PART V: APPENDIX

Historical and Current Salmonid Populations, Life Histories and Habitat Conditions—Draft Report

Historical and Current
Salmonid Populations, Life Histories, and Habitat Conditions
Draft Report

Executive Summary

Green River Chinook Population Trends

The Green/Duwamish River system currently supports an average yearly total run (fish returning to the river and those caught in fisheries) of about 41,000 adult chinook salmon. The run is divided into hatchery and naturally spawning populations of which the wild component is unknown.

The hatchery population is descended from the native chinook of this system and has been used in fish culture for nearly 100 years. The total run of hatchery chinook has averaged about 24,000 fish over the period 1968 - 1996.

The naturally spawning component of the chinook run contains a mixture of wild and stray hatchery chinook. The total run size from 1968-1996 is about 17,000 fish of which an average of 5,700 have spawned in the river. The escapement goal for adult spawners was established in the mid 1970s by the Washington Department of Fisheries at 5,750 fish. The Green Rive has not experienced the same decline in naturally spawning fish as has occurred in other streams in Puget Sound and the spawning goal has been met six of the last ten years. However, changes in methodology for counting chinook may revise these spawner counts downward.

Comparisons of the rate of survival of tagged juvenile chinook, from release at the hatchery to either returning adult or capture in a fishery, indicate that the survival of Green River chinook is highly relative to chinook in other Puget Sound rivers. The persistence of the naturally spawning component of the run is consistent with a high survival rate. Overall, Green River chinook are resilient and have survived the effects of large-scale production of hatchery fish, high harvest rates, and habitat alteration.

The major question pertaining to the status of Green River chinook is the contribution of hatchery production to maintaining the numbers of natural spawning fish. If high numbers of hatchery produced adults stray to the spawning grounds, then the observed spawning population is being sustained by stray hatchery chinook. If the contribution of hatchery fish is small, then the Green River chinook run is self-sustaining and is very healthy relative to other runs in Puget Sound. Resolution of the composition of the naturally spawning population in the Green River is a priority for proper conservation and management of this chinook run.

River Life History of Chinook

Naturally spawning chinook are most abundant in the mainstem of the Green River from the City of Tacoma water diversion downstream to Soos Creek. Spawning also occurs in

Newaukum Creek and the Soos Creek drainage. Spawning occurs from mid-September through October. The eggs spend the fall and winter incubating in the spawning areas and the fry "emerge" from the gravel in late February and March.

Summer/fall chinook are dominant in the system, but the remnants of a spring chinook run appears to be present. Summer/fall chinook are termed "ocean-type" chinook as they do not spend a full year in freshwater as juveniles. The rearing phase of the juvenile chinook is complex due to the plasticity of habitat use and timing of emigration to saltwater. Ocean-type chinook spend from several days to several months in freshwater prior to migrating to the Duwamish River estuary and associated estuarine shorelines. For clarity, the discussion of life history for WRIA 9 distinguishes three different life history "trajectories" for juvenile ocean-type chinook that are defined by the timing and size at which the fish reach the Duwamish estuary. The fish on these trajectories spend differing amounts of time in the freshwater and estuarine rearing habitats within the WRIA. For example, fish on one trajectory (termed "emergent fry") migrate to the estuary immediately after emerging from the gravel and spend months there, while fish on another trajectory (termed "fingerling") migrate to the estuary in late May or June and reside there a few days.

The endpoint of each rearing trajectory is a juvenile that is ready to move offshore from near the river mouth into the greater Puget Sound estuary. Juvenile ocean-type chinook need to achieve a length of approximately 70 mm (approximately 3 inches) to make the transition in feeding, physiology, and behavior that allows them to use the Puget Sound estuary. It is at this length that the needs of the different life history trajectories converge.

Due to their different habitat needs, the fish on these rearing trajectories have been affected differently by the habitat changes that have occurred in WRIA 9. Understanding the habitat needs of the rearing trajectories, provides clarity and focus for determining the opportunities for conservation and recovery of Green River chinook.

Green River Chinook Population Trends

The Green/Duwamish River system supports an abundant run of hatchery chinook and a relatively large run of naturally spawning chinook. The hatchery run is descended from the native chinook from this system and has been used in fish culture for nearly 100 years. The total run (fish returning to the hatchery and those caught in fisheries) of hatchery chinook has averaged about 24,000 fish over the period 1968-1996.

The naturally spawning component of the chinook run contains a mixture of wild chinook and stray hatchery chinook. The total numbers of chinook that spawn naturally in the system has averaged 5,700 over the period 1968-1996, while the total run of naturally spawning fish has averaged about 17,000 fish. The escapement goal for adult spawners was established in the mid-1970 by the Washington Department of Fisheries at 5,750 fish. The Green River has not experienced the same decline in naturally spawning fish as has occurred in other streams in Puget Sound and the spawning goal has been met six of the last ten years. However, changes in methodology for counting chinook may revise these spawner counts downward.

Comparisons of the rate of survival of tagged juvenile chinook, from release at the hatchery to either returning adult or capture in a fishery, indicate that the survival of Green River chinook is high relative to chinook in other Puget Sound rivers. The persistence of the naturally spawning component of the run is consistent with a high survival rate. Overall, Green River chinook are resilient and have survived the effects of large-scale production of hatchery fish, high harvest rates, and habitat alteration.

The major question pertaining to the status of Green River chinook is the contribution of hatchery production to maintaining the numbers of natural spawning fish. If high numbers of hatchery produced adults stray to the spawning grounds, then the observed spawning population is being sustained by stray hatchery chinook. If the contribution of hatchery fish is small, then the Green River chinook run is self-sustaining and is very healthy relative to other runs in Puget Sound. Resolution of the composition of the naturally spawning population in the Green River is a priority for proper conservation and management of this chinook run.

Chinook River Life History

Naturally spawning chinook are most abundant in the mainstem of the Green River from the City of Tacoma water diversion downstream to Soos Creek. Spawning also occurs in Newaukum Creek and the Soos Creek drainage. Spawning occurs from mid-September through October. The eggs spend the fall and winter incubating in the spawning areas and the fry “emerge” from the gravel in late February and March.

Summer/fall chinook are dominant in the system, but the remnants of a spring chinook run appears to be present. Summer/fall chinook are termed “ocean-type” chinook as they do not spend a full year in freshwater as juveniles. The rearing phase of the juvenile chinook is complex due to the plasticity of habitat use and timing of emigration to saltwater. Ocean-type chinook spend from several days to several months in freshwater prior to migrating to the Duwamish River estuary and associated estuarine shorelines. For clarity, the discussion of life history for WRIA 9 distinguishes three different life history “trajectories” for juvenile ocean-type chinook that are defined by the timing and size at which the fish reach the Duwamish estuary. The fish on these trajectories spend differing amounts of time in the freshwater and estuarine rearing habitats within the WRIA. For example, fish on one trajectory (termed “emergent fry”) migrate to the estuary immediately after emerging from the gravel and spend months there, while fish on another trajectory (termed “fingerling”) migrate to the estuary in late May or June and reside there a few days.

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Due to their different habitat needs, the fish on these rearing trajectories have been affected differently by the habitat changes that have occurred in WRIA 9. Understanding the habitat needs of the rearing trajectories, provides clarity and focus for determining the opportunities for conservation and recovery of Green River chinook.

Green River Chinook Salmon Population Trends

Chinook salmon in the Green River consist primarily of summer/fall run fish. Historically, a spring run also occurred in the watershed but re-routing of the White River to the Puyallup drainage in 1906 (natural and man-induced), re-routing of Lake Washington and Cedar River to the Ship Canal in 1916, construction of the Tacoma Diversion Dam in 1913 and construction of Howard Hansen Dam in 1961 eliminated access to much of the headwater habitat typically needed by spring chinook salmon in this region (Grette and Salo 1986). These changes reduced the Green River watershed to approximately 30% of its historical size. Presently, nearly all chinook production occurs in the mainstem Green River below the Tacoma Diversion Dam, Soos Creek, and Newaukum Creek. Although spring chinook salmon are occasionally found in the Green River it is not known if these fish constitute a self-sustained run.

Chinook salmon returning to the Green River have been a mixture of natural spawning and hatchery chinook salmon since approximately 1904 when the first hatchery fish returned to the Green River Hatchery on Soos Creek. Harvest and spawning escapement data for the Green River (and other Puget Sound drainages) are unavailable prior to the mid-1960s. The only index of chinook salmon returns to Puget Sound during the early 1900s is commercial and sport harvests in the Strait of Juan de Fuca and Puget Sound. However, these data are confounded by the presence of chinook salmon destined for British Columbia and the interception of Puget Sound-bound chinook in Washington coastal troll and other interception fisheries.

Commercial harvests of chinook salmon in Puget Sound were high during 1913-1933 (200,000 to 450,000 per year), then declined sharply in 1934 due to prohibition of set gillnets and traps (Fig. 1). Commercial harvests remained low during 1934-1960 (avg. 60,000 per year), then gradually increased to peak levels in 1975-1990 (avg. 235,000 per year). This period of increasing harvests corresponded to increasing releases of hatchery salmon. Commercial harvests declined sharply during 1991-1998 (avg. 88,000 per year). The harvest in 1998 was the lowest since 1962. Sport harvests are available since 1946.

Total harvests in Puget Sound (commercial and sport) peaked in 1975 (587,000 chinook), then declined steadily to 138,000 chinook in 1997 (sport data not available for 1998).

As a result of recent efforts by the WDFW and tribes, more accurate records of chinook spawning escapement and stock-specific harvests are available since 1968. Enhanced accounting of chinook escapements and runs in Puget Sound drainages arose, in part, as a response to the 1976 Boldt decision which influenced managers to switch from harvest rate based management to spawning escapement based management. However, the harvest component in the stock-specific WDFW run reconstruction database is limited to commercial harvests (mainly net harvests) in Puget Sound (treaty and non-treaty Indian). Many chinook salmon having their origin in Puget Sound are harvested by sport and commercial fishermen in British Columbia. To account for Green River chinook salmon harvested in fisheries other than commercial net harvests in Puget Sound, NRC (1999) integrated annual distributions of total mortalities (including incidental mortalities) associated with each fishery in each geographic region (PSC 1999) with the WDFW harvest data to reconstruct total annual runs of chinook salmon returning to the Green River. The results of this run reconstruction are described below for natural spawning and hatchery chinook salmon.

