these together are expected to take approximately 3-5 years. The in-water construction (e.g., dredging and capping of contaminated sediments), which follows design phase, has been estimated to take 7 years. The construction phase of the sediment cleanup, which will be followed by a period of natural recovery, may not be completed until after the 2028 time horizon of this Salmon Plan update. Given the Superfund cleanup timeline, WRIA led salmon habitat restoration projects in the Duwamish should be undertaken cautiously. It is currently not known if clean up actions will occur from upstream to downstream, but current source control strategy by Dept. of Ecology is planned for an upstream to downstream approach. This will likely reduce the risks of recontaminating WRIA sponsored salmon habitat restoration projects, but not eliminate the risks of recontamination. The areas of lower contamination, and thus less cleanup construction, are found in the upper mile of the waterway (RM 4-5). Thus restoration projects sponsored or funded by the WRIA in upper portion of the waterway could begin before full completion of the sediment cleanup with relatively lower risk of being recontaminated by cleanup activities. Until more information is available, a conservative project approach for WRIA funded capital projects over the next ten years in the Duwamish would be to continue to implement projects from the Duwamish Blueprint while taking the following into account:
    - The WRIA should invest resources into a monitoring/research study to evaluate if previously constructed WRIA restoration projects within the Duwamish have become contaminated.
    - For all areas of the Duwamish, emphasize acquiring and restoring the largest sites possible in order to provide a variety of elevations and slopes within the restoration sites to accommodate climate change and reduce the impacts of “coastal squeeze” (see climate change paper for more details), as well as having enough space to create habitats that retain at least a foot of water at low tide. Restoration sites should be designed with large openings, and focused on areas with brackish waters (typically where streams enter the Duwamish River or there is a reduced influence of the salt wedge).
    - From river mile 0 to 4.3 (just upstream of Slip 6), given the known contamination and long timeline for intended clean up actions of the primary area of the Superfund site:
        - Focus WRIA salmon recovery resources on acquiring large parcels for future restoration projects versus actually undertaking restoration projects until issues

associated with current contamination and potential recontamination are better understood or addressed.
        - Work with parties responsible for implementing Natural Resource Damage Assessment (NRDA) projects to find ways to enhance or enlarge project sizes with the intent of increasing the ecological benefits.
    - River mile 4.3 to 11: while it is much less contaminated than the downstream reach, it is still known to have some sediment contamination. The section from RM 4.3 to 5.0 is still located within the Superfund site, though remedial actions (e.g. dredging) that could have a higher likelihood of leading to recontamination are fewer in number and smaller in size.
        - Same as conditions noted above, but if a WRIA salmon habitat project sponsor moves forward with salmon restoration projects in this reach, it is recommended that the WRIA work with the project sponsor to fund more extensive feasibility analyses that evaluate the existing contamination issues as well as the likelihood of recontamination of the salmon habitat restoration site before fully funding the design phase of the project.

Nearshore

The bulk of the findings from the many new studies on marine nearshore habitat and fish uses issues reinforce or put more certainty behind previous findings and/or assumptions versus providing new information that would generally change the Salmon Plan's nearshore programs, priorities, or projects associated with the marine nearshore environments. Somewhat unusual, is that most of the recent literature for Puget Sound is based on data collected along various areas of WRIA 9's marine shoreline, which provides greater certainty about the applicability of the findings to the WRIA. Figure 7 below summarizes many of the findings from work over the last five to ten years (Dethier et al. 2016)

