Final

WRIA 9 Chinook Salmon Research Framework

Identifying Key Research Questions about Chinook Salmon Life Histories and Habitat Use in the Middle and Lower Green River, Duwamish Waterway, and Marine Nearshore Areas

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SUMMARY

The Water Resource Inventory Area 9 (WRIA 9) Technical Committee needed a synthesis of technical information about Green River Chinook salmon and their habitat to determine research priorities for development of a salmon habitat plan to recover the WRIA 9 Chinook population. The WRIA 9 Chinook Salmon Research Framework was undertaken to provide guidance about which research efforts should be implemented in the Green/Duwamish and Central Puget Sound Watershed to inform recovery planning. As part of the framework, a conceptual model of how Chinook salmon appear to utilize salmon habitat in WRIA 9 was developed from past and ongoing research in order to provide a basis for developing and testing research hypotheses. The model identifies juvenile growth as a key determinant of survival and spatial distribution and diversity of habitat types as a key determinant of Chinook life history diversity in order to examine feasibility and to facilitate implementation. The framework also identified several key monitoring projects that are needed to evaluate salmon recovery and effectiveness of habitat conservation activities in WRIA 9.

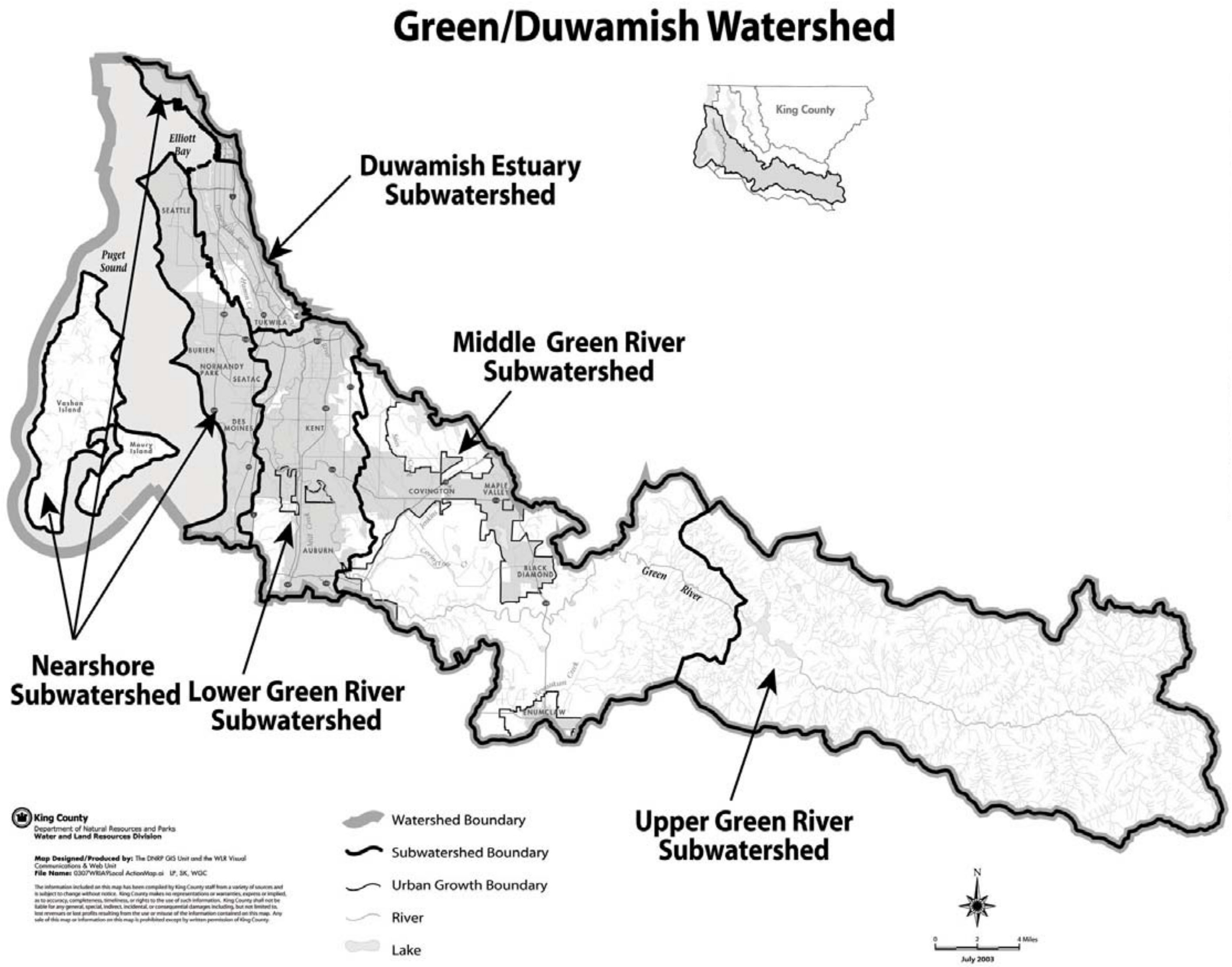
INTRODUCTION

Early in the salmon recovery planning process, the Water Resource Inventory Area 9 (WRIA 9) Technical Committee needed to make decisions about funding research projects to support development of a salmon habitat plan to recover the WRIA 9 Chinook population. While the initial Limiting Factors report (Kerwin and Nelson 2000) listed data gaps, there had been no attempt to evaluate which of these gaps was most important to address in order to develop a meaningful habitat plan. To remedy that situation, the WRIA 9 Chinook Salmon Research Framework (framework) was undertaken with the intent that the framework would provide guidance about which research efforts should be implemented in the Green/Duwamish and Central Puget Sound Watershed (Figure 1) to inform recovery planning. Development of the framework relied upon synthesis of existing scientific information to provide hypotheses about how WRIA 9 Chinook salmon use the system and to identify pertinent knowledge gaps. Development of the framework also contributed to the design of studies conducted in 2003.

The framework is based upon the use of scientific information, specifically, data and analysis regarding Chinook salmon in the Green River system and in other areas, where applicable. The use of science allows identification of the most effective strategies to address issues facing Chinook salmon. This identification then targets limited funding in those areas that can contribute the most to salmon recovery.

Originally, the framework was based upon the survival of naturally-produced juvenile Chinook salmon in the lower Green River (RM 11 to 32), Duwamish Waterway (RM 0 to 11), and the Puget Sound nearshore. As the project evolved, the scope of the effort broadened considerably to include all life stages of Chinook salmon within WRIA 9, including the middle Green River (RM 64.5 to 32), and to examine all parameters of viable salmon populations. One way to describe all Chinook life histories in WRIA 9 was to develop a conceptual model that synthesizes information on how Chinook salmon use habitats in WRIA 9 (see the next section). The appendix of this report provides some of the research questions and background information relevant to the initial objective of assessing juvenile salmon survival in WRIA 9.

Figure 1. The Green/Duwamish and Central Puget Sound Watershed (WRIA 9).



The framework consists of four main sections. The first section is the conceptual model, which serves as a structure for organizing information about how and when Chinook utilize habitat in the Green River system. The model also identifies significant gaps in our knowledge. The second section of the framework lists prioritized research hypotheses and sub-hypotheses that need to be answered. Research hypotheses were not developed for the upper Green River watershed, as this area is currently inaccessible to anadromous salmon (research priorities are expected to be developed when fish passage becomes possible). The prioritized research list was used to develop planning-level research scopes (section three), which will be used as a starting point to choose and develop research project plans in the future. Section four is a brief overview of ongoing monitoring activities that need to be continued to assist WRIA 9 with evaluating and tracking Chinook salmon recovery.

The framework will be used by the WRIA 9 Technical Committee to support and fund research in WRIA 9. Additionally, the framework provides the basis for other Technical Committee and WRIA activities, including development of the Strategic Assessment and the identification of Functional Linkages and conservation hypotheses.

CONCEPTUAL MODEL OF NATURAL GREEN RIVER CHINOOK SALMON

A watershed-specific model of Chinook salmon life history can be a useful tool to help formulate research ideas and to assist in recovery planning (Figure 2). This model is proposed as a foundation to assist in strategic assessment and planning of conservation efforts, noting what we know, what we think we know, and what we don't know about Chinook use of the Green/Duwamish watershed. The model provides guidance for developing research questions and as a template to augment with future research findings. This working model will likely be modified as new information is obtained. In presenting this model we will first discuss life history diversity of Green River Chinook salmon, specifically the timing and general areas used by fish with various life history trajectories. Then, we focus on the habitat utilized by juvenile Chinook salmon as they pass through their life cycle in the Green/Duwamish River, WRIA 9 nearshore marine areas, and Puget Sound offshore areas.

Information Used to Develop the WRIA 9 Conceptual Model

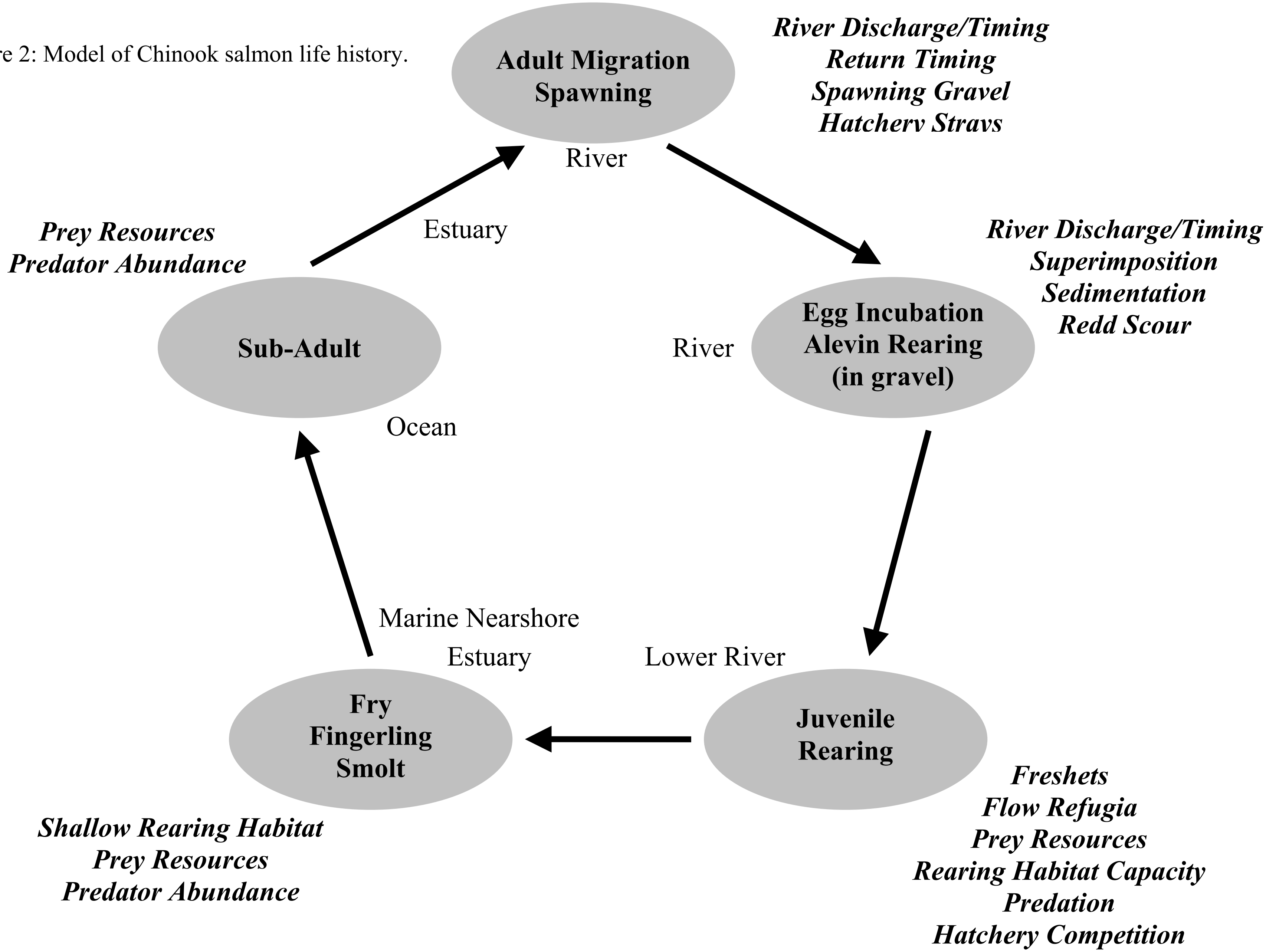
The majority of the information in the conceptual model is from research studies in the Green/Duwamish River system. It is recognized that information gathered in other watersheds is essential for comparison to those data gathered in WRIA 9. Furthermore, collaboration with research in other watersheds will be useful to address some key questions about Chinook, particularly in the marine nearshore.

Basic Concepts of the Conceptual Model

This document refers to natural and hatchery salmon. These are defined as:
Naturally-Produced Chinook ("natural"): Progeny of salmon that spawned in the natural riverine environment, including hatchery fish that strayed to the spawning grounds. Natural Chinook salmon differ from wild or native Chinook salmon in that wild salmon infers little or no interbreeding with hatchery salmon. Significant interbreeding of hatchery and natural salmon has occurred in the Green River since the early 1900s, therefore all Chinook salmon are considered natural rather than wild.

Hatchery Chinook: Fish that are spawned, incubated and temporarily reared at the hatchery or other controlled, artificial facilities (e.g., rearing ponds).

Figure 2: Model of Chinook salmon life history.



This document also refers to life history types and trajectories. While there are no formal definitions for these terms, in this document "life history type" refers to the two general rearing patterns that Chinook can exhibit: ocean-type and stream-type. Ocean-type Chinook spend a limited amount of time (i.e., weeks to months) rearing in freshwater, while stream-type fish spend approximately one year rearing in freshwater habitats. Life history types are believed to be largely influenced by genetic characteristics, but environmental conditions can influence year-to-year variations. "Life history trajectories" are variations in fish behavior (around the two general life history types) largely based on responses to environmental conditions and habitat availability. Trajectories are defined by fish size, duration, and season in which fish use habitats along the migration corridor, including the upper watershed, lower watershed, estuary, and marine waters.

Viable Salmonid Populations

NOAA Fisheries developed the Viable Salmonid Population (VSP) concept as guidance for regional conservation efforts to restore the viability of salmon populations. This guidance has been adopted by WRIA 9 and the conceptual model and research hypotheses address these concepts at the population level within the Puget Sound Evolutionarily Significant Unit (ESU). A viable salmonid population is defined as "an independent population of any Pacific salmonid (genus *Oncorhynchus*) that has a negligible risk of extinction due to threats from demographic variation, local environmental variation, and genetic changes over a 100-year time frame (McElhany et al. 2000)." Four population attributes are used to evaluate population viability:

- AbundanceProductivitySpatial Structure
- DiversityWhile these attributes each have particular aspects of a salmon

population associated with them, there is overlap in the types of information used to assess population status for each attribute.

Abundance. Abundance is a measure of the number of fish at various life history stages. Abundance is important to ensure that a population can persist when faced with environmental fluctuations and anthropogenic alterations to the environment. A population should also be large enough to maintain genetic diversity over the long term and to provide ecological functions (McElhany et al. 2000).

Productivity. Productivity measures the ability of the population to replace itself, and is linked to survival of both juveniles and adults in the river, estuary, marine nearshore and ocean environments. Habitat quality and population size have major effects on productivity.[1] For adults, reproductive success is an important indication of productivity, typically measured as the number of fry per spawner. For juveniles, growth and fish size often serve as proxies for productivity and survival. Larger juvenile salmon tend to have higher probability of survival to adulthood (Parker 1971; Juanes 1994; Koenings et al. 1993), although few data are available for juvenile Chinook salmon to directly test this hypothesis (Simenstad and Wissmar 1984). However, analysis of coded-wire-tagged (CWT) subyearling Chinook salmon released into Puget Sound streams indicated greater growth during the first year at sea (primarily Puget Sound and Strait of Georgia) was correlated with higher survival (Ruggerone and Goetz 2004).

Habitat provides the opportunity for salmon to grow. Factors that cause fish to move downstream prematurely (e.g., low habitat capacity, peak flows at fry life stage, low prey availability, and high fish densities) likely lower the potential for survival, although it is possible that high quality habitat down the migration pathway can compensate for low upstream habitat quantity and quality. Alternatively, habitat in freshwater areas that allow fish to rear and grow before reaching marine waters may help maintain survival during periods of unfavorable ocean conditions, such as that which has occurred during the past 20 years (Ruggerone and Goetz 2004). Fish are opportunistic in many behaviors and a diversity of habitat types along the migration path can provide opportunities for a variety of individuals. Ultimately, the lives of salmon are relatively simple: grow rapidly, avoid being eaten, and return to the spawning grounds to successfully reproduce. The key goal for resource managers, therefore, is to provide the opportunity for salmon to grow rapidly while avoiding predators. A central theme of the conceptual model is growth rate, and its link to survival and productivity.

Spatial Structure. Spatial structure is the geographic distribution of individuals in a population and the factors that affect that distribution. Although the spatial distribution of a population is influenced by many factors, it is heavily dependent upon the quantity, quality, and distribution of

[1] Productivity is sometimes defined as survival when population size is exceptionally small and has no effect on survival. This is useful when trying to distinguish productivity (habitat quality) from abundance (habitat capacity). However, most indices of productivity are measured at various population sizes, e.g., egg-to-fry survival, smolt-to-adult survival, adult return per spawner, etc.

accessible habitat. Therefore, spatial structure can be thought of as the differential use of rearing and spawning habitats in space and time. This difference in habitat use reduces the vulnerability of the population to common environmental fluctuations (e.g., temperatures, flow) and catastrophic environmental risks (e.g., landslides, major climate change).

Diversity. Diversity of life history trajectories, measured primarily as the differences in timing and use of various habitats, have evolved over time in response to available habitat and a changing environment. Diversity is an important component of Chinook populations because it enables them to utilize a variety of habitats and it provides the species with greater resilience to changes in climate and habitat. Chinook salmon life history types and trajectories are influenced by both genetic characteristics and fluctuating environmental conditions. The genetic component of life history trajectories in a population can be expressed as the long-term mean of a pattern (e.g., mean percentage of ocean- versus stream-type juveniles, spring versus fall adult run timing, and mean age at maturation, etc.). Fluctuating environmental conditions produce annual deviations from these typical life history trajectories and it is assumed that greater habitat diversity provides the opportunity for more diverse life history trajectories to be exhibited. While genetic characteristics are important in determining life history diversity, the linkage between the genetic composition of a population (genotype) and specific life history trajectories is not well understood and is further complicated by environmental factors and interactions with hatchery stocks.

Existing life history diversity in the Green/Duwamish River or any other Pacific Northwest basin may or may not reflect the diversity that was originally present prior to man's intensive harvest and habitat modification that began in the late 1800s. However, it is probable that the existing stocks retain the potential to increase life history diversity in response to greater habitat diversity. Salmon show evidence of a substantial range within each life history category defined by biologists. It is probable that this range would allow some individuals to take advantage of new habitat types, thereby expanding the life history types we recognize. However, it should be noted that quantitative evaluations of juvenile Chinook life history trajectories are lacking in all but a few watersheds. Also, each watershed should not be expected to support all potential life history trajectories because life history patterns represent adaptations to watershed-specific characteristics.

Life History Diversity

In Chinook, diversity is often expressed in 1) the migration and spawn timing of returning adults, 2) the age composition of adults, and 3) the residence time and body size of juveniles in different parts of the watershed (e.g., river, estuary and nearshore habitats). For this conceptual model, we focus primarily on adult migration timing and juvenile residence time and size in various habitats. A variety of Chinook life history trajectories may have historically existed in the Green River watershed. The existing population may have the potential for life history trajectories that are not evident because habitat types have been reduced or research has yet to identify more subtle patterns. The interactions between hatchery and natural Chinook salmon in the Green/Duwamish is an important issue; however, the framework focuses on the ecological effects of such interactions as they relate to habitat rather than the genetic effects of interbreeding on natural Chinook salmon.

Adult Migration Timing

Historically, the Green River watershed, encompassing what is now the Green, White, and Lake Washington/Cedar River watersheds, supported both spring and summer/fall runs of Chinook salmon. In the past, spring Chinook primarily occurred in the White River, which now runs into the Puyallup River rather than the Green River. The upper Green River may also have supported a spring run of Chinook salmon, based on the timing of egg take at the Green River eyeing station (near RM 61) during 1911-1920 (Grette and Salo 1986). However, records also show that the Washington Department of Fisheries planted spring Chinook from the Columbia River into the Green during this time period. The spring run of Chinook salmon to the Green River is now considered extinct (Nehlsen et al. 1991, WDFW/WWTIT 1994, NMFS 2003), but a spring run continues to return to the White River (although that river is now part of the Puyallup basin).

Historically, adult Chinook salmon entered the estuary from approximately May though early November (WDF 1975), allowing sufficient time and flow conditions for fish to gain access to specific spawning grounds. In the early 1900s, access to upper watershed areas where spring Chinook runs might have spawned was blocked or altered (e.g., diversion/channel migration of the White River in 1906),[2] and the self-sustained run of spring Chinook salmon was essentially

[2] Access to the upper Green River was blocked by the Tacoma Diversion Dam (RM 61) in 1913 and access to the Lake Washington/Cedar River watershed was blocked in 1916. Spring Chinook salmon use of the Lake Washington drainage is unknown.

eliminated from the Green River basin[3]. Currently, the Green River watershed supports a summer/fall Chinook run with adults beginning to enter the Duwamish River in mid-June, peaking in August and continuing to enter the river through November[4].

Juvenile Residence Time

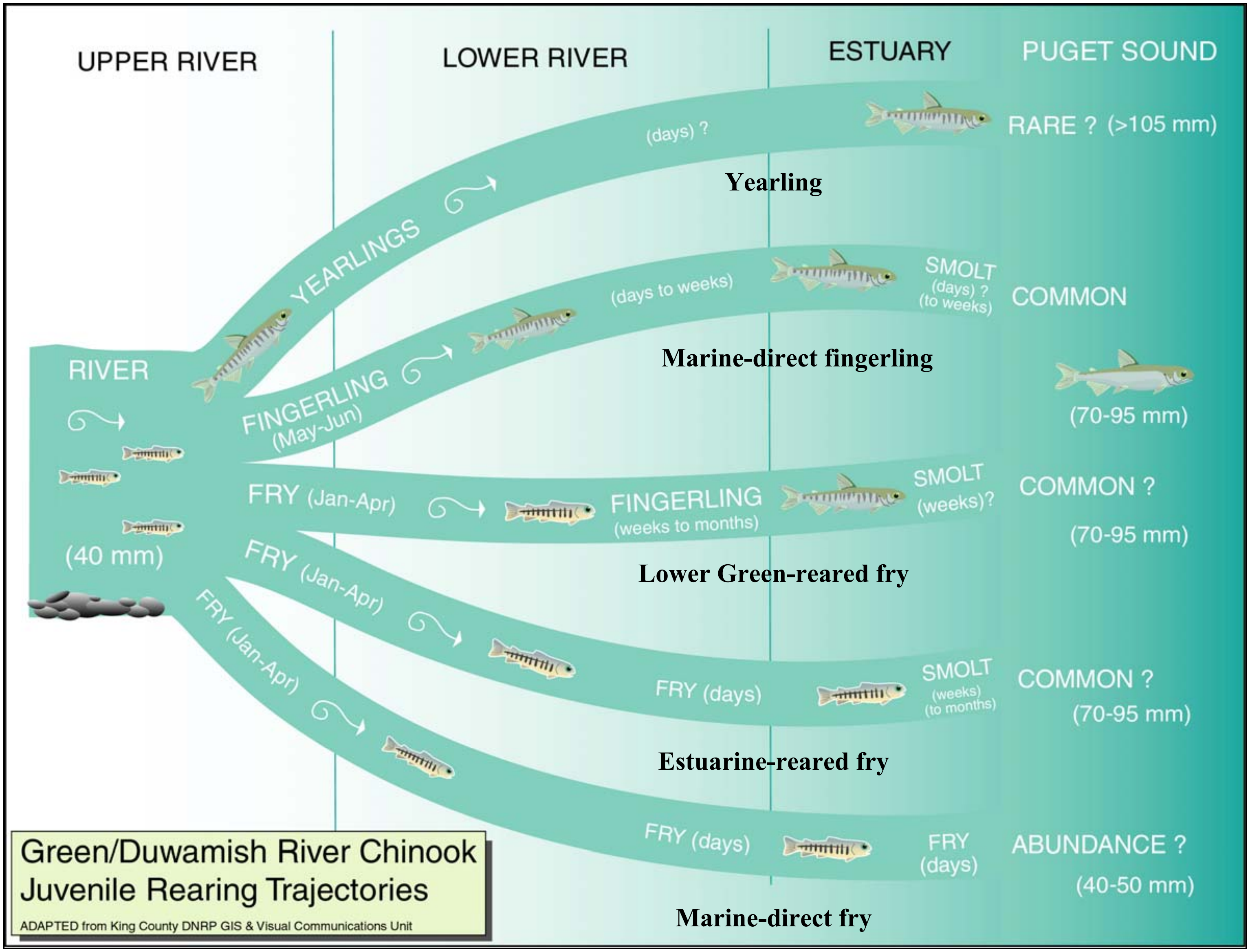
Chinook salmon populations exhibit considerable diversity in the duration of time that juveniles spend in freshwater and estuarine habitats. This diversity represents the upper end of a continuum among Pacific salmon that begins with pink salmon, which spend little time in freshwater and estuaries and therefore express little juvenile diversity. Residence times of Chinook salmon in freshwater and estuarine habitats may be related to environmental conditions and/or to genetic traits of the population (Healey 1991). Five potential Chinook rearing trajectories are shown in Figure 3, but the most common trajectories currently in the Green River appear to be 1) fry that migrate soon (days to weeks) after emergence from the spawning grounds in the middle Green River, then rear in the lower river and/or the Duwamish estuary (up to three months) before entering Puget Sound (lower Green and estuarine-reared fry; Figure 3), and 2) marine-direct fingerlings that rear near the spawning grounds for approximately three to four months before migrating relatively quickly (possibly weeks or days) through the estuary to Puget Sound (Figure 3). These trajectories are based on the recent sampling (years 2001-2003) of emigrating juveniles at RM 34, RM 13, and in the Duwamish estuary (Nelson et al. 2004). Recent and past sampling in the estuary indicated a decline in juvenile abundance (mixed hatchery and natural stocks) during late June and July.

After leaving the middle Green River subwatershed, fry and fingerling migrants may be further classified into various rearing trajectories depending on residence time in lower river, estuarine, and nearshore marine habitats. In some watersheds, some fry move quickly to and through the estuary (marine-direct fry in Figure 3), but this pattern appears to be uncommon in most watersheds (Healey 1991). Survival of fry that enter marine waters after little or no rearing in freshwater has been hypothesized to be very low (Reimers 1971), but few studies have

[3] Spring Chinook salmon are occasionally found in the Green River, but it does not appear that these fish constitute a self-sustained run.

[4] Historical data suggest the return timing of adult hatchery Chinook has occurred significantly earlier in recent decades, largely due to past hatchery practices that spawned a greater proportion of early arriving fish (Miller and Stauffer 1967). The date at which 50% of the hatchery run returned to the Green River Hatchery decreased from October 20 in 1944 to October 5 in 1965. Timing of naturally produced Chinook returning to the spawning grounds has not been evaluated, but it likely has been altered because many hatchery fish spawn in the river.