Readers should be aware that the reconstructed run estimates for Green River chinook salmon are subject to a variety of measurement errors, which are typical of fishery estimates such as these. For example, the spawning escapement in the Green River is estimated by counting chinook redds (spawning nests) in a portion of the basin, expanding redds counts by a factor of 2.5 to account for numbers of fish per redd, then expanding this estimate of spawning fish to the entire basin based on an estimate of total habitat believed to support spawning chinook salmon (Smith and Castle 1994). For mainstem Green River, the latter expansion factor is 2.6, indicating that most of the spawning grounds are not sampled each year. This expansion factor is currently under review and the reanalysis may lead to somewhat lower spawning escapement estimates (T. Cropp, WDFW, pers. comm.). Spawning escapement estimates include hatchery strays, a fact that leads to overestimation of the "wild" chinook run produced by naturally spawning parents. Ongoing efforts to remove this bias are discussed. The most accurate component of fishery statistics is commercial harvest, but significant error may occur when allocating the harvest to the various watersheds in Puget Sound and British Columbia using the FRAM (Fishery Regulatory Assessment Modeling) and Pacific Salmon Commission models.

For this report, we describe Green River chinook runs returning to the hatcheries and to the spawning grounds. The natural spawning population includes hatchery salmon that stray to the spawning grounds. Thus, “wild” chinook, which are produced by naturally spawning parents (wild and hatchery origin), are overestimated to the extent that hatchery chinook stray to the spawning grounds. Because the WDFW run reconstruction approach utilizes the ratio of chinook returning to the hatchery compared to the spawning grounds to estimate hatchery versus “wild” chinook salmon in harvests, the true wild run is overestimated and the hatchery run is underestimated. The confounding effect of hatchery strays on wild chinook production estimates in systems such as the Green River was identified in the NMFS status review as a key concern leading to the listing of Puget Sound chinook salmon (Myers et al. 1998).

For this report, we use the term “wild” chinook salmon to mean fish produced by natural spawning parents that return to the spawning grounds plus hatchery fish that stray to the spawning grounds. This terminology is used because existing WDFW escapement data do not distinguish between true wild fish and hatchery strays. Ongoing efforts are being made to use coded-wire-tag recoveries in the hatcheries and spawning grounds to estimate stray rates.

“Wild” Chinook Salmon

During 1968-1996, the estimated”wild” run of summer/fall Green River chinook salmon ranged from 5,600 in 1973 to 41,000 in 1983 and averaged 17,400 fish (Fig. 2). Run size tended to be higher during recent years (1983-1996) compared to earlier years (1968-1982), indicating the downward trend common to other Puget Sound stocks is not evident among ”wild” Green River chinook salmon. The trend of greater runs during recent years compared to earlier years is also evident from WDFW’s estimated commercial net harvests of Green River ”wild” chinook and spawning ground escapement estimates.

WDFW estimates the spawning population of chinook salmon in the Green River by counting chinook salmon redds (spawning nests) within selected stream reaches, expanding these redd counts to unsurveyed spawning habitat, then expanding redd counts to the total spawning population. The spawning escapement goal of 5,800 natural spawners was established in the mid-1970s using average escapement of wild and hatchery strays during 1965-1976 (Ames and Phinney 1977). The estimated spawning escapement during 1968-1997, including unknown hatchery strays, averaged 5,700 fish and it exceeded the goal during 12 (40%) of 30 years (Fig. 3). During the past 10 years (1988-97), spawning escapements have been relatively large (avg. 7,280 fish) and escapements have exceeded the goal during 7 of 10 years.

A Ricker recruitment curve was generated from the run reconstruction dataset in order to evaluate the spawning escapement level that would lead to maximum sustained harvests (Ricker 1954). This analysis assumed that adult runs four years after the spawning escapement were representative of the multiple-age adult return since most Green River chinook mature at age-4.

The recruitment curve shows considerable variability in adult returns from escapements between 3,000 to 12,000 fish (Fig. 4). Such variability in returns from escapements is common among salmon populations because many factors affect survival after spawning adults are enumerated and because return and spawning estimates contain measurement error. The average return per spawner during 1968-1992 was 3.8 fish, a value that suggests production of Green River chinook salmon is high compared to other chinook stocks (Salo and Rogers 1984). Adult runs consistently exceeded the replacement line indicating the Green River produced more fish than spawn in the river.

The spawning escapement leading to maximum harvests is approximately 6,060 fish (Fig. 4) (see Hilborn 1985). However, the variability in adult returns from the observed escapements and the gentle slope of the recruitment curve shows that annual deviations of 1,000 fish or so from a mean of 6,060 spawners will have little effect on adult returns. This approach suggests the WDFW escapement goal of 5,800 chinook salmon may be slightly low for the purpose of maximizing harvests, but escapements have exceeded 6,060 fish during six of the past 10 years. It is worth noting that escapements greater that 6,060 fish tended to produce greater returns, on average, compared to somewhat smaller escapement. This suggests the risk of producing small returns is reduced when allowing somewhat larger escapements. Large escapements leading to overcompensation (declining returns from large escapements) was not clearly evident within the range of observed escapements, indicating the risk of reduced returns at escapements less than 10,000 fish is probably low.

This run reconstruction analysis of “wild” chinook salmon includes stray hatchery chinook salmon that spawned in the Green River. Hatchery chinook salmon on the spawning grounds may have originated from fish released from the hatcheries or from off-station releases such as those at Icy Creek and above Howard Hansen Dam. The implication is that the wild run, harvest, and escapement of Green River chinook salmon is overestimated to the extent that hatchery fish contribute to natural spawners on the Green River. Harvest estimates of wild chinook are affected by hatchery strays because the run reconstruction approach used by WDFW is dependent on the estimated escapement to the spawning grounds. For example, if 30% of the chinook escaping to the river return to the spawning grounds and 70% return to hatcheries, then WDFW assumes 30% of the harvest of Green River chinook (hatchery and wild) is allocated to the “wild” run and 70% to the hatchery run.

A modeling exercise is underway to reconstruct wild chinook runs and escapements based on a range of stray rates for cultured chinook salmon in the Green River (NRC 1999). The analysis will use recoveries of coded-wire-tagged hatchery salmon recovered on the spawning grounds and hatcheries to estimate stray rates. This analysis removes stray hatchery fish from escapement and harvest estimates during the year of return and it removes estimates of future production produced by stray salmon spawning in the river. Preliminary results suggest that while the revised wild chinook runs and escapements are smaller than those reported above, the productivity of the system, in terms of adult returns per spawner, remains relatively high.

Hatchery Chinook Salmon

Large numbers of chinook salmon have been released into Puget Sound watersheds since the early 1900s as a means to enhance commercial and sportfishing opportunities. Prior to 1950, approximately 5-40 million chinook salmon were annually released into Puget Sound (Fig. 5, NRC 1995). During the early 1950s, approximately 15 million chinook were released into Puget Sound per year. Chinook releases increased steadily over the years as new hatcheries and production capabilities increased. In the late 1980s, releases of chinook salmon peaked at near 70 million fish per year, but production has declined somewhat in the 1990s.

The Green River Hatchery, located on Soos Creek, has been one of the most productive hatcheries in the state, representing approximately 14% of the total hatchery chinook production in Puget Sound since 1950 (range: 7-52%, Fig. 5). It was constructed in 1901 and the original brood stock is believed to have originated from the Green River. Few non-native chinook salmon have been released into the Green River, although fall (tule) chinook salmon from the Columbia River were transferred into the hatchery during 1918-1925 (Fuss et al. 1993). Recent genetic stock identification studies suggest these transplants were not successful.

WDFW attempts to minimize interactions between hatchery and wild juvenile salmon by rearing fish to relatively large size (80 fish/pound, on-station releases) so they will spend relatively little time in the river (Fuss et al. 1993). However, the effectiveness of this strategy in minimizing interactions with smaller wild salmon has not been investigated. Actual size of fish released on-station since the mid-1980s has ranged from 0.7 to 7.6 g (NRC 1995). Satellite rearing ponds are located at Icy Creek and Crisp Creek where juvenile chinook are reared to approximately 4.5-45g and 1-50g fish, respectively (WDFW releases). The large delayed release fish contribute to the blackmouth fishery in Puget Sound. The Muckleshoot Indian Tribe has operated the Keta Creek Hatchery (located on Crisp Creek) since the late 1970s. Subyearling chinook released from this facility, including those released above Howard Hansen Dam, are relatively small (avg. 1.7g, NRC 1995).

Approximately 3-12 million chinook salmon have been released into the Green River each year since 1953 (Fig. 6). Peak releases occurred during 1986-1991. Off-station sites, such as Icy and Crisp creeks, for rearing and release began in the late 1970s. During this recent period, approximately 14% of the fish have been released from Icy Creek Ponds, 22% from the ponds and Keta Creek Hatchery on Crisp Creek, 4% into streams above Howard Hansen Dam, and the remaining fish have been released at the Green River Hatchery.

During 1968-1996, annual runs of hatchery chinook salmon to the Green River Hatchery have ranged from 11,200 fish in 1991 to 46,800 fish in 1990 (Fig. 7). Run size has averaged 23,900 fish. No time trend is apparent, although the three largest runs occurred after 1988. Hatchery production contributed, on average, 15,800 fish per year to commercial and sport harvests in Washington and British Columbia. Because the Green River is managed to maintain adequate escapement of "wild" chinook salmon to the spawning grounds, approximately 8,200 fish per year escaped to the hatcheries (Fig. 3). This escapement greatly exceeds the Green River Hatchery goal of 3,658 chinook salmon (Fuss et al. 1993). These estimates of hatchery production are somewhat low because they do not account for strays that returned to the river rather than the hatchery. A few chinook produced by naturally spawning parent probably stray from the river to the hatchery.