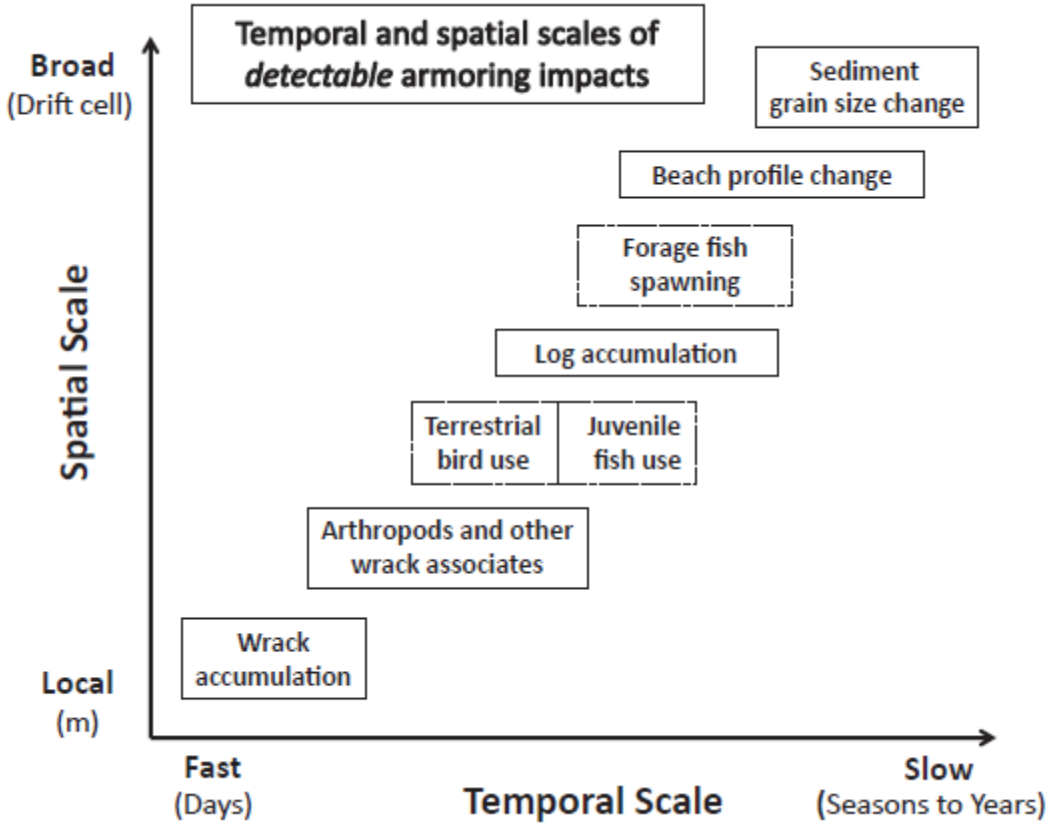

Figure 7. Temporal and spatial scales at which different types off impacts of armoring can be detected. Impacts in dashed boxes are hypothesized but not thoroughly demonstrated. Speed of responses following restoration (armor removal) may follow the same temporal and spatial patterns (Modified from Dethier et al. 2016).

The primary recent findings include:

- Armored versus not armored shorelines.
    a. Importance of vegetated riparian areas near the marine shoreline for Chinook salmon has been verified via diet analysis within Elliott Bay. The research showed Chinook salmon rearing along developed shorelines with riparian vegetation had more terrestrial insects in their diet than Chinook rearing along developed shorelines without riparian vegetation had far fewer terrestrial insects in their stomachs (Toft et al. 2007).
    b. Differences in predominately armored versus unarmored drift cells have shown impacts to sediment processes (Dethier et al. 2016) that create skinnier beaches, beaches with fewer drift logs, and beaches with fewer prey species, etc. However, there has not been as much work to look for a direct link to Chinook salmon.
    c. Rice 2006 showed that armored beaches get more sunlight (due to less riparian vegetation being present), which in turn causes higher air temperatures, which in turn leads to hotter substrate temperatures, which in turn leads to reduced humidity. At a minimum, this combination of environmental changes leads to reduced forage fish egg survival on armored beaches compared to unarmored beaches. The environmental changes likely lead to many other similar biological responses, but they have not been studied yet.