Figure 3. Green/Duwamish River juvenile Chinook salmon rearing trajectories.



thoroughly measured survival of this trajectory while accounting for age (days) of the migrants[5]. Early entry of Green River fry into Puget Sound is known to occur, but its relative abundance, contribution to adult returns, and whether or not it is an active or passive migration are not known (see additional discussion below). Presently, little information is available to evaluate relative abundance of the Chinook rearing trajectories shown in Figure 3, largely because information on the residence time of juveniles in the lower river and estuary has not been quantified. However, ongoing field studies by King County, the U.S. Army Corps of Engineers (ACOE), and the Port of Seattle will help identify these trajectories, in part, because most hatchery salmon are now visually marked for easy identification. Also, an otolith chemistry/daily growth increment technique is being applied to individual juvenile Chinook salmon captured in the Duwamish estuary and Elliott Bay in an attempt to quantify days spent in freshwater versus estuarine waters (Volk and Ruggerone 2004).

It has been hypothesized that the Duwamish no longer supports an abundance of estuarine-reared fry (Figure 3) because much estuarine habitat has been lost or degraded. It has also been hypothesized that nearshore marine rearing areas may compensate for lost rearing opportunities in the estuary, but this has not been evaluated. However, as discussed below, recent data suggest some natural fry arrive in the upper Duwamish estuary in winter and apparently rear there for weeks or months (Nelson et al. 2004). Still, the relative abundance of various life history trajectories and their contribution to adult returns in the Green River and in other Puget Sound watersheds with less degraded estuaries are not well-known.

The yearling or stream-type Chinook salmon life history trajectory (i.e., juveniles that overwinter in the watershed before seaward migration) is a life history type that appears to be less common in the Green/Duwamish watershed (Grette and Salo 1986). Numerous hatchery yearlings have been released from Icy Creek ponds[6] and yearlings have also been found in Mill Creek. In addition, during early May 2003 a relatively large number of natural yearling Chinook salmon were captured in the 1st Avenue Bridge off-channel area (Ruggerone and Jeanes 2004) and some were captured in the mainstem (Nelson et al. 2004). These unmarked fish were smaller than

[5] These small fry are relatively young compared with fingerling migrants, therefore survival from this young stage (fry) would be expected to be relatively low. Thus, studies need to identify which rearing trajectories contribute to adult production.
[6] Stream-type Chinook salmon are often produced by spring-run Chinook salmon, although they can also be produced by summer/fall run fish. The Soos Creek Hatchery releases numerous yearling Chinook salmon from Icy Creek ponds.

marked hatchery yearlings (~105 v. 120 mm). It is unlikely that these fish originated from fry plants upstream of Howard Hansen Dam since most planted Chinook were fin-clipped by the Muckleshoot tribal hatchery (D. Moore, Muckleshoot Indian Tribe [MIT], pers. comm.). A likely explanation is that the cooler temperatures in 2002 led to reduced growth and greater numbers of overwintering juvenile Chinook salmon. The effect of temperature on age of seaward migration is commonly observed in sockeye and coho salmon in Alaska (most Alaskan Chinook migrate as yearlings). While it is also possible that these fish could have moved into the Duwamish River from Puget Sound, the fish described above were much smaller than other Chinook that have been occasionally captured in the lower estuary during the winter after apparently moving in from Puget Sound (T. Nelson, King County, pers. comm.). More yearling Chinook likely inhabited the Green River watershed when access to the upper watershed, especially the White River, was available and the potential for extended rearing in the river was greater than under current conditions (e.g., greater availability of side channel and off-channel habitats).

The White River produces spring run Chinook salmon and these fish often produce yearling smolts. Also, water temperature in the upper watershed is typically colder, potentially leading to more fish that overwinter in the watershed. Yearling Chinook smolts, which are relatively large, likely emigrated to marine waters during early spring (prior to most subyearlings) and they probably spent relatively little time in the estuary (Healey 1991, Goetz and Ruggerone, unpublished analysis). Preliminary analyses of recapture rates of salmonids in off-channel habitats in the Duwamish during 2002 indicated that yearling salmonids spent relatively little time in estuarine habitats (Goetz and Ruggerone, unpublished analysis). Conceivably, the frequency of naturally produced stream-type Chinook salmon could increase after the ACOE installs a fish passage system in Howard Hanson Dam and Chinook runs are re-established in the upper Green River. However, growth of Chinook salmon fry in Howard Hanson Reservoir appears to be great (Paul Hickey, City of Tacoma, pers. comm.) and may not lead to a high percentage of overwintering fish after juvenile fish passage structures are installed.

Both subyearling and yearling Chinook salmon utilize nearshore marine waters after leaving the estuary. In general, smaller subyearling Chinook salmon appear to spend more time in nearshore habitats than larger subyearlings and yearling Chinook salmon (Healey 1991). In Elliott Bay, abundance of natural subyearling Chinook salmon typically peaked in July, but some fish remained in nearshore waters through at least September (Nelson et al. 2004). Salmon typically move from nearshore to near-surface offshore waters of Puget Sound as they feed and grow. Many yearlings move out of Puget Sound and into the North Pacific Ocean before late summer, whereas most subyearlings appear to remain in Puget Sound and the Strait of Georgia until fall (Healey 1991).

Overall, there is a general idea about the types of life history trajectories expressed by Green River Chinook salmon, however, their abundance and contribution to adult returns is poorly understood.

Chinook Use Of Habitat Through The Salmon Life Cycle

Habitat types utilized by Chinook salmon in the Green/Duwamish River and Central Puget Sound varies by life history stage, e.g., migrating adults, spawning, egg incubation, juvenile emergence, juvenile migration, and juvenile rearing. In some cases, each of these life history stages may be further broken into life history trajectories (e.g., fry, fingerling) or watershed areas (e.g., lower Green River, Duwamish River) to further illustrate differences in habitat use among life stages. While there is much general knowledge about how Chinook interact with nearshore and freshwater habitats, their ability to opportunistically adapt to a variety of river and nearshore habitats makes it important to validate these general concepts in WRIA 9 where WRIA specific information is not available. In addition, there are several instances where observations about habitat use and behavior come from personal observations rather than quantitative analyses. While useful, documentation and studies of habitat use and behavior will be important to confirm these general observations and to clarify how Chinook use the Green River and Puget Sound.

Adult Migration

Maturing Green River Chinook salmon migrate south along coastal waters of British Columbia and enter Puget Sound beginning in approximately June and July. Feeding during this period (primarily fish) is intense and growth rate is typically rapid. However, upon approach to the natal river, Chinook salmon (and other salmon) stop feeding and physiologically prepare for transition back into fresh water, the more turbulent stream environment, and physical competition for mates.

After entering the Duwamish River, many early migrating Chinook salmon hold in the lower river area (Duwamish to Kent area) until approximately mid-September, depending on temperature and flow (T. Cropp, Washington Department of Fish and Wildlife [WDFW], pers. comm.). Holding may occur for weeks in pools (e.g., Trimaran site (RM 6.5)[7], Turning Basin (RM 5.5) or river areas with low velocity. Water temperature, which is influenced by air temperature and long water residence time (related to flow), may reach stressful levels (22-25°C) during this holding period (Caldwell 1994, Kerwin and Nelson 2000), but little information is available on the physiological condition of migrating Chinook salmon in recent years. The environmental conditions (i.e., water temperature and flow) adults face while migrating has not been well studied and remains somewhat of an uncertainty. Initial movement of most fish on to the spawning grounds typically coincides with a freshet (autumn rain storms or reservoir releases).

Adult Spawning

Habitat supporting the spawning and egg-to-fry life stages has perhaps the most influential effect on population viability parameters (i.e., abundance, productivity, diversity, and spatial distribution). Distance between spawning areas contributes to reproductive isolation and is therefore an important factor contributing to genetic and life history diversity. Spawning location also establishes the suite of potential rearing habitats available to progeny as they move seaward. The spawning and embryo incubation period may be the most sensitive life stage to habitat disturbances because there is little opportunity to seek alternative habitats. In contrast, juvenile salmon have the ability to migrate and seek out more suitable habitats that might be available.

Mainstem spawning in the Green River occurs between RM 24 and 61. Additional spawning occurs in Soos Creek (primarily RM 0.5-10 and some tributaries) and Newaukum Creek (RM 0-10). There is limited spawning in Burns and Covington creeks. The Soos Creek population is largely maintained by numerous strays and fish released from the Soos Creek Hatchery. Genetic (allozyme) data indicate natural Newaukum Creek and Soos Creek hatchery stocks are similar (A. Marshall, WDFW, pers. comm.), but insufficient data have been collected from mainstem and other tributary spawners to determine whether they represent discreet stocks or one common

[7] Slight differences in river miles exist for the Duwamish/Green watershed depending on the map that is used.

stock. Given the apparently high stray rates in the Green River between the hatchery and natural spawning areas (avg. ~56% hatchery fish on spawning grounds)[8], it is likely that the genetic difference is small. (If distinct populations were detected, it would be desirable to manage the individual populations to ensure their reproductive success because each stock would represent unique genetic information within the Puget Sound Evolutionary Significant Unit.)

Peak spawning typically occurs in early October, although some Chinook spawn from early September through November. Spawning information, including areas of high density, is documented annually by WDFW. Most females spawn soon after reaching the spawning grounds in the Green River. Time of spawning is important because it determines, along with water temperature, the date of embryo hatching and emergence of fry from gravels. Average spawn timing has been hypothesized to be influenced by the date when prey, such as chironomids (midges), become available for juveniles (Miller and Brannon 1982). The variability in spawn timing may reflect tradeoffs between early emergence when prey resources may be low but more time is available for growth versus later emergence when prey resources are more abundant, but less time is available for growth. Tradeoffs in growth and survival in relation to early versus late emergence timing have not been documented and are largely hypothetical. However, this concept seems to explain much of the variation that is apparent in spawn timing of undisturbed populations. Relationships between spawning timing and emergence timing have not been well studied on the Green River.

Spawning Chinook commonly use areas with gravel substrate (~1.3-10 cm), subsurface water flow, little sand or silt, adequate water depth to cover most or all of the adult fish (i.e., >25 cm depth, depending on fish size), adequate velocity (range: ~0.3-1.1 m/s), adequate stream area to dig a redd (~2.5-10 m^2), and declining water temperatures (<13.9°C; Bjornn and Reiser 1991, Healey 1991). Significant redd superimposition can occur in some reaches of the mainstem Green River that are especially attractive to spawners, including high-density spawning areas

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[8] NMFS (2003) stated the percentage of hatchery fish on the Green River spawning grounds averaged 70% during the recent 5 year period (range: 0-100%). NMFS also estimated that only 547 natural fish spawned in the river each year (geometric mean). The NMFS estimate of straying is higher than that estimated by WDFW who used coded-wire-tag expansions (56%, T. Cropp, pers. comm..). The variance about these estimates is very high. The estimated number of natural spawners by NMFS appears too low, especially given that the recent mark recapture study by WDFW found that the earlier escapement enumeration method in the Green River under counted spawners by approximately 50%. WDFW also estimated that 40% of the fish returning to the hatchery had originated from naturally-spawning parents. Thus, stock composition on the spawning grounds and the hatchery are approximately the same. This suggests the natural and hatchery stocks are likely homogeneous.

below Flaming Geyser Park and near the Tacoma pipeline (T. Cropp, WDFW, pers. comm.). The high concentration of spawners near the pipeline probably reflects the presence of high quality gravel and its proximity to the upstream migration barrier. During spawning Chinook typically modify gravel within the redd by changing the stream bed profile and removing fine sediment as they move large quantities of gravel with their tail. Land slides have occurred in the Green River gorge and near Flaming Geyser Park (1997) and have contributed excessive fine sediment to the river; however, sediment quantities appear to have returned to pre-slide conditions and abundance of spawners was not reduced in these areas. Areas of spawning gravel are not abundant in the Green River (T. Cropp, WDFW, pers. comm.) and it is likely that blockage of gravel transport by dams has reduced gravel in spawning areas. Plans have been made to add gravel to spawning areas in the upper reaches of the middle Green River.

Salmon actively seek patches of spawning gravel, which are often near pool tail-outs or at the heads of riffles. Chinook redds may be constructed near the stream bank or near mid-channel, depending on size characteristics of the stream and stream flow conditions. In the Green River, significant spawning occurs in pool tail outs and along large broad riffles. Somewhat greater numbers of Chinook appear to spawn in the outer two thirds of the river channel compared with the thalweg area (T. Cropp, WDFW, pers. comm.), but this pattern has not been quantified. Low flows during the fall may influence the percentage of fish spawning near the thalweg (i.e., increase), but flows related to reservoir releases do not typically vary significantly from year-to-year during the spawning period. Therefore the percentage of adults spawning in the thalweg probably does not vary significantly from year to year. However, it is uncertain how redds established under low flow conditions may be affected by moderate to high flows in the winter.

Larger salmon, such as fall Chinook (typical redd size: 5 m^2), require greater spawning area per fish than smaller salmon such as coho (2.8 m^2). Once a spawning site is selected, the female digs the nest and, in doing so, much of the fine material is carried downstream. Removal of fine material from the spawning gravel allows oxygen-rich water to flow across the incubating embryos and also removes metabolic wastes from the redd. Adequate oxygen supply (temporary reductions no less than 5 mg/l), and therefore subsurface flow, is especially important to Chinook salmon because their eggs are large compared with other salmon species. Large eggs equate to small-surface-to-volume ratio and presumably greater sensitivity to reduced oxygen. Thus, Chinook salmon tend to survive best in spawning areas with relatively low silt and relatively high oxygen concentrations. Most spawning areas in the Green River basin appear to have relatively low levels of silt (T. Cropp, WDFW, pers. comm.), but sedimentation levels have not been quantified.

Spawning habitat is perhaps the most critical area of the watershed, as it influences the highly sensitive and immobile life stages (eggs and alevins). As such, there are several questions about spawning habitat quantity, quality, and spatial distribution that should be examined in more detail. Most of the current understanding stems from WDFW's annual redd surveys and not direct study of spawning habitat itself. Relationships between spawning habitat and egg-to-fry survival and spawning locations and river flows (e.g., scour, downstream displacement of emerging fry) in the Green River are also not well understood (Seiler et al. 2002).

Egg Incubation and Hatching

The embryo and alevin (post-hatch larvae in the gravel) stages are generally subject to high mortality compared with other life stages, largely due to sedimentation and scouring of the spawning redds. Scouring is related to high stream flow, whereas sedimentation is related to land use development and geologic characteristics of the watershed. Egg to emergence mortality rates may range from 40-100% (Healey 1991) and are commonly within the upper end of this range. In 2000, Seiler et al. (2002) estimated egg-to-migrant mortality to be 92.7% in the Green River and 96.2% in Soos Creek. The somewhat higher mortality in Soos Creek was believed to be related to the large number of hatchery Chinook salmon passed upstream and subsequent superimposition of redds. However, estimates of egg-to-fry survival are also sensitive to error in the estimate of spawning escapement. No information is available for other spawning areas, such as Newaukum Creek, and downstream of RM 34.5. Sedimentation of redds in the Green River does not appear to be a significant source of mortality (T. Cropp, WDFW, pers. comm.), but this has not been systematically evaluated. Dams often moderate peak winter flows, thereby reducing scour potential because scour typically increases exponentially with flow. However, this important factor of salmon survival has not been field-tested in the Green River and there is concern that longer duration of moderately high flows may lead to scouring of redds (Kerwin and Nelson 2000).

Juvenile Emergence

Embryo development and fry emergence timing are influenced by water temperature, and in general, fry emergence occurs at a time when prey availability and duration of the growing season allows adequate survival. Thus, spawn timing, embryo incubation, and emergence timing are co-evolved characteristics of salmon populations. Natural fluctuations in weather can influence water temperature and emergence timing, which presumably influence year class strength. Reservoirs, such as those behind Howard Hanson Dam and the relatively small Tacoma Diversion Dam, can alter the temperature regime during incubation and fry rearing periods, and therefore may influence growth. However, Howard Hansen Reservoir (RM 64.5) and the small reservoir behind the Tacoma Diversion Dam (RM 61) are largely run-of-the-river from mid-November through mid-February (F. Goetz, ACOE, pers. comm.), so water temperature would not be altered during this period. Some alteration of water temperate may occur during the initial embryo incubation period (late September and October) and after mid-February, however water temperature would likely return to normal levels within a few miles of the Tacoma Diversion Dam.

Spawn timing of the hatchery stock has shifted earlier over the years and presumably this has led to early spawning of the natural stock because stray rates are high. Earlier spawn timing could lead to earlier emergence timing because time of emergence is dependent on cumulative water temperature.

Initial Juvenile Rearing and Migration

Seaward migration timing of subyearling Chinook salmon from the spawning reaches of Puget Sound watersheds tends to be bimodal. Some Chinook salmon fry begin moving downstream soon after emergence (typically the majority), whereas others remain upriver to rear in areas closer to the spawning grounds (Healey 1991, Seiler et al. 2002, Nelson et al. 2004). Often the migration of these two groups is separated by a period (~1 month) of relatively few migrants.

In the Green River during 2000, approximately 68% of the juvenile Chinook sampled at RM 34.5 migrated during January 1 to April 15 ("fry migrants"), whereas 32% migrated during April 16 to July 13 ("fingerling migrants") (Seiler et al. 2002). Peak migration of fry typically occurs in early March, followed by few fish migrating during late March through April, and then fingerlings migrating May through July. Size of "fry migrants" was approximately 35-45 mm, whereas size of the later migrating "fingerling migrants" increased over time from 46 mm to 93 mm. Nelson et al. (2004) provides additional data for 2001-2003.

Downstream movement of fry migrants (ocean-type or summer/fall Chinook) from the spawning and incubation areas may be dependent on a variety of factors, including quantity of available habitat (capacity), interactions between individual fish, prey availability, and water flow that affects habitat quantity. There is concern that the lack of edge habitat and the river flows may force some small fish downstream (Nelson et al. 2004). Downstream displacement may also be affected by the percentage of the parent population spawning near the river thalweg. Some researchers have speculated that the downstream migrations are a dispersal mechanism to reduce competition for space and food (Healey 1991). Appropriate low-velocity rearing habitat changes in quantity and location with changes in river discharge. Some modeling of the relationship between flow and quantity of juvenile Chinook salmon habitat has been conducted in the Green River near Kent (Caldwell and Hirschey 1989) and upstream of the Tacoma Diversion Dam (Caldwell 1992).

In the middle Green River, Jeanes and Hilgert (2001) found subyearling Chinook salmon in low velocity habitats, including mainstem river margin areas, pools, and off-channel areas. Higher flows commonly reduce habitat capacity for small juveniles and likely displace juveniles downstream if they cannot find suitable habitat. Spawning near the river thalweg may produce fry that are initially carried downstream because emerging fry are exposed to high velocity areas before finding low velocity areas near the river margin (D. Seiler, WDFW, pers. Comm.). Greater percentages of fish spawning near the thalweg likely occurs when spawning flows are relatively low, but fall flows in the Green River do not vary considerably and year-to-year shifts in the lateral distribution of spawners appear to be small (T. Cropp, WDFW, pers. comm.).

Nelson and Boles (2002) noted that the change in size over time of migrating subyearling Chinook salmon at the WDFW screw trap (0.46 mm/day; RM 34.5) and at RM 13 (0.47 mm/day) were greater than that of juveniles rearing in the middle Green River (0.29 mm/day). This finding might reflect, in part, the tendency for larger juvenile salmon to actively migrate earlier in the season, thereby leaving smaller individuals to rear in the middle Green River.

Nelson et al. (2004) noted that the presence of these small fish in the lower Green River during 2001 may have been related to low water velocities because fry in the lower Green River have been observed holding in low velocity areas behind root wads and in cut-outs along the river margin when the flow was 1500-2000 cfs. However, these fry then disappeared when flows increased and the low velocity refuge was lost. There is concern that the lower Green River lacks habitat that provides refuge from high flows and that fish prematurely migrate downstream. However, fingerling migrants, which are actively migrating from the middle Green River, may be stimulated by freshets (Nelson and Boles 2002). Thus, various habitat and flow conditions may be necessary to support both fry and fingerling migrants.

As noted previously, there has been little sampling of juvenile Chinook salmon in the Duwamish estuary and nearshore marine areas during February and March when numerous fry are moving downstream from the middle Green River. Data collected in the Skagit Bay, 1999, indicated numerous 40-42 mm fry can be present in marine waters during February (Beamer et al. 1999). In the Duwamish estuary and nearshore marine areas, numerous fry were observed during February, 2003 (W. Taylor, Taylor Associates; Nelson et al. 2004). Some fry were also present during March, but very few were present in April, suggesting the fish moved out of the area (or died). The fry in the marine areas appeared healthy, but it is not known whether their presence in marine waters was voluntary or influenced by the high winter river flows, or both. Some Chinook fry were observed in the estuary during January and February 2001 (T. Nelson, King County, pers. comm.). The viability of Chinook fry having little rearing in freshwater is not known, but some have suggested it is low (Reimers 1971, Healey 1991). The mechanism of mortality at this stage is unknown, but their small size would make them vulnerable to predators.

Juvenile Rearing

<u>Lower River and Duwamish Estuary</u>

Fry migrants often occupy upper estuarine habitats that are dominated by fresh water, but fry also occupy low salinity areas up to 15-20‰ (Healey 1991). Studies have shown that some Chinook fry can tolerate seawater (26-32‰). Fry transition into lower estuary habitats with higher salinity and somewhat higher velocities as they grow. Rearing habitats are typically marshes and tidal sloughs, which provide protection from potentially high velocities of the main river channel.

Early migrating fry from reaches in the middle Green River can potentially rear in the lower river and/or in the Duwamish estuary. In 2003, a mark and recapture study indicated most fry moved downstream from Soos Creek to RM 6.5 (upper estuary; Trimaran site) within two days, although some took much longer (Nelson et al. 2004). Data from several recent years of sampling indicate juvenile Chinook salmon aggregate in the upper estuary in vicinity of the Trimaran and Turning Basin sites (Nelson and Boles 2002, Nelson et al. 2004, Goetz and Ruggerone, unpublished analyses). This area has considerably greater densities of all salmonids compared to other sites, although little data has been collected in the immediately surrounding areas. This area has been labeled the transition zone because it is the first area where freshwater meets saltwater. Juveniles gradually move down from the upper estuary to the estuary and nearshore marine areas during May and June.

In the Green River, most fingerlings migrate to the lower river and upper estuary during May and June after reaching sizes of ~65-80 mm (Seiler et al. 2002, Nelson et al. 2004, Goetz and Ruggerone, unpublished analyses). At this time, they may be similar in size to fry migrants, which moved downstream one or two months earlier and reared in the upper estuary before gradual movement through the estuary. Visual identification of fry versus fingerling migrants in the Duwamish estuary may not be possible (without marking) since both likely have similar size. Both groups probably utilize similar habitats (shallow, low velocity areas often near river margin) in the lower river and estuary, but Healey (1991) suggested that fry migrants left the Nanaimo and Nintinat estuaries upon arrival of fingerling migrants, possibly a response to crowded habitat. The following discussion refers to both fry and fingerling migrants.

Areas of known Chinook concentration in the Duwamish include large eddies near the Trimaran site (RM 6.5) and Turning Basin (RM 5.5) (Nelson et al. 2004). These sites provide the first consistent opportunity for juvenile Chinook salmon seeking low velocity habitat containing both fresh (surface) and marine waters (bottom). Upriver intrusion of saltwater is inhibited by the small tidally influenced cascade immediately upstream of the Trimaran site. As the tide ebbs, the salt water wedge moves downstream from this area and occupies less of the water column. Little information is available to determine whether juvenile Chinook salmon move back and forth from low to higher salinity areas or to what extent juvenile movement depends on tidal flows. In 2003, a mark and recapture study in off-channel estuarine habitats indicated some upstream movement of juveniles (Ruggerone and Jeanes 2004). Estuaries offer habitats where salinity fluctuates with tidal exchange, both vertically in the water column and horizontally along the river channel.

Catch per effort data along the estuarine migration corridor during 1999, 2000, and 2002 (Turning Basin, Hamm Creek, 1st Avenue Bridge, Herring's House, Terminal 5, Slip 27 and Pier 90/91) indicated gradual downstream movement of juveniles from early May through June (Nelson et al. 2004). However, residence of individuals within specific habitats, such as off-channel habitats, typically was less than 24 hours during 2002. In 2003, residence time of marked Chinook salmon in off-channel habitats declined significantly immediately after the release of 3 million hatchery Chinook salmon (Ruggerone and Jeanes 2004). This is likely a response to dewatering of the off-channel habitat and fluctuating conditions in adjacent mainstem habitats, including flow, salinity, and temperature. An otolith chemistry/daily increment study will provide some quantitative estimates of individual juvenile Chinook residence times in estuarine versus freshwater habitats (Ruggerone et al. 2001).

Fish size is probably the key factor influencing habitat selection since larger fish can tolerate higher velocities and are more likely to occupy higher salinity and deeper waters. Residence time of fingerling migrants in the Duwamish River and estuary may be less than that of fry migrants since they initiated downstream migration at a later date and at a relatively large size. Presumably, fry and fingerling migrants are similar in size when they enter Elliott Bay. Thus, fry migrants may be more dependent on habitat in the lower Green River and upper Duwamish than fingerling migrants, which are more dependent on rearing habitat in the middle Green River.

Habitat utilization by juvenile Chinook salmon may vary considerably with tide stage. At high tide in undisturbed estuaries, juvenile Chinook salmon are often scattered along the edges of marshes at the highest points reached by the tide (Healey 1991). As the tide recedes, juveniles retreat into tidal channels that retain water during low tide. The distribution of tidal elevations during the spring migration period provides middle and lower level intertidal habitat to Chinook fry most of the time in natural estuaries. Man's alteration of the Duwamish estuary has removed most of this habitat, especially at the highest and lowest intertidal elevations. As the season progresses, the major concentration of juveniles moves seaward through the estuary and river delta. This movement occurs in part because larger fish appear to prefer deeper water (Meyer et al. 1981) and they readily tolerate higher salinity. Larger fish tend to be distributed further offshore than smaller fish (Healey 1991). In some estuaries, fry concentrate in nearshore surface waters during day, then disperse offshore and randomly occupy the water column during night. In other systems, juvenile Chinook typically rear in estuarine nursery areas until they reach a length of approximately 70-80 mm before dispersing to nearby marine areas.

Juvenile Chinook salmon utilize lower Duwamish habitats such as Kellogg Island (RM 1.3) and Herring's House (RM 1.0) where abundance appears to peak during late May and early June. These habitats are unique in the Duwamish because they provide gradual slopes in shallow water with low velocity. Most of the lower Duwamish is a deep navigation channel and shallow habitat generally only occurs along the channel margin in steep substrate areas without bulkheads or under pier aprons. Velocities along the channel margin vary with river flow and tide stage (approximately 0 to 3 ft/sec). As noted above, residence time of individual fish in habitats, such as Herring's House, is typically less than 24 hours. Nelson et al. (2004) found that densities of juvenile Chinook salmon near Kellogg Island and Terminal 5 (RM 0) were much lower that the area where freshwater initially mixed with salt water (RM 5.5-7).

Habitat use by Chinook salmon in the Duwamish estuary varies considerably with tide elevation, which may vary up to approximately 15 ft during a spring tide cycle (approximately –2.9 to +12.5 ft MLLW). During high tide, some juvenile Chinook salmon move into the few off-channel habitats that become flooded, whereas others remain in the main channel where river flow has been inhibited by the flooding tide. As the tide recedes, Chinook must leave existing off-channel habitats since most become dry when the tide drops below +6 ft MLLW. Some lower intertidal habitat occurs along the dredged navigation channel of much of the Duwamish upstream from about RM 3. Although juvenile Chinook and other salmon appear to prefer habitat in the freshwater/saltwater transition zone near RM 5.5-6.5, there are few data to evaluate preferences for habitat types outside this area.