The Green River Hatchery has been one of the most productive chinook hatcheries in the state. Consistent excess in numbers of chinook returning to the Green River Hatchery during the past 90 years allowed eggs from this facility to be transferred throughout Puget Sound (NRC 1995). This activity has raised concerns about the genetic diversity of receiving chinook stocks in Puget Sound (Myers et al. 1998). Although reliance on this stock in hatchery programs is declining as a result of recent policy changes in inter-hatchery transfer of chinook salmon, 20 hatcheries and 10 net-pen programs regularly released Green River fall chinook salmon as late as 1995 (Marshall et al. 1995). The NMFS considers the long history of hatchery salmon outplants and the genetic integrity of chinook salmon stocks to be a key issue leading to the threatened status of chinook salmon in Puget Sound.

Survival From Release to Return

Survival during 1972-1993 was estimated from coded-wire-tagged (CWT) subyearling chinook salmon released into the Green River and recovered in harvests and at the Green River hatcheries. Survival averaged 0.76% during this period (range: 0.09% to 3.2%, Fig. 8). Although there was considerable variation from year-to-year, survival tended to be somewhat higher during the 1970s compared to more recent years. The pattern of lower survival during recent years was also observed when all hatchery fall chinook stocks in Puget Sound were combined (Mahnken et al. 1998).

Survival of Green River hatchery chinook salmon (CWT-based estimates) was compared to survival estimates of chinook in several other watersheds in Puget Sound (Nisqually, Sammamish, Snohomish, Skagit, Hood Canal) using CWT releases and recoveries. The time period of analysis encompassed brood years 1972-1993, but annual estimates were not available for all stocks in all years. No statistical difference in survival was found between systems (single factor ANOVA, df= 5,69, p=0.338). However, survival of Green River fall chinook salmon (avg. 0.76%) tended to be somewhat higher than that of Nisqually (0.45%), Hood Canal (0.51%), Snohomish (0.45%), and Skagit (0.23%), but similar to chinook released from Issaquah hatchery (0.87%) (Fig. 9).

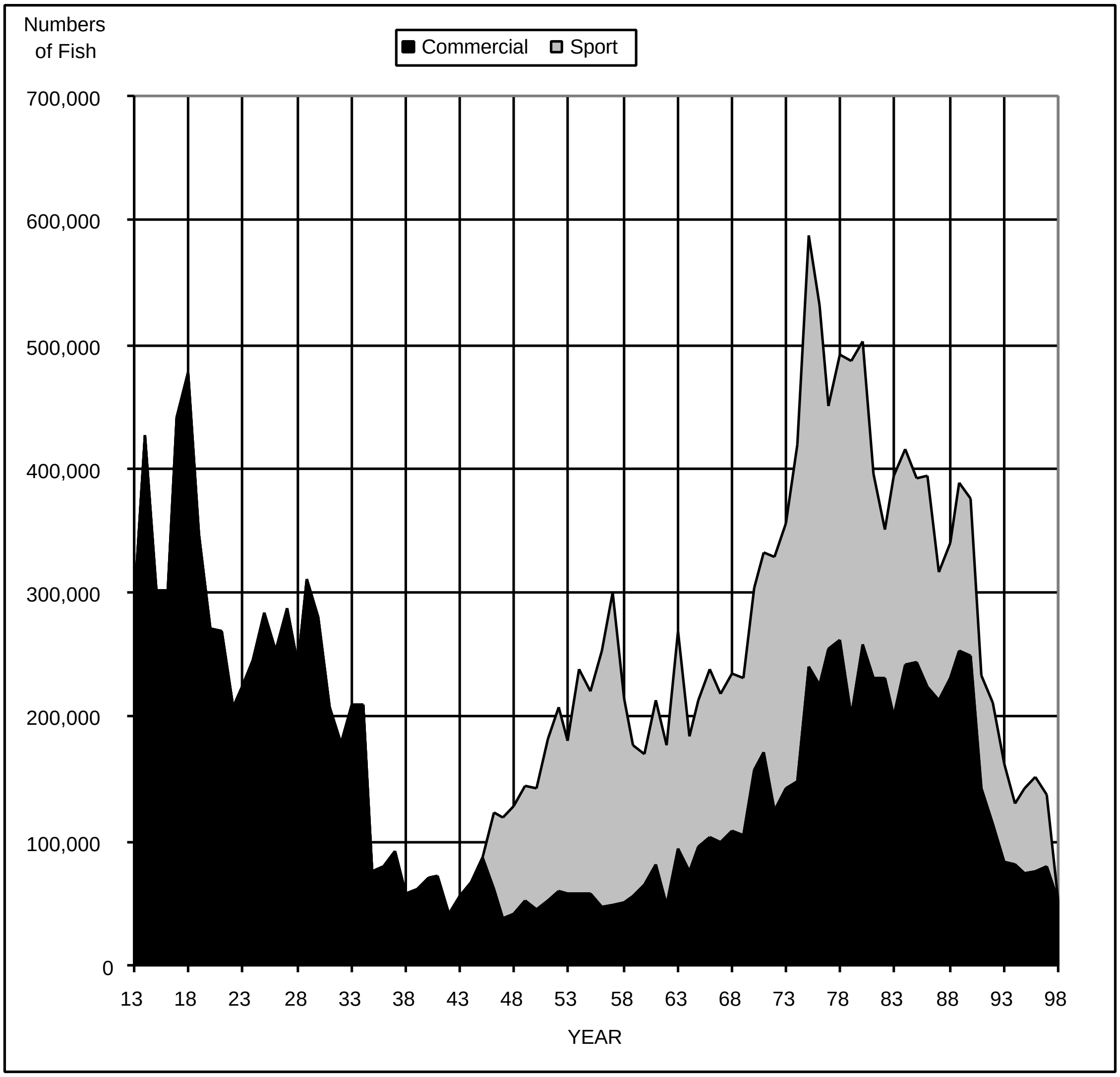


Figure 1. Commercial (tribal and non-tribal) and sport harvests of chinook salmon in Puget Sound, 1913-1998. Sport harvest data not available prior to 1946 and in 1998. Harvests include chinook salmon destined for Canadian streams. Hatchery and wild stocks are included. Tribal harvests increased markedly in 1976 following the Boldt decision. Data source: WDFW annual reports.

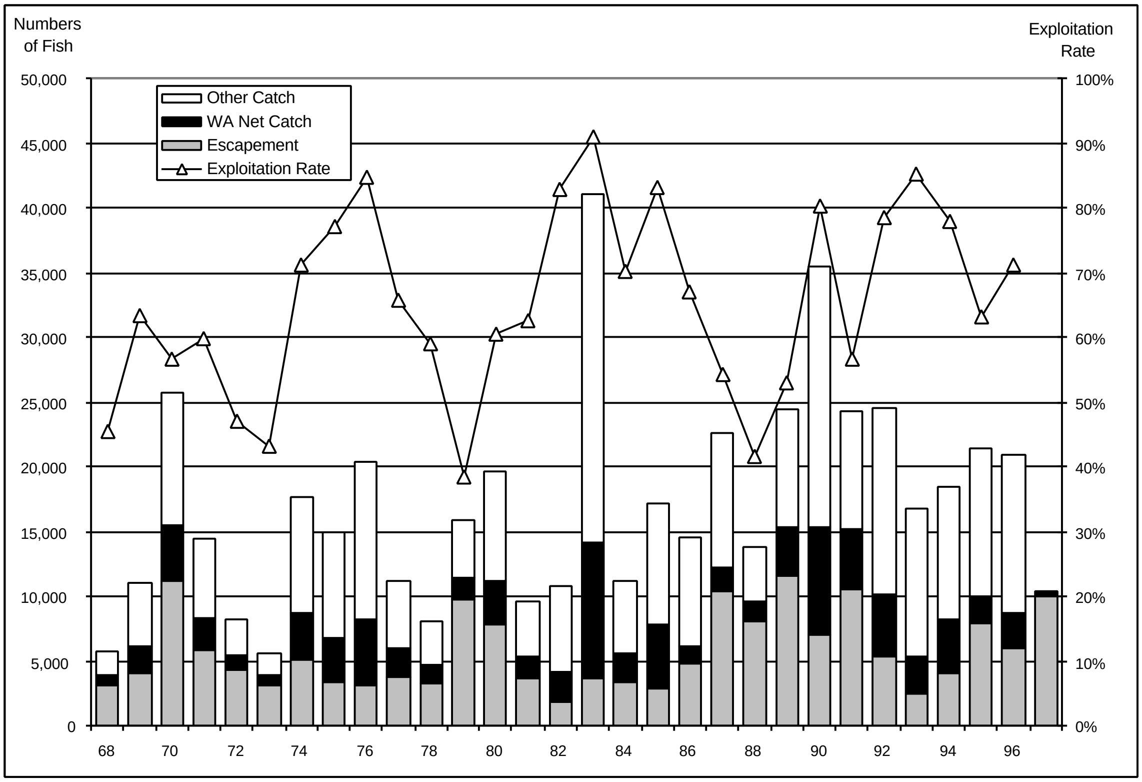


Figure 2. Estimated annual total run, harvest and escapement of Green River "wild" chinook salmon, 1968-1997 (NRC 1999). Washington net catches are treaty Indian and non-treaty commercial harvests as reported by WDFW (1998). "Other catch" includes total chinook mortalities related to harvests in Washington sport and troll fisheries, and sport and commercial fisheries in British Columbia and Alaska (PSC 1999, NRC 1999). Total mortality estimates include estimated mortality of fish released after capture in fisheries (e.g., chinook non-retention fisheries and sublegal-sized fish, PSC 1999). "wild" chinook estimates include hatchery fish that stray onto spawning ground. "Other catch" estimates were not available in 1997.