d. Recent report showed that vegetated shorelines significantly contribute to the detritus on adjacent beaches versus it all being marine derived, helping drive the detrital food web (Dethier et al. 2016, Heerhartz). This further reinforces the importance of marine riparian areas.
e. Toft et al. 2014 showed that the beach restoration at Seahurst Park had mixed results in how quickly the site's biological community re-established in density and richness compared to a nearby restoration site. The higher beach invertebrate community most quickly recovered to close to reference conditions, while the invertebrate community at the mid tidal elevations was much slower to respond. It is not clear if the slower response was caused by long term armoring impacts or by the beach nourishment restoration action.
f. Before and after monitoring of the Olympic Sculpture Park (Toft et al. 2013) showed: increased densities of larval fishes, increased densities of juvenile salmon, increased observance of juvenile feeding behavior, and had different invertebrates, and higher invertebrate taxa richness than nearby armored shorelines. All of these positive changes in habitat condition or use occurred on a site that is highly constrained, has high public use, and is surrounded by a highly urbanized environment.
g. Munsch et al. 2016 found smaller juvenile salmon preferentially utilized low gradient shorelines, which were mostly unarmored, while larger juvenile salmon were associated with armored shorelines with deeper water and higher gradient transitions.
h. Munsch et al. 2014 found that fish assemblages were different for seawall versus created beach sites in Elliot Bay. They found that chum and pink salmon were correlated with the beach sites at high tide while chum, pink and Chinook salmon were correlated with beach sites at low tides. They also found similar results to past studies that found most fish species avoided the heavily shaded areas under the piers in downtown Seattle.
i. Munsch et al. 2015a found that for the diets of juvenile Chinook that insects were more abundant in smaller juvenile Chinook, while crab larvae were more abundant in larger juvenile Chinook. Chum salmon were found to preferentially consume harpacticoid copepods which had greater taxa richness at the beach habitats, but also found that they selected planktonic prey species predominately associated with armored shores.
j. Munsch et al. 2015b found that fish species that are strongly associated with the bed of Puget Sound were impacted by the changes caused by shoreline armoring. They found fewer flatfish species associated with rocked/armored shorelines, while they found more lingcod associated with the armored shorelines. The flatfish results were similar to the results of Toft et al. 2007, where they found the densities of flatfish were reduced by shoreline armoring.
k. Recent Puget Sound data has shown shoreline armoring impacts bird species, reducing the likelihood of song birds and shorebird presence, while increasing the frequency of gulls and crows. The results are similar to findings in California (Dugan et al. 2008). This information shows that there is a multi-species benefit to the removal of shoreline armoring (Heerhartz 2013).

- Beamer et al. 2013 looked at fry migrant Chinook use of non-natal streams along the marine shorelines in north of WRIA 9. While they did not directly sample streams in WRIA 9, they did find four factors that appeared to determine whether fry migrant Chinook would use non-natal streams: distance from a Chinook bearing stream/river; watershed area greater than 45 hectares; stream gradient less than 6.5%; and absence of a culvert at the mouth of the creek.

- A 2014 Report has shown that new unpermitted armor has offset many of the restoration gains by the WRIA as of 2014, and many repairs to armoring are not going through the permit process (Higgins 2014).
- New surveys by WDFW show that forage fish spawn close to year round within the South Central Basin (unpublished data WDFW), combined with previous work on the importance of marine riparian vegetation for forage fish survival point to increased importance of riparian vegetation in WRIA 9, especially in south facing shorelines (Rice 2006).
- A new population of herring was found spawning in small numbers in Elliott Bay, near the Seattle Art Museum's Olympic Sculpture Park in 2012. It is not clear what the parent stock is for this new spawning aggregation, or how long they have been spawning in Elliott Bay (Stick et al 2014). Given herring are an important food source for salmon, understanding this new population would be advantageous so it can be protected and enhanced.

Technical recommendations and potential implications for recovery actions:

- Using the approach by Beamer et al. 2013, an analysis should be done of coastal streams throughout WRIA 9 to help prioritize which streams are most likely to support non-natal use by fry migrant Chinook so that those areas can be prioritized for future funding.
- Findings by Munsch et al. 2016 point to the need to provide shallow water edge habitats in the marine environment, especially for the younger fry migrants that are smaller and in greater need of shallow habitats. Given the lower survival rates of the fry life history type noted in other sections above, providing this shallow water habitat like the pocket beach at the Olympic Sculpture Park should be a higher priority closer to the Duwamish where small salmonids first transition to the marine environment.
- Future beach nourishment projects, like Seahurst Park, should be evaluated in a similar fashion as in Toft et al. 2014 to see if lower tidal elevations also experience slow recovery of invertebrate populations. Designs and monitoring should be implemented in a way to help differentiate the original impact of the shoreline armor versus the nourishment actions.
- Undertake more spring and summer spawner surveys of forage fish in order to better understand how important riparian areas are to forage fish spawning in the WRIA 9 area are, especially for south facing beaches.
- The issue of a high percentage of marine shoreline actions like bulkhead repairs and tree clearing being unpermitted, needs to be addressed or restoration gains will continue to offset by new impacts.
- Continue to focus on restoring sediment recruitment and transport processes.