Habitat connectivity is important when considering availability of habitat to the juveniles. Long reaches of the migratory route without suitable habitat may inhibit movement or reduce the probability of fish finding suitable habitat. Areas such as the lower Green River and upper

Duwamish River that have little shallow water with low velocities may lead to rapid movement where fish would otherwise rear for longer periods. This may result in more small fry reaching the lower Duwamish earlier than if more upstream habitat were available. Nelson et al. (2004) noted that fry utilized low velocity habitats behind root wads in the river and cut-outs along the river margin. However, at higher flows, these areas did not provide refuge from high velocities and the fish appeared to be carried downstream.

Diet and Growth. Rapid growth is likely a key determinant of survival because larger fish are less vulnerable to most predators and large size may enhance overwinter survival. A variety of studies have shown larger size generally leads to higher survival. As noted below, recent evidence from CWT data indicates subyearling Chinook salmon rearing in Puget Sound and Georgia Strait experienced lower growth and lower survival when migrating during even-numbered years along with numerous juvenile pink salmon. Beamish and Mahnken (2001) proposed the critical size hypothesis, which suggests salmon need to meet certain size or experience physiological failure during winter. Their hypothesis was supported by the observed mortality of salmon held in net pens while being fed at various rations. Thus, we assume prey availability and low velocity habitats where juveniles can efficiently process food are important to survival.

Recent analyses of Chinook stomach contents indicate juveniles captured in mainstem areas of the Duwamish estuary frequently consumed atypical prey compared with those in less disturbed estuaries, whereas those captured in off-channel restoration consumed more typical prey, including terrestrial insects (J. Cordell, University of Washington [UW], pers. comm.). It has been hypothesized that the significant loss of habitat in the Duwamish estuary has reduced its capacity to support natural Chinook salmon. If true, then fish leaving the Duwamish would likely be smaller in size compared with the past or with fish in less disturbed estuaries, assuming similar densities of fish. However, information to test this hypothesis was previously lacking, largely because past data was confounded by the inability to distinguish hatchery from naturally produced Chinook salmon. Emaciated fish have not been observed in the Duwamish and fish generally appear robust, but it remains uncertain whether reduced and altered habitat has reduced rearing time or growth in the Duwamish estuary. Uncertainties about this issue also extend into the lower Green and marine nearshore. Recent sampling may help answer these questions.

Analysis of natural subyearling Chinook salmon collected in the mainstem Duwamish estuary indicated the change in size averaged 0.44 mm to 0.36 mm per day during spring and summer of 2002 and 2000, respectively (Nelson et al. 2004). In off-channel habitats during 2002, change in size averaged 0.37 mm per day during early June, declining to 0.18 mm per day during mid- to late June when numerous hatchery fish were present. Nelson et al. (2004) also documented that natural Chinook salmon growth declined significantly immediately after the release of hatchery salmon in 2003, then growth increased in early July after most salmon had left the watershed. These estimates reflect immigration, emigration and growth of juvenile Chinook, and therefore are considered approximations of growth rather than actual measurements. Size of subyearling natural Chinook leaving the Duwamish during June was typically 70-95 mm, and size was consistently 5 to 10 mm greater during 2000 compared with 2002, a relatively cool spring. An ongoing otolith study may provide more quantitative estimates of individual growth rate in estuarine versus fresh water habitats compared with the current approach of examining change in size over time. Daily growth of subyearling Chinook salmon in the estuaries of Sixes River, Oregon, and San Francisco Bay was reported to be less than 0.2 mm per day (NPAFC 2003). Nelson et al. (2004) noted that daily growth of Green River Chinook salmon was in the middle of the growth range of Chinook from other watersheds, except for the low growth period during hatchery release. Growth rate typically increases after juveniles enter coastal and offshore marine waters. The ability of the marine environment to support rapid growth of large fish was likely a key factor leading to anadromy in salmon.

Habitat Capacity and Residence Time. Factors affecting year-to-year variance in residence time of juvenile Chinook salmon in lower river and estuarine habitats are poorly understood. Residence time is likely related to habitat availability, fish abundance, food availability, and interactions between fishes. Downstream movement of natural Chinook salmon may be accelerated if they do not find adequate prey, habitat, or if habitats are occupied by other fish (Beamer et al. 1999). Accelerated downstream movement may lead to smaller juveniles leaving the estuary, which may lead to lower survival at sea.

During the period of peak utilization of the lower Duwamish estuary by natural Chinook salmon, approximately 3.5 million juvenile Chinook salmon are released from the Soos Creek Hatchery. During the release period, hatchery Chinook salmon are exceptionally abundant in all habitats.

Although hatchery salmon appear to move through the river and estuary relatively rapidly, many hatchery salmon utilize the same habitats as natural Chinook salmon and it seems probable that natural Chinook salmon may be displaced from some habitats. Preliminary analysis of recapture rates of subyearling Chinook salmon in off-channel estuarine habitats in 2002 indicated recapture rates declined from 30% during late May to 4% during mid-June immediately after release of approximately 3.5 million hatchery Chinook salmon (Goetz and Ruggerone, unpublished analyses). In 2003, recapture rates of natural Chinook salmon in off-channel habitats significantly declined after release of hatchery salmon (Ruggerone and Jeanes 2004). Likewise, Nelson et al. (2004) reported that use of the transition zone (RM 5.5-6.5) declined during the period of high overall salmon abundance, suggesting the capacity of this preferred habitat had declined.

As noted previously, Nelson and Boles (2002) and Seiler et al. (2002) suggested that juvenile migration in the middle (RM 34.5) and lower Green River (RM 13) was stimulated by freshets. The effect of freshets on residence time in the estuary has not been examined, but presumably it would have a smaller effect in tidally influenced waters than in the river.

A preliminary estimate of the total percentage of Chinook populations utilizing estuarine off-channel habitats in 2002 (Hamm Creek, 1st Ave Bridge, Herring's House combined) was 1.2 to 1.5% for natural Chinook salmon and 0.6 to 1.2% for hatchery Chinook salmon (Goetz and Ruggerone, unpublished analyses). On average, natural Chinook salmon resided in the off-channel habitats for 1.6 high tides, whereas hatchery salmon occupied the habitats for 1.4 high tides. In 2003, less than 1% of the natural Chinook population utilized the off-channel habitats; residence time in the habitats was approximately 1.5 tides (Ruggerone and Jeanes 2004). The somewhat small percentage of the populations utilizing these habitats reflects the small size of the habitats and daily dewatering during low tide.

Water Quality. The Duwamish estuary is a highly industrial waterway having low water and sediment quality. Recent investigations for the Lower Duwamish Waterway Group indicated that PCBs and PAHs in diets likely to occur in the Duwamish do not adversely affect the immune system of Chinook (Powell et al. 2003, Palm et al. 2003). Other investigations (Arkoosh et al. 1998, 1999) reported that young Chinook migrating through the Duwamish River have higher concentrations of organic contaminants than those released at the hatchery, and that fish exposed to PCBs were more susceptible to disease when challenged by *Vibrio anguillarum*. PCBs and mercury were measured in juvenile Chinook salmon collected from the East Waterway and Kellogg Island during 2002 (Windward 2002). No differences were seen in the tissue mercury concentrations measured in Chinook collected in the East Waterway compared to the Chinook collected at Kellogg Island. However, higher total PCB concentrations were measured in hatchery and wild Chinook collected from the East Waterway compared to the hatchery and wild Chinook collected from Kellogg Island. Additional sampling of PCBs will be conducted in 2003. The ultimate effect of these chemicals (in both water and sediment) on the survival of natural Chinook salmon remains unknown.

Water temperature in the Green River and Duwamish River can reach stressful levels for salmon during summer and fall, as noted previously. During the peak juvenile migration in May and June, mainstem water temperatures are not stressful. However, during exceptionally warm days in June, some off-channel habitats can experience stressful temperatures. For example, during a warm period in June 2003, water temperature in the C.B. Moses off-channel site reached 24°C during the low tide period when the pond was disconnected from the mainstem; no salmon were seen in the pond or along the banks (Ruggerone and Jeanes 2004). These warm conditions during extreme summer tide periods are typical of estuaries with large tide flats, but fish in undisturbed habitats typically have access to deeper, cooler waters.

Predation. Predation is often considered a primary source of mortality of juvenile salmon after emergence. In part, predation is considered important because it is a direct source of mortality that has been quantified in many freshwater and coastal marine areas. Other than extreme occurrences of low water quality, stranding, injury associated with dams, or fishing, few mechanisms have been identified that directly affect salmon mortality after emergence from gravel. Mortality has been linked to habitat characteristics through reduced growth rates or low residence times, but the actual mechanism of mortality is typically not quantified. Predation rates can be influenced by habitat characteristics such as temperature or water flow. Rapid growth is one mechanism that can lead to reduced predation because predation is often highest on smallest individuals.

In the Duwamish River and estuary, few studies have directly attempted to quantify important predators (Kerwin and Nelson 2000). Nevertheless, fish sampling in the estuary has not indicated an abundance of potential predators that might lead to significant mortality (Nelson et al. 2004). One potentially important predator that is not readily sampled by most sampling gear is the river lamprey (*Lampetra ayresi*), which is known to kill numerous salmon in the Fraser River plume. In the Duwamish estuary, lamprey marks have been observed on juvenile Chinook and chum salmon during late spring and early summer. In 2002, lamprey marks were present on up to 20% of juvenile Chinook and chum salmon captured by beach seine near Terminal 5 during a brief period in late June (G. Ruggerone, NRC, pers. comm.). Lamprey marks were also observed on juvenile salmon in Elliott Bay during the 1960s (Weitkamp and Ruggerone 2000). Therefore, there are remaining uncertainties about predation in the estuary, as well as the lower Green River.

Marine Nearshore of Puget Sound

In shallow nearshore marine habitats, juvenile Chinook salmon rear, grow and migrate weeks to months (moving on- and offshore) before moving to epipelagic waters of Puget Sound. The migration patterns of juvenile salmon in Puget Sound are not well understood. Some movement of juvenile salmon may be influenced by currents in Puget Sound, although juveniles are capable of swimming against most currents. Recent recoveries of CWT subyearling Chinook salmon indicate rapid, long-distance movements of fish throughout Puget Sound. In 2001, 72 CWT Chinook, representing 9 different hatchery stocks, were caught within the nearshore marine waters of WRIA 9. Of the 72 Chinook, 27 (38%) originated from WRIA 9, while the Wallace River Hatchery comprised 53% of the Chinook caught in WRIA 9 nearshore waters (Brennan and Higgins 2004). In 2002, 70 CWT Chinook were captured, representing 8 different hatchery stocks. Of the 70 Chinook, 39% originated in WRIA 9, while 40% of the Chinook came from the Wallace River Hatchery. In a different study within Elliott Bay (Pier 90/91 and outer Terminal 5) during 2002, 54% of 76 hatchery CWT Chinook salmon were from watersheds other than the Green River (G. Ruggerone, NRC, unpublished analysis). Approximately 45% had originated from the Wallace River Hatchery, 4% from Puyallup, 2.6% from Grover Creek, 1.3% from Tulalip Hatchery, and 1.3% from Minter Creek. Most CWT Chinook captured in Elliott Bay after mid-June were from other watersheds. In comparison, all CWT salmon recovered from upriver sites in the Duwamish estuary [Turning Basin to Herring's House] had originated from the Green River, suggesting few juveniles from other watersheds move upstream into the middle and upper estuary. Nelson et al. (2004) reported the presence of a non-local CWT Chinook as far upstream at Kellogg Island.

King County sampled juvenile Chinook salmon in a variety of nearshore habitats ranging from Vashon Island to Picnic Point during May to October, 2001 and 2002. Approximately 88% of 58 CWT Chinook salmon originating from Soos Creek Hatchery migrated south after entering Puget Sound; few individuals were captured in nearshore waters of WRIA 8 (Brennan and Higgins 2004). Comparison of individual fish lengths and weights with the mean values of each tag group frequently produced negative growth rates. This may suggest biased sampling of CWT fish at the hatchery or low growth rates.

Types of nearshore marine habitat preferred by juvenile Chinook salmon are not well documented, although gentle sloping areas with eelgrass, macrophytes and less wave action may support more salmon. Key nearshore marine habitats utilized by juvenile Chinook salmon was the focus of the "CORE Areas" study funded by King County (Martin Environmental and Shreffler Environmental 2002). Preliminary findings indicated little correlation between catch rates and time of day, tide elevation, or tide stage, though the amount of sampling effort was low. However, the presence of numerous salmonids at one site may have been related to physical features (tides, currents, eddies) rather than kelp. Similar results were found by Brennan and Higgins (2004) with no correlation between time of day, tide elevation, tide stage, presence of submerged aquatic vegetation and substrate. Anecdotal evidence further suggests that physical features (current, spits, wind) may explain some of the distribution pattern seen. These data suggest the relative abundance of salmonids in the nearshore areas may be difficult to predict based on habitat features. The distribution of Green River Chinook salmon in marine waters has not been documented, but areas closer to the river are more likely utilized than distant habitats based on random dispersal from the river to nearshore areas. Nelson et al. (2004) reported that catch rates of juvenile Chinook salmon in Elliott Bay were considerably smaller than catch rates in the Duwamish estuary (RM 0-7), reflecting rapid dispersal along marine habitats. Furthermore, CWT Chinook salmon originating from the Soos Creek Hatchery were essentially gone by late June, but were replaced during summer and early fall by CWT Chinook salmon originating from other watersheds.

Diet and Growth. Juvenile Chinook salmon are opportunistic foragers in Puget Sound, feeding on epibenthic and pelagic invertebrates, insects (possibly from drift out of streams, marine riparian vegetation, or recent feeding in freshwater), and small fishes (Fresh et al. 1981, Healey 1982, Healey 1991). D. Beauchamp (UW, pers. comm.) noted that many Chinook captured off the Snohomish estuary had consumed insects, which may imply that fish recently left the river, availability of marine prey was somewhat low, or that marine riparian vegetation supplied insects to the nearshore environment. Based on recent work by Brennan and Higgins (2004), Chinook under 150 mm ate a highly varied diet, while Chinook larger than 150 mm ate mostly juvenile fish. Chinook under 150 mm consumed high amounts of polychaetes early in their marine residence and high levels of insects later in the summer. The polychaetes found in the diet were composed mostly of one species, which is generally associated with shallow vegetated habitats (i.e., kelp and eelgrass). Anecdotal evidence and studies in other regions (Locke and Corey 1985) indicate that marine riparian areas are very important for insect prey production.

Recent analysis of CWT data (53 million tagged fish) suggested that growth and survival of Puget Sound Chinook salmon was reduced and age-at maturation was delayed when juvenile Chinook salmon enter Puget Sound during even-numbered years along with numerous juvenile pink salmon (produced by the dominant odd-year return of adult pink salmon) (Ruggerone and Goetz 2004)[9]. Survival of even-year Chinook migrants was 62% less than that of odd-year migrants. Analyses also indicated the odd- and even-year growth and survival patterns were influenced within Puget Sound and Georgia Strait and that survival was influenced by the 1982/83 El Nino and subsequent climate events that appeared to influence prey production. These findings suggest that the capacity of Puget Sound to support Chinook salmon (i.e., food availability) may be reduced in some years, but few data are available that examine food availability and/or growth of salmon in Puget Sound over a series of years. The trophic interactions that would lead to this significant effect are poorly understood. Nevertheless, if reduced growth is the mechanism leading to the 62% reduction in Chinook survival, then it may be possible to draw inferences about the importance of habitat protection and restoration in freshwater and nearshore marine areas. The implication is that habitat restoration in freshwater

[9] The survival estimates provided the strongest and most compelling evidence of an odd/even pattern. Although the odd/even growth pattern was statistically significant, the difference in growth was relatively small. Additional analyses are needed to evaluate differential growth during odd- versus even-numbered years in Puget Sound. Dr. V. Bugaev, a Russion salmon scientist

and nearshore that leads to greater size of Chinook salmon in Puget Sound can lead to greater survival, especially during periods of unfavorable climate and ocean conditions.

Habitat Capacity and Residence Time. Subyearling Chinook salmon rear in Puget Sound and Georgia Strait from winter through at least fall (Mavros and Brennan 2001) and some overwinter within these protected waters (Williams et al. 2001, NPAFC 2003). During summer and fall most juvenile Chinook are located in surface waters (< 20m) (Beamish et al. 1998). Stock-specific distribution of juvenile Chinook in off-shore waters of Puget Sound are not known. During summer and fall, many juvenile Chinook exit the Strait of Juan de Fuca and migrate north along the outer coast of Vancouver island and beyond. Yearling Chinook salmon leave these inshore waters before subyearling Chinook salmon (Healey 1991). However, a portion of juvenile Chinook are known to remain in Puget Sound as they mature to adults instead of moving into the larger ocean (i.e., Blackmouth). As discussed above, CWT data indicate that the capacity of Puget Sound to support juvenile salmon may be reduced in some years.

Predation. Predator-prey interactions in Puget Sound are poorly understood (Fresh et al. 1981). In marine waters, dogfish (*Squalus acanthias*), hake (*Merluccius productus*), lamprey, and piscivorous birds may consume numerous juvenile salmon (Beamish et al. 1992, Beamish and Neville 2001, 1995). However, the abundance of these species in Puget Sound appears to have been relatively low in recent years (PSWQAT 2002). If so, then growth-related mortality, such as that suggested by the critical size and period hypothesis (Beamish and Mahnken 2001) and the CWT study described above, may be key to low Chinook survival at sea since the 1970s (Ruggerone and Goetz 2004).

Ocean Residence

Green River Chinook salmon typically spend two or three winters at sea before returning to spawn. Large percentages of maturing Green River Chinook salmon can be taken in British Columbia fisheries as they migrate south along the outer coast of Vancouver Island, while others are taken in the Strait of Juan de Fuca and Puget Sound. Ocean residence, while important for

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with Kamchatka TINRO, has observed Russian Chinook salmon population abundances that are inversely related to pink salmon abundance (pers. comm.).

Green River Chinook, are mostly outside the influence of the WRIA and therefore, are not discussed in detail.

Summary

Potential human impacts on Chinook salmon and the viability of various life history patterns include over-harvests, genetic alterations of the population, and habitat modifications. WRIA 9 must be concerned with these factors, since greater diversity in life history patterns is likely to lead to greater long-term stability and persistence of a population, especially when confronted with changing climatic regimes (McElhany et al. 2000). Broad spatial distribution of spawners and diversity of rearing habitat types are important factors contributing to diversity of life history patterns. Diverse life history trajectories are unlikely to develop in uniform habitats, therefore, adequate habitat quantity and quality throughout WRIA 9 is necessary for salmon to opportunistically utilize habitat. Future research should build upon existing data and identify: 1) additional life history patterns; 2) habitat qualities that support each Chinook life pattern and maximize growth potential; and 3) factors that affect survival and abundance of juvenile Chinook salmon. This information is necessary for resource managers to identify and efficiently develop effective restoration measures to improve the viability of Green/Duwamish Chinook salmon.

RESEARCH HYPOTHESES

Based on the conceptual model, a number of hypotheses were developed for areas that lacked adequate information to draw conclusions (e.g., types and relative abundance of juvenile life history trajectories). A sub-committee of the WRIA 9 Technical Committee prioritized the hypotheses based on existing information and usefulness of the research in Chinook conservation planning for WRIA 9.

Hypotheses were grouped into tiers, with tier 1 hypotheses having the highest priority and tier 3 having the lowest priority. The tiered list of hypotheses is listed below, grouped by VSP attributes (i.e., abundance, productivity, spatial structure and diversity). In some cases, hypotheses may address more than one VSP attribute. In such cases, the hypothesis is listed with the most relevant VSP attribute and a reference to other attributes is noted. Additionally, some hypotheses are rather broad, and more-specific sub-hypotheses are listed under the broad hypotheses. It is important to note that the hypotheses listed below are stated as null hypotheses so that studies can be conducted to possibly reject them (generally we believe that the null hypothesis is false, but data are needed to test the hypothesis). Tier 1 hypotheses were used to develop planning level Research Scopes of Work, which are presented in the following section.

Tier 1

Productivity

- Habitat in the lower Green River, Duwamish estuary and marine nearshore areas is adequate to support natural juvenile Chinook salmon.
  - The upper estuary (Trimaran, Turning Basin and adjacent areas) is a key rearing habitat that supports both fry and fingerling migrants with adequate habitat capacity (abundance, diversity).
  - Habitat in the lower Green River is adequate for supporting all potential Chinook life history trajectories during both high and low flow periods (abundance, diversity).
  - Juvenile Chinook salmon utilize estuarine habitat types randomly.

  - Chinook salmon utilize marine nearshore habitat types randomly.
  - Growth of natural juvenile Chinook salmon in the lower river, estuary and nearshore is adequate and are not influenced by releases of hatchery fish. Diet is opportunistic and adequate (abundance).
- Chinook spawning habitat is adequate in terms of quality, quantity, and spatial distribution (spatial structure).
  - Chinook egg-to-fry survival is adequate compared with that of other populations.
  - There is adequate spawning habitat to support Chinook salmon (abundance, diversity).
  - The Green River has adequate spawning quality to support Chinook salmon.
- Green River flow regime does not affect Green River juvenile Chinook survival by either 1) concentrating spawning in the thalweg and increasing risk of scour above natural levels or 2) scouring eggs or alevins from the gravel as a result of high flows during late fall through early spring (abundance).
  - Fry production is not related to winter flow patterns (abundance).
  - The depth of scour during flood events is not sufficient to disturb Chinook redds.
  - A large proportion of adult Chinook do not spawn in the thalwag of the river.

Diversity

- Life history diversity and productivity of Green/Duwamish Chinook salmon are adequate (productivity).
  - The Green River produces multiple juvenile Chinook salmon life history trajectories.
  - Productivity and capacity of natural Green River Chinook salmon are adequate and comparable to other summer/fall Chinook salmon populations.

Tier 2

Productivity

- The relative abundance of fry versus fingerling migrants originating from the middle Green River is dependent on available habitat, which is influenced by river flow, fish density, and food availability. Alternatively, the migration pattern is genetically programmed or is related to the percentage of adults spawning in the river thalweg and numbers of emerging fry that are carried downstream before reaching suitable, low velocity habitats (abundance).

- The capacity of nearshore habitats in Puget Sound (quantity and quality), including prey availability, are adequate to support both natural and hatchery Chinook salmon populations, i.e., growth, residence time, and survival are adequate.

Diversity

- River flow during late winter and early spring "pushes" fry migrants into the estuary and marine waters, whereas freshets during May and June stimulate migration of fingerling migrants (diversity).
- Residence time of fingerling migrants in the estuary is similar to that of fry migrants; it is independent of existing habitat quantity; and residence time is not affected by hatchery releases (productivity).

<u>Tier 3</u>

Productivity

- The Duwamish/Green River provides an adequate migration corridor for returning adult salmon, i.e., flow and temperature are adequate.
- Water temperature and adult spawn timing have not altered emergence timing.
- Water quality in the estuary is adequate to support Chinook salmon.
- Predation has little effect on Chinook survival in the river, estuary and nearshore marine areas.
- Growth of juvenile Chinook salmon in Puget Sound is not influenced by climate-induced prey availability, and competition for prey has little effect on Chinook growth and survival.
- Duwamish sediment quality does not affect juvenile salmonids.

Spatial Structure

- Migration patterns of juvenile Chinook salmon in Puget Sound are random.

Diversity

- Spawning aggregations in the present Green River watershed, including spatially and temporally segregated stocks and the hatchery stock, are genetically similar. Migration timing of spawning aggregations is similar (spatial structure).

RESEARCH SCOPES OF WORK FOR PRIORITY HYPOTHESES

A number of hypotheses and questions were developed from the conceptual model of Chinook salmon utilization of habitat in WRIA 9. These hypotheses and questions were developed as a means to identify information needs, but without consideration of cost or feasibility of testing the hypotheses. The list of hypotheses was reviewed and prioritized by the WRIA 9 Technical subcommittee, and several hypotheses and research questions were selected for development of planning level research scopes. The following text identifies hypotheses, sub-hypotheses and questions, and provides information that can be used to develop more detailed study plans. In most cases, multiple approaches can be used to answer the same hypothesis or question, and in those cases multiple approaches are described. Finally, it is noteworthy that investigations will often lead to specific new questions that were not originally considered. Thus, multi-year studies should be flexible enough to incorporate modifications that can address new questions that arise.

Information on the relative effort and potential success of testing the hypothesis is provided below. Success at testing a hypothesis relies heavily upon statistical power in the data analysis. The key determinants of statistical power are variability among samples (standard deviation) and sample size. Greater sample size (e.g., numbers of fish) is needed to detect an effect (i.e., reject the null hypothesis) when variability among the samples is high. The required number of samples can be estimated through statistical procedures if previous data are available or if assumptions about variability are assumed. Sample sizes noted below are not based on rigorous statistical procedures. Of course, other assumptions, such as random sampling of the population or presence of confounding factors, must also be addressed before conclusions about a hypothesis can be developed. These assumptions can be difficult to verify in field studies because it is often difficult to control all potentially influential factors. Nevertheless, field studies are needed to better understand how fish respond to environmental factors in light of potentially confounding factors.

Many factors can influence the cost of projects and they are difficult to estimate without more detailed considerations. Nevertheless, potential annual costs of the projects were categorized as follows:

Low: Less than $50,000

Moderate: $50,000 to 250,000

High: Greater than $250,000

Priority research hypotheses for WRIA 9 are discussed below. Table 1 provides a brief overview of these hypotheses, along with sub-hypotheses and questions, and identifies the research status of these topics in WRIA 9.

Table 1. Overview of hypotheses, sub-hypotheses and questions and their research status. "Salmon" refers primarily to Chinook.

Hypothesis or Research Action	Research Status
1.1 The upper estuary (RM 5.5-7) is key rearing habitat.	Nelson et al. (2004) provides data that support this hypothesis. See 1.1a-1.1d, below.
1.1a High salmon density boundaries occur near RM 5.5-7.	See 1.1 above. More effort is needed to identify the boundaries.
1.1b Salmon diet and growth is adequate at high and low densities.	Some diet information has been collected in 2002 & 2003, but has not been analyzed to answer this question.
1.1c Habitat capacity adequately supports salmon.	Nelson et al. (2004) provides some information, as well as ongoing research on the Skagit River. However, more research is needed to evaluate this complex question.
1.1d Salmon residence time is influenced by density.	Nelson et al. 2004 and Volk and Ruggerone (2004) have some information, but this question is not specifically addressed.
1.2 Residence time in the lower Green River is affected by flow and habitat.	Observations by Nelson et al. (2004) provide some information, but a targeted experimental approach is needed to answer this hypothesis.
1.3 Identify estuarine habitats preferred by salmon.	Previous studies show there are high densities of salmon at RM 5.5-7, but habitat preferences have not been identified in the Duwamish River. Studies in other estuaries may be useful. Morley and Toft (2004) have proposed a study that would look at differences between armored/unarmored and vegetated/unvegetated shorelines.

Hypothesis or Research Action	Research Status
1.4 Identify marine nearshore habitats preferred by salmon.	Studies have been proposed by King County ("Core Areas" study) and J. Toft (UW). A pilot "core area" study was undertaken by King County to examine this hypothesis and Toft et al. (2003) looked at the feasibility of various fish sampling methods in the marine nearshore.
1.5 Growth, diet, and prey resources of salmon in the lower estuary and river is adequate.	Nelson et al. (2004) and Morley and Toft (2004) provide some information on growth and prey resources, respectively. UW will be analyzing diet of Chinook and chum collected in the estuary during 2002 and 2003. Additional stomach samples collected in 2004 could be analyzed and compared with invertebrate samples collected in the Duwamish as a first glance at this hypothesis.
2.1 The Green River produces multiple life history trajectories.	Nelson et al. (2004) provides some initial estimates of juvenile trajectories, however some more specific information is needed. See 2.1a and 2.1b below.
2.1a Identify life history trajectories.	Some data is available from Nelson et al. (2004), however, more research is needed for this hypotheses.
2.1b Measure survival of fry vs. fingerling migrants.	No data for the Green River.
2.2 The productivity and capacity of Green River Chinook is adequate.	Initial work was conducted by Weitkamp and Ruggerone (2000), but recent revisions of the escapement methodology indicates that the database and analysis needs to be revised.
3.1 Egg-to-fry survival is adequate.	Work by WDFW can provide information on this hypothesis. Seiler et al. (2002) provides one year of data. Three years of additional data have been collected, but need to be analyzed and reported.
3.2 Quantity of spawning habitat is adequate.	WDFW conducts annual spawner surveys, but habitat quantity has not been measured or compared to spawning numbers.
3.3 Quality of spawning habitat is adequate.	WDFW conducts annual spawner surveys, but habitat quality has not been quantified. However, gravel supplementation does occur near the Tacoma Diversion Dam.