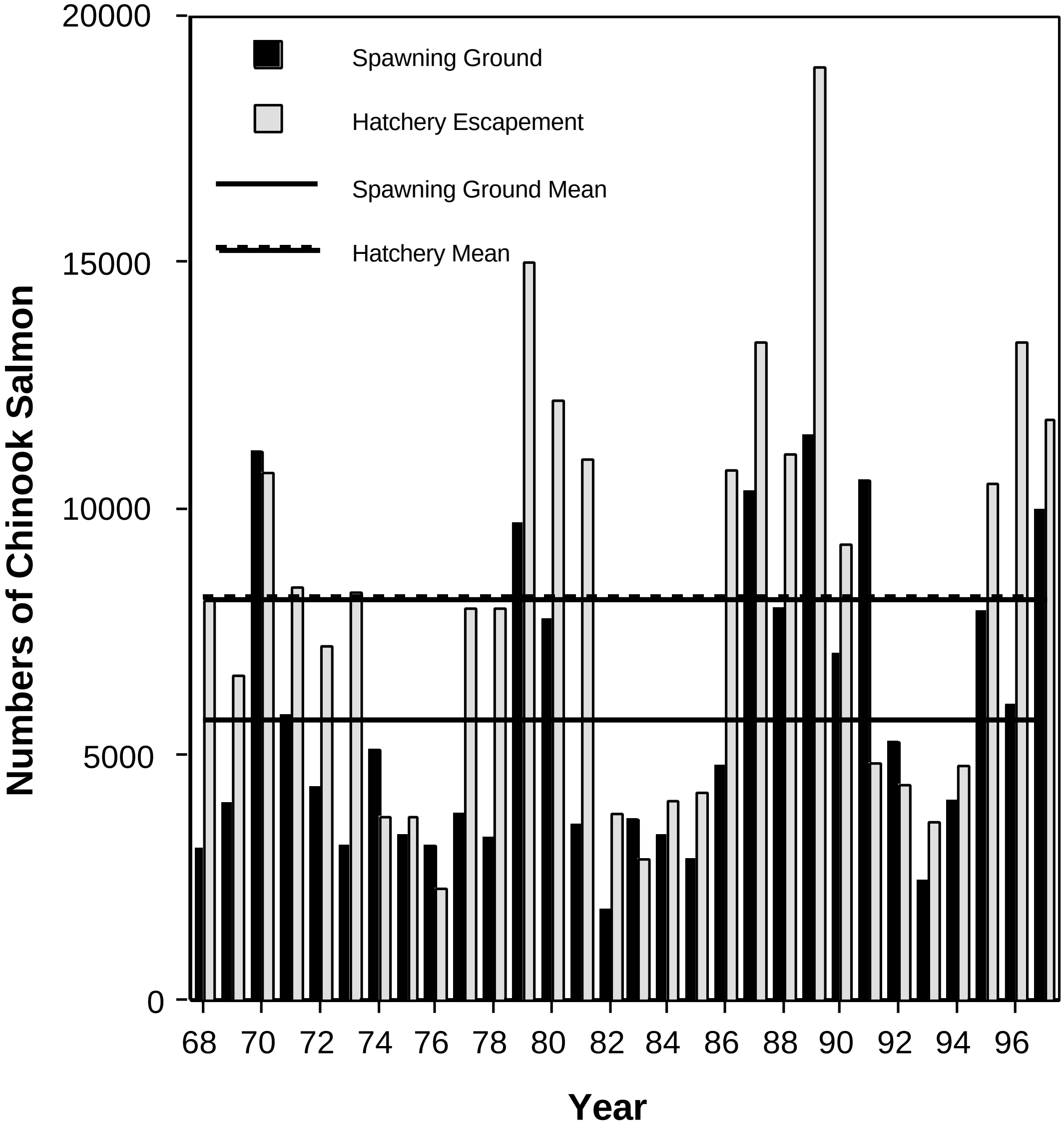


Figure 3. Time series of chinook salmon returning to the spawning grounds and to the hatcheries, 1968-1997. Spawning ground estimates include an unknown number of stray hatchery salmon. Mean values are shown. Data source: WDFW 1998.

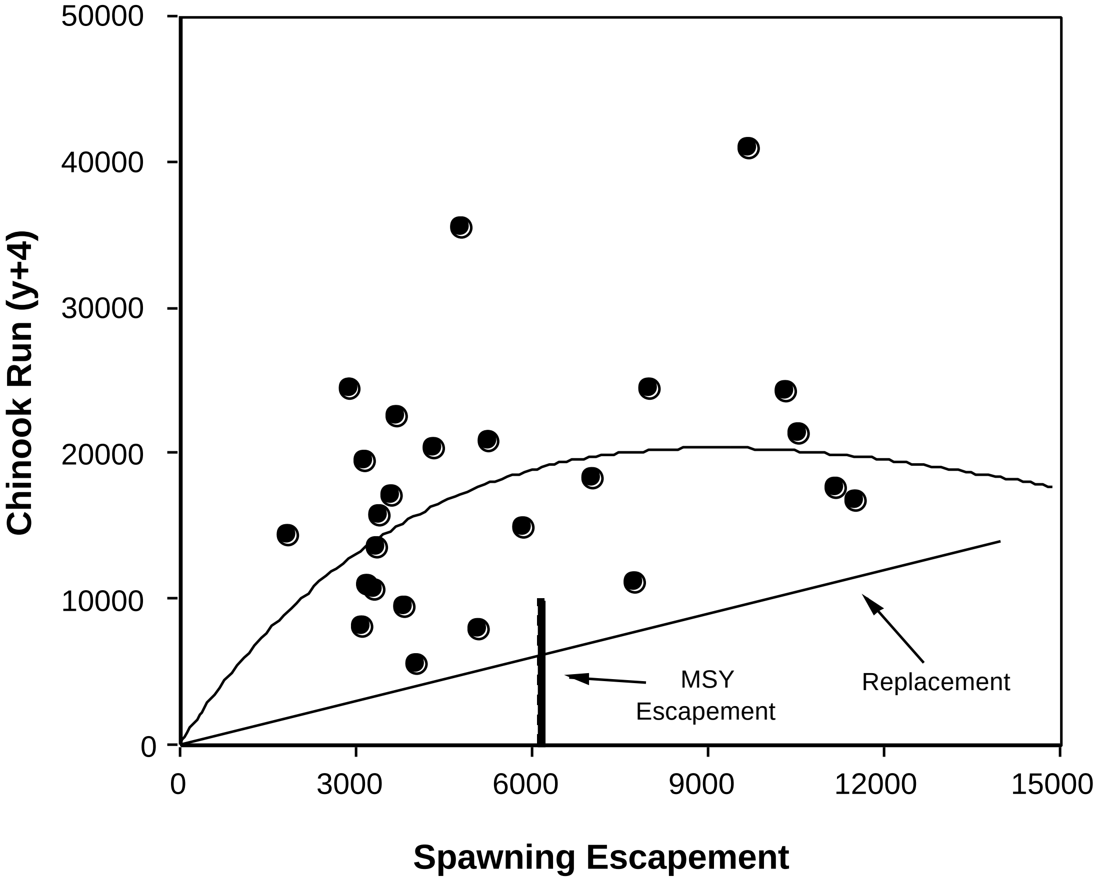


Figure 4. Ricker recruitment curve for natural spawning Green River chinook salmon based on run reconstruction data, brood years 1968-1992 (NRC 1999). Graph shows relationship between estimated escapement and run four years later. Vertical dash line shows the estimated escapement level (6,060 spawners) that would produce maximum sustained harvests. Replacement line is where recruitment equals escapement level. Predicted recruitment curve (solid line) based on linear regression:

LN(R/S) = 1.80 - 0.000109 * (Escapement), $R^2 = 0.34$, $p = 0.002$.

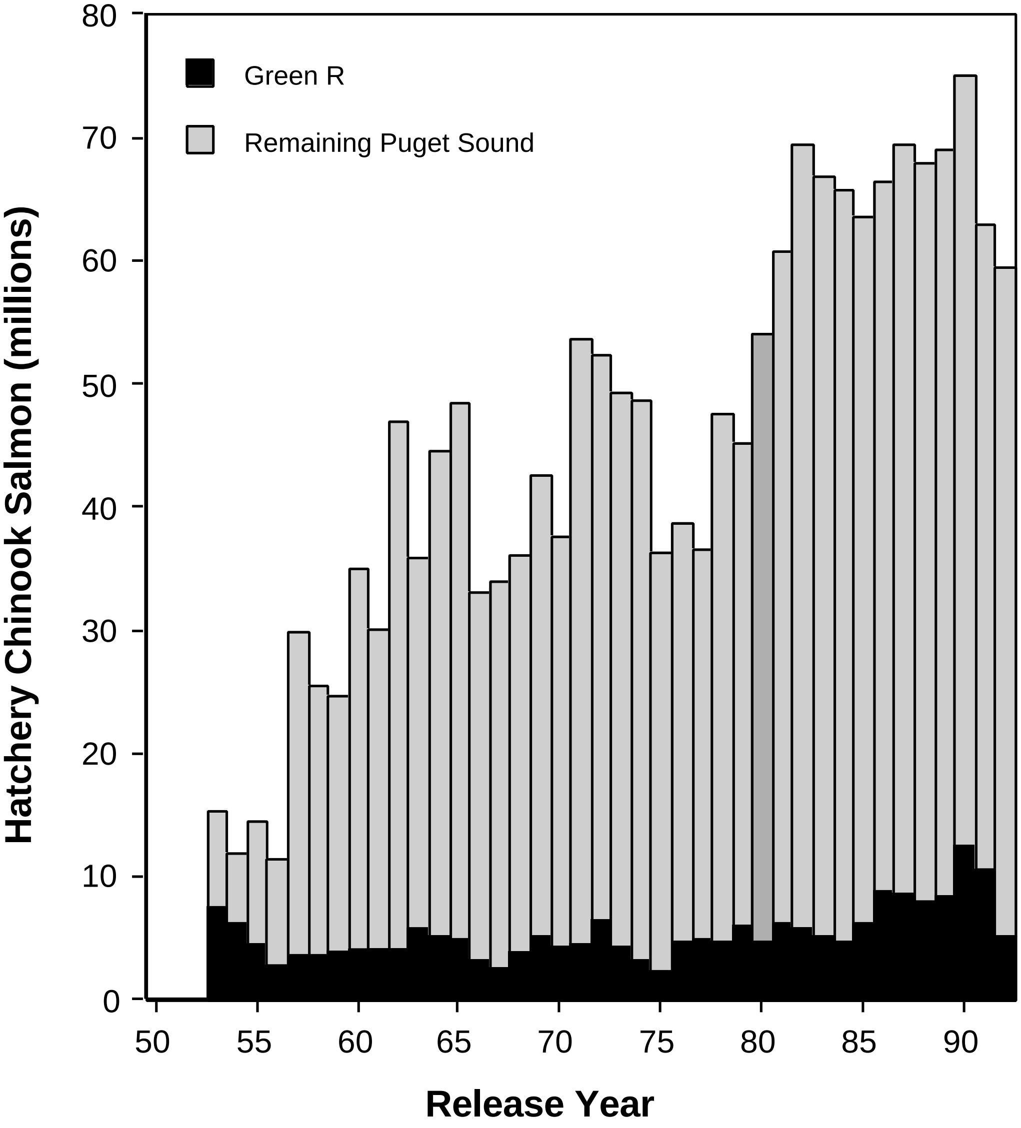


Figure 5. Numbers of chinook salmon (all runs) released from hatcheries into Puget Sound and the Green River, 1903-1992. Numbers of chinook released into Green River are shown when data available, otherwise total for Puget Sound is shown. No data available for some years. Prior to 1950, releases "into" Green River may include chinook transferred from Green River Hatchery to other drainages. Data source: WDF annual reports, NRC 1995.