References by Section

General & non-Green River specific

1. Bowerman, Tracy, M. Keefer, C. Caudill, 2016. Pacific Salmon Prespawn Mortality: Patterns, Methods, and Study Design Considerations. Fisheries, Vol. 41, No12.
2. Bryant, Mason D., 2000. Estimating Fish Populations by Removal Methods with Minnow Traps in Southeast Alaska Streams. North American Journal of Fisheries Management, 20: 923-930.
3. Feyrer, Fredrick, T. Sommer, and W. Harrell. 2006. Importance of Flood Dynamics versus Intrinsic Physical Habitat in Structuring Fish Communities: Evidence from Two Adjacent Engineered Floodplains on the Sacramento River, California. North American Journal of Fisheries Management, 26:408-417.
4. Harza 1995. Comprehensive Fisheries Assessment of Springbrook, Mill and Garrison Creek Watershed for the City of Kent. Bellevue, Washington.
5. Henry, R. E., T.R. Sommer, C. R. Goldman, 2010. Growth and Methylmercury Accumulation in Juvenile Chinook salmon in the Sacramento River and Its Floodplain, the Yolo Bypass. Transactions of the American Fisheries Society 139:550-563.
6. Henning, Julie, 2004. An evaluation of fish and amphibian use of restored and natural floodplain wetlands. Prepared by Washington Department of Fish and Wildlife for Environmental Protection Agency, Region 10.
7. Jeffres, C. A., J. J. Opperman, and P. B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes **83**:449-458.
8. King County, 2005. WRIA 9 Strategic Assessment Report-Scientific Foundation for Salmonid Habitat Conservation. Prepared for WRIA 9 Steering Committee, by King County Water and Land Resources Division, Seattle WA.
9. Kubo, J., 2017. Green River Temperature and Salmon. Prepared for the WRIA 9 Implementation Technical Committee, by King County Water and Land Resources Division, Seattle, WA.
10. Lestelle, L.C., McConnaha, W.E., Blair, G., Watson, B., 2005. Chinook salmon use of floodplain, secondary channel, and non-natal tributary habitats in rivers of western North America, Report prepared for the Mid-Willamette Valley Council of Governments, U.S. Army Corps of Engineers, and Oregon Department of Fish and Wildlife, Vashon, WA and Portland, OR.
11. Moyle, P. B., P. K. Crain, and K. Whitener. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. San Francisco Estuary and Watershed Science **5**
12. Price, David M., T. Quinn, and R.J. Barnard, 2010. Fish Passage Effectiveness of Recently Constructed Road Crossing Culverts in the Puget Sound Region of Washington State. North American Journal of Fisheries Management 30.5: 1110-1125
13. Quinn, T.P. 2005. The behavior and ecology of Pacific salmon and trout. University of Washington Press, Seattle, WA.
14. Ruggerone, G.T. and D. E. Weitkamp 2004. WRIA 9 Chinook Salmon Research Framework. Prepared for WRIA 9 Steering Committee. Prepared by Natural Resource Consultants, Inc., and Parametrix, Inc. Seattle WA.
15. Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer, and L. Schemel. 2001a. California's Yollo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries **26**:6-16.
16. Sommer, T. R., W. C. Harrell, and M. L. Nobriga. 2005. Habitat use and stranding risk of juvenile Chinook salmon on a seasonal floodplain. North American Journal of Fisheries Management **25**:1493-1504. Sommer, T. R., W. C. Harrell, A. M. Solger, B. Tom, and W. Kimmerer. 2004.

Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems **14**:247-261.
17. Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001b. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences **58**:325-333.
18. United States Army Corps of Engineers, 1998. Final Feasibility Study Report and Final Environmental Impact Statement. Seattle District.
19. WRIA 9 ITC, 2012. WRIA 9 status and trends monitoring report: 2005-2010. Seattle WA.

Upper Green

1. Patterson et al. 2016 (DRAFT). Upper Green River Post-AWSP Habitat Monitoring: 2012/2013 Report. Tacoma Public Utilities – Water Division, Tacoma, WA.
2. R2 Resource Consultants (R2). 2007. Upper Green River Baseline Habitat Monitoring: 2005/2006 Report. Prepared for the US Army Corps of Engineers, Seattle District, Seattle, WA.
3. Winans, G. A., M. Baird, J. Baker, 2010. A Genetic and Phenetic Baseline before the recolonization of Steelhead above Howard Hanson Dam, Green River, Washington.

Middle Green

1. Anderson, J. H. and P. C. Topping, 2017. *Draft* Juvenile Life History Strategies and freshwater productivity of Green River Chinook Salmon. Prepared for the WRIA 9 Implementation Technical Committee, Seattle WA.
2. Booth, D.B., J.B. Lando, E.A. Gilliam, T.E. Lisle, 2012. Investigation of fine sediment and its effect on salmon spawning habitat in the Middle Green River, King County, Washington.
3. Patterson, T., L. Sievers, R. Lamb, J. Lowry, and G. Volkhardt. 2015. 2011 RFM-02A Middle Green River Juvenile Salmonid Use Study. Tacoma Public Utilities Water Division, Tacoma Washington.
4. Konrad, C., H. Berge, R. Fuerstenberg, K. Steff, T. Olsen and J. Guyenet. 2011. Channel dynamics in the Middle Green River, Washington, from 1936 to 2002. Northwest Science 85:1-14.
5. R2 Resource Consultants (R2). 2013. Monitoring of Juvenile Salmonid Habitat in Relation to Streamflow in the Middle Green River, Washington, Draft 2010 Data Report for the U.S. Army Corps of Engineers, Seattle District.
6. R2 Resource Consultants (R2). 2006. Juvenile salmonid use of lateral habitat in Middle Green River, Washington, final data report for the U.S. Army Corps of Engineers, Seattle District.
7. R2 Resource Consultants (R2). 2013. Middle Green R. Habitat, Large Woody Debris Monitoring
8. R2 Resource Consultants (R2) 2014. Zone 1 Nourishment Gravel Stability Green River, Washington 2011/2012 monitoring results
9. Topping, P. C. and J. H. Anderson, 2014. Green River Juvenile Salmonid Production Evaluation: 2013 Annual Report.

Lower Green

1. Gregersen, C. 2017. Draft 2014 Juvenile Salmonid Use of Aquatic Habitats in the Lower Green. King County Water and Land Resources Division. Seattle WA.
2. Lucchetti, G., K. Higgins, and J. Vanderhoof, 2014. A salmon-based classification to guide best management practices for agricultural waterways maintenance. King County Water and Land Resources Division, Seattle WA.
3. McCarthy, S., C. Gregersen, K. Akyuz, L. Brandt, and J. Koon. 2014. Reddington levee setback project year 1 monitoring report. Water and Land Resources Division, King County. Seattle, Washington

4. McCarthy, S., C. Gregersen, K. Akyuz, L. Brandt, and J. Koon. 2014. Reddington levee setback project year 1 monitoring report. Water and Land Resources Division, King County. Seattle, Washington
5. R2 Resource Consultants (R2). 2014. Lower Green/Duwamish River habitat Assessment.