Hypothesis or Research Action	Research Status
4.1 Fry production is affected by winter flows.	WDFW fry trapping may provide insight for this hypothesis. Seiler et al. (2002) provides one year of data. Three years of additional data have been collected, but need to be analyzed and reported. These data could be used to correlate survival with flow.
4.2 Scour from high flows impacts salmon redds.	No data for Green River, but studies in other watersheds.
4.3 Chinook spawn in river thalweg resulting in greater scour of redds.	No data for Green River.

Hypothesis 1: Habitat in the lower Green River, Duwamish estuary, and marine nearshore areas is adequate to support natural juvenile Chinook salmon.

1.1 The upper estuary (Trimaran, Turning Basin and adjacent areas, ~RM 5.5-7) is a key rearing habitat that supports both fry and fingerling migrants with adequate habitat capacity.

The upper estuary (~RM 5.5-7) is an area where freshwater and marine water initially mix. It is also an area where the channel broadens, eddies form, and current can be negligible (e.g. flooding tide). Recent research (Nelson et al. 2004) sampled this area in 2002 and 2003, as well as other habitats in the lower river, estuary and nearshore marine areas, and found considerably higher catch rates of natural subyearling Chinook salmon (and other salmon species) at RM 5.5 (Turning Basin) and RM 6.5 (Trimaran). Much lower catches occurred near Kellogg Island (RM 1) even though this area has a somewhat large shallow area with low water velocity. Relatively low catches also occurred at RM 13 where there is little refuge from higher velocities and no marine water. Relatively high beach seine catches at RM 5.5 and RM 7 occurred from mid-February to late June, indicating this habitat is important throughout the migration period and that fish likely spend more time in this area compared with other areas. However, Nelson et al. (2004) reported that the presence of both hatchery Chinook salmon and chum fry might have caused the density of natural Chinook salmon at RM 7 to decline, due to competition for space. These results indicate that habitat capacity may not be adequate to support all fish using the area.

This question about adequate habitat capacity can be addressed by 1) documenting the area (boundaries) of high Chinook density, 2) examining Chinook diet and growth during periods of high and low density to determine whether prey consumption declines (or changes) and/or growth declines during periods of high abundance, 3) determining whether Chinook density reaches an asymptote (levels off) in response to increasing numbers of juveniles moving into the area, and 4) examining residence time of individuals to determine whether they are displaced when a pulse of fish moves into the area.

Question 1.1a: *What are the boundaries of the high density area in the upper estuary and how does that relate to physical conditions (e.g., salinity, temperature)?*

Sampling Area: Areas to sample should include the Turning Basin (RM 5.5) and Trimaran sites (RM 6.5), since these are sites where previous data were collected, plus two sites above and below these areas. Data collected by Nelson et al. (2004) in 2003 indicated catches were somewhat high at RM 4, but sampling was not intensive at RM 4. Two sites should be identified upstream of the rapids (near RM 7) because salinity is much lower above this site and the channel is generally narrower. Additional areas might include RM 4 and another site near RM 3, although resolution of the boundaries will depend on distance from the Turning Basin and Trimaran sites. Additional sites may be sampled if time permits.

Methods: Sampling should be conducted through the use of beach seines, with two sets in each area. Sampling of sites should occur on the same day. Captured fish should be counted and measured, and their species, origin (hatchery, wild), and age class (subyearling, yearling) should be recorded. Near surface salinity, temperature, and tidal stage should be measured.

Sample Timing: Sampling should occur during the period of peak migration to enhance probability of detecting differences between sites; this may occur after the release of hatchery Chinook since they also were captured in high densities at RM 5.5 and RM 7. Sampling once per week for three or four consecutive weeks (beginning mid-May) should be sufficient to determine the approximate boundaries of the high density area for fingerling-size Chinook salmon. (Note: sampling could be conducted within a narrower period, but sampling over a broader period is useful for other study questions). The study could also be conducted during peak migration of fry: ~mid-February to mid-March.

Effort and confidence: This project is straightforward and has a reasonably high chance of success if effort is sufficient. The key will be to find suitable areas to set a beach seine and to include areas where catches decline significantly so that high density boundaries can be approximated. Some exploratory sampling could be useful to help refine choice of sampling areas. One year of sampling may be sufficient, but more effort may provide greater certainty and confidence in findings. Data from this project can be shared with study objectives of other investigations, thus there is some cost savings if associated with other objectives.

Cost: Moderate.

Question 1.1b: *What is the diet and growth of juvenile Chinook in the upper estuary during high and low density periods?*

A reduction in stomach contents or change in composition of prey in the diet of natural Chinook salmon during periods of high salmon density may indicate the capacity of habitat is constrained. High density of salmon might affect Chinook diet by either reducing prey or by disrupting foraging activity. The release of numerous hatchery Chinook may provide an opportunity to test this hypothesis while also testing the hypothesis that hatchery salmon affect natural Chinook salmon. Utilization of the hatchery release in the experimental design enhances the probability of detecting a shift in diet because hatchery fish abundance is great and it occurs within a relatively short time period (less chance of confounding seasonal effects on diet). Diet information from 2002 and 2003 will be analyzed by Alex Vonsaunder and Jeff Cordell (UW), but it is unlikely that they will look at this specific question (A. Vonsaunder, UW, pers. comm.).

Sampling Area: RM 5 to RM 7

Methods: Stomach contents of natural Chinook salmon should be sampled prior to the hatchery release (late April), during the hatchery release (late May-early June), and after most of the hatchery fish have left the area (late June-early July). Stomach contents can be compared (ANOVA) before, during and after periods of high Chinook abundance. Abundance of other species, such as chum salmon, should be considered in this study because Nelson et al. (2004) reported that both chum and hatchery Chinook salmon might have influenced the density of natural Chinook salmon at RM 7 to decline relative to other areas. Fish length, and if possible, weight should be recorded, along with water temperature (set recording thermograph). Identify prey species, weigh wet and dry prey, calculate percentage of body weight consumed. Lab time and cost could be reduced if prey are lumped into categories rather than identifying to species level. If weight is not measured for each fish, then a subsample of fish should be used to develop a regression to estimate Chinook weight from length. Sample size should be approximately 30 natural fish per period per each of the two sites (RM 5.5, RM 7). Diet information may be collected with a stomach pump, recognizing that this activity requires more time in the field but it reduces Chinook mortality. Diet of abundant potential competitor species, such as chum fry, should be examined and compared with Chinook diet.

Prey availability could also be sampled along with the fishes, but this sampling may provide less information about salmon prey availability because salmon are selective and they likely have different selectivity for prey compared with prey sampling gear. Nevertheless, some sampling of prey availability (insect traps, benthos grab samples, zooplankton hauls) would be worthwhile for comparison with Chinook diet.

Average daily growth rate of natural Chinook salmon can be approximated by comparing mean size from week to week. This approach has been commonly used in estuarine studies of Chinook salmon (Healey 1991, Nelson et al. 2004), but the approach often leads to an underestimation of growth rate (~50%) and can be confounded because fish migrate into and out of the study area. Nelson et al. (2004) reported that daily growth of natural Chinook salmon in 2003, based on this approach, was significantly lower during three weeks following the release of hatchery fish compared with growth prior to and after the emigration of most hatchery fish from the watershed. This approach requires at least three weeks of data before and after the period of high salmon abundance in addition to data during high salmon abundance. At least 30 natural subyearling Chinook salmon are needed from both RM 5 and RM 7 each week.

A more direct approach to examining growth in relation to fish density would be to mark fish at RM 5 and RM 7, then recapture them and measure them over time, both before, during and after periods of high fish density. Large numbers of fish can be spray marked with florescent dye (up to five colors: see Nelson et al 2004, Fresh et al. 2003), but numbers of marked fish will be limited by the number of fish that can be captured. Spray-marked fish should be measured and released on the same day. Searching for marked fish can be labor intensive. This approach suffers from the limited ability to recapture marked fish and because growth is based on mean length rather than length of individuals. Other methods can be used to mark fish (Passive Integrated Transponder tags [PIT], Coded Wire Tags [CWT], branding). These methods are more labor-intensive and produce fewer marked fish per effort, assuming large numbers can be captured. PIT tagging is limited to fish that have achieved some growth. However, fish marking can also provide information on residence time in the study area (see below).

One of the most direct approaches to examine fish growth in relation to fish density would be to examine daily otolith ring widths before and after the hatchery release period. Otoliths record daily rings[10] that are correlated with fish growth: wider spacing equates to more rapid growth (Fukuwaka 1998). Fish and their otoliths could be sampled immediately before, during and after the period of high salmon abundance. The objective would be to determine whether daily widths were narrower after the initial large release of hatchery fish (or chum fry) compared with growth prior to it (day of capture and ring counts would be used to identify the number of rings corresponding to the period of abundant hatchery fish). One problem would be to determine whether fish were in the lower river or estuary (where competition would occur) rather than the middle Green River during the period of high salmon abundance. The increase in Strontium (Sr) in otoliths can be used to estimate time of entry to brackish marine waters and may be useful for this task, but Sr analysis adds to the overall cost and effort. The otolith study by Volk and Ruggerone (2004) on Duwamish fish will shed light on this approach, and initial analyses look promising. However, this approach is still relatively new and it needs to be evaluated before applying the approach on a large scale. The ongoing otolith study will estimate residence time in brackish and marine water (see question below), fish length at time of entry to the estuary, fish

[10] Daily otolith ring development was confirmed in an thermal marking experiment conducted in the Duwamish River, 2002, for mean daily rings, but there was some error among individual fish (Volk and Ruggerone, in prep). Counts of daily rings near the time of emergence from gravel are uncertain.

growth before and after entry to saltwater, and hatchery versus natural origin during 2002. If time permits, they may test the feasibility of the question addressed here. A key objective of the study will be to describe the feasibility and utility of the otolith approach. Some unexpected, yet interesting, findings have delayed publication of this report[11].

Sample Timing: Weekly between late April to early July (the studies could also be conducted during the fry migration period, but this time period is complicated by uncertain levels and timing of fry movement).

Effort and confidence: The diet study has a reasonable chance of success if adequate samples (numbers of fish) can be achieved. Sampling would entail one or two sample days per week. Stomach pumping will require more effort in the field compared with sacrificing the fish. The average size approach to estimating growth and potential growth reduction was used in 2002 and 2003. Weekly sampling is essential. Interpretation of findings based on change in size over time can be confounded by immigration and emigration, i.e., nonrandom sampling of the population. The otolith-based approach is appealing because each fish is an independent data point. Otolith chemistry, which is more costly than visual reading of daily otolith increments, is not critical, but it would add refinement and more precise estimates to the study design. It would also provide data on residence time in brackish marine water prior to capture (see below). Sampling of fishes needed for this project can be shared with study objectives of other investigations.

Cost: Moderate to High.

Question 1.1c: *Does density reach an asymptote, indicating that habitat capacity is being reached or exceeded?*

One approach to examining the capacity of the RM 5.5 and RM 7 area to support Chinook salmon is to determine whether the density of natural Chinook salmon continues to increase or reaches an asymptote as increasingly large numbers of fish move into the area. If an asymptote is reached or if density of Chinook begins to level off at high abundance, then the capacity may

[11] A statistical procedure was developed to detect the inflection of Sr along the otolith transect. Volk and Ruggerone discovered that hatchery salmon experienced a small Sr inflection before entering marine waters that was initially identified as movement into marine waters. This unexpected finding allowed the researchers to develop a new and accurate approach to identify hatchery versus natural Chinook salmon. However, it also meant that some of the initial analyses had to be redone.

have been exceeded. This approach has been recently utilized by the Skagit System Cooperative on the Skagit River estuary. Critics of this approach might argue that density might not increase during periods of greater migration because the fish are migrating rather than searching for rearing habitat.

Sampling Area: RM 18, and RM 5 to RM 7.

Methods: Chinook density could be quantified as catch per beach seine haul at RM 5-7. A screw trap could be deployed at RM 18 (see Nelson et al. 2004) to determine relative numbers of fish moving into the RM 5-7 area. Regression analysis of fish density (beach seine) on fish abundance (catch per day) could be used to determine whether density increases linearly (capacity not reached) or curvi-linearly (capacity reached) in relation to numbers of migrating fish at RM 18. Data values would likely be based on weekly mean capture rates. The analysis should consider a number of potential independent variables, including hatchery Chinook salmon, total Chinook salmon, total salmon, and total fish abundance. Flow, water temperature, and tide stage are potential influential factors that should be examined.

Sample Timing: Weekly between late April to early July.

Effort and confidence: This approach is fairly straight forward and builds upon previously described efforts. Catch rates can be highly variable, thus two years of data collection is recommended. Sampling effort overlaps with that of other objectives, although the RM 18 screw trap is needed here. As noted above, some interpretation of the findings is required. If leveling-off of fish densities is observed, it could be due to habitat capacity being reached or fish actively migrating rather than seeking rearing habitat.

Cost: Moderate.

Question 1.1d: *Does individual fish residence time in the upper estuary change in relation to density?*

Sampling Area: RM 5 and RM 7.

Methods: There are several potential methods to examine residence time: 1) large numbers of Chinook salmon could be spray marked with one of five colors (see above), 2) fish could be injected with a PIT tag (more expensive and time consuming to mark), and/or 3) daily otolith rings in conjunction with Sr levels could be used to identify residence time in brackish and marine water prior to capture. Residence time of marked fish would be determined by regular (at least twice per week) sampling at RM 5 and RM 7; sampling for otoliths would require less sampling in the field but more lab time. Sampling effort should be consistent each sampling day (i.e., equal sets per day per area) and regularly-spaced over time. An index of residence time could be calculated and compared among fish marked before and after high densities of salmon. Otoliths could be examined to determine whether residence time in brackish and marine water declined in response to greater fish abundance, e.g., when hatchery fish are released.

Sample Timing: Twice per week between late April and early July.

Effort and confidence: The mark/recapture approach requires a large amount of field effort that will likely result in relatively small numbers of recaptured marked fish. For example, in 2003, only 17 of 43,000 marked fish (mostly migrating fish at Soos Creek) were subsequently recaptured at downstream locations (Nelson et al. 2004). The benefit of the mark/recapture findings relative to the effort is believed to be lower than other studies noted above. The otolith approach would require less field effort and each fish represents a data point. An otolith residence time study could be combined with the otolith growth study, as noted above. However, results of the ongoing otolith study should be reviewed before initiation of additional otolith analyses.

Cost: Low to Moderate.

1.2 Habitat in the lower Green River is adequate for supporting all potential Chinook life history trajectories during both high and low flow periods.

The lower Green River (RM 11 to 32) is channelized for flood control and there appears to be relatively little habitat where small juvenile salmon fry can rear, especially during periods of higher flows. Little or no side channel habitat occurs in this area. The objective of this investigation is to determine whether habitat in this area is sufficient to support Chinook salmon during periods of high and low river flow (velocity). Opportunistic visual observations in 2003 indicated juvenile Chinook salmon were present behind root wads or other refuges from velocity during low flows (<1,500 cfs), but few fish were apparent during higher flows (>2,000 cfs). Beach seining at RM 13 and screw trap sampling at RM 18 demonstrated fish were moving through the area at higher flows (Nelson et al. 2004). There was some evidence that low flow may have led to prolonged rearing of smaller Chinook salmon at RM 13, but additional effort is needed to examine this question.

Sampling Area: RM 11 to RM 32.

Methods: This hypothesis could be approached from a habitat-based methodology and/or from a fish sampling methodology. The habitat approach would be to examine a number of river cross sections (number depends on identification of unique reaches) and quantify the percentage and area of habitat, including water velocity, depth, substrate type, cover, etc, at various flows. Relationships between river flow and usable habitat area for Chinook fry and fingerlings could be developed using habitat preference curves for Chinook salmon (after verification in field). This approach is known as the Instream Flow Incremental Methodology (IFIM), which was developed by the USFWS (www.fort.usgs.gov/products/Publications/3910/chapter1.html). However, this labor-intensive approach does not provide data on whether Chinook salmon will actually utilize the lower river reach for extended rearing. A baseline description of habitat in the lower Green River was developed for King County by Anchor Environmental during 2003.

The fish-based approach could utilize two types of observations: 1) observations of fish within the existing river habitat at various flows (and velocities), and 2) an experimental approach in which habitat is experimentally manipulated. The objective would be to determine whether similar numbers and sizes of juvenile Chinook salmon utilize habitats in this area during both high and low flows.

Observations of salmon in existing habitat should be made at a number of sites. Visual observations may be made from the riverbank, from a boat, or while snorkeling (visibility can be poor especially when flow increases). Electrofishing may also be used if permits can be obtained from NMFS. It is anticipated that fish will seek shallow areas. Species identification and approximate fish size should be recorded in addition to information on habitat, velocity, and area of habitat surveyed. Specific sites should be revisited during low, moderate and high flows. These observations could be made during height, moderate, and low flows during the peak fry migration period and the peak fingerling migration period.

The experimental approach would be to create refuges from higher river velocity, then make observations to see whether Chinook salmon utilize these habitats. Refuges could be created with root wads, but a simpler, more cost effective approach would be to establish small seines angling into the current from the riverbank (e.g., Harvey et al. 1997). Numbers and sizes of fish holding in the areas could be determined by 1) visual observation (less likely), 2) dip netting fish until zero catch, or 3) electrofishing. Residence time could be approximated by marking fish, placing them in the refuge area, and then sampling daily. This type of information could be useful to determine whether Chinook salmon will utilize habitat if created in the lower Green River.

Sample Timing: High, moderate, and low flows during peak fry and peak fingerling migrations.

Effort and confidence: This fish-based approach likely requires less effort compared with beach seine studies described above. Some simple monitoring, even of existing habitat, could provide important information regarding the use of habitat in the lower Green River during various flow levels. The IFIM approach is much more effort-intensive, but it would provide more quantitative information on habitat in relation to flow.

Cost: Low to Moderate for the fish-based approach; moderate to high for the IFIM study depending on the number of reaches sampled.

1.3 Juvenile Chinook salmon utilize Duwamish estuarine habitat types randomly.

Sampling Area: RM 0 to RM 7.

Methods: The first part of this study would be to define habitat types. There have been previous studies of habitat types in the area. Some habitat types that might be considered include: mainstem armored and unarmored shorelines, areas with and without vegetation, steep slope versus gentle slope, mainstem versus off-channel sites (Herrings House, T105, Hamm Creek, 1st Ave Bridge water retention facility, C.B. Moses Park), uncovered versus habitats with overwater structures, mid-channel versus littoral areas.

In 2003, Morley and Toft (2004) mapped habitat types (armored unvegetated shoreline versus unarmored vegetated shoreline). They identified eight paired sites (armored versus unarmored) and have proposed to test for differences in fish abundance, fish stomach contents, and prey abundance in 2004, pending funding. They plan to use a beach seine to sample fishes during the peak month of juvenile Chinook salmon. The experimental design of pairing armored and unarmored habitats in the same reach is a favorable approach.

Sampling could be expanded to include other habitat types, but complications may arise if catch rates are based on different gear types. Recent field studies have developed catch rates of juvenile salmon in mainstem using beach seine (Nelson et al. 2004) and off-channel sites using a blocking seine (Ruggerone and Jeanes 2004). Although funds have not been appropriated, these datasets could be compared by standardizing the data by water volume or water surface area sampled.

Comparison of fish abundance with and without overwater structures could be conducted using an Oneida trap. The Oneida trap is a floating net box with a lead net that guides fish into the box. The trap could be set in adjacent areas with and without overwater structures (Weitkamp and Schadt 1982, Ratte 1985, Nelson et al. 2004). Catch rates would not be directly comparable with other gear types.

Toft et al. (2003) developed an enclosure net approach to sample fishes in complex boulder habitats where beach seines are typically inefficient. This gear type requires high effort per sample (e.g., crew of 3 and a boat for 1 day to obtain 1 sample), but it can be used in complex habitat areas. Catches could be standardized by water volume or surface area sampled.

Fishes in mid-channel areas could be sampled by research purse seine (low catch per effort) or by two-boat tow net (higher catch rates, but descaling of fish and mortality is likely). Catch rates could be standardized by surface area or water volume sampled.

Testing for fish preferences of habitat types can be confounded by a variety of factors, thus it is best to identify areas where each habitat type can be sampled in proximity to each other. Tide stage is one factor that will be difficult to control. Nevertheless, these gear types could be deployed in a systematic manner such that differences in habitat preference might be detected if these differences are relatively great; small differences will likely go undetected.

Sampling should be conducted during peak migration of fingerlings and/or peak migration of fry in order to have better probability of detecting differences in fish density. Sampling before and after the peak migrations could be beneficial but catch rates may be too low in some areas to detect a potential difference between habitats. For example, Nelson et al. (2004) reported that geometric mean beach seine catches at Kellogg Island and Terminal 5 were typically less than two natural Chinook salmon per set when sampling outside the peak migration period, whereas catch rates near RM 4, RM 5.5 and RM 7 were approximately 10 natural Chinook per set. The fingerling migration period will likely include hatchery Chinook salmon, which must be identified by adipose fin clip and a CWT wand. Catch rates are likely to be highly variable, thus sample size (number of gear sets) should be high. Ideally, each habitat type should be replicated in at least three areas. Each habitat and areas should be sampled twice per week for a month at the peak migration period.

<u>Sample Timing</u>: May to late June.

<u>Effort and confidence</u>: This investigation can require considerable effort if a variety of habitat types are sampled. Morley and Toft (2004) estimated the cost to sample weekly eight-pair sites (two habitat types) by beach seine for one month to be $52,000. Sampling fishes by snorkeling in the Duwamish would likely be unsuccessful because water clarity is typically poor (< 2 m). High variability is anticipated, but trends in catch rates by habitat type may emerge after considerable effort. We already know fish aggregate near RM 5.5 and RM 7 (i.e., freshwater transition zone, large eddy), so the study might focus on other areas. An interesting question is why fish do not aggregate near Kellogg Island compared with 5.5 and RM 7 (Nelson et al. 2004).

Cost: Low to moderate depending on number of sites selected and duration of study.

1.4 Chinook salmon utilize marine nearshore habitat types randomly.

After leaving the river and estuary, many juvenile Chinook salmon rear in nearshore waters before moving offshore. Types of habitats preferred by juvenile Chinook salmon are thought to include areas with structure and complexity such as eelgrass, macrophytes, cobble areas. However, in Puget Sound and within WRIA 9 little quantitative information is available on types of habitat preferred by juvenile Chinook salmon.

Sampling Area: Nearshore habitats across at least three areas, each with two or more habitat types. Habitat types to be studied must be defined.

Methods: Sampling in nearshore areas poses some problems for most sampling gear. King County has proposed a "Core Areas" study to identify specific areas and habitat types where juvenile salmon aggregate in nearshore marine areas, although the study has yet to be funded. The pilot work for this study, which utilized a beach seine, found that it was difficult to identify specific areas or habitat areas where juvenile salmon aggregate, partly because there are many factors that contribute to the abundance of juvenile salmon (e.g., proximity to major river, tide stage, substrate type, beach slope, eelgrass and macrophyte abundance, exposure to wind and waves, current, topography). Sampling with greater effort, as initially proposed, may have provided greater resolution in catch rates between sampling sites. Substrate in some nearshore areas prohibited use of the beach seine.

The roughness of shoreline habitat made it desirable to develop sampling gear that could be used in areas having vegetation or boulders. Recently, the UW developed an enclosure net approach (fish corral) whereby an area of nearshore is fenced at high tide and then fishes are sampled after the tide ebbs (Toft et al. 2003). Additionally, snorkel surveys along transects provide the means to gather fish abundance data more rapidly when water clarity is sufficient (>3.5 to 4 m Secchi depth). Enclosure nets and snorkel surveys could be used to sample Chinook preference for specific habitat types and plans are being developed for this purpose in 2004 (J. Toft, UW, pers. comm.). Habitat types to be studied must be defined. Ideally, to test preference, each habitat type should be present in each sampling area (i.e., an area where the only difference is the type of habitat). In nature, this does not occur often because many factors lead to the variety of habitats that are available. Thus, a first step would be to identify two or more habitat types are located within the same area. A least three areas should be sampled. Next, enclosure nets should be used to sample fish during each high tide.

Densities of juvenile Chinook salmon can be relatively low in nearshore marine areas (compared with river and estuary) because fish disperse across numerous miles of shoreline (Nelson et al. 2004). In 2002, the enclosure nets set in Shilshole Bay yielded, on average, 5.5 natural Chinook and 5.0 hatchery Chinook salmon per set during late May to early July. Thus, this study should target the time period when juvenile Chinook salmon are most likely to be abundant in the nearshore areas (June and July). During the sampling period, fish should be sampled several times per week in order to capture sufficient numbers of fish to detect a potential difference in abundance (or size) by habitat type. Catch data collected by the UW could be used to refine sampling efforts. Analysis of variance could be used to test preference hypotheses.

One approach to take a first step at examining this hypothesis is to conduct a landscape scale analysis of linkages between marine nearshore habitat and usage patterns of juvenile salmonids, with an emphasis on Chinook salmon. This analysis could be accomplished through examination of previously collected datasets related to the WRIA 9 geographic area and forming an overall picture of how juvenile salmon use shoreline habitats. Such an approach will involve linking fish sampling data directly to a habitat classification scheme, to determine if salmon are selectively using specific habitat types. Once there is a better understanding of whether salmon actually prefer specific habitat types, fish use data could be matched with a GIS survey of habitat types to examine factors of overall fish densities, taxa richness, and diversity as related to current and historic fish usage patterns. This effort would require mostly data gathering and analysis, with possibly some field verifications (summer months) as needed.

Sample Timing: During peak juvenile abundance between late May and June in south sound area, over two years. Synthesis efforts of fish density data could take place anytime; however, any field verification should occur during summer months.

Effort and confidence: Determining habitat preferences of Chinook salmon in nearshore marine areas is challenging because Chinook density is generally low and variable and because it may be difficult to conduct a controlled experiment (i.e., different habitat types in same locale). A two-year study is recommended because catch rates are likely to be low and a large sample size would likely be needed to detect a difference between habitats. The setting and sampling of an enclosure net requires considerable effort. Toft et al. (2003) noted that an intensive effort of snorkeling and sampling with an enclosure net would require one day for four people and a boat, assuming net poles were previously set up. Snorkeling can cover more areas in less time and can be used to sample overwater areas, but snorkeling can be limited by water clarity and salmon species identification; hatchery/wild determinations can be especially difficult.

Intensive sampling with a beach seine, as initially proposed by the "Core Areas" study, might identify areas where salmon tend to aggregate along the nearshore marine habitats. A beach seine is relatively quick to deploy, especially if the sampling effort focused on salmonids, and many areas could be sampled (except for rough bottom areas, as previously noted). The beach seine approach would be useful for identifying and describing areas where salmon aggregate. However, the beach seine approach would be less suitable for examining habitat preferences of salmon because some rough-bottom areas would not be suitable for sampling. Conceivably, the enclosure net and beach seine approach could be combined in order to take advantage of the benefits of both gear types. For example, fish densities could be calculated and compared using water volume sampled by the two gears.