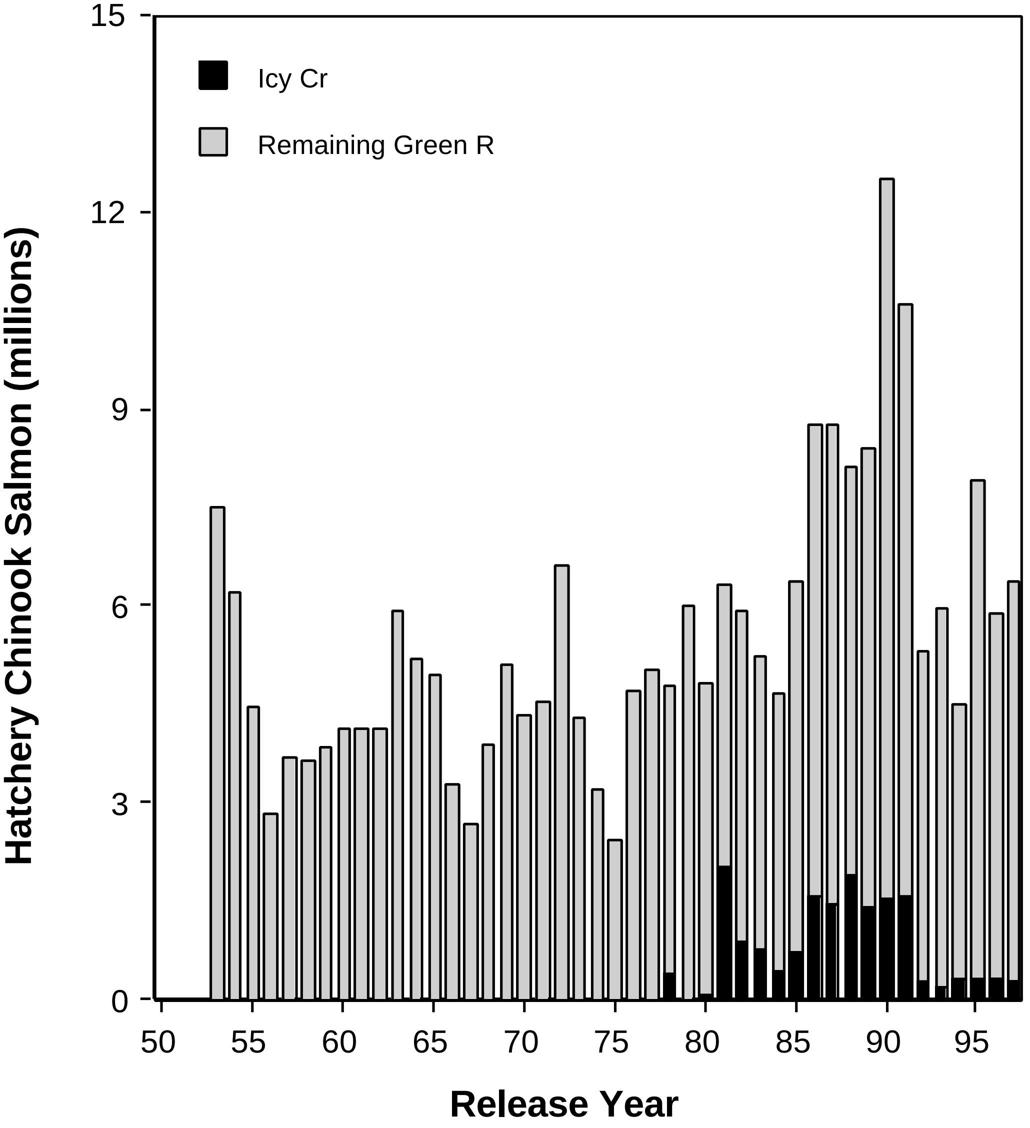


Figure 6. Numbers of hatchery fall chinook salmon released into the Green River system, including Icy Cr, 1953-1997. Icy Cr chinook are identified separately because an adult collection facility is not available to trap returning adults and many Icy Cr chinook likely spawn in the Green River. Releases of subyearling chinook salmon above Howard Hansen Dam are included in the total estimates. Sources: NRC 1995, PSMFC database.

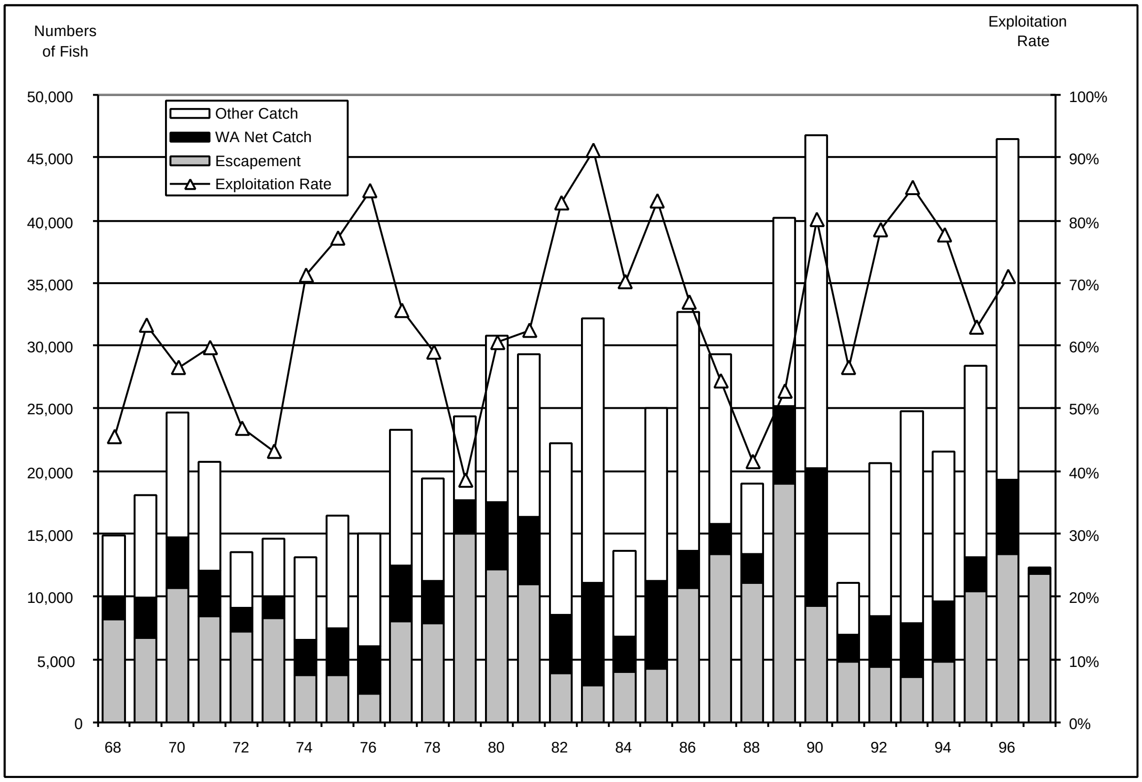


Figure 7. Estimated annual total run, harvest and escapement of Green River hatchery chinook salmon (NRC 1999). Washington net catches are treaty Indian and non-treaty commercial harvests as reported by WDFW (1998). “Other catch” includes total chinook mortalities related to harvests in Washington sport and troll fisheries, and sport and commercial fisheries in British Columbia and Alaska (PSC 1999). Total mortality estimates include non-retention mortalities such as mortality of legal-sized fish in chinook non-retention fisheries and mortality of sublegal-sized fish in retention and non-retention fisheries. Hatchery chinook estimates do not include hatchery fish that stray onto spawning ground. “Other catch” estimates were not available in 1997.

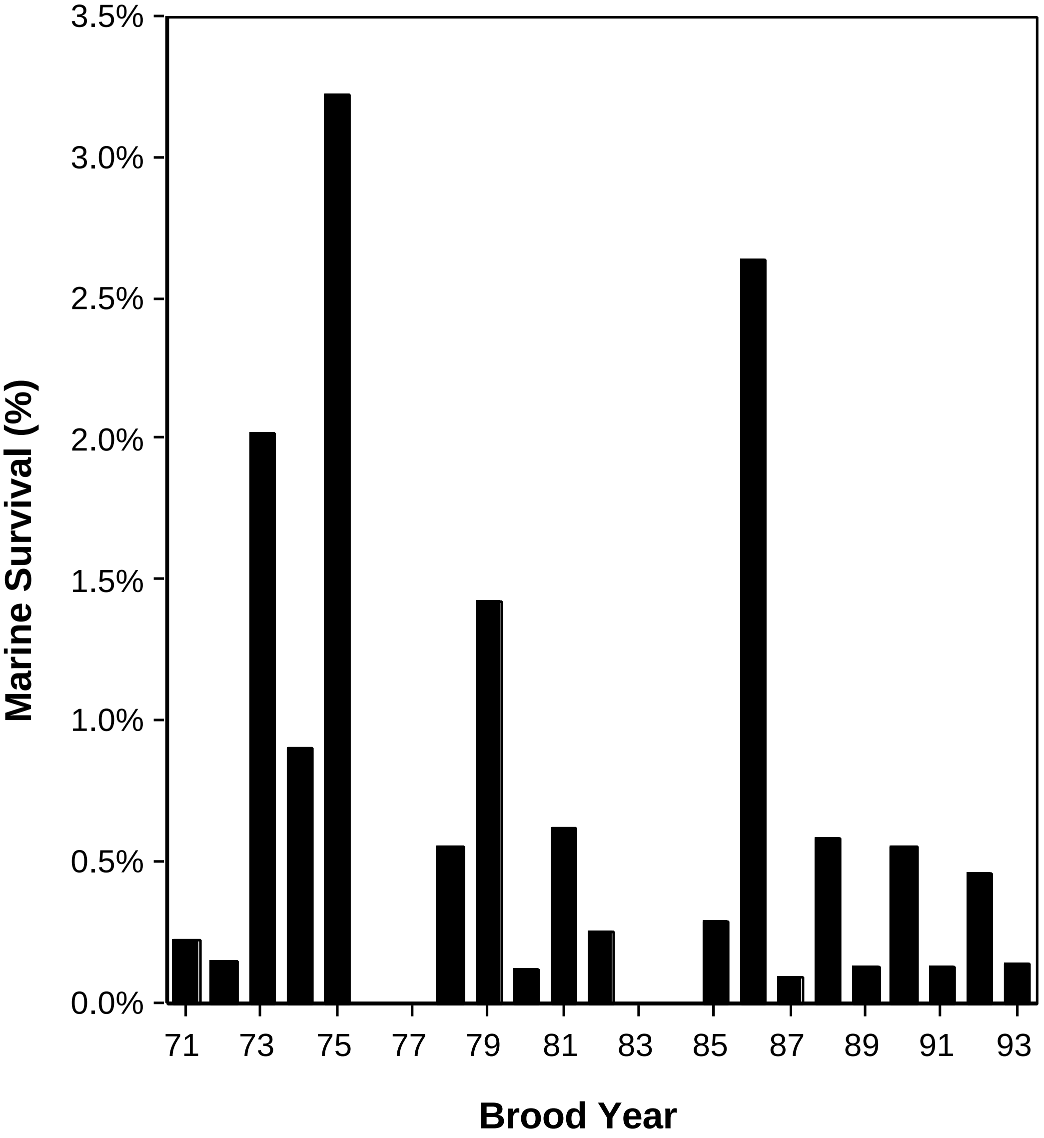
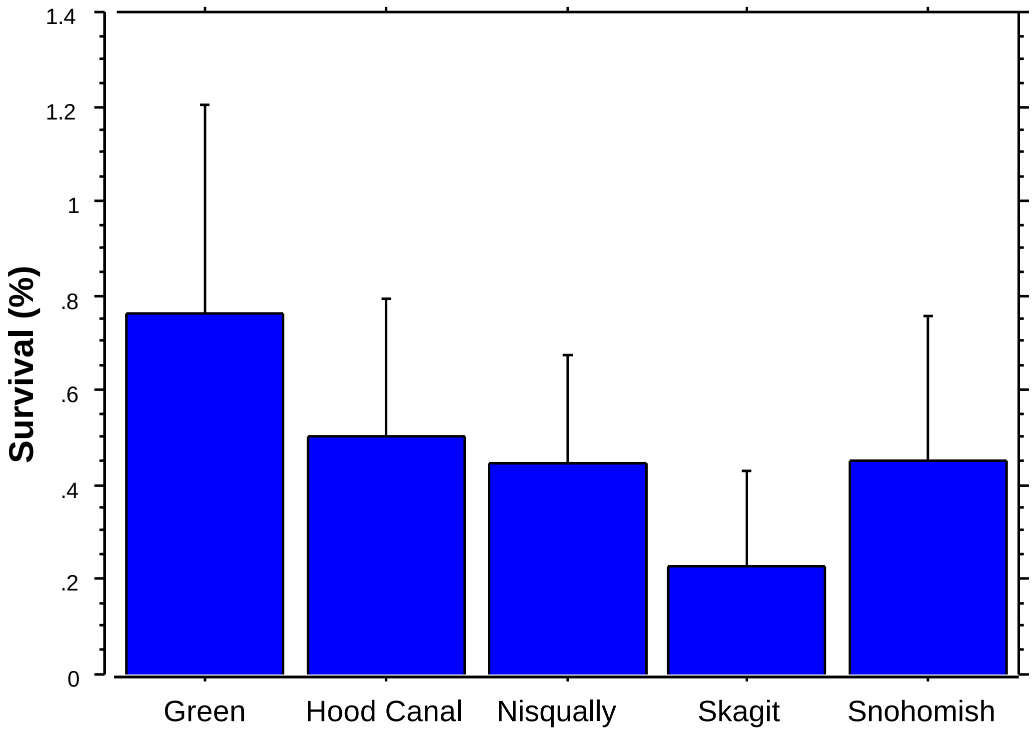


Figure 8. Estimated survival of subyearling CWT chinook salmon released into the Green River and recovered in fisheries and the hatchery. No data available in 1976, 1977, 1983, and 1984. Data source: PSMFC 1999.


Survival (%)
1.4
1.2
1
.8
.6
.4
.2
0
Green
Hood Canal
Nisqually
Skagit
Snohomish

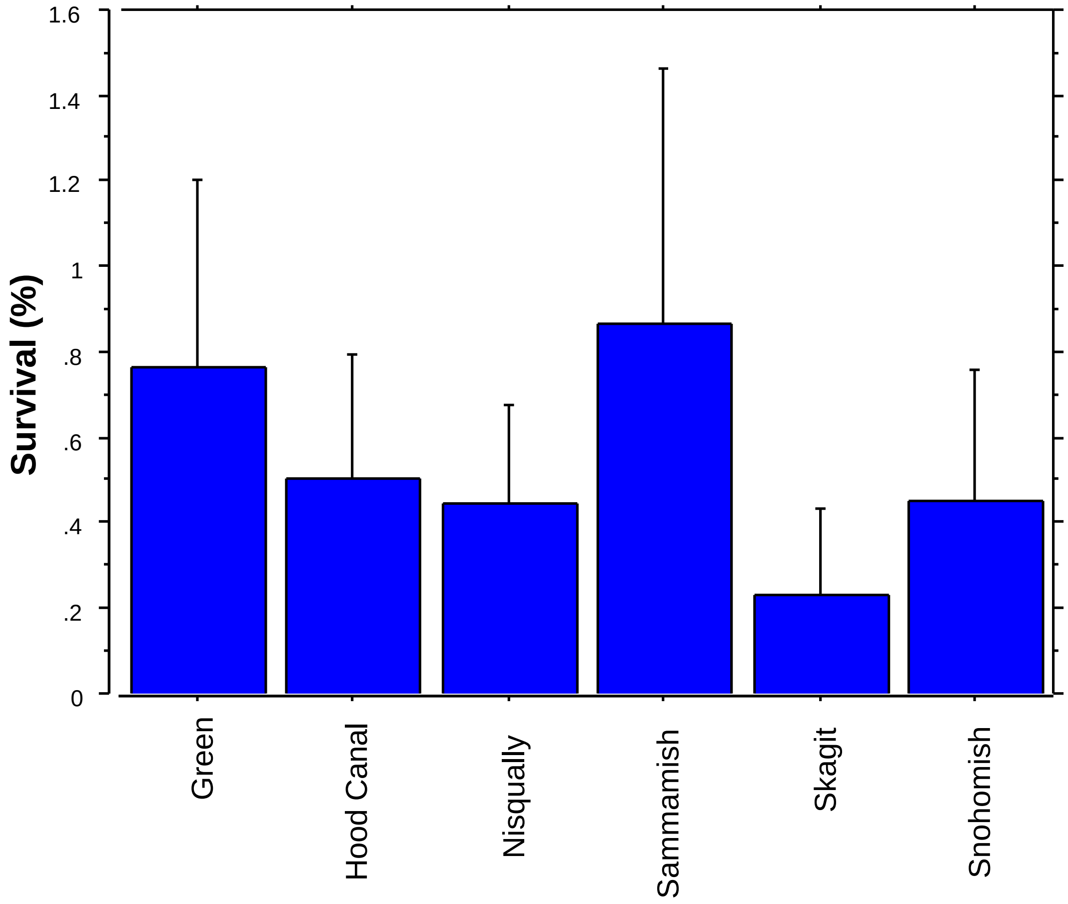


Figure 9. Average survival of CWT summer/fall chinook subyearling salmon (hatchery stock) released into selected river drainages of Puget Sound, brood years 1971-1993. Brood years from which survival rates were calculated are shown below. 95% confidence intervals are shown. Data source: PSMFC.

Green: 1971-75, 1987-82, 1985-93: 19 years
Hood Canal: 1971-72, 1974-75, 1978-83, 1985-93: 19 years
Nisqually: 1971, 1979-93: 16 years
Sammamish 1972, 1978-81, 1985-87: 8 years
Skagit: 1971-72, 1985-85, 1993: 5 years
Snohomish: 1972, 1985-91: 8 years

Spawning And Incubation

Chinook spawn in the Green River from River Mile (RM) 24.0 to RM 61.0 (Williams et al. 1975) from mid-September through late October. The peak of the spawning occurs in early October?. Spawning is not continuous through the identified reach; some riffles are heavily used while others are not used. The heaviest concentrations of spawners occurs from RM 29.6 to RM 47.0 and from RM 56.0 to RM 61. These reaches have been the historic spawner index areas (Grette and Salo 1986). Spawning locations are limited within the Green River gorge (RM 45 to RM 57) compared to downstream areas, but recent changes in survey methodology indicate heavier use than was previously thought. Specifically, helicopter surveys are now used to count redds in this area rather than fixed-wing aircraft. Therefore, older spawner escapement data (pre-1990?) underestimates use in this area.

Spawning also occurs in Soos Creek (primarily from RM 0.5 to RM 10+ including Soosette Creek, Little Soos Creek, and Jenkins Creek), and in Newaukum Creek primarily from RM0 to RM 10+.

The eggs spawned in these areas will incubate for the period from October into March depending upon spawning date and water temperature. During this period, the eggs and subsequent alevins differ with respect to their sensitivity to changes in water quality and flow velocity. Eggs are immobile and at the mercy of changes in water levels. Alevins are mobile but have high oxygen requirements. The stage just before the egg shell hatches freeing the alevin is particularly sensitive to oxygen levels as the demand is high and the shell inhibits oxygen diffusion (*Reference*).

Survival from egg deposition to emergence is variable for chinook and under natural conditions 30% of less of the eggs result in fry (Healey 1991). The stability of the gravel within the redd and the rate of flow of water through the redd are the most important factors identified as influencing survival (Healey 1991). Small gravel with fines yields much lower survival than larger gravel. In urban areas other water quality parameters (e.g., metals) would be expected to lower the survival to emergence.

Alternative Rearing Trajectories

Introduction

Chinook salmon exhibit great variability with respect to the duration and types of habitats used for rearing. Juveniles can spend anywhere from several days to a year in freshwater prior to migrating to the estuary (Healey 1991). Such variability can occur within a single stock of chinook, but more typically a single stock would be classed as either “ocean-type” or “stream-type”, with the latter type representing those fish which spend one year in freshwater.

The first detailed description of the variability in rearing life histories for chinook was presented by Reimers (1973) for the Sixes River, a coastal river in Oregon. Reimers (1973) identified five juvenile life history types. This number was later increased to seven based on scale analysis by Schluchter and Lichatowich (1977). These life histories or trajectories (in the terminology of Lichatowich and Mobrand 1995) varied most markedly in their timing and utilization of the Sixes River estuary. Reimers' work and subsequent investigations changed the prevailing view of chinook life history from simplicity to complexity.

Due to the variability in life histories, a basic description, as might suffice for other salmonid species, is not adequate for determining the relative importance of different habitats and life history trajectories for recovery of a chinook population. For example, the freshwater phase of coho and steelhead can be described as being separate from the saltwater phase with a distinct physiological, morphological, and behavioral change (smoltification) delineating the phases. Similarly, pink and chum, which typically do not rear in freshwater prior to migrating to saltwater, are distinctive in their reduced dependence upon freshwater habitats. Stream–type chinook exhibit a rearing life history that is comparable to that of coho and steelhead, although it differs in detail. In contrast, rearing by ocean-type chinook is variable temporally and spatially, and lacks the sharp distinctions in habitat use and physiological capabilities of other Pacific salmon.

For ocean-type chinook, rearing is a transition in size and habitat use by which an individual grows from a newly emerged fry to a saltwater-tolerant juvenile without necessarily exhibiting a distinct smolt phase. Rearing occurs in one or more of the following habitat types: freshwater, estuarine, or marine shoreline. The different life history trajectories are expressed through the duration of use of these habitats. Each trajectory is a different way of producing the pelagic phase of the chinook, while co-occurring with a number of specialized salmonid competitors. All of the trajectories yield the same end, a fish of appropriate size that has successfully moved from a freshwater existence to a saltwater existence in the pelagic zone. However, each trajectory may occupy different habitats while reaching size, behavioral, and physiological thresholds that allow the transition.

Due to the importance of size, behavior, and physiology, this life history section presents discussions on feeding, growth, behavior and physiology to provide a context for the rearing trajectories described in Section 4.2.4.

Feeding, Growth, and Behavior

Feeding and growth are discussed together because they are inseparable biologically. They are also linked to habitat quality and the productivity (the yield of adults per spawner) of a particular life history trajectory. Successful feeding supports rapid growth, which increases survival and allows the transition to a new array of prey resources in new habitats. Behavior is discussed within this section due to its relationship to feeding territories and size-related migration.

Immediately after emergence, chinook fry migrate downstream to rearing habitats. This initial migration can taken them to relatively close freshwater habitats, the estuary (Congleton et al. 1981; Levy and Northcote 1981; 1982; Levings 1982; Hayman et al. 1996), or high salinity shoreline habitats (Healey 1991). In streams and tidal channels of estuaries, fry are located at the margins in low water velocities (Congleton et al. 1981;

Healey 1991; Hayman et al. 1996). As the fry grow to fingerlings they broaden the range of habitats occupied in freshwater by moving to higher water velocities and farther from shore. Use of off channel ponds appears to be limited in comparison to coho (Murphy et al. 1989; Hayman et al. 1996). Hayman et al. (1996) reported heavy use of backwater habitats in the lower portion of the Skagit River.

The behavior of juvenile chinook depends upon the habitat occupied and size. Fry and fingerlings in freshwater feed in territories and defend them with agonistic behavior (Reimers 1973; Taylor 1988; Taylor 1990). Their aggressive behavior is not as marked as that of coho or steelhead and is more pronounced for stream-type chinook than for ocean-type chinook (McMahon and Holtby 1992). For ocean-type chinook agonistic behavior appears to be more pronounced in those populations that spend a greater length of time in freshwater (Taylor 1990).

As with other species of juvenile salmonids in freshwater, chinook are cryptically colored with prominent parr marks and spots, which serve as means of communication in agonistic encounters and camouflage from predators. Territorial salmonids use stream structure for cover, visual isolation, and focal points for their territories. Little is known about the relationship of ocean-type chinook to cover, although in large river systems they are often associated with logjams or other structures (Hayman et al. 1996). These connections to structure may not be as marked as for other salmonids due to lesser territoriality of chinook. Further, the abundance of food during the spring period when chinook are rearing may modify the nature of territorial behavior.

Feeding and growth are functions of fish size and the habitat occupied. The diet of fry (40mm) is dominated by insects whether the fish is rearing in a stream or the tidal channel of an estuarine marsh (Dunford 1972; Levy and Northcote 1981; Meyer et al. 1981; Levings et al. 1995) although other prey are taken (Cordell et al. 1997). The diet of fingerlings (55-70mm) is very dependent upon the habitat occupied. Fingerlings in freshwater feed on insects, while those in more saline areas feed on a number of epibenthic crustaceans, particularly *neomysis*, *corophium*, and amphipods (Dunford 1972; Levy and Northcote 1981; Meyer et al. 1981; Levings et al. 1995), while taking insects opportunistically (Meyer et al. 1981; Levings et al. 1995). In altered estuaries the diet can be dominated by pelagic species such as calanoid copepods (Weitkamp and Schadt 1982). Growth is typically higher in estuarine habitats than in freshwater habitats (Healey 1991).

For ocean-type chinook, there is a convergence of rearing habitat needs as they reach a length of about 70 mm. At 70 mm fish are physiologically capable of osmoregulating in full strength seawater (Clarke and Shelbourn 1985) and are large enough to feed on larger prey including larval and juvenile fish (Healey 1991). Ocean-type juvenile chinook that have been using estuarine or marine shoreline habitats will have typically migrated offshore at about this length.

Chinook residing within upstream freshwater habitats (or hatcheries) can be in excess of 70 mm when they reach the estuary. These fish are capable of moving offshore very soon after migrating from the river. Chinook longer than 70 mm are captured along estuarine and marine shorelines, they are likely facultative rather than obligate residents of this habitat relative to feeding and physiology. It is possible these fish are not behaviorally ready to leave the shoreline although they are morphologically and physiologically ready. A similar behavioral staging has been noted for coho salmon smolts in the lower Chehalis River (Moser et al. 1991).

Juvenile chinook, accustomed to feeding in shallow water where there are shorelines and structures, must adapt to pelagic and oceanic environments, where there are few edges or structures. This detachment from shorelines and structure probably occurs during estuarine residence. At smoltification, juvenile salmonids are changed from their cryptic coloration to a silvery appearance and they abandon their territories and migrate downstream. For coho, this behavioral change has its roots in physiology (Baggerman 1960; McMahon and Holtby 1992). Although the distinct point of smoltification for ocean-type chinook is harder to identify than for other species, the behavioral changes also closely follow the physiological changes.

Chinook >70 mm that are residing in saltwater typically feed on pelagic prey of variable sizes including pelagic crustaceans, and juvenile fish (Healey 1991) as their predominant prey. These fish will also take smaller prey such as calanoids. Typically these large fish are no longer tied to either freshwater food webs (drifting chironomids) or the detritus-based food webs (epibenthic zooplankton and crustaceans) of the estuary, but they will take these organism opportunistically. Instead, the pelagic habitats and prey offered by the greater Puget Sound estuary support them.

Physiology

Newly-emerged chinook fry can tolerate high salinity as can newly emerged pink and chum fry (Wagner et al. 1969). However, chinook cope by tolerating elevated blood chloride levels, while pink and chum regulate blood chloride levels. Therefore, most chinook fry are not actually fully adapted to osmoregulate in seawater. Exposure to increasing salinity yields fry that regulate blood chloride levels sooner than if direct transfer to seawater occurs (Wagner et al. 1969). It is possible that some stocks of chinook fry are genetically adapted to regulate blood chloride levels similar to pinks and chums. The marine rearing chinook reported by Lister and Genoe (1970) are a possible example.

The relationship of elevated blood chloride to fitness is unknown but would be expected to be adverse. Clarke et al. (1989) suggests that ocean-type chinook fry exploit estuarine habitat by seeking out lower salinity regions of the estuary, rather than through greater salinity tolerance. This may explain why fry that rear in estuaries are typically concentrated in areas with very low salinity (<5 ppt), though high quality habitats (with high salinity) may be available in adjacent areas.

Older and larger chinook fry and fingerlings have greater tolerance to salt water than do younger and smaller fish (Taylor 1990). Growth rate is also important with faster growing fish at any length being more tolerant than slower growing fish (Wagner et al. 1969). The salinity tolerance benefit of growth is most noticeable in smaller fish than in larger fish.

Once fingerlings achieve a length of 55-60 mm, salinity tolerance is increasing rapidly and survival upon direct transfer to seawater is high (Wagner et al. 1969). By 65 mm chinook can fully osmoregulate and maintain blood chloride levels below a threshold of 170 meq/l (Wagner et al. 1969, Clarke and Shelbourn 1985, Clarke et al. 1989). Environmental factors (photoperiod and temperature) also influence seawater tolerance and the other endocrine mediated changes involved in smoltification. Overall, increasing salinity tolerance creates a cascade effect of changes in response to both environmental and physiological events that support continued salinity resistance and growth (Wedemeyer 1980). Smolting is a prerequisite for juvenile salmon to continue rapid growth after converting to seawater (Wedemeyer 1980). Based on physiological studies, smolting of ocean-type chinook appears to be complete at a length of 65-70mm.

Potential Rearing Trajectories

Different potential rearing trajectories are distinguished by habitat needs and duration of habitat use. The trajectories differ in exposure to direct (e.g., predators) and indirect (e.g., habitat quality) agents of mortality. Therefore, the productivity (the yield of adults per spawner) is likely different for each trajectory (Lichatowich and Mobrand 1995). A primary example is the timing of migration to the estuary. Wetherall (1971) reported that mortality was higher for hatchery fish migrating in low flows relative to high flows and that overall mortality can be high. In effect, the presence of multiple trajectories within a single river system creates a within-drainage multiple stock question similar to that posed by the hatchery-produced and naturally-spawned components of the overall run. This life history diversity has ramifications for habitat and harvest management decisions and recovery planning.

Four major potential rearing trajectories provide a means to discuss rearing in the Green/Duwamish River. The potential trajectories are defined along the lines of Hayman et al. (1996), and are based on the timing of entrance to the estuary:

Emergent Fry – migrate to estuarine rearing habitats immediately after emergence at a length of approximately 40 mm.

Fry/Fingerlings- migrate to estuarine or marine shoreline habitats at a length of approximately 45-70 mm. This trajectory could be represented by an array of sub-trajectories defined by the length at entry into the estuary.

Fingerlings – migrate to estuary or marine shoreline habitat at a length of approximately 70 mm or more.

Yearlings- these stream-type fish migrate to estuarine habitat at one year of age. They are not considered to linger in estuarine and marine shoreline habitats.

The discussion below draws on information from other river systems, specifically the Skagit (Hayman et al. 1996), Fraser (Levings 1982; Levy and Northcote 1982), Nanaimo (Healey 1980), and Qualicum (Lister and Genoe 1970) for those trajectories that are not well represented in the Green/Duwamish River system. Existing data from previous beach seine, purse seine, and townet sampling conducted in the lower Duwamish River, Duwamish estuary, and estuarine shorelines of Elliott Bay are used to describe the status, habitat use and timing of use by these life history trajectories in WRIA 9 (Miller and Stauffer 1967; Weitkamp and Campbell 1980; Meyer et al. 1981; Weitkamp and Schadt 1982; Warner and Fritz 1995; Taylor et al. unpublished data).

A series of figures has been prepared from these data to describe timing and duration of use in different habitat types.*)*. Catch data have been expressed on the basis of "percent cumulative catch." The slope of these lines reflect the broad or peaked nature of the migration (broad run timings yield flatter slopes). This graphic form was selected to allow a visual comparison of run timing in a sequence of habitats. Generally, the distance between two "percent cumulative catch" lines is an indication of timing differences between locations, which reflect the duration of residence of individuals in the population. The duration of use by the population is indicated by the overall season when substantial catches occur. When available, length data and hatchery releases were plotted to decipher life history types and the contribution of hatchery fish, respectively.

Emergent Fry

These fish typically enter the estuary after several days or less of rearing in upstream habitats. This trajectory can include fry that are rearing in essentially freshwater habitats (typically marshes and tidal sloughs) (Hayman et. al 1996; Healey 1980; Levings et al. 1995) to those that are rearing in moderate salinity (Levings et at. 1986; Macdonald et al. 1988). Of the two types, the freshwater rearing fry are more common.

The total production from the estuarine environment can be substantial. For example, in the Skagit River system up to 50% of the chinook may rear as fry in the freshwater-dominated portions of the estuary (Hayman et al. 1996). Heavy use also occurs in the Fraser River, although in this system a much smaller percentage of the total chinook run appear to use this habitat type (Levy and Northcote 1981). In these systems, small chinook (40mm) arrive in freshwater-dominated estuarine habitats early in the spring (mid-March to mid-May). In some systems, the spawning areas that produce these fry are very close to the estuary. These fish remain and grow in the estuary until either migrating offshore directly from the estuary or making an intermediate stop in more saline shoreline habitats.

The behavior, feeding habitats, and physiological state of these fish are very similar to fry in freshwater. They are found in shallow water and at habitat margins, particularly tidal channels within salt marshes, and are closely associated with the shorelines (Levy and Northcote 1981; Hayman et al. 1996). A high proportion of the diet is composed of insects, although euryhaline species are also taken. The fry can tolerate salinity up to 15-20 ppt (Healey 1991). However, the bulk of the fry are located in either low salinity habitats such as the marsh of the Fraser River (Levy and Northcote 1982) or in the low salinity strata of the water column (Healey 1991).

This life history trajectory can be best understood as an adaptation for utilization of high quality estuarine rearing habitats that have few salmonid competitors. The use of this habitat is either dictated by density (excess fry are displaced from upstream freshwater rearing habitats due to competition) or genetics. Both may contribute; however, the persistence of this trajectory even under conditions of depressed overall spawner escapements in the Skagit River suggests a genetic role.

Based on sampling that has been conducted in the lower Duwamish River and estuary, this life history trajectory is absent (Figures 1 through 5). Sampling dates back to 1978 and indicates essentially zero catches of chinook in this size range (i.e., ≤40mm) reach the estuarine portion of the lower river. Newly emerged fry appear to be more abundant in the totally freshwater habitats located immediately upstream of the head of navigation (Warner and Fritz 1995).

If this trajectory were represented in the system, the fry should be abundant in the beach seine catches in the upper estuary for two reasons. First, if they were rearing in the area, they should be over-represented in the catch relative to fish with much shorter stays in the estuary. Second, small fish are highly susceptible to capture by a beach seine due to their slower swimming speed relative to larger fish.

It is possible that under conditions of higher spawner abundance fry could occupy the Duwamish estuary if other upstream rearing habitats were at capacity. However, spawner escapements have been relatively high in the Green/Duwamish system (the spawner escapement of goal of 5,800 adults is typically met), and no fry appear to reach the estuary. Further, releases of fed-fry from hatcheries do not yield immediate catches of fry in the upper estuary (see early March fry releases on Figure 1).

Fry/Fingerlings

These fish rear in the upstream habitats for a variable number of days or weeks prior to migrating downstream. These fish rear in both mainstem and side channel habitats within the middle reach of the Green River (R^2 Resource Consultants 1999). Very high catches occurred in a side channel habitat near RM 34. They reach the estuary with much greater seawater tolerance than do fry although great variability in osmoregulation capability would be shown by this group due to the range in sizes.

Diets in upstream freshwater habitats would be dominated by insects in the stream drift. These fish may have limited territorial behavior and their downstream migration may involve a slow migration with continuous feeding. In the estuary, diets are likely dominated by epibenthic zooplankton and crustaceans, but these fish may also show an early shift to calanoid copepods prey species if the latter are abundant relative to the former. Prey selected are highly variable based on location and rearing season (Cordell et al. 1997, Cordell et al. 1998)

Small numbers of chinook less than 60 mm arrive in the freshwater-dominated habitats of the lower Duwamish River in April through May (Julian day 90-120, Figure 1). This arrival timing in the estuary corresponds well with reductions in densities of chinook in the 50-60 mm size range from rearing habitats in the middle Green River (R^2 Resource Consultants 1999). Histograms of length distribution presented in Weitkamp and Schadt (1982) indicate that fish less the 70 mm are present in small numbers through the end of May. This distribution suggests that small naturally-spawned fish arrive in the estuary through the month of May.

The fry/fingerlings are more abundant in the upper estuary than Kellogg Island during April and early May (compare Figures 1, 2, and 3). They likely remain and grow in the Duwamish Waterway or the estuarine shoreline until migrating offshore in May or June. Individuals of this trajectory would have the longest potential rearing period within the estuary, given that estuary rearing by emergent fry is not occurring.

The catches of the fry/fingerlings from the lower Duwamish Waterway and the estuarine shorelines of Elliott Bay are lower and difficult to track with catch data due to the arrival of wild and hatchery fingerlings. The fry/fingerlings are not recaptured along the estuarine shorelines of the bay, while they are small (<70 mm) (Figure 6).

With higher escapements or higher survival during incubation, more chinook of this trajectory may be produced in the Green/Duwamish than are presently available. Limited habitat is available in the estuary for fish on this trajectory, although catches are so low that existing habitats are not likely utilized beyond their capacity with typical spawner escapements. This situation changes after early May when hatchery chinook appear in greater numbers (Figures 1 through 4).

Fingerlings

This group includes naturally-spawned and hatchery chinook. These fish are dependent primarily on the freshwater habitats within the Green/Duwamish River. Recent sampling data verifies that a portion of the chinook population attains a length of 70 mm or greater prior to migrating from the middle reach of the Green River (R^2 Resource Consultants 1999). They would be expected to exhibit territorial behavior based on the length of their period of rearing in freshwater (Taylor 1990). Diets in upstream freshwater habitats would be dominated by insects in the stream drift. This group likely undergoes smoltification more comparable to coho, steelhead, or stream-type chinook while in freshwater. Based on their size they are expected to have full osmoregulation capability when they reach the estuary.

The bulk of the migration to the estuary occurs during May and early June and the peak of migration is narrow (Weitkamp and Campbell 1980, Meyer et al. 1980, Warner and Fritz 1995) (Figure 1). This pattern is determined by the timing of hatchery releases in May. Large chinook (>80 mm) have found rearing in the middle reach of the Green River (above RM 34) until late June (R^2 Resource Consultants 1999).

These fish arrive in all portions of the estuary at once and are present on the estuarine shorelines, although the peaks of the runs differ slightly in each area (Figure 9). Their numbers peak in the upper estuary slightly earlier than in lower parts of the estuary (Figure 8). This suggests a period of residence within the estuary. Comparison of the timing catches at the estuary locations versus catches at