Duwamish

1. Campbell, Lance. 2017. New Otolith Study by WDFW from 2016 CWM grant. Results likely available late spring.
2. Cordell, J., J. Toft, A. Gray, G. Ruggerone, and M. Cooksey. 2011. Functions of restored wetlands for juvenile salmon in an industrialized estuary. Ecological Engineering 37:343-353.
3. Cordell, J., J. Toft, M. Cooksey, and A. Gray. 2006. Fish Assemblages and Patterns of Chinook Salmon Abundance, Diet, and Growth at Restored Sites in the Duwamish River. In *2005 Juvenile Chinook Duwamish River Studies*. University of Washington, Seattle, WA.
4. David, A.T., P.A.L. Goertler, S.H. Munsch, B.R. Jones, C.A. Simenstad, J.D. Toft, J.R. Cordell, E.R. Howe, A.Gray, M.P. Hannam, W. Matsubu, and E.E. Morgan. 2016. Influences of Natural and Anthropogenic Factors and Tidal Restoration on Terrestrial Arthropod Assemblages in West Coast North American Estuarine Wetlands. Estuaries and Coasts, 39: 1491
5. ICF International, 2010. Duwamish River Navigation Maintenance Dredging FY 2010: Water Quality Monitoring and Salmonid Report. Final Report; Seattle WA.
6. King County 2013. *Draft*. Juvenile Chinook Migration, Growth and Habitat Use in the Lower Green and Duwamish Rivers and Elliot Bay Nearshore. King County Department of Natural Resources and Parks, Water and Land Resources Division, Seattle WA.
7. Meador, J. P. 2014. Do chemically contaminated river estuaries in Puget Sound (Washington, USA) affect the survival rate of hatchery-reared Chinook salmon? Canadian Journal of Fisheries and Aquatic Sciences 71:162-180.
8. Morely, S., J. Toft, and K. Hanson. 2012. Ecological Effects of Shoreline Armoring on Intertidal Habitats of a Puget Sound Urban Estuary. Estuaries and Coasts. Springerlink.com.
9. Oxborrow, B., J.R. Cordell, and J. Toft, 2016. Draft: Evaluation of Selected U.S. Army Corps of Engineers Habitat Restoration Projects, 2016. School of Aquatic and Fishery Sciences, University of Washington.
10. O'Neill, Sandra M., A. J. Carey, J.A. Lanksbury, L.A. Niewolny, G. Ylitalo, L. Johnson, and J.E. West, 2015. Toxic Contaminants in Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) migrating through estuary, nearshore and offshore habitats of Puget Sound.
11. Ostergaard, E., D. Clark, K. Minsch, S. Whiting, J. Stern, R. Hoff, B. Anderson, L. Johnston, L. Arber, and G. Blomberg. 2014. Duwamish Blueprint: Salmon Habitat in the Duwamish Transition Zone. Prepared by the Duwamish Blueprint Working Group for the WRIA 9 Watershed Ecosystem Forum. Seattle, WA.
12. Ruggerone, G. T. and E. Jeanes. 2004. Salmon utilization of restored off-channel habitats in the Duwamish Estuary, 2003. Draft. Prepared for Environmental Resource Section, U.S. Army Corps of Engineers, Seattle District. Prepared by Natural Resources Consultants, Inc. and R2 Consultants, Inc. Seattle, Washington
13. Ruggerone, G., T. Nelson, J. Hall, E. Jeanes, J. Cordell, J. Toft, M. Cooksey, and Ayesha Gray. 2006. 2005 Juvenile Chinook Duwamish River Studies. Habitat Utilization, Migration Timing, Growth, and Diet of Juvenile Chinook Salmon in the Duwamish River. Seattle, WA
14. Ruggerone, G. T. and E. C. Volk. 2004. Residence time and growth of natural and hatchery Chinook salmon in the Duwamish Estuary and Elliott Bay, Washington, based on otolith chemical and structural attributes. Report to Army Corps of Engineers, Seattle District and Port of Seattle.

15. Simenstad, C., C. Tanner, C. Crandell, J. White, J. Cordell. 2005. Challenges of habitat restoration in a heavily urbanized estuary: evaluating the investment. Journal of Coastal Research. 40:6-23.
16. Toft, Jason D. and J.R. Cordell, 2017. Densities of Juvenile Salmon at Restored Sites in the Duwamish River Estuary Transition Zone, 2016, School of Aquatic and Fishery Sciences, University of Washington.
17. U.S. Army Corps of Engineers, 2013. Duwamish River Fish Sampling Effort January-February 2013.