With sufficient data, an analysis of linkages between marine nearshore habitat and usage patterns of juvenile salmonids may be a good first step to refining marine nearshore habitat hypotheses before conducting extensive field efforts.

Cost: Moderate for field studies. Low for analysis and field verification of existing data.

1.5 Growth of natural juvenile Chinook salmon in the lower river and estuary is adequate and not influenced by releases of hatchery fish. Diet is opportunistic and prey resources are adequate.

The approach used for this hypothesis would be similar to that for Question 1.1b (see above), with an expanded study area.

Sampling Area: RM 0 to RM 32.

Methods: Capture fish to estimate their length, weight, and stomach contents before, during and after hatchery releases, as well as at times of high abundance of other salmonids species (see Methods for Question 1.1b). Additional methods could include mark and recapture studies or otolith analysis. To examine prey resources, invertebrate samples should be taken from a variety of habitat types and compared with stomach samples. Morley and Toft (2004) examined physical and biological differences in 2003 between eight paired sites characteristic of rip-rap bank armoring and riparian vegetation in the Duwamish River. Preliminary results indicated that significant differences exist between sites in terms of temperature regime and invertebrate abundance at sites with and without riparian vegetation. In 2004, they have proposed to directly link observed differences in habitat quality with fish use data through collecting temperature and invertebrate data, as well as monitoring fish use, condition, and diet at a sub-set of their eight study sites. The 2004 study currently has no funding. However, it may be useful to compare stomach samples collected in 2003 (in connection with Nelson et al. 2004) with invertebrate samples collected under the Morley and Toft 2003 effort to examine 1) how invertebrate compositions at various sites compare with fish diets; and 2) whether any relationships can be established between preferred prey types and the habitats that produce them (armored/unarmored, vegetated/unvegetated). Additional stomach samples and invertebrate samples collected through other efforts (e.g., Port of Seattle/Taylor Associates, UW Wetland Ecosystem Team) may also be useful in generating a picture of diet and prey resources in the Duwamish River. Additionally, automated invertebrate sampling developed by Taylor Associates may be helpful for gathering prey availability information related to habitat types.

Sample Timing: Weekly between late April to early July.

Effort and confidence: The diet study has a reasonable chance of success if adequate samples (numbers of fish) can be achieved. Sampling of fishes needed for this project can be shared with study objectives of other investigations (e.g., Question 1.1b). Analysis of existing stomach and invertebrate samples and conducting a synthesis of all existing data may be a good first step toward addressing the diet/prey portion of this hypothesis, as well as the diet portion of Question 1.1b. An effort to correlate fish diet with prey availability in a specific habitat may be confounded by movement of fish into the study area from other habitats.

Cost: Moderate to High, although analysis and synthesis of existing diet and prey samples would be very low cost.

Hypothesis 2: Life history diversity and productivity of Green/Duwamish Chinook salmon are adequate.

2.1 The Green River produces multiple juvenile Chinook salmon life history trajectories.

Field studies in the Green/Duwamish watershed have been conducted since the mass marking of most hatchery Chinook salmon began and these studies have provided information on juvenile life history trajectories of natural Chinook salmon. We now know that there are both fry and fingerling migrants that leave the middle Green River, and these trajectories have been observed in several Northwest watersheds. We also know that these fry and fingerlings rear in the upper estuary and other areas, though the length of residency is still unknown. However, we do not know whether fry migrants actively leave the middle Green River and actively enter Puget Sound with little rearing in the lower river and estuary. Fry migrants represent the majority of fish leaving the middle Green River, although this is in part because they are relatively young and have not undergone periods of mortality. Healey (1991) reviewed the literature and suggested that fry migrants typically rear in the estuary before migrating into marine waters. In addition to the rearing behavior of fry migrants, it is uncertain how these fry and fingerling trajectories contribute to adult returns.

Question 2.1a: *What is the migration behavior and habitat use of fry in the estuary and marine nearshore?*

Data collected in 2003 by Nelson et al. (2004) suggested some fry actively migrated from the middle Green River because numerous fry were captured at RM 34.5 during one period of low flow (1,000 cfs). Some fish were also observed entering nearshore marine waters with little or no rearing, but flows were also high and may have flushed fry out of the watershed.

Sampling Area: RM 7 to RM 0 and marine nearshore areas.

Methods: An experimental approach could be utilized to address the question whether fry actively and rapidly migrate through the estuary to marine waters. One approach involves mass marking numerous fry in the river, then trying to recapture them near Terminal 5 (RM 0), Seacrest, Alki and/or Pier 90/91 to determine residence time. Fry could be captured by beach seine and spray marked (one of five colors) at the Turning Basin and Trimaran areas during the peak migration period. Holding pens could be used to hold large numbers of marked fry for one or two days before release. Alternatively, fish could be injected with a CWT or PIT tags[12]. However, tagging fish requires more time and cost, therefore fewer fish could be marked. A large number of fry must be marked and released on the same day. After release, beach seining should commence on a daily basis at nearshore marine sites to determine time between release and capture (black light boxes needed to detect marked fish). Fish could also be sampled by a two-boat surface tow net, but this method produces somewhat higher mortality (this method was developed 50 years ago in Alaska using small skiffs). River flow should be recorded. Spray marking could be repeated five times, each with a different color. High capture rates during periods of relatively low flow would suggest active migration.

Alternatively, and in conjunction with the above approach, residence time in marine waters prior to capture could be estimated from otoliths of Chinook fry captured near Terminal 5. Daily rings would be counted within the zone of high Sr concentration to determine time spent in marine waters (Volk and Ruggerone 2004). Residence time (days) could be compared with travel distance from approximately RM 7 and RM 0 (Terminal 5) to determine whether some fish actively moved out of the system (e.g., typical cruising speed of salmon is one body length per second). The focus here would be on numbers of fish with short residence time since longer residence time may reflect earlier migration. Samples could be collected during periods of high, moderate and low flow to test whether high flow pushes some fish into Puget Sound.

Sample Timing: Peak fry migration (~Mid-February to early March).

Effort and confidence: The mark and recapture study could require considerable effort over the one-month period in order to capture, mark, and then recover sufficient numbers of fish.

[12] The question of whether fry survive after moving quickly through the estuary to marine waters is a separate question that is addressed below. Tracking with ultrasonic tags is not possible with fry. New technology may allow

Identification of spray marked fish in a black-light box is a tedious one-fish-at-a-time process. The otolith study would require less field time but more lab time to count daily rings and identify the zone of high strontium, which corresponds with marine waters. This study does not address an important, related question, which is to identify the relative adult returns and/or survival rates of fry versus fingerling migrants.

Cost: Low to Moderate.

Question 2.1b: *What is the survival and contribution to adult returns of the fry and fingerling life history trajectories?*

Sampling Area: Juveniles: RM 34.5 screw trap. Adults: fishery and spawning grounds.

Methods: Survival of fry and fingerling migrants and their contribution to the adult return could be estimated by uniquely marking a large number of fry and fingerlings at the RM 34.5 screw trap, then recovering marked fish in the adult returns. Sampling of 100% of adults for the marks is unlikely, therefore the percentage of adults sampled for marks must be estimated in order to calculate a survival rate for each trajectory. Adults must be sampled for marks for several years after release because they will mature at several ages (most after two and three winters at sea).

Fry would be marked at RM 34.5 during the peak migration during late February through March; fingerlings would be marked during the peak fingerling migration in approximately May through early June. Several approaches are available to mass mark large numbers of fry versus fingerling migrants. A unique thermal mark on the otolith could be rapidly applied to large numbers of Chinook salmon. Thermally marking is now widespread among hatcheries and it can be applied to fishes of all sizes. Alternatively, the two size groups could be tagged. Although pink salmon in Alaska have received CWT, salmon typically receive a CWT after some growth. A third marking approach would be to remove either the left or right pelvic fin. However, pelvic fins can regenerate if removal is incomplete, so quality control is essential. Also, literature of the survival of fish after pelvic fin removal should be examined (note: pelvic fins of steelhead are commonly removed). Scale patterns may not work for this specific question because the scale

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tracking of fish as small as ~90-100 mm, but effects of large tag on fish behavior has not been determined. Radio tags do not work in salt water.

pattern reflects growth and may not identify whether the fish emigrated downstream as a fry or as a fingerling.

Sample Timing: Peak fry and fingerling migrations (~Mid-February to early March; ~May to early June).

Effort and confidence: Each marking approach has advantages and disadvantages. The thermal marking procedure should be fairly straight-forward, but it will require holding tanks, refrigeration, and oxygenation of the aquaria at the RM 34.5 trap site. Many adult otoliths must be examined in order to find fish that have thermal marks. The WDFW and ADFG have laboratories that perform these tasks on a regular basis. The CWT procedure requires significant effort to place a CWT in 40-45 mm fish (feasibility of this must be determined). All technicians that sample adults must use CWT wands to detect the CWT in the snout of fish. Pelvic fin clipping is a relatively slow process (especially for 40 mm fish) that requires careful quality control, but clipped fish would be relatively easy to sample as adults. This study does not address the question of whether fry that rapidly migrate through the estuary and enter Puget Sound survive to adults.

Cost: Low to Moderate, depending on whether juvenile trapping and most adult sampling are ongoing.

2.2 Productivity and capacity of natural Green River Chinook salmon are adequate and comparable to other summer/fall Chinook salmon populations.

Sampling Area: Watershed-wide.

Methods: Productivity and capacity of a salmon population can be described from the relationship between adult returns and the number of spawners that produced the return (Ricker 1954). This relationship is often called a recruitment curve and it can be used to describe the status of a stock. Values of productivity (slope of curve near origin), capacity (asymptote) and rate of annual growth (lamda) can be calculated and compared with those of other salmon stocks.

Many historical data are available for the Green River but the database needs considerable attention. A new reconstruction of the Green River Chinook salmon run is needed to overhaul the existing dataset. First, new escapement and stray data need to be examined in an effort to make historical data consistent with current data and to provide the most accurate data possible. Next, the terminal harvest estimates (hatchery and natural) need to be adjusted to account for the new spawning escapement estimates. Next, CWT data need to be examined in an effort to estimate non-terminal harvests of Green River Chinook salmon, including sport catches and harvests in British Columbia (see Weitkamp and Ruggerone 2000).

With a revised dataset, a recruitment curve can be developed. Sensitivity analysis can be used to incorporate uncertainty in the hatchery stray rate. Additionally, the rate of annual population growth (lamda) can be calculated with these new data. These values can be compared with other systems where recruitment curves exist.

Alternatively, juvenile growth rates can be used as an index of productivity and compared with other stocks (see Nelson et al. 2004).

<u>Sample Timing</u>: Not applicable.

<u>Effort and confidence</u>: This project will require some effort to analyze and synthesize existing data, but less effort than most field projects. Issues of stray rates, productivity of hatchery fish spawning in wild, and harvests in non-terminal areas will remain, but variability in estimates can be modeled into the effort.

<u>Cost</u>: Low.

Hypothesis 3: Chinook spawning habitat is adequate in terms of quality, quantity, and spatial distribution

Recent mark and recapture studies by WDFW indicate the previous methodology for estimating numbers of Chinook salmon on the spawning grounds of the Green River may have underestimated spawners by approximately 50% during 1997-2002 (T. Cropp, WDFW, pers. comm.). During 1997-2003, an estimated 13,000 fish (hatchery and natural origin) spawned in the river, on average. Spawning distribution is presently confined to mainstem reaches between RM 25 and RM 61 where migration is blocked by the Tacoma Diversion Dam. Additional spawning occurs in Soos and Newaukum creeks. Thus, spawning distribution is limited to a moderate portion of the watershed. Malcom (2002) investigated the distribution of spawners on the spawning grounds during 1997-2000. Recent unpublished WDFW spawning data, based on relatively intensive sampling of the spawning grounds, indicate the percentage of spawners above and below RM 34.5 varies considerably from year-to-year, but factors contributing to patterns of spawner distribution have not been examined. The key limitations to spawning distribution in the Green River are blockages of the mainstem channel by the Tacoma Diversion Dam and Howard Hanson Dam. The ACOE plans to trap and haul spawners around these structures. Downstream of these structures, there are concerns about the amount of spawning habitat and the quality of that habitat (sedimentation).

3.1 Chinook egg-to-fry survival is adequate compared with that of other populations.

While there are several hypotheses to look at the quantity and quality of spawning habitat, it is important to first assess whether egg-to-fry survival is a problem in the Green River, relative to other populations. If egg-to-fry survival is low, then causes for that reduced survival need to be examined.

Sampling Area: Spawning grounds: RM 25 to RM 61.

Methods: Screw trap data at RM 34.5 have been collected by WDFW during 2000, 2001, 2002, and 2003. This data provides an estimate of egg-to-fry survival, based upon spawning and fecundity estimates. Although there is a limited amount of data, this information can be used to determine if egg-to-fry survival is low in the Green River, relative to other systems. However, only one year of WDFW's data has been analyzed and reported and additional data will need to be analyzed before any conclusion can be reached.

Alternatively, redd capping could be conducted to look at egg-to-fry survival in individual redds in a variety of habitats. Redds would need to be identified during the spawning season and their spawning date known. From that date and water temperature, expected emergence timing could be estimated and the redds capped at the appropriate time to capture the majority of fry emerging from the gravel. Traps would need to be visited daily to count and release any trapped fry. A large enough number of redds would need to be sampled to allow for a robust egg-to-fry survival estimate. Fecundity might be estimated from female length, if it can be estimated while guarding the redd, and previously published relationships between fecundity and length.

Sample Timing: Fry trapping and redd capping: January to July. For redd capping, field surveys would be needed during the spawning season as well.

Effort and confidence: Data from the screw trap are important for a variety of studies and would be extremely useful for answering this hypothesis as WDFW typically calculates egg-to-fry survival (e.g., Seiler et al. 2002). Looking at past years' reports would require little effort but confidence in the answer would depend upon at least the remaining three years of data, plus additional years. Unfortunately, WDFW has not secured future funding to operate the trap. Conducting a study to cap redds could yield good data as this approach has been used in numerous studies; however, it would require a high level of field effort during the emergence period, as well as a moderate effort during the previous spawning season. As noted by Healey (1991), there are not numerous published reports on egg-to-fry survival of Chinook salmon. Published estimates indicate survival can vary considerably between years and locations.

Cost: Low to moderate. Low (i.e., none) to look at past WDFW including trapping effort. Moderate costs to support future WDFW efforts or to conduct a redd capping project.

3.2 There is adequate spawning habitat quantity to support spawning Chinook salmon.

Sampling Area: Spawning grounds: RM 25 to RM 61.

Methods: Adequacy of the quantity of spawning habitat can be evaluated by 1) field observations and/or 2) by developing a recruitment curve that shows the relationship between adult returns from a given spawning level.

Field observations can be used to identify the capacity of the Green River to support spawning Chinook salmon by 1) estimating average redd area utilized by a spawning pair, 2) estimating area of habitat utilized for spawning of all species spawning when Chinook are present[13], and 3) comparing the calculated spawning capacity with the observed spawning estimates. The area of redd excavation by spawning Chinook salmon has been documented in other studies (range: 0.5-44.8 m^2, but often 4-10 m^2; Healey 1991, Cedar River data collected by SPU and KCDNRP) and could be applied to the Green River. Redd area estimates should be verified in the Green River by observing and measuring redds in high quality areas when relatively few fish are present (i.e., so redd area can be measured without potential influence of crowding). Areas of spawning can be mapped and quantified (m^2). Total spawning area utilized by salmon in the Green River may expand and contract depending on the number of spawners. Fish will likely utilize less desirable spawning habitat when densities are high, whereas high quality areas will be selected when densities are low[14]. Salmon are exceptional at finding individual patches of spawning area. Given limited resources to conduct this study, it would be worthwhile to discuss field logistics with WDFW biologists that conduct spawning surveys in order to identify key spawning areas to be surveyed. Existing redd counts per river mile could be compared with that of other Puget Sound rivers to determine whether density is high in the Green River (we suspect density is very high in the Green). Similar data could be collected for other salmon species, if funding was sufficient.

A recruitment curve (see above) can also be used to identify the spawning level at which spawning capacity is reached. Spawning capacity is indicated by the spawning level at which

[13] Salmon species tend to spawn in different areas, but there can be significant overlap and interaction. For example, Puget Sound chum salmon, which tend to spawn late, have reportedly impacted survival of pink salmon, which spawn early. Chinook will tend to spawn in deeper, somewhat swifter, larger cobble areas compared with other salmon, but there can be overlap. Coho tend to spawn later than Chinook salmon and could disrupt some Chinook redds.

[14] If this is true, an interesting question is whether natural origin fish tend to utilize higher quality spawning habitats compared with hatchery fish. Given the high percentage of stray hatchery fish on the spawning grounds, production of natural origin Chinook salmon might decline if hatchery fish are abundant and the distribution of hatchery and natural spawners is random.

recruitment curve approaches an asymptote. However, since a recruitment curve is based on the total life cycle, an asymptote can also reflect the capacity of juvenile rearing. Recruitment curves typically have considerable variability and identification of an asymptote may be difficult to identify (see Weitkamp and Ruggerone 2000). This approach should only be taken after updating the spawner and adult return database (see above).

Sample Timing: Mid-September through October (peak spawning is ~mid-October).

Effort and confidence: WDFW presently counts number of redds by river reach. The level of survey detail has varied over the years; more detail was provided in recent years when the mark/recapture study was conducted. In 2002, the data were shown for 32 reaches in the mainstem. Thus, the primary field task would be to verify redd size and its variability. Revised historical redd counts can be used to examine the capacity question. This is a relatively straight-forward task having a moderate cost. One year of field data can be applied to a number of past datasets. One problem in interpreting the data is whether total redd area is the proper unit of measurement. For example, is egg-to-fry survival or spawning success reduced if there is some overlap in redd area, or should this calculation be based on the smaller area occupied by the egg nests? Alternatively, some researchers have argued that capacity should be based on an area larger (e.g., 4x) than the total redd area because females defend a larger area. Comparison of redd counts per river mile in the Green River and other watersheds would have low cost (it will likely show that the Green River has high density, in part, because many hatchery fish spawn in the river).

As noted above, the recruitment curve approach requires re-working of the WDFW database. There will be considerable variability in the recruitment curve, as is typical, because many factors affect recruitment. The cost is relatively low since field work is not needed. Most time would be spent reconstructing the database, which could also be used for other questions.

Cost: Low to Moderate.

3.3 The Green River has adequate spawning habitat quality to support Chinook salmon.

A number of factors contribute to the quality of spawning habitat, but a key factor is the level of sedimentation (Bjornn and Reiser 1991). Chinook salmon eggs are relatively large and have a low surface area to volume ratio; therefore, Chinook eggs may be more vulnerable to effects of low oxygen. Additionally, sedimentation can inhibit movement of alevins in the gravel, an important factor if fish are spawning near the river margin where low flow may dewater redds. Some fine sediment is removed by currents during redd construction, but some fines return to the redd sites over time depending on the level of sediment transport. T. Cropp (WDFW) suggested sedimentation of redds in the Green River was not unusually high, but this question has not been examined quantitatively.

Sampling Area: Spawning grounds: RM 25 to RM 61, areas above and below recent landslides.

Methods: The composition of fines in salmon redds can be sampled using the freeze core/gravel permeability procedure, which is described in the literature (e.g., Barnard and McBain 1994). Gravels in proximity to the egg pockets can be sampled, but this procedure can lead to mortality of embryos. The experimental design should include testing of fines in areas of high, moderate, and low spawning densities (see WDFW detailed spawning data records), both above and below recent landslide areas. Sample size in each area will depend on variability of fines, but at least three samples from each area are needed. Redds must be identified and marked during the spawning period for sampling after the female has died; it may be worthwhile to resample several redds over time to determine sedimentation rate. Gravel size composition can be measured with a series of sieve sizes. Researchers have associated embryo survival with a variety of fines indices, so the literature should be examined to identify and apply these indices to the Green River gravel dataset.

Sample Timing: October to March (peak spawning is ~mid-October).

Effort and confidence: This project requires a moderate to high level of effort in the field and lab during at least one season. The project should be able to identify whether sedimentation is a significant problem in the Green River.

Cost: Low to Moderate.

Hypothesis 4: Green River flow regime does not affect Green River juvenile Chinook survival by either 1) concentrating spawning in the thalweg and increasing risk of scour above natural levels, or 2) scouring eggs

or alevins from the gravel as a result of high flows during late fall through early spring.

Significant mortality of salmon typically occurs during the embryo incubation period because high flows can scour and kill embryos, and redds may receive considerable fines. Scouring occurs in undisturbed systems, but it may be exacerbated by human activities. It has been hypothesized that low water levels during the spawning period may concentrate spawners in the river thalweg (deepest part of channel), an area that is often most subjected to scouring during peak flows.

This hypothesis may be tested by 1) plotting fry production at the RM 34.5 screw trap in relation to peak winter flows, 2) measuring scour depth in relation to flows and depth of egg pockets, and 3) identifying the number and percentage of Chinook that spawn in the thalweg.

4.1 Fry production is not related to winter flow patterns.

Sampling Area: RM 34.5

Methods: Screw trap data at RM 34.5 have been collected by WDFW during 2000, 2001, 2002, and 2003. Ideally, it would be good to have six more years of data in order to include a range of peak flows and to better identify flow levels that affect fry production. Spawning levels should be used to calculate egg-to-fry survival. Catches of juvenile Chinook salmon at RM 34.5 (not expanded for trap efficiency) were markedly higher during 2001, a year of exceptionally low late fall to early spring flows and relatively high percentage of spawners above the trap (Nelson et al. 2004).

Sample Timing: January to July

Effort and confidence: Data from the screw trap are important for a variety of studies, including this study. WDFW typically calculates egg-to-fry survival (e.g., Seiler et al. 2002). However, reports for the 2001, 2002, and 2003 sampling years have not been prepared as of January 2004. WDFW requires funding to operate the trap. This approach could yield important information about peak flow effects on egg-to-fry survival, but a number of years of data are needed because one year represents only one data point.

Cost: Moderate, including trapping effort.

4.2 *The depth of scour during flood events is not sufficient to disturb Chinook redds.*

Sampling Area: Spawning grounds: RM 25 to RM 61.

Methods: Scour chains (wiffle balls on a wire) can be used to measure depth of scour during a flood event and replenishment of gravels as the flood subsides (Nawa and Frissell 1993, Rennie and Millar 2000, DeVries 2000). Scour chains are relatively easy to build and are deployed by pounding the cable of balls and anchor into the gravel. Scour chains should be placed in areas of known Chinook salmon spawning. Placement of chains relative to nests may be important: a recent study indicated placement of chains in the tailspill behind the egg pockets over-estimated mortality due to scour (Rennie and Millar 2000). Scour depths can be compared with literature values of depth of Chinook salmon eggs (~20-30 cm) and depth of eggs can be measured in the Green River. Chains should be located on redds within river thalweg areas and in non-thalweg areas in order to test whether scouring is greater in the thalweg. Scour depths can be highly variable (Rennie and Millar 2000) so a number of chains should be deployed to examine this variability.

Sample Timing: Setup: Mid-September through October. Observe after each flood event October through March.

Effort and confidence: This project requires a number of days in the field to identify redds, anchor the chains, and monitor the chains after flood events. The experiment is dependent on flows during winter; therefore, two years of data may be beneficial, although data from one year could be quite useful. The cost will vary depending on the number of chains installed. A low cost pilot study could provide sufficient information to determine whether additional sampling is warranted.

Cost: Low to Moderate.

4.3 *A large proportion of adult Chinook do not spawn in the thalweg of the river.*

Sampling Area: Spawning grounds: RM 25 to RM 61.

Methods: Reaches with numerous spawners should be identified from the WDFW database (e.g., RM 33.3-34.5), but it is possible that cross-sectional distribution of spawners changes with fish density. Redds located within the thalweg versus redds in adjacent channel areas should be quantified for each study reach. Criteria to identify the thalweg area should be defined. For example, the thalweg area might be defined as 25% of the river cross-section within proximity of the thalweg. This definition can be refined. The cross-sectional profile (depth) should be measured to identify whether the channel is uniform or relatively deep at the thalweg. Since scouring is more likely in reaches where the thalweg is somewhat deep, sampling might focus in these areas. River flows at the approximate time of redd construction should be recorded. Flagging can be used to mark redds and to note time of construction. These spawning distribution data will provide a measure of Chinook salmon spawning within, versus adjacent to, the river thalweg. Depending on river flows throughout the spawning season, multiple years of data may be necessary to gain sufficient data on the percentage of spawners in the thalweg in relation to river flow. This relationship may vary with spawning reach; therefore, characteristics of each sampling area should be described.

Sample Timing: Mid-September through October (peak spawning is ~mid-October)

Effort and confidence: This project is a fairly straight-forward description of spawning distribution relative to the river thalweg. A pilot study could be conducted with relatively low cost. This study might entail examination of spawning distribution at possibly 25 reaches (each reach is one data point). This could be done within two weeks of fieldwork. The statistical test is to determine whether the percentage of spawners in the thalweg exceeds the percentage of river cross-section represented by the thalweg. River area that is poor spawning habitat (substrate, flow, and depth) should be excluded from the calculation.

Cost: Low, if WRIA 9 works collaboratively with WDFW and their spawning surveys.

MONITORING NEEDS

A starting point for any research program is generating baseline information about the overall status of the naturally spawning stocks. Salmon habitat in the lower Green River, Duwamish Waterway, and Puget Sound marine nearshore areas have undergone significant changes over many decades and it is logical to link Chinook salmon survival to these habitat alterations. Unfortunately, historical records are insufficient to allow us to describe pristine runs of Chinook salmon, and the current status of the naturally spawning population is confounded by the presence of hatchery Chinook salmon in the spawning escapement. Thus, a basic issue is to describe the status of the current natural Chinook salmon population. This will involve both ongoing monitoring programs and targeted research. Basic monitoring of Chinook populations is essential for tracking their recovery and for evaluating the effectiveness of habitat conservation activities.

A research program in WRIA 9 will depend on several important ongoing monitoring programs.

First, numbers of marked and unmarked (adipose fin clipped) hatchery Chinook salmon released into the watershed must be accurately enumerated at the hatchery and the hatcheries must strive to achieve 100% fin clipping. Fin clipping of hatchery fish is critical to understand the portion of the total Chinook run produced by naturally spawning fish. Juvenile hatchery Chinook are much more abundant than natural Chinook and even small percentages of unmarked hatchery Chinook, as a result of poor fin clipping, can confound interpretation of natural fish abundance, growth and survival. Thus, it is essential that juvenile research in the lower river and estuary be well coordinated with hatchery operations and that hatcheries accurately record marked and unmarked releases. Also, as noted below, additional methods to identify hatchery versus naturally produced fish (in the absence of fin clips) should be developed.

Second, operation of the screw trap at RM 32 is important for providing estimates of fry and smolt migrant abundances (and size) leaving the middle Green River area and entering the targeted study area (Seiler et al. 2002, Nelson et al. 2004). Additionally, the screw trap can be used to estimate egg-to-migrant survival rates (assuming spawner abundance and fecundity are measured) and timing and size of migrating juvenile Chinook salmon.

Third, accurate estimates of spawners originating from natural and hatchery parents is important to the development of a natural Chinook recruitment curve, which can provide a quantitative basis for management decisions and for tracking population recovery. A recruitment curve can be used to quantify the capacity and productivity of the population, which can then be compared with that of other Chinook populations. Furthermore, area-specific spawning estimates can be used to estimate production of specific habitats (patches), such as mainstem versus tributary spawning areas (i.e., spawning components that may be important to population diversity). A key factor presently confounding the evaluation of productivity of natural salmon in the Green River is the large number of hatchery Chinook salmon that spawn in the wild. Selective fishing for marked hatchery salmon could remove these hatchery fish from the spawning grounds and greatly improve quality of salmon productivity estimates. Greater certainty in the productivity estimates is needed to track and evaluate recovery of WRIA 9 Chinook salmon.

Fourth, analyses of CWT releases and recoveries in pre-terminal and terminal fisheries is important to run reconstruction and development of a recruitment curve because these fisheries typically intercept Chinook salmon from a variety of watersheds. Aside from the preliminary effort by Weitkamp and Ruggerone (2000), analysis of CWT recoveries have not been utilized for the development of a recruitment curve for the Green River basin. A recruitment curve is important for establishing spawning escapement goals to achieve maximum sustained harvests (or other targets). Also, estimates of harvests are important when estimating salmon survival and for evaluating characteristics of juvenile Chinook salmon that contribute to survival in nearshore marine and offshore waters. The Puget Sound Technical Recovery Team (TRT) has recently begun to utilize CWT data while reconstructing the natural run of Green River Chinook salmon, but a preliminary report of their finds is not yet available.

This baseline information will help identify changes in stock production over time which may be linked to actions taken under the WRIA plan. In addition, this ongoing work, especially operation of the screw trap and mass marking of hatchery salmon, will be foundational for addressing questions in this research framework.

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APPENDIX A

DETAILED REVIEW OF HYPOTHESES

This appendix represents work completed early in development of the WRIA 9 Chinook Salmon Research Framework. Below are the suggested hypotheses, key questions, and summaries of the current state of our knowledge in each suggested research area. Hypotheses are grouped by categories, which include 1) Life History Diversity, 2) Habitat Capacity, and 3) Productivity, Survival and Abundance. A number of miscellaneous research questions, some of which relate to the above three categories, are also included at the end of the appendix. The hypotheses and information in this appendix was used in constructing the conceptual model of Chinook salmon in WRIA 9, as well as identification of key research questions.

Life History Diversity

1. *Hypothesis:* Spawning aggregations in the present Green River watershed, including spatially and temporally segregated stocks and the hatchery stock, are genetically similar. Migration timing of spawning aggregations is similar.

   Key Questions:
   - Are spawning populations (including hatchery stock) genetically distinct?
   - Do spawning populations enter the watershed during somewhat different periods, or is it random?
   - Will fish access to upper Green River above Howard Hanson Dam lead to an increase in the early run component of the Chinook population?

2. *Hypothesis:* The Green River produces multiple juvenile Chinook salmon life history trajectories.

   Key Questions:
   - What is the relative frequency of juvenile Chinook life history trajectories leaving the watershed and returning as adults?
   - Do fry migrants contribute to adult returns at a similar rate as fingerling migrants after adjusting for juvenile age?
   - Will salmon passage upstream of Howard Hanson Dam lead to greater frequency of yearling Chinook salmon?

General Information

The most obvious life history strategies of juvenile Chinook salmon in the Northwest are fry migrants, fingerling migrants, and yearling migrants (Healey 1991). Other researchers (e.g., Reimers 1971) have suggested additional strategies, which are largely estuarine residence time variations on the above strategies. Taylor and Larkin (1986) observed behavioral differences among different populations of Chinook within the same streams.

Early and late migrations of subyearling Chinook salmon appear to be common in the Northwest (Healey 1991), including the Green River (Seiler et al. 2002). The viability of these life strategies is important because early migrants may depend on estuarine and nearshore marine habitats more than fingerling migrants. Early migrants typically are much more numerous and smaller than fingerling migrants. High mortality of early migrants may indicate the need to protect or restore habitats utilized by this life strategy. Some researchers have suggested that few if any early migrants survive (Lister and Walker 1966, Reimers 1971).

Few fry to adult survival studies of naturally-produced Chinook salmon have been conducted due to difficulties of marking fish and recovering them on the spawning grounds (Coronado and Hilborn 1998).

WRIA 9 Specific Information

Little is known about the presence and relative abundance of life strategies other than the fry and fingerling migrant work by Seiler et al. (2002). Small numbers of natural yearling Chinook may still be present, although many of these fish were lost to the Green River when the White River changed course.

Nothing is known about the survival of early vs. late migrants in the Green River because the juvenile migration type of returning adults has not been examined.

Current WRIA 9 Research for this Question

An ongoing residence time study of subyearling Chinook salmon in the Duwamish River, based on otolith microchemistry and daily growth rings, may provide information on this issue (Volk and Ruggerone 2004).

NMFS (L. McComas) and others are developing micro-acoustic tags that can be attached to salmon smolts, enabling their migration route to be quantified (F. Goetz, ACOE, pers. comm.). Presently, the target is to attach tags to 90 mm smolts, a size that is too large for most Green River subyearling Chinook salmon in the Duwamish River. This tag may be appropriate for larger fish in Puget Sound and yearling Chinook salmon. The tags will be tested at the Ballard Locks in 2003.

Otolith analysis by Ruggerone and Volk may provide information leading to a method to examine the question of survival of early and late migrants.

Habitat Capacity

3. *Hypothesis:* Chinook spawning habitat is adequate in terms of quality, quantity, and spatial distribution.

   Key Questions:
   - What is the spawning capacity of existing habitat?
   - Does redd superimposition occur in some habitats?
   - Does flow affect spawning capacity and/or quality of spawning habitats available to salmon?
   - Is spatial distribution of spawners broad enough to allow potential differentiation of spawning aggregations?
   - What habitat features are associated with high density versus low density spawning areas?
   - Will spawning above Howard Hanson Dam lead to different life history trajectories?

   (See questions below regarding egg-to-fry survival as means to assess quality and abundance of spawning habitat)

General Information
Gravel quantity and quality varies tremendously from watershed to watershed and from stream to stream. It is dependent on many factors, including local geology and stream gradient.

WRIA 9 Specific Information
Chinook natural spawning is most abundant in the mainstem of the Green River from Soos Creek upstream to the City of Tacoma water diversion. Substantial natural spawning also occurs in Soos Creek and Newaukum Creeks (WDFW/WWTIT 1994; WDF 1975). Nearly all spawning occurs upstream from about RM 24, therefore the amount of gravel is not a crucial factor in Chinook habitat in the reach downstream from this location.

The ACOE and City of Tacoma recognize gravel replenishment is reduced by Howard Hansen Dam and the City of Tacoma water diversion dam. Efforts have recently been made to add spawning gravel to upper areas of the middle Green River.

Current WRIA 9 Research for this Question
Monitoring of gravels in the middle Green River is likely to continue.

4. *Hypothesis:* The habitat capacity in the middle and lower Green River and Duwamish estuary is adequate (habitat type, quantity and quality) to support all potential juvenile life stages produced by natural and hatchery Chinook salmon.

   Key Questions:
   - Are habitats in the middle and lower Green River and Duwamish estuary sufficient to support a productive, abundant and diverse natural Chinook population?
   - What percentage of the Chinook population is supported by existing restoration sites and do these sites support higher densities of Chinook compared with other areas?
   - Do hatchery salmon affect feeding and residence time of natural Chinook salmon?

General Information
It appears juvenile Chinook use essentially any shoreline habitat type they encounter in their migration. Most investigations have documented presence and abundance in one or more habitat types without obtaining information that demonstrates preference.

In Sinclair Inlet during 2002, K. Fresh (NMFS) examined habitat types used by juvenile Chinook salmon, temporal pattern of distribution (seasonal and time of day), trophic interactions, residence time in the study area (fluorescent dye marking), and stocks that use the area (coded-wire-tags [CWTs]). Some results of the research will likely be available in 2004.

WRIA 9 Specific Information
In WRIA 9, juvenile Chinook have generally been found in shallow water shoreline areas, particularly with some protection from wave and current energy, but also under piers and along the face of piers and inside marinas (Meyer et al. 1980, Weitkamp and Campbell 1980, Weitkamp and Schadt 1982, Parametrix Inc. 1984, Tanner and Williams 1990, Tanner and Williams 1991, Taylor and Willey 1997). It appears that areas of relatively low current velocity and absence of substantial wave energy provide habitat conditions preferred by young Chinook during their lower river and estuarine rearing.

Current WRIA 9 Research for this Question
Studies on the use of nearshore marine habitats in vicinity of WRIA 9 are underway by King County and

the City of Seattle.

The USFWS monitored fish presence/absence at two restoration sites (Herring House and Hamm Creek) and two reference sites (Kellogg Island and Turning Basin 3) during 2001 and 2002, and they plan to repeat this effort in 2003, possibly adding work at Cecil Moses Memorial Estuary Park (K. Myers, USFWS, pers. comm.). The USFWS effort included measurements of slope erosion, vegetation, fish use, invertebrates, and birds. In 2002, the USFWS collaborated with the off-channel fish abundance and residence time study by Goetz and Ruggerone.

Si Simenstad (UW) is conducting studies at three Puget Sound locations (none in WRIA 9) to develop a wave energy model for determining factors affecting beach morphology. This information may be relevant to restoration planning in nearshore marine areas.

J. Brennan (King County) sampled juvenile salmon and other species in nearshore marine habitats of WRIAs 8 and 9 during 2000 to 2002. The 2000 sampling was considered pilot work and the level of detail and effort has increased in each subsequent year. He enumerated species, measured fish length and weight, and looked for fin clips (hatchery v. natural fish), PIT tags and CWTs. Sampling occurred every two weeks from mid-May through mid-October at 8 to 12 sites depending on year. Gastric lavage was used to non-lethally remove stomach contents of fish; year 2000 stomachs were sent to J. Cordell (UW) for analysis but have not been completed.

D. Martin and D. Shreffler conducted a pilot study during May 2003 to evaluate juvenile salmon use in various habitat types (e.g., eelgrass, kelp, sand, gravel, etc.) in nearshore marine waters surrounding Vashon and Maury Island during the period of peak use by Chinook salmon (Martin Environmental and Shreffler Environmental 2002). The Vashon Island area was selected because long stretches of unaltered habitat still remain. Forty-nine beach seine sets were made at 10 sites in May 2002.

Martin and Shreffler plan to conduct an expanded study that may include areas inside and outside King County (e.g., possibly sampling every 0.5 km around Vashon Island taking three samples around predicted peak migration. The goal of the study is to correlate fish numbers with habitat types, including eddies and currents, to predict habitats where salmon are likely to be found. Such areas might be protected more or selected for restoration. Additionally, in the Snohomish Snoqualmie rivers, they snorkeled 100 m areas and plan to correlate salmon abundance with habitat features. King County refers to this study as the "core habitat study."

In nearby Shilshole and Salmon bays, juvenile Chinook salmon tended to prefer sand substrate over cobble substrate (B. Footen, Muckleshoot Indian Tribe, pers. comm.).

5. *Hypothesis:* The relative abundance of fry versus fingerling migrants originating from the middle Green River is dependent on available habitat, which is influenced by river flow, fish density, and food availability. Alternatively, the migration pattern is genetically programmed or it is related to the percentage of adults spawning in the river thalweg and numbers of emerging fry that are carried downstream before reaching suitable, low velocity habitats.

   Key Questions:
   - What is the rearing capacity of the middle Green River for supporting juvenile Chinook salmon?
   - How is rearing capacity influenced by peak, average and low flows?
   - Is food availability adequate?

- Is there significant predation risk in middle Green?

6. *Hypothesis:* River flow during late winter and early spring “pushes” fry migrants into the estuary and marine waters, whereas freshets during May and June stimulate migration of fingerling migrants.

7. *Hypothesis:* The upper estuary (Trimaran, Turning Basin and adjacent areas) is a key long-term rearing habitat that supports both fry and fingerling migrants and the capacity of this habitat is adequate.

   Key Questions:
   - What is the density of juveniles in the upper estuary and how long do individuals remain in the area?
   - What are the upstream and downstream boundaries of the high-density area (are there any areas in the lower river)?
   - Is density related to the initial encounter with low salinity or to higher availability of low velocity habitat, or both?
   - Will additional habitat in this area lead to greater capacity for rearing juveniles?
   - What are the sizes of juveniles in this habitat throughout the season?
   - Are food and growth rate adequate?
   - Do predators seek out aggregations of juveniles?

General Information

Ellis (1957) found Chinook fry adapted rapidly to high salinity with high survival to adult returns with only five days incremental adaptation to saltwater (25-75%). Kreeger (1995) reported a difference in saltwater adaptation capability of Chinook fry from two watersheds. Under laboratory conditions 65% of Trask River Chinook survived 32‰ salinity at 50 days after first feeding, while only 40% of the Rogue River fish could tolerate this salinity. Both populations required 108 days following first feeding to competently osmoregulate in seawater. Wagner et al. (1969) found Chinook alevins were able to tolerate 15-20‰ salinity immediately following hatching, and tolerated higher salinities with increasing size. Fry of 65 mm (3 g) were able to tolerate 30‰. Sims (1970) reported young Chinook in the Columbia River that were marked one day in a fresh water area were found the next day in a high salinity area 43 km downstream.

WRIA 9 Specific Information

Existing data indicates high fish use in this location, suggesting this may be an important area for restoration (increasing capacity), but this observation might also be the result of habitat type (large, mostly shallow eddy).

In the Duwamish River the upstream extent and degree of salinity intrusion varies with tide stage and river flow. Dawson and Tilley (1972), Stoner et al. (1975) and Prych et al. (1976) provide information on the characteristics of saltwater intrusion in the Duwamish River. Surface salinities remain low (1-5‰) over high bottom salinities (20-30‰). Surface salinities of less than 5‰ extend downstream anywhere from about RM 4 to near the mouth of the river depending on river discharge and tide stage.

Warner and Fritz (1995) found that Chinook were more abundant in the freshwater portion of the Duwamish than in the more saline areas. Chinook fry have the capacity to readily adapt to seawater, as do yearlings following smoltification.

E. Warner, Muckleshoot Indian Tribe, collected an additional 1.5 years of data beyond that reported by Warner and Fritz (1995) (E. Warner, MIT, pers. comm.). This study examined relative abundance of fishes in the Duwamish River and provided additional information on temperature, salinity and dissolved oxygen. He hopes to prepare a report based on these data, but no timeline has been established.

Current WRIA 9 Research for this Question

During 2002, Taylor and Ruggerone observed large numbers of salmonids (including Chinook salmon) at Turning Basin 3, which is near the upper end of the salt water wedge. However, the abundance of fish in this area also probably reflects the presence of the large eddy.

8. *Hypothesis:* Habitat in the lower Green River is adequate for supporting all potential Chinook life history trajectories during both high and low flow periods.

9. *Hypothesis:* Residence time of fingerling migrants in the estuary is similar to that of fry migrants; it is independent of existing habitat quantity; and residence time is not affected by hatchery releases. (Residence time is a measure of dependence on this habitat; also see fry migrant Hypothesis.)

   Key Questions:
   - What is the residence time of fingerling versus fry migrants in the Duwamish estuary?
   - Do smaller juvenile Chinook rear longer (i.e., depend more) in lower river and estuarine habitats than larger juveniles?
   - How does this compare with juveniles from other less disturbed estuaries?
   - What is residence time in off-channel habitats?

General Information

Off-channel sites can provide important habitat for juvenile salmonids because these areas provide refuge from high velocities and abundant food production, including terrestrial prey.

WRIA 9 Specific Information

No previous work known.

Current WRIA 9 Research for this Question

During spring 2002, G. Ruggerone and F. Goetz (ACOE) developed and implemented a plan to estimate residence time and abundance of Chinook and other salmonids in four off-channel habitats in the Duwamish River, including two restoration sites. Preliminary analysis indicates that few individuals return to the off-channel sites after leaving the site as it dewaters at low tide (see Ruggerone and Jeanes 2004). Probably, only a small percentage of the population used each site, although large numbers of fish were counted on some days, especially during release of hatchery fish. The study was repeated in 2003. The study can be used to estimate the percentage of natural and hatchery Chinook salmon that utilize the sites and the duration of use by individuals. This information can be used for restoration planning and development.

F. Goetz (ACOE) and E. Jeanes (R2 Resource Consultants) have documented Chinook use of off-channel sites in the middle Green River.

10. *Hypothesis:* Growth of natural juvenile Chinook salmon in the lower river and estuary is adequate and is not influenced by releases of hatchery fish. Diet is opportunistic and adequate.

11. *Hypothesis:* Juvenile Chinook salmon utilize estuarine habitat types randomly. Juvenile Chinook salmon move through the estuary (RM 8 to 0) at a constant rate without influence by hatchery fish.

12. *Hypothesis:* The capacity of nearshore habitats in Puget Sound (quantity and quality), including prey availability, are adequate to support both natural and hatchery Chinook salmon populations (i.e., growth, residence time, and survival are adequate).

    Key Questions:
    - What is the growth rate of juvenile Chinook in Puget Sound?
    - Is growth of Chinook salmon in Puget Sound dependent on the abundance of juvenile hatchery Chinook and/or other salmonids such as pink salmon?
    - Do El Nino events lead to shifts in the capacity of Puget Sound to support juvenile Chinook salmon?
    - Can habitat restoration or hatchery management lead to improved growth and survival of Chinook salmon in Puget Sound?

General Information

A new analysis of the CWT database indicates reduced growth and survival of CWT subyearling Chinook salmon released into Puget Sound streams during even-numbered years, corresponding to years when juvenile pink salmon are abundant (Ruggerone and Goetz 2004). The mortality and growth effect occur during the first year at sea and evidence suggests these effects occur within the first growing season (i.e., in Puget Sound). These data suggest reduced prey availability (including forage fishes) during even-numbered years, however field data on prey abundance are not available to further evaluate this observation. The study indicates prey in Puget Sound has a significant effect on growth and survival of Chinook salmon and that efforts to maintain or enhance prey availability could lead to greater survival.

WRIA 9 Specific Information

This CWT study includes analysis of Green River Chinook salmon along with nine other Puget Sound populations.

Current WRIA 9 Research for this Question

None identified in WRIA 9, but research by D. Beauchamp (UW) may help evaluate this question in adjacent areas (Duffy et al. 2002).

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13. *Hypothesis:* Migration patterns of juvenile Chinook salmon in Puget Sound are random.

    Key Questions:
    - What are the general migration patterns of Chinook salmon in Puget Sound, based on CWT recoveries?

14. *Hypothesis:* Chinook salmon do not prefer specific types of nearshore marine habitats.

Productivity, Survival, and Abundance

15. *Hypothesis:* Productivity and capacity of natural Green River Chinook salmon, as determined from analysis of recruitment curve, are adequate and comparable to other summer/fall Chinook salmon populations.

16. *Hypothesis:* The Duwamish/Green River provides an adequate migration corridor for returning adult salmon (i.e., flow and temperature are adequate).

    Key Questions:
    - Where do adults hold in the river, especially those that return early?
    - Is size of the holding areas adequate for the spawning migration?
    - Does holding temperature influence pre-spawning mortality or viability of embryos?
    - Do adults seek cold water refuges from high river temperatures; where are cold water refuges (e.g., Black Diamond springs in Gorge)?
    - Can higher flows lead to reduced water temperature in the lower river?

17. *Hypothesis:* Egg-to-fry survival is variable but within "normal" range.

    Key Questions:
    - What is egg-to-fry survival in relation to river flow?
    - Does moderation of peak winter flows by Howard Hanson Dam lead to relatively high survival rates, or do the prolonged moderately high flows lead to reduced survival?
    - Does egg-to-fry survival vary among tributaries?
    - Is egg-to-fry survival high or low compared with that of other stocks?
    - Does spawning in the thalweg lead to greater scouring and lower embryo survival in high flow years?
    - Are there sediment sources, such as landslides, that contribute to sedimentation and lower survival?

General Information

Healey (1991) reviewed estimates of Chinook egg-to-fry survival. High egg-to-fry mortality (e.g., >80%) is not uncommon (Healey 1991). As expected, estimates are highly variable. However, fall run Chinook egg-to-fry survival might be expected to be less compared to other salmon species because they tend to spawn in mainstem areas where flows do not fluctuate as much (% change) as in smaller tributaries.

Winter flow commonly influences survival by either exposing developing embryos to desiccation and freezing conditions by extreme low flows or removal from redds by erosion during extreme high flows. Peak winter flow has been shown to be inversely related to salmon survival in other Puget Sound drainages (D. Seiler, WDFW, pers. comm.). DeVries (2000) found embryos buried deeper than 2-2.5 D_{90} of the spawning gravel were not likely to be scoured by winter flows. Montgomery et al. (1995, 1999) reviewed the apparent adaptations of Pacific Northwest salmon to scour conditions in gravel-bedded streams. Late winter flows may displace emerged fry from suitable habitat and may greatly reduce the amount of suitable rearing habitat in upstream areas. Few fry are present in lower river and estuarine areas during peak winter flows.

Sedimentation can affect survival of embryos in redds, as a result of reduced oxygen, concentration of metabolic waste products, and restricted movement of alevins. Commonly this is sedimentation that occurs following construction of the redd. Sediment within the spawning gravel tends to be removed from the egg pocket during construction of the redd. Tappel and Bjornn (1983) found a high percentage of fines reduced size of steelhead, but not significantly. Chapman (1988) concluded most measurements of fines do not represent conditions within the egg pocket of a redd.

WRIA 9 Specific Information

Seiler et al. (2002) presented the first estimates of egg-to-fry survival for the middle Green River and Soos Creek. Survival was 7.3% and 3.8%, respectively. The higher mortality in Soos Creek was thought to be related to high density of spawners, leading to redd superimposition. Estimates are based on average fecundity estimates (4,500 eggs per female) and estimates of spawners upstream of the traps (e.g., 1,625 female Chinook based on a count of 1,625 redds).

Too few data are available to answer the question of the influence of winter flows. Some landslides are known to occur in middle Green River that may increase sedimentation of nearby redds.

Current WRIA 9 Research for this Question

Egg-to-fry mortality is currently estimated as part of the WDFW screw trap operation. Estimates will likely continue as long as the screw trap is operated. The WDFW screw trap data will also help answer the question but at least five years of data are needed along with variations in winter flow.

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18. *Hypothesis:* Water temperature and adult spawn timing have not altered emergence timing.

Key Questions:

- What is the potential effect of altered water temperature or altered spawn timing on emergence timing?
- What effect might this have on growth and survival of juvenile Chinook salmon?

General Information

Levings (1984) suggested that year-to-year changes in temperature may override fish density as a factor affecting growth. Water temperature information by habitat type has rarely been reported. Deeper water areas tend to change slowly over the season while shallow water areas can have substantial temperature variations within hours during major tidal exchange on sunny days with daytime low tides. Because of their surface orientation young salmon moving into shallow tideflat areas likely experience substantial temperature variation within one to several hours.

Investigation of sublethal temperature effects can be conducted by measuring Hsp 70 mRNA and Hsp 30 mRNA in juvenile salmonids potentially exposed to high temperature conditions (Lund et al. 2002).

Levings (1984) noted that growth in estuaries may be density independent, i.e., factors such as temperature may override biological factors. Juvenile salmon growth, behavior and survival can be affected by low dissolved oxygen (Davis 1975, Ruggerone 2000). Davis (1975) and Ruggerone (2000) review some dissolved oxygen effects on juvenile salmon.

WRIA 9 Specific Information

King County has deployed thermographs in the Green River (Kerwin and Nelson 2000). Temperatures in the mainstem lower and middle Green River have reached 23-24 °C and may affect adult Chinook salmon (e.g., inhibit upstream migration and increase stress). High temperatures have been recorded in some tributaries of the Mill (Hill) and Springbrook subbasins and Soos Creek tributaries and may be of concern for juvenile salmon; however, few juvenile Chinook salmon probably rear in small tributaries since adults tend to spawn in larger tributaries.

King County (2000) has collected and reviewed dissolved oxygen (DO) concentrations in many habitats in the Green River. They state that DO levels in the Duwamish and lower Green rivers are of concern for rearing salmon on some occasions. DO levels in the middle Green River are occasionally of concern during incubation. King County states that DO is likely a factor of decline in several tributaries, including Springbrook Creek, Mill (Hill) Creek, Soos Creek, and Newaukum Creek. Fewer data are available in off-channel habitats of the Duwamish River.

Current WRIA 9 Research for this Question
Ruggerone and Goetz deployed thermographs in a few off-channel habitats in 2003. Collection of such data is relatively simple and inexpensive. Kerwin and Nelson (2000) collected and reviewed dissolved oxygen concentrations and temperature in many habitats in the Green River. Monitoring by King County is continuing.

19. *Hypothesis:* Water quality in the estuary is adequate to support Chinook salmon.

Key Questions:
- Do toxic sediments and low water quality affect growth or survival of juvenile salmon?
- Are juvenile salmon sufficiently exposed to toxic sediments and water to accumulate body burdens?
- Does warm water lead to stress or mortality of juvenile salmon in some off-channel habitats?

General Information
Available investigations of survival to adult return have not separately identified survival of fish exposed as juveniles to toxic compounds. Investigations of this nature would require large numbers of test and control juveniles to provide adequate numbers of returning adults.

WRIA 9 Specific Information
Arkoosh et al. (1998) reported the mean concentrations of PCBs in small numbers of Chinook from the Duwamish estuary to be 270 ng/g wet weight in 1993 and 90 ng/g in 1994. These concentrations were 3-5 times higher than fish sampled from several hatcheries and the Nisqually River estuary. O'Neill et al. (1998) reported PCB concentrations in adults collected from several rivers averaged 74 µg/kg, with Duwamish River fish similar to Deschutes, Nisqually, Nooksack, and Skagit River fish, with the exception of a single sample.

Lab studies by NMFS suggest exposure to toxic chemicals in the Duwamish Waterway may reduce resistance of juvenile Chinook salmon to disease and reduce growth, leading to reduced survival to adults. This hypothesis has not been tested. A controlled field study involving marked (CWT) Chinook salmon released at strategic locations could help evaluate the NMFS hypothesis. Alternatively, exposed fish could be held in large net pens for a year or so rather than released.

Current WRIA 9 Research for this Question
Sampling of PCBs in Chinook collected from highly contaminated sites occurred in 2003, but results are not yet available.

20. *Hypothesis:* Predation has little effect on Chinook survival in the river, estuary and nearshore marine areas.

Key Questions:

- What are the potential predators in the river and estuary and are they abundant enough to consume significant numbers of juvenile salmon?
- Do lamprey kill many Chinook salmon?

General Information

There is considerable information on predators of young salmon from other areas, but little from the WRIA 9 area. Literature indicates juvenile salmon are preyed upon by a wide variety of other animals. Birds (Caspian terns, cormorants, mergansers, etc.) have been shown to consume large numbers of young salmon in lower river and estuarine areas. In nearshore areas murres, diving ducks, and gulls have been found to prey on young salmon. Fish predators include other larger salmonids such as cutthroat trout, Dolly Varden/bull trout, and juvenile coho. Few non-salmonid fishes have been found to prey on young salmon. Pacific staghorn sculpins have been found to prey on young salmon in one study and not in others. Lamprey have been observed to attack a substantial number of young salmon in the Fraser River (Beamish and Neville1995). Harbor seals were observed to be predators of substantial numbers of young salmon in one investigation (Yurk and Trietes 2001).

In lower river areas, native fish such as northern pike minnow may be substantial predators along with introduced species such as small mouth bass. Avian predators such as mergansers, Caspian terns and cormorants have been identified as substantial predators in lower river and estuarine habitats from other areas. Avian and mammalian predators potentially cover large geographic areas within short periods of time.

Predation has been shown to be a major factor in the freshwater survival rates of some Chinook populations (e.g., Columbia River pike minnows, Fraser River lamprey, etc.). Avian predators tend to prey in general habitat types and geographic areas and may change prey preference related to availability of alternative prey species. Studies suggest lower survival at low flows due to predation (e.g., Cedar River; D. Seiler, WDFW, pers. comm.), but predation rates are not quantified in relation to flow.

Recently, Tiffan et al. (2002) determined juvenile Chinook rearing habitat in the Hanford Reach of the Columbia River generally decreased as flows increased from low levels to moderate levels. The smallest decreases in amount of rearing habitat occurred with changes in the middle of the flow range.

Few studies of salmon have documented species that create a predation buffer for another salmon, but this idea has frequently been suggested. Lamprey ammocoetes, hatchery Chinook, and forage fish, among others, provide large populations of potential prey that may distract predators from smaller populations of Chinook. Young sand lance and herring likely provide alternative prey at much higher abundance in most nearshore areas.

Ruggerone (1992) demonstrated that three-spine stickleback provided a refuge for sockeye fry from predation by juvenile coho salmon. Movement of the location of the nesting colony of Caspian terns in the Columbia River estuary to a location that provides access to alternative prey species has decreased the predation rate on young salmon (Collis et al. 2001, Collis et al. 2002).

WRIA 9 Specific Information

Little information is available for the WRIA 9 area on predation by birds. Lamprey have been observed to attack a substantial number of young salmon in the Duwamish River (Wetherall 1971). However, the evidence of predation was only on 1.5% of fish recovered from an unhealthy group of hatchery fish.

Little information is available about potential predator populations in the WRIA 9 area. Some information on the distribution of potential predatory fish species is available for the Duwamish estuary based on past fish sampling. Sampling data indicate few potential predatory fish species other than salmonids are present within the shallow water habitat preferred by young Chinook and chum. Little information is available on the abundance of lamprey, which may be an important factor in the survival of Chinook and chum salmon in the lower Duwamish and Elliott Bay, based on past and recent observations (G. Ruggerone (NRC), W. Taylor, Taylor and Associates, observations in 2002).

Little information is available about the portion of the Chinook population consumed by predators in WRIA 9. Salo (1969) noted that 7% of more than 7,000 Chinook sampled in the Duwamish River had lamprey marks. Others sampling young salmon in this area have not noted similar evidence, but observations made during spring and summer 2002 indicated attacks by lamprey were seasonal (greatest frequency was late June/early July). Wetherall (1972) reported evidence of lamprey predation on 1.5% of the marked fish that were recovered from a relatively unhealthy group of hatchery Chinook in the Duwamish estuary and Elliott Bay. A healthy group of marked Chinook released two years later had lamprey predation rates approximately one tenth of the first group. B. Footen (Muckleshoot Indian Tribe) sampled potential predators in Shilshole and Salmon bays. He reported that the key potential predators on salmon were cutthroat trout, staghorn sculpin, and resident Chinook salmon (blackmouth). Juvenile Chinook salmon tended to prefer sand substrate over cobble substrate.

Current WRIA 9 Research for this Question

No known research has been directed at predation in WRIA 9, but observations in 2002 suggest lamprey might be important in the lower Duwamish and Elliott Bay during specific time periods.

In nearshore marine areas north and south of WRIA 9, D. Beauchamp (UW) and colleagues are sampling potential predators of juvenile salmon. In 2001 and 2002, cutthroat trout were the key predator on salmon; relative abundance averaged approximately one trout per beach seine set (Duffy et. al. 2002; D. Beauchamp, UW, pers. comm.). However, chum salmon, which are relatively small (45-75 mm), were more vulnerable to predation than Chinook salmon (70-90 mm). Numerous perch were captured but they did not consume salmon. Sculpin contained relatively few salmon.

21. *Hypothesis:* Growth of juvenile Chinook salmon in Puget Sound is not influenced by climate-induced prey availability, and competition for prey has little effect on Chinook growth and survival.

    Key Questions:

    - What is the growth rate of juvenile Chinook salmon in freshwater and estuarine habitats?
    - How does it compare with that of less disturbed watersheds?
    - Does growth rate influence residence time in the lower river and estuary?
    - Does insulin-like growth factor-I (IGF-I) indicate some fish are stunting?
    - What do juveniles eat in each habitat type?
    - Does bioenergetic modeling indicate reasonable growth rates?

General Information

There is a great deal of prey information available from locations outside the WRIA 9 area. These data include lower river to nearshore areas with much of the information collected from estuarine areas (e.g., Fresh et al. 1979, Simenstad et al. 1979, Healey 1980, Healey 1991, Simenstad and Wissmar 1984, Duffy et al. 2002).

Juvenile Chinook and chum appear to use similar prey resources. Young salmon appear to be opportunistic eating those prey of appropriate size and behavior that makes them available to the young salmon. In general Chinook fry have been reported to commonly prey on epibenthic and pelagic invertebrates. Epibenthic prey include harpacticoid copepods and chironomid (dipteran insects) larvae and pupae which may be either epibenthic or pelagic. The benthic amphipod *Corophium* is a common food source in some areas. Insect larval prey include other dipterans, hymenopterans, coleopterans, ephemeropterans, and tricopterans. Pelagic prey include these insects, cladocerans, calanoid copepods, gammarid amphipods, cumaceans, euphausids, mysids, decapod larvae, and fish larvae (herring, sand lance).

In Sinclair Inlet during 2002, K. Fresh (NMFS) examined habitat types used by juvenile Chinook salmon, temporal pattern of distribution (seasonal and time of day), trophic interactions, residence time in the study area (fluorescent dye marking), and stocks that use the area (CWTs). Some results of the research will likely be available in 2004.

Prey species consumed varies substantially among individuals, at locations over time, and among habitat types. Available data does not provide information adequately addressing this issue. Juvenile Chinook have been found to consume a wide variety of species and general types of prey.

WRIA 9 Specific Information

In the Duwamish estuary Meyer et al. (1981) found Chinook in the estuary consumed by weight 25% gammarids, 15% calanoid copepods, 5% dipterans and small amounts of many other prey. Fish feeding in shoreline areas tended to eat more epibenthic prey than those collected away from the shoreline.

Young Chinook in the WRIA 9 have been found to consume a wide variety of prey including chironomids (dipteran insect larvae), calanoid copepods, gammarid amphipods, fish larvae, with more of the marine prey eaten at downstream locations (Meyer et al. 1980). Fish collected near shorelines ate primarily epibenthic prey, while those collected in deeper water ate pelagic prey.

Recently, Cordell et al. (2001) found young Chinook at habitat restoration sites on the Duwamish River had eaten a variety of terrestrial insects, as well as other prey types. Numerous investigations in other areas have shown Chinook eat terrestrially based prey in those areas, as well as a wide variety of other epibenthic and pelagic organisms. In Chinook taken at Kellogg Island, Tanner and Williams (1990) found different relative weights of prey at three transects within a small area. Prevalent prey included Neomysis, gammarids, Corophium, cumaceans, fish larvae, homoptera, and barnacle larvae, along with lesser amounts of a number of prey species. Jones and Stokes also sampled Chinook across from Kellogg Island. They found Chinook ate by weight 41% gammarids 29% adult chironomids, 10% Corophium, and lesser amounts of cumacea, coleoptera larvae, and fish larvae.

Prey consumed by habitat type has not been reported by most of the investigations dealing with Chinook prey. Cordell et al. (1999) sampled Chinook in 1996 and 1997. Chinook consumed similar prey at three sites from the upper estuary to lower estuary. Dominant prey were benthic amphipods, mysid shrimp and drift insects. The composition of drift insects varied among the years with dipterans dominant in 1996, while psyllids, hymenoptera, and formicidae were more important in 1997.

In the nearshore habitat of Elliott Bay, Tanner (1990) and Tanner and Williams (1991) found Chinook ate primarily sand lance larvae (75-85% by weight) with euphausiids and chironomids comprising most of the remaining prey consumed. These studies indicate that young Chinook consume a variety of prey as they migrate through the lower river to the near shore habitat with their prey changing at least with major changes in habitat type.

Weitkamp and Campbell (1980) evaluated the stomach contents of a large number of juvenile Chinook sampled from both shoreline and deep water sites. Those taken at shoreline sites ate 29% (by weight) fish larvae, 18% Neomysis, 12% chironomids, and 9% Daphnia. Chinook collected from deep water areas ate 58% calanoid copepods, 12% crab larvae, and a variety of other prey.

Cordell et al. (2001) found Chinook fry in Duwamish River restoration sites ate different prey at different locations, at different times during the migration season, and in different years. J. Cordell (UW, pers. comm.) noted that juvenile Chinook salmon collected from mainstem Duwamish habitats tended to eat somewhat unusual prey, including clam siphons, whereas those collected from off-channel sites contained more terrestrial prey.

Current WRIA 9 Research for this Question

J. Cordell (UW) will analyze stomachs collected in the Duwamish River during 2002 and 2003. He is also under contract with USFWS to sample benthic invertebrates and fallout insects at Hamm Creek and Herring House restoration sites. Cordell is also analyzing stomach contents of approximately 400 salmonids collected by King County in 2000 and 2003.

Trout Unlimited is currently collecting Chinook salmon diet data in the Green River (H. Boynton, Trout Unlimited, pers. comm.). Samples of Chinook salmon collected in the Duwamish and nearshore marine areas during 2002 for the otolith study have been frozen (preservation with formalin is preferred for stomach analysis but formalin may affect otolith chemistry) and J. Cordell (UW) may examine the stomach contents. King County (J. Brennan) collected stomachs from Chinook in nearshore marine areas for analysis by J. Cordell (UW).

W. Taylor (Taylor & Associates) is developing an automated technique for estimating net prey production originating in off-channel habitats and carried to mainstem areas during ebbing tides. The pilot project is being conducted at the 1st Avenue Bridge stormwater control facility. Prey composition is being monitored during flooding and ebbing tides and estimates are adjusted for water volume. No funding identified for 2002 and 2003.

During April-September (sampling twice per month) 2001 and 2002, D. Beauchamp (UW) and R. Buckley (WDFW) sampled the diet and estimated growth (bioenergetic modeling) of juvenile Chinook (hatchery v. natural), chum, pink, coho salmon and cutthroat trout in nearshore and immediately offshore marine waters of Port Susan/Port Gardner Bay and in south Puget Sound near Chambers Creek. These nearshore data, which were collected by beach seine and surface tow net, will be compared with diet data collected by R. Beamish (CDFO), who is using the R/V Ricker and large mid-water and surface trawl to sample juvenile salmonids in Puget Sound (Port Townsend to Tacoma) during June and September, 2001 and 2002 (see Beamish et al. 1998). During 2001, subyearling Chinook salmon captured at the northern sites consumed primarily insects, whereas those captured in southern Puget Sound consumed mostly crustaceans (Duffy et al. 2002). The diet of Chinook salmon was more diverse compared with that of chum salmon and fish became a more important part of the Chinook diet during June through September. Bioenergetic modeling indicated growth rate of Chinook was slightly greater in southern Puget Sound. This research was funded by the Hatchery Scientific Research Group.

Some fish samples collected in 2002 and analyzed by J. Cordell and students may help answer this question, but frozen quality of stomach samples, due to otolith preservation, (and funding) may inhibit analysis (see comment above).

In conjunction with USFWS (D. Low, K. Myers), J. Cordell (UW) is quantifying benthic invertebrate abundance and terrestrial insect fallout at two Duwamish restoration sites (Herring House and Hamm Creek in 2001, 2002). An additional site was monitored in 2003 (Cecil Moses Memorial Estuary Park near Boeing foot bridge), but the site was logistically difficult to sample. Furthermore, researchers found that salmon may become trapped in the shallow pond when water temperature rises to 24°C in response to air temperature (Ruggerone and Jeanes 2004).

22. *Hypothesis:* Fry actively migrate to Puget Sound with little rearing in fresh water and contribute to adult returns.

Key Questions:

- How many fry enter Puget Sound with little rearing in freshwater and estuarine habitats?
- Is this movement associated with high flows or do fry attempt to seek refuges from high water velocity?
- Would large woody debris or constructed off-channel sites in the lower Green River increase residence time there?
- What is the survival rate of early fry and do they contribute to adult returns compared with other trajectories?

General Information

Reimers (1971) reported that Chinook fry that spent little time in the estuary had much lower survival to adult compared with fry that reared in the estuary. Little research has been done to test this hypothesis. It is important to note that Reimers results may have been confounded, in part, by the use of scales because scale growth typically lags behind body growth and Reimers did not account for this effect (G. Ruggerone, NRC, pers. comm.). Thus, Reimers likely over estimated numbers of fry spending little time in the estuary.

WRIA 9 Specific Information

None identified.

Current WRIA 9 Research for this Question

The otolith research by Volk and Ruggerone (2004) may shed light on a potential methodology to test this hypothesis. This study will be completed during summer 2004.

23. *Hypothesis:* Residence time of fingerling migrants in the estuary is similar to that of fry migrants. (also see fry migrant Hypothesis)

Key questions:

- What are the preferred rearing habitats in the estuary?
- How does preferred habitat vary with tide, river flow, fish size and season?
- What is the capacity of these habitats to support juvenile Chinook salmon?
- Do preferred habitats appear to “hold” fish for longer periods?

General Information

Nearly all investigations of young Chinook in lower rivers and estuarine areas have shown a strong propensity for the fry-fingerlings to remain near the shoreline within the near-surface layer of the water column (~1 m). Frequently this means the fish are in habitats with shallow depths and fine grain substrates; however, other shoreline habitats also successfully provide appropriate functions for young Chinook.

Some estimates of residence time in estuaries have been made in other watersheds (reviewed by

Simenstad and Wissmar 1984). A variety of methods have been used, including scale growth patterns, mark and recapture, and frequent sampling over time. Although young Chinook may use these habitats over prolonged periods, it appears that individual fish commonly spend only a few days or weeks within a specific habitat. Shreffler et al. (1992) reported a mean residence of 5 days for fry in a constructed Puyallup River wetland. Beamer et al. (2000) determined fry reared in the Skagit River estuary habitats an average of 34.2 days based on otolith checks, but not within a specific habitat site.

In Sinclair Inlet during 2002, K. Fresh (NMFS) examined habitat types used by juvenile Chinook salmon, temporal pattern of distribution (seasonal and time of day), trophic interactions, residence time in the study area (fluorescent dye marking), and stocks that use the area (CWTs). Some results of the research will likely be available in 2004.

WRIA 9 Specific Information

In the Duwamish River, juvenile Chinook have been collected from shallow water shorelines having a variety of slope and substrate conditions, as well as from surface water along the deep nearshore areas of piers (Meyer et al. 1980, Weitkamp and Campbell 1980, Weitkamp and Schadt 1982, Parametrix Inc. 1984, Tanner and Williams 1990, Tanner and Williams 1991, Taylor and Willey 1997). The young fish appear to show a dominant preference for surface water (within 1m of surface) and shorelines, with a substantially lower preference for substrate type and slope. As the fish grow they appear to increase their depth distribution to several meters and move further from the shorelines. Thus, habitat preferences appear to vary somewhat depending on fish size and possibly by early (smaller) versus late (larger) migrants. Previous work was not able to differentiate hatchery versus natural juveniles.

Some attempts have been made to estimate residence time of Chinook in the Duwamish, but these studies are confounded by the presence of hatchery salmon that likely have different residence times.

Current WRIA 9 Research for this Question

Some sampling of mainstem and off-channel habitats (W. Taylor, G. Ruggerone, F. Goetz, T. Nelson) and nearshore marine (J. Brennan, D. Shreffler, W. Taylor, G. Ruggerone) was conducted in 2002 and hatchery vs. natural fish were identified. However, most of this work was not designed to compare habitat utilization by early and late migrants. A method to identify early and late migrants in nearshore marine and estuarine samples is needed. Otolith and scale measurements have potential to assist this question.

G. Ruggerone (NRC) and E. Volk (WDFW) are developing a new approach to estimate residence time of hatchery (fin marked) versus natural (unclipped) Chinook salmon in the Duwamish estuary and Elliot Bay (Pier 90/91) based on otolith microchemistry and daily growth rings. If the procedure works, then residence times (days) can be estimated for early, middle, and late migrating natural and hatchery Chinook salmon. Approximate days within freshwater may also be estimated but this estimate is somewhat complicated by the determination of the date of emergence from the otolith. Relative abundance of hatchery and natural Chinook salmon moving through the Duwamish River and Elliott Bay was collected by W. Taylor. This study has implications for 1) potential exposure and uptake of toxic chemicals, 2) importance (based on residence time) of the existing estuary to Chinook salmon, 3) the duration of potential competition between hatchery and natural Chinook salmon in the estuary and nearshore marine environment, and 4) identification of life history patterns.

24. *Hypothesis:* Chinook salmon prefer specific types of nearshore marine habitats.

    Key Questions:
    - What nearshore habitats and physical conditions are preferred by juvenile Chinook salmon, e.g., gentle or steep slope; boulder, cobble, or sand; eelgrass & kelp; embayment or exposed areas; high or low wave action areas?
    - What depths are preferred in nearshore areas?

25. *Hypothesis:* The capacity of habitats in Puget Sound (quantity and quality), including prey availability, are adequate to support natural Chinook salmon populations.

Miscellaneous Research Questions and Related Information

1. What is the recruitment curve for natural Chinook?

    - Analyses of recruitment curves are a basic tool for managing salmon stocks (Hilborn and Walters 1992).
    - Data gathered from a recruitment curve can be used to evaluate characteristics of juveniles that lead to higher survival at sea.
    - It can also be used to evaluate the status of the stock in terms of abundance and productivity.
    - Best if CWT data are used to estimate harvests of Green River Chinook in non-terminal fisheries (e.g., British Columbia).
    - Need to exclude production from hatchery strays by identifying origin of fish on spawning grounds (natural or hatchery).

2. What is the abundance, size at age (days) and timing of juveniles emigrating from the middle Green River (screw trap)?

    - Juvenile abundance, migration timing, and size leaving spawning areas are needed for downstream research.
    - Screw trap provides best estimate of juvenile abundance.

General Information
Typically, most emigration of relatively small subyearling Chinook occurs during spring, followed by larger subyearlings approximately a month or two later (Healey 1991). Migration timing patterns are often bimodal.

WRIA 9 Specific Information
WDFW began operating a juvenile salmon trap immediately upstream of Soos Creek hatchery and in the Green River itself in 2000 (Seiler et al. 2002). The Green River pattern of migration is typical of that observed in other Northwest watersheds. Year-to-year estimates of abundance have been highly variable, suggesting significant egg-to-fry mortality in some years (e.g., 2002). In 2000, the estimated production of subyearling Chinook salmon, including spawning areas above and below the trap, was 1.08 million fish.

Current WRIA 9 Research for this Question
The trap is expected to be operated during 2003, but no funding is available for 2004 and beyond (D. Seiler, WDFW, pers. comm.).

Beginning in 2001, monitoring of Chinook salmon migration timing and size has been conducted by T. Nelson (King County) at RM 13, which is near the upper end of the Duwamish River. This monitoring was intended to complement data collected at the screw trap in that it collected both hatchery and naturally-produced Chinook salmon and examined fish for hatchery fin clips and CWTs approximately 19 miles below the screw trap. Typically, 6-10 beach seine sets were made once every week, May 8-July 3, 2001. In 2002, this study was expanded to include weekly sampling at RM 7 and Kellogg Island from late January to early September. Also, in 2002, 1000 PIT tags were inserted into hatchery Chinook salmon and another 200 tags were placed into natural Chinook salmon collected at the screw trap (too few fish available in 2002 for additional tagging). The goal of this pilot study was to examine the feasibility of the PIT approach for estimating time in the river between release and recapture locations. Only one fish was recovered (RM 7) approximately two weeks after release at the hatchery. In a related pilot study by D. Houck (King County), two yearling Chinook salmon were tagged with ultrasonic tags at Icy Creek and released. One fish appeared to have been identified approximately one week later near Harbor Island. See Nelson et al. (2004).

3. What is survival to adult return of CWT (hatchery) subyearling Chinook salmon released into the Green River compared to other watersheds in Puget Sound?

   - Very few natural Chinook have been tagged.

General Information
Unites States and Canadian agencies began tagging salmon with CWTs in approximately 1972. Often approximately 5% of hatchery releases are tagged; however, fish are not tagged in all years for all hatcheries. More fish have been tagged since the early 1980s compared with earlier years. Two key objectives of the tagging is to help identify the origin of salmon in coastal fisheries and to help evaluate hatchery production. Previously, all fish receiving CWTs also received a visual mark (adipose fin clip) that helped fishery personnel identify CWT fish. In recent years, most agencies are attempting to fin clip 100% of hatchery Chinook and coho salmon, which means that the missing adipose fin no longer identifies CWT fish and a magnetic wand must now be used to identify CWT fish.

WRIA 9 Specific Information
The CWT dataset extends back to 1972, but it is not complete for all years. Among Chinook hatcheries in Puget Sound, the CWT database for the Green River hatchery is most complete.

Current WRIA 9 Research for this Question
This question is currently being examined (Ruggerone and Goetz 2004). Analysis of the CWT database has revealed a significant odd/even-numbered year pattern in growth, survival and age at maturation of Puget Sound subyearling Chinook salmon. This pattern appears to be established within the first growing season through competition with Puget Sound pink salmon, which have been relatively abundant in recent years. Competition may have been exacerbated by the significant decline in herring, a major prey of juvenile Chinook salmon. The loss of sand lance and surf smelt spawning habitat at upper intertidal levels of Puget Sound beaches may also contribute to reduced prey availability when substantial numbers of young salmon are present.

4. Does survival of hatchery fish vary by watershed and is it related to the degree of estuarine degradation?

General Information
None identified.

WRIA 9 Specific Information
Weitkamp and Ruggerone (2000) presented a preliminary analysis of CWT Chinook salmon released into various Puget Sound watersheds. This analysis indicated release to recovery survival of Green River subyearling Chinook salmon was not significantly different from that of other watersheds, including those having less industrialized conditions.

Current WRIA 9 Research for this Question
This question is currently being addressed by G. Ruggerone, but the newly discovered odd/even year pattern of survival has complicated and delayed analysis of survival by watersheds.

5. What methods can be used to identify hatchery versus natural Chinook salmon?

- Tools are needed to identify hatchery and natural juvenile Chinook salmon. Potential methods: scale pattern analysis, length at time (some error), otoliths (lethal).

General Information
CWT wands must be used to detect unmarked CWT fish, but many unsuccessfully marked, non-CWT fish remain and these fish can confound research and monitoring.

WRIA 9 Specific Information
Presently, over 3 million subyearling Chinook salmon are released into the watershed each year. The hatcheries attempt to mark 100% of these fish with an adipose fin clip, but typically only about 95% are successfully marked. Additionally, WDFW releases approximately 200,000 CWT Chinook without adipose fin clips (double index program). Thus, many hatchery Chinook are unmarked. In comparison, Seiler et al. (2002) estimated total juvenile natural Chinook production in 2000 to be 1.08 million fish or approximately 30% of the hatchery release of subyearling Chinook salmon.

Current WRIA 9 Research for this Question
Ruggerone (NRC) collected scales from numerous hatchery and natural Green River Chinook salmon in 2002 in anticipation of further analysis. Preliminary analysis of the otolith method (lethal) may be attempted this winter, if time permits (Ruggerone & Volk 2004).

6. If significantly different survival between early and late migrants exists after adjusting for age, what factors affect numbers of fry vs. fingerling migrants?

- Test for habitat link to life history types or link to genetics (Healey 1991). Leads to questions about how fry and smolt migrants utilize lower river, estuarine, and marine nearshore habitats.

General Information
D. Seiler (WDFW, pers. comm.) and Beamer et al. (1999) have suggested that habitat availability and flow may affect numbers of fry and fingerling migrants (i.e., more fry when higher spring flows;

existence of freshwater habitat). Alternatively, Healey (1991) suggested this migration pattern may have a genetic link, which could be identified by genetic study. If related to habitat availability and fry migrants have very low survival, then there may be need to protect and restore upstream habitat.

WRIA 9 Specific Information
A relatively large outmigration of fry during February to early April, followed by a smaller outmigration of larger fingerling migrants during May to June, has been observed in the Green River (Seiler et al. 2002).

Current WRIA 9 Research for this Question
Continued monitoring of screw trap by WDFW can help answer this question.

7. Is the habitat use and migration timing pattern consistent with concept that smaller fish need freshwater and estuarine habitat more than larger fish?

   - For tested groups (size at age) this may help identify high mortality regions.
   - Mark juveniles/recover adults: groups released by location: ~RM 30, RM 7, RM 0, nearshore marine.
   - Size and timing are complicating issues.
   - Conceivably, a study modeled after the Levings study could help identify the importance of specific habitat types in WRIA 9. For example, if release to adult recovery survival of fish released at RM 30 was significantly lower than that of fish released at RM 13, then mortality would appear to be high between RM 13 and 30.

General Information
Transport studies have been conducted in other watersheds in an effort to evaluate the importance of specific habitats, such as the estuary (Kjelson et al. 1982, Levings et al. 1989). Such experiments can be coupled with additional observations to evaluate effects of osmoregulation, stress, feeding, and predation.

WRIA 9 Specific Information
None identified.

Current WRIA 9 Research for this Question
None identified.

8. What is survival of hatchery and natural Chinook from hatchery/screw trap to RM 13, to RM 7, to lower Duwamish River, to marine nearshore?

9. How does survival vary with water flow?

   - Determine if a high mortality area is present.
   - If juvenile abundance could be accurately estimated at key locations along the migration route, then areas of high direct mortality could be identified. Such a procedure would be difficult because juvenile population estimates typically have low precision and are subject to error.

General Information
Bax (1983) and others have used a multiple day mark/recapture procedure (fluorescent dye) to estimate survival of migrating salmon at a specific time. This procedure also involves an estimate of maximum emigration away from the recapture site. This approach was used by Nelson et al. (2004).

Generally the survival rates for specific reaches of a river have not been investigated with the exception of the Columbia River. Incremental survival rates through dams and reservoirs on the Columbia River are not relevant to the WRIA 9 conditions.

WRIA 9 Specific Information
Wetherall (1972) marked (dye) juveniles and released them at the hatchery (RM 32) and near RM 13 in an attempt to examine travel time and survival to the estuary. Too few data were available to evaluate site-specific survival.

Current WRIA 9 Research for this Question
Marking studies were conducted during 2003 (Nelson et al. 2004).

10. Do hatchery yearling coho and Chinook salmon and steelhead consume significant numbers of natural Chinook salmon?

General Information
The resource management plan for Puget Sound Chinook salmon hatcheries (WDFW/PSTT 2002) concluded that predation by hatchery Chinook salmon on natural Chinook salmon in Puget Sound is largely unknown, but a review of literature led the authors to believe predation rates were likely low. Flagg et al. (2000) examined a broader range of the literature and found evidence of predation by hatchery Chinook and steelhead on natural Chinook salmon in California and British Columbia. Coho salmon are highly piscivorous and will consume large quantities of small juvenile salmon when available. Predation rates will vary with numbers and size of hatchery fish and the size and number of natural Chinook salmon. Research on size selective predation indicates that salmon predators may consume juvenile salmon up to 50% of the predators' length (Ruggerone 1989), but predation is most frequent on smaller fishes. The key factor influencing predation by hatchery salmon on native Chinook salmon is the degree of spatial and temporal overlap, especially overlap with recently emerged salmon fry. Predation by yearling hatchery salmon may also occur in Puget Sound nearshore waters.

WRIA 9 Specific Information
No studies are known to have examined predation by hatchery salmonids on natural Chinook salmon in WRIA 9. However, the City of Tacoma has recently observed numerous large (6-8") coho and Chinook salmon near the Tacoma Diversion Dam from late summer through winter (P. Hickey, City of Tacoma, pers. comm.). These fish originated from hatchery releases above Howard Hansen Dam. In 2002, approximately 0.5 million subyearling Chinook and 0.5 million subyearling coho salmon were released above the dam by the Muckleshoot Indian Tribe. Similar numbers have been released in previous years. These fish apparently rear upstream of the dam for one or two years, then pass through the outlet structure during summer and fall and through additional passages when the reservoir is lowered in preparation for fall and winter flood events. The question here is whether these late migrating salmonids consume natural Chinook salmon emerging in the Green River during winter and spring. These salmonids were robust, but stomachs from 10 fish collected at the Diversion Dam during early winter were empty. These fish did not have access to recently emerged Chinook salmon. In the 1980s, Weitkamp noticed that chum and juvenile Chinook salmon seemed to leave Duwamish sampling areas when coho salmon arrived, then they reappeared after the coho migration was over.

Current WRIA 9 Research for this Question
No research is currently planned, but opportunistic sampling of yearling salmon during 2003 by T. Nelson (King County) may provide some insight. However, Nelson's work is primarily near RM 13 and below, whereas potentially more significant predation would likely be occurring near the spawning areas.

11. How many juvenile Chinook experience physical damage, such as that caused by flow fluctuations and stranding?

    - Stranding from flow fluctuations can be important, especially in some regulated rivers (predation in pools, desiccation as water recedes).

General Information
Stranding within riverine areas has been observed in upstream portions of the Skagit and Columbia Rivers. Tiffan et al. (2002) found stranding occurred in pools isolated by reduced flows. The amount of stranding pool area increased as flows increased from low to moderate discharge rates. Flow decreases in the middle of the flow range produced the greatest stranding pool area. Skagit River studies (Pflug et al. 1987) identified stranding was greatest in upstream portions of the area influenced by flow reductions. Stranding commonly occurred in areas of depressions in the substrate, with down ramping rate a substantial factor. Monk (1989) found, in experimental conditions, that stranding of Chinook fry was influenced by substrate slope and size, dewatering rate, and water velocity. Time of day was not found by either study to be a significant factor.

WRIA 9 Specific Information
Significant stranding and physical damage from flow fluctuations has not been reported from the WRIA 9 area. Fish surveys in off-channel habitats of the middle Green River are documenting potential stranding as a result of flow fluctuations (Jeanes and Hilgert 2001).

Current WRIA 9 Research for this Question
A minor amount of stranding (several fry) was observed during 2002 at the Herring House restoration site as the tide receded (G. Ruggerone, NRC, personal observation).

12. Do juvenile Chinook experience disease outbreaks?

    - Disease in salmon is rarely observed/reported in wild juvenile salmon (common in hatchery fish), possibly because unhealthy individuals may be quickly eaten by predators.

General Information
The importance of disease as a factor influencing wild juvenile salmon in freshwater or marine nearshore environments is largely unknown (Wedemeyer 1982, Stephen and Iwama 1997). Pathogens (virus, bacteria, etc.) are often present in the environment, but disease often requires a stressor, such as high temperature or chemical contamination before it causes significant mortality. Disease problems in wild salmon may go unnoticed, especially chronic parasitic infections that do not lead to mass mortalities. Hershberger (2002) suggested disease may be more important to wild anadromous fishes than previously thought. Fungus can be an important mortality source for eggs and embryos in spawning gravels.

Most information on disease in juvenile salmon comes from hatchery conditions where fish are held at unnaturally high densities. Some disease organisms such as *Ceratomyxa shasta* and *Flexibacter columnaris* have been shown to infect juvenile salmon during their freshwater rearing/migration (Becker and Fujuhara 1978, Bartholomew et al. 1990). Infectious hematopoietic necrosis virus and infectious pancreatic necrosis that have caused substantial mortality in hatchery populations have also been identified in migrant populations and non-salmonid estuarine fishes (Groberg et al. 1980). These disease conditions may not be detected as mortality factors until the adult stage when the fish return to fresh water.

WRIA 9 Specific Information
Studies of disease and survival of natural juvenile Chinook salmon in WRIA 9 have not been conducted, but NMFS scientists and others have conducted lab studies attempting to link contaminant exposure with reduced resistance to disease (see contaminant section below).

Current WRIA 9 Research for this Question
During early summer 2002, G. Ruggerone and W. Taylor observed hypermucosis among numerous juvenile Chinook and chum salmon captured near Terminal 5; this condition may have been caused by irritants in the water originating from jelly fish, contaminants, or plankton bloom according to pathologist Dr. R. Roberts, editor of the Journal of Fish Diseases, who observed the fish.

Observations of the presence or absence of stress and/or disease among salmon in the Duwamish Waterway and Elliott Bay would help to evaluate the potential effects of contaminants in the water column.

13. Do peak winter flows and sedimentation of spawning redds significantly reduce egg-to-fry survival?

   - The egg-to-fry life stage typically represents the period of greatest mortality and it can be highly variable from year-to-year (Healey 1991).
   - See comments in the Chinook salmon production section.

14. Survival: Do larger individuals of similar age have greater survival to adult return?

   - Helps to verify importance of characteristics to be monitored in freshwater (growth rate; size at age) and leads to question of what habitat features lead to greater growth (see below).

General Information
Greater growth is generally believed to enhance salmon survival, largely because bigger fish are vulnerable to fewer predators (Parker 1971, Healey 1991). Larger sockeye salmon smolts are known to have higher survival rates (Koenings et al. 1993), but few data are available to test this widely accepted hypothesis for juvenile Chinook salmon. However, higher release to recovery survival rates of CWT subyearling Chinook released into Puget Sound were associated with greater growth during the first year at sea (Ruggerone and Goetz 2004).

WRIA 9 Specific Information
None identified.

Current WRIA 9 Research for this Question
None identified. However, the ongoing study of CWT Chinook salmon indicated survival of Green River (and other Puget Sound stocks) Chinook salmon was associated with greater size after the first year at sea.

15. What is the weight and length of natural Chinook in each geographic area and each time period?

16. What is the size frequency distribution of the natural Chinook emigration (i.e., weight weekly samples by relative abundance)?

17. How does size vary from year to year and with overall fish abundance? How does this compare with other systems?

    - Sampling during multiple years may allow density-dependent relationships to be developed, including an assessment of whether capacity of specific habitats is being exceeded.

General Information

Little information is available for naturally produced populations. Fish released from culture facilities can vary widely in size. Identification of hatchery fish versus wild fish is difficult unless hatchery fish are visibly marked, as adipose fin clips.

WRIA 9 Specific Information

Relative abundance and size of juvenile Chinook salmon in the Duwamish Waterway have been collected sporadically for a number of years. However, until mass marking of hatchery fish began in 2001, interpretation of these data was confounded by the presence of numerous hatchery salmon.

Current WRIA 9 Research for this Question

Data were collected in the Duwamish and Elliott Bay and lower Green River during 2001 and 2002 (W. Taylor (Taylor & Associates), T. Nelson (King County), G. Ruggerone (NRC), D. Low (USFWS), F. Goetz (ACOE). Data were also collected from off-channel areas of the middle Green River (R2 Resource Consultants). Mavros and Brennan (2001) collected data on presence/absence of Chinook salmon in marine areas of WRIA 9 and additional work by King County was conducted in 2001 and 2002 (Brennan and Higgins 2004). These data may provide basic information on size of fish (and life types) in relation to habitats and seasons, which may help identify specific habitats for restoration.

D. Beauchamp (UW) is using bioenergetics to examine Chinook salmon growth in nearshore marine areas north and south of WRIA 9 during 2001 and 2002 (see comment below) (Duffy et al. 2002).

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18. What is the growth rate of Chinook in each geographic area and each time period? How does it vary by year and overall abundance?

    - Growth rate is an important variable for survival but it can be more difficult to estimate. Requires residence time or age estimate, possibly via otolith analysis or marking; bioenergetic modeling requires some basic assumptions.

General Information

Growth rate of Chinook salmon in various habitats within other regions has been described (Healey 1980, Healey 1991). The reported changes in fry size during rearing periods in field studies imply the lower growth rates in the range of 1-2%/day are probably common in nature.

WRIA 9 Specific Information
Attempts have been made to examine growth rates in the Duwamish River (Warner and Fritz 1995), but hatchery fish and the migratory nature of Chinook may confound interpretation. Data collected during 2001 and 2002 (see above) may be used to generally describe growth rates based on changes in size over time, but this approach is affected by immigration and emigration.

Current WRIA 9 Research for this Question
Otoliths, which will be examined by E. Volk (WDFW) and G. Ruggerone (NRC) during summer 2004, may provide insight into relative growth rates in freshwater versus estuarine versus Elliott Bay, but this analysis is just underway. Size of fish over time was measured during 2002 in each of the studies described above.

19. How does the release of hatchery Chinook affect 1) natural Chinook densities in specific habitats, 2) duration in preferred habitats (displacement), 3) prey consumption, 4) growth rates (direct and modeled)?

    - Typically more than 3 million subyearling Chinook released into watershed each year. WDFW assumes large size at release leads to little competition, but few data available to verify this.

General Information
Competition between hatchery and natural juvenile Chinook salmon may have a significant effect on natural Chinook salmon through competition for prey and displacement from preferred habitat (genetic issues are addressed elsewhere) (Levings et al. 1986, Levin et al. 2001). Also, the recent finding of the odd/even survival pattern suggests interspecific competition between pink and Chinook salmon in Puget Sound (Ruggerone and Goetz 2004). Thus, intraspecific competition with hatchery Chinook may be important in Puget Sound since approximately 47 million subyearling Chinook salmon are released into Puget Sound streams per year. Competition is an important issue to examine because managers can alter hatchery practices, if necessary.

WRIA 9 Specific Information
Previous investigations of juvenile Chinook in the Duwamish River have not distinguished hatchery and naturally spawned Chinook. This is also true of most other investigations from other areas.

Little information is available for the Duwamish, but WDFW assumes competition is minimized by the release of relatively large fish that presumably migrate rapidly through the watershed and marine nearshore habitats. Larger fish have a tendency to move further offshore than smaller fish (Healey 1980), potentially providing some partitioning of the available habitat by hatchery and natural fish.

Current WRIA 9 Research for this Question
The otolith work and mainstem and off-channel work during 2002 may provide information on this subject. Stomach data provided to J. Cordell may be used to compare the diet of hatchery and natural Chinook salmon. Some samples were collected during periods of high hatchery fish density, so it would be interesting to determine if the large numbers of hatchery fish led to reduced stomach contents of natural fish.

The diet analysis and bioenergetic modeling by D. Beauchamp (UW) and E. Duffy will compare hatchery and natural Chinook salmon collected from adjacent areas of Puget Sound (Duffy et al. 2002). See comments above.

20. Do preferences (fish densities) for habitat types vary with tide stage? Where are low tide refuges in estuary? To what extent do Chinook move from one habitat to next during tide change?

    - Marine nearshore and estuarine habitats are continually influenced by tide levels, thus tide level must be incorporated into evaluations of habitat types.

General Information
Juvenile salmon are physically displaced from some shallow shoreline areas by the tidal exchange that changes the water surface elevation by 6-16 ft within periods of slightly greater than 6 hours.

WRIA 9 Specific Information
The characteristics of these movements have not been defined for WRIA 9. Juvenile Chinook have been commonly sampled in deeper water areas of WRIA 9 (Weitkamp and Campbell 1980, Meyer et al. 1981, and Parametrix 1984), however movement of these fish between shallow and deeper water areas was not evaluated in these investigations.

Current WRIA 9 Research for this Question
None identified.

21. Are Chinook fry preferentially seeking protected habitat types (protected from current and wave energy)?

    - Verify this common observation.

General Information
Investigators appear to be inherently convinced the more protected locations are the better places to seek young salmon. Healey (1991) and Bjornn and Reiser (1991) provide information on habitat characteristics preferred by juvenile Chinook salmon.

WRIA 9 Specific Information
Much of the sampling for juvenile Chinook within WRIA 9 and other areas has been conducted in habitats that are protected from wave and current energy, but similar exposed habitats have commonly not been sampled. Parametrix (1979) and Weitkamp et al. (1981) collected and observed young salmon primarily in the more protected portions of Terminal 90/91 in the northeast corner of Elliott Bay.

Current WRIA 9 Research for this Question
Sobocinski (2003) evaluated the effect of marine shoreline armoring on invertebrate production (both benthic and terrestrial fall out), especially invertebrates favored by juvenile salmon. A number of paired sites (adjacent armored & non-armored sites) were selected in central Puget Sound, including WRIA 9.

In 2002, J. Toft (UW) conducted a feasibility study to evaluate methods of monitoring and sampling juvenile salmon in highly structured shorelines (e.g., docks and piers, large boulder habitat). Methods tested included video (stationary and snorkel), snorkel, beach seine, overwater view from docks, and construction of a corral at high tide. The corral method worked well (Toft et al. 2003). The corral and snorkel methods were used in a more systematic fashion in 2004 to evaluate fish abundance and prey selection in various habitat types (e.g., docks/piers, bank armoring; Toft et al. 2004).

22. How much of each habitat type exists in each geographic area?

- Information needed when determining capacity of area to support Chinook salmon and when evaluating habitat restoration options.

General Information
Information is available for some other estuaries, but is not sufficiently relevant to WRIA 9 to make compilation worthwhile for this effort.

WRIA 9 Specific Information
Blomberg et al (1988) evaluated the historic and recent amounts of basic habitat types within the Duwamish River estuary.

Other general information is available (Tanner 1991, Weitkamp and Ruggerone 2000) on amounts of shallow water habitat types available in the Duwamish River and Elliott Bay. Kerwin and Nelson (2000) reviewed habitat within WRIA 9 and Williams et al. (2001) assessed the nearshore marine habitat. Systematic quantitative evaluations of habitat amounts and locations using discriminating criteria have not been conducted, although inventories of habitat conditions for the marine shoreline and the Duwamish River were completed in early 2004.

Current WRIA 9 Research for this Question
WRIA 9 completed an inventory of the lower Green River, Duwamish River and marine nearshore area in 2003 and 2004.

The ACOE/WDFW is planning a five-year "Nearshore Ecosystem Restoration Study" that will include WRIA 9 (F. Goetz, ACOE, pers. comm.). Details of the study have not been developed but it will involve monitoring and restoration of marine sites. This study will focus more on habitat rather than monitoring for fish use.

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23. Are certain "built" habitats avoided (or preferred) by Chinook (overwater structures, deep channels, bulkheads)?

- Information may help in identification of restoration activities. Methods: field observations, experimental manipulations.

General Information
The shoreline along built structures is used by young Chinook as a migration corridor and probably foraging. However, these habitats are likely limited by the energy environment just as natural habitats appear to be.

WRIA 9 Specific Information
Weitkamp and Farley (1976), Weitkamp (1977), and Weitkamp and Campbell (1980) found young Chinook and other salmon along the face of riprap shorelines, constructed piers, and under pier aprons supported by concrete piles, but not under pier aprons supported by dense wood piles.

Taylor and Willey observed juvenile Chinook within the Bell Harbor Marina along the riprap shoreline and offshore among floats. Similar observations have been made at other locations outside WRIA 9. These reports do not attempt to evaluate habitat values of the various constructed habitats.

Current WRIA 9 Research for this Question
See Sobocincki (2003) and Toft et al. (2004). K. Sobocinski (UW) evaluated the effect of marine shoreline armoring on invertebrate production (both benthic and terrestrial fallout), especially invertebrates favored by juvenile salmon. Toft et al. (2004) examined fish abundance and prey selection in various habitat types.

24. What percentage of Chinook fry reside in deep channel areas (~>10 ft) compared with shallow areas (~<10 ft)?

General Information
Although juvenile Chinook and other young salmon have been found in both shallow water and deep channel areas, systematic evaluations have not been conducted that provide information appropriate for determination of relative portions of the population. Likely there is some movement back and forth with changing tide conditions, and some variation as the fish migrate through reaches of varying habitat conditions. Fish size is also a factor in determining the tendency of young Chinook to move away from shorelines (Healey 1980).

WRIA 9 Specific Information
Most of the Duwamish River has been dredged but it is not well known whether fish use deep or shallow habitats; it is often assumed fish occupy more shallow habitats.

Current WRIA 9 Research for this Question
None identified.

25. Are fish in deep main-channel areas more transient or larger than fish using shallow water habitats?

General Information
None identified.

WRIA 9 Specific Information
Available information indicates young salmon present over the deeper areas tend to be larger than those in the shallow water areas, although the size ranges overlap considerably (Weitkamp 1977, Weitkamp and Campbell 1980, Weitkamp and Schadt 1982, Parametrix 1984).

Current WRIA 9 Research for this Question
None identified.

26. Does density in each habitat type linearly increase with Chinook abundance (seasonally, annually) or does habitat utilization appear to be saturated at high abundance, indicating capacity is reached?

- Question addresses issue of whether habitat type is already fully utilized and whether more of this habitat type might increase capacity. Identification of preferred habitat types and evaluation of Chinook densities in relation to total abundance may provide key information on types of habitats to restore and may provide information that could be used to evaluate the effectiveness of the restoration projects.

General Information

Levings (1984) reviewed literature and found that subyearling Chinook densities in estuaries rarely exceeded 0.9 fish/m^2 and noted that "it may be difficult to enhance juvenile salmon through put when these densities are exceeded." Levings (1984) also noted that growth in estuaries may be density-independent (i.e., factors such as temperature may override biological factors). In contrast, Beamer et al. (1999) reported that densities of Chinook salmon in preferred habitats in the Skagit River estuary did not increase linearly with Chinook salmon abundance, suggesting that the capacity of estuarine habitats had been exceeded.

Information on rearing capacity is provided by several studies from other areas. Beamer et al. (2000) estimated the rearing capacity of estuarine side channels in the Skagit River delta to range from about 1,000 fish /hectare to almost 16,000 fish/hectare. A Beaverton-Holt relationship shows maximum capacity to be about 22,000 fish/hectare. Beamer and LaRock (1998) determined the average density of young salmon within a Skagit delta slough was 6.6-17.9 Chinook/100m^2, and 7.6-33.2 chum/100m^2. Healey (1979) estimated 4.1 million chum fry reared within the Nanaimo River estuary in 1975, growing at a rate of 6%/day. He estimated the total amount of epibenthic and pelagic prey consumed during this rearing was 6,184 kg. Bailey et al. (1975) estimated 1-7 million fry were present during each of the three years studied in Traitor's Cove, Alaska. They estimated the carrying capacity of Traitor's Cove to be in the range of 50-100 million fry.

WRIA 9 Specific Information

Few data of this type are available for the Duwamish and most other areas.

Current WRIA 9 Research for this Question

None identified.

27. At what size and time period do Chinook tend to leave the Puget Sound nearshore?

- Little information on salmon use of nearshore, so nearshore habitat is focus here. These data are needed to identify peak use of the nearshore by salmon as well as duration of use. Information can be used in efforts to evaluate potential restoration projects.

General Information

Chinook salmon reside in Puget Sound longer than pink and chum salmon; Chinook salmon are present into the fall and some overwinter in Puget Sound (Healey 1980, Beamish et al. 1998). General information on nearshore use by juvenile Chinook, followed by movement to offshore waters as they grow has been described by several researchers (Healey 1991). However, the complexity of hatchery and wild fish together with ocean-type and stream-type fish makes definition of size at which they leave nearshore habitat difficult to address. The dispersal of fish into a very large area as they move offshore has made investigation of this issue impractical for most researchers.

WRIA 9 Specific Information

In 2002, W. Taylor captured by beach seine some juvenile Chinook salmon (130-160 mm) near Terminal 5 in Elliott Bay as late as early October.

Current WRIA 9 Research for this Question

Presently, King County has funded research within marine waters of WRIA 9 to evaluate salmon use of the Puget Sound nearshore (Mavros and Brennan 2001, Brennan and Higgins 2004).

In marine areas north and south of WRIA 9, Duffy et al. (2002) sampled juvenile salmon twice per month, April-September, 2001 and 2002, using beach seines and surface tow nets. In 2001, juvenile Chinook salmon (mostly hatchery fish) peaked in May-June and again in July-August (north sound only). Sampling by the R/V Ricker in offshore areas of Puget Sound during 2001 and 2002 (see Beamish et al. 1998) will provide additional information on residence time in Puget Sound waters.

28. Do salmon from other watersheds utilize WRIA 9 nearshore marine areas?

- If so, activities in nearshore may impact fish from multiple watersheds. Methods: CWT analysis, possibly genetics.

General Information
Little information of this nature is available for juvenile Chinook in other regions. In most cases identifying information is not available to determine the origin of the fish.

WRIA 9 Specific Information
None identified.

Current WRIA 9 Research for this Question
Brennan and Higgins (2004) collected salmon with CWT during 2001 and 2002. Preliminary analyses of the data suggest Chinook from a variety of watersheds utilize WRIA 9, including fish from northern Puget Sound drainages. Preliminary analysis of 104 CWT Chinook collected as part of the otolith research in 2002 indicated approximately 70% of the fish collected in Elliott Bay during June had originated from outside WRIA 9 (mostly Wallace Hatchery on the Snohomish River; G. Ruggerone, NRC, unpublished data). During July and later, the percentage of Green River CWT Chinook in Elliott Bay declined to 30% or less.

29. Do juvenile Chinook undergo physiological failure or stress in response to abrupt salinity or temperature change? Do high flows push fry into 30 ppt salinity?

- Some fish may have low tolerance to high salinity (lab studies) but importance unknown in field. Temperature and oxygen unlikely to kill juveniles but temperature during late migration period may be stressful.

General Information
See comment above. Most Chinook fry appear to have the capacity to adapt to high salinity levels within a shore period of time, although growth reduction has been observed in some lab studies when Chinook fry were placed in high salinities (Weatherley and Gill 1995).

Investigation of sublethal temperature effects can be conducted by measuring Hsp 70 mRNA and Hsp 30 mRNA in juvenile salmonids potentially exposed to high temperature conditions (Lund et al. 2002).

WRIA 9 Specific Information
A freshwater or low salinity layer is present in the lower Duwamish River. High river discharge produces low surface salinities throughout most of the Duwamish River providing much more low salinity habitat than low flow conditions. No evidence is available indicating salinity conditions reduce survival or growth of young Chinook in the Duwamish River. Salinity conditions in the Duwamish River are naturally highly variable with depth and, over time, at the surface for many locations as tide and river discharge change.

Current WRIA 9 Research for this Question
None identified.

30. What is the survival benefit of additional "preferred" habitat? Is existing habitat saturated? What density does this habitat support? Given habitat area, how many fish are supported? What is turnover rate or residence time in preferred habitat? What is the growth benefit?

    - These are key questions for restoration projects but difficult to address given migratory nature of salmon. Is existing habitat saturated? (Modeling approach: estimate growth benefit of preferred habitat [fry vs. smolt], numbers of Chinook that would be supported, approximate survival benefit of increased growth; assumptions will be needed here but data from other areas would be useful.)

General Information
This is a very difficult question to quantify. Although additional preferred habitat could provide the potential for increased survival and abundance of Chinook salmon, there are many other factors that affect survival and abundance. Simenstad and Wissmar (1984) and Levings (1984) provide interesting commentary on this issue. Levings (1984) notes that predation (e.g., coho predation on chum fry) could overwhelm potential benefits of preferred rearing habitat that might lead to increased estuarine residence time and growth.

WRIA 9 Specific Information
No information available for the Duwamish. No obvious indications of habitat saturation have been reported in the available reports. Collected Chinook fry have not shown obvious signs of poor condition or an abnormally high rate of empty stomachs.

Current WRIA 9 Research for this Question
None identified.

31. What is the frequency of diseased salmonids in the Duwamish or other indicators of immune response deficiency?

General Information
None identified.

WRIA 9 Specific Information
Arkoosh et al. (1998) concluded young Chinook migrating through the Duwamish River estuary were more susceptible to disease than fish from non-urbanized estuaries as indicated in disease challenge tests using Vibrio anguillarum (now Listonella). A more recent investigation for the Lower Duwamish Waterway Group indicated that PCBs in dietary exposure likely to occur in the Duwamish do not adversely affect the immune system of Chinook (Powell et al. 2002) and are therefore unlikely to make fish more susceptible to disease.

Current WRIA 9 Research for this Question
None identified.

32. If disease is observed, what is the disease agent (bacterial, viral, parasite)?

General Information
A variety of diseases and infectious agents have been identified in juvenile salmon; however, these diseases are commonly associated with hatchery fish.

WRIA 9 Specific Information
Disease has not been reported in juvenile Chinook populations as they migrate through lower Duwamish River, estuarine and nearshore habitats. Unless disease conditions were substantial it is unlikely that past sampling efforts would identify the presence of a disease. Generally fish have been found in good condition, except for hatchery reared fish known to have substantial disease conditions prior to release.

Current WRIA 9 Research for this Question
None identified.

33. What is the concentration of PCBs and other toxic chemicals of concern in juveniles (excluding stomachs) captured at the Duwamish/Elliott Bay confluence by time period?

General Information
O'Neill et al. (1998) found elevated levels of PCBs in young Chinook from marine areas as compared to those from river areas and as compared to coho in Puget Sound. Potential adverse effects were postulated, but not observed.

WRIA 9 Specific Information
PCBs and mercury were measured in juvenile Chinook salmon collected from the East Waterway and Kellogg Island during 2002 (Windward 2002). Within each location no differences were seen between hatchery and wild Chinook in terms of their individual lengths and weights and the lipid content, mercury concentrations and total PCB concentrations measured in the tissue composite samples. No differences were seen in tissue mercury concentrations measured in Chinook collected at Slip 27 compared to the Chinook collected at Kellogg Island. Higher total PCB concentrations were measured in hatchery and wild Chinook collected from Slip 27 compared to the hatchery and wild Chinook collected from Kellogg Island.

Recent investigations for the Lower Duwamish Waterway Group indicate that PCBs in dietary exposure likely to occur in the Duwamish do not adversely affect the immune system of Chinook (Powell et al. 2002). Other investigations (Arkoosh et al. 1998) have found young Chinook migrating through the Duwamish River have higher concentrations of organic contaminants than those released at the hatchery, and that the fish passing through the estuary were more susceptible to disease when challenged by Vibrio anguillarum.

Current WRIA 9 Research for this Question
None identifed.

34. What is the concentration of PCBs and other toxic chemicals of concern in juveniles captured at the most toxic site?

    - Given results of lab studies, are these levels of concern for survival?

General Information
None identified.

WRIA 9 Specific Information
Arkoosh et al. (1998) reported the mean concentrations of PCBs in small numbers of Chinook from the Duwamish estuary to be 270 ng/g wet weight in 1993 and 90 ng/g in 1994. These concentrations were 3-5 times higher than fish sampled from several hatcheries and the Nisqually River estuary. O'Neill et al. (1998) reported PCB concentrations in adults collected from several rivers averaged 74 µg/kg, with Duwamish River fish similar to Deschutes, Nisqually, Nooksack, and Skagit River fish, with the exception of a single sample.

Current WRIA 9 Research for this Question
None identified.

35. Do juveniles exhibit abnormally high levels of stress, which is often a precursor to disease?

General Information
Generally migrating juveniles have not been evaluated to determine the level of stress they might demonstrate. Most means of collection produce sufficiently high levels of commonly measured stress parameters to make such evaluations difficult.

WRIA 9 Specific Information
Young Chinook migrating through WRIA 9 have not been evaluated to identify stress levels. Most reports providing information about fish collected in this area do not provide any indication of stress being observed in these fish. During early summer 2002, G. Ruggerone (NRC) and W. Taylor (Taylor and Associates) observed hypermucosis among numerous juvenile Chinook and chum salmon captured near Terminal 5; this condition may have been caused by irritants in the water originating from jelly fish, contaminants, or plankton bloom.

Current WRIA 9 Research for this Question
None identified.

36. Does stormwater quality, especially during the first storm of the season, affect juvenile Chinook salmon?

General Information
Few if any young fish are present during the first storms of the wet season. The first storms of the migration period occur during the latter half of the wet season.

WRIA 9 Specific Information
King County analyzed CSO discharge events in 1999 and results indicated these discharges do not increase the risk of young salmon being exposed to adverse concentrations of contaminants in the water column. They also concluded there was no increased dietary risk due to the CSO discharges.

Current WRIA 9 Research for this Question
None identified.