Nearshore

1. Beamer, E.M., W. T. Zackey, D. Marks, T. Teel, D. Kuligowski, and R. Henderson. 2013. Juvenile Chinook salmon rearing in small non-natal streams draining into the Whidbey Basin. Skagit River System Cooperative, LaConner, WA.
2. Duffy, E. J. and D. A. Beauchamp. 2011. Rapid growth in the early marine period improves the marine survival of Chinook salmon (*Oncorhynchus tshawytscha*) in Puget Sound, Washington. Canadian Journal of Fisheries and Aquatic Sciences 68:232-240.
3. Dethier, M.N., W.W. Raymond, A.N. McBride, J.D. Toft, J.R. Cordell, A.S. Ogston, S.M. Heerhartz, and H.D. Berry. 2016. Multiscale impacts of armoring on Salish Sea shorelines: Evidence for cumulative and threshold effects. Estuarine, Coastal and Shelf Science 175:106-117.
4. Dugan, J.E., Hubbard, D.M., Rodil, I.F., Revell, D.L. & Schroeter, S. (2008). Ecological effects of coastal armoring on sandy beaches. Mar. Ecol., 29, 160-170
5. Heerhartz, S.M., Dethier, M.N., Toft, J.D., Cordell, J.R., Ogston, A.S., 2014. Effects of shoreline armoring on beach wrack subsidies to the nearshore ecotone in an estuarine fjord. Estuary and. Coasts 37, 1256e1268. http://dx.doi.org/10.1007/s12237-013-9754-5 Publication: Multiscale impacts of armoring on Salish Sea shorelines: Evidence for cumulative and threshold effects.
6. Heerhartz, S.M., Toft, J.D., Cordell, J.R., Dethier, M.N., Ogston, A.S., 2015. Shoreline armoring in an estuary constrains wrack-associated invertebrate communities. Estuary and Coasts.
7. Heerhartz, S.M. 2013. Shoreline armoring disrupts marine-terrestrial connectivity across the nearshore ecotone. School of Aquatic and Fishery Sciences, University of Washington, PhD dissertation.
8. Higgins, K. F. 2014. WRIA 9 Marine Shoreline Monitoring Compliance Pilot Project, King County Department of Natural Resources. Seattle WA.
9. Munsch, S.H., J.R. Cordell, J.D. Toft, and E.E. Morgan. 2014. Effects of Seawalls and Piers on Fish Assemblages and Juvenile Salmon Feeding Behavior. North American Journal of Fisheries Management, 34:814-827
10. Munsch, S.H., J.R. Cordell, and J.D. Toft. 2015a. Effects of seawall armoring on juvenile Pacific salmon diets in an urban estuarine embayment. Marine Ecology Progress Series, Vol. 535: 213-229.
11. Munsch, S.H., J.R. Cordell, and J.D. Toft. 2015b. Effects of shoreline engineering on shallow subtidal fish and crab communities in an urban estuary: A comparison of armored shorelines and nourished beaches. Ecological Engineering, V 81, 312-320.
12. Munsch, S.H., J.R. Cordell, and J.D. Toft. Fine scale habitat use and behavior of a nearshore fish community: nursery functions, predation avoidance, and spatiotemporal habitat partitioning. Marine Ecology Progress Series, Vol 557: 1-15.
13. Rice, C.A. 2006. Effects of shoreline modification in northern Puget Sound: beach microclimate and embryo survival in summer spawning surf smelt (*Hypomesus pretiosus).* Estuaries and Coasts 29(1):63-71.
14. Sitck, K.C., A. Lindquist, and D. Lowry. 2014. 2012 Washington State Herring Stock Status Report. Washington Department of Natural Resources, Olympia WA.

15. Toft, J.D., J.R. Cordell, C.A. Simenstad, and L.A. Stamatiou. 2007. Fish distribution, abundance, and behavior along city shoreline types in Puget Sound. North American Journal of Fisheries Management 27: 465-480.
16. Toft, J.D., A.S. Ogston, S.M. Heerhartz, J.R. Cordell, E.E. Flemer. 2013. Ecological responses and physical stability of habitat enhancements along an urban armored shoreline. Ecological Engineering, 57, 97-108.
17. Toft, J.D., J.R. Cordell, and E.A. Armbrust. 2014. Shoreline armoring impacts and beach restoration effectiveness vary with elevation. Northwest Science 88:367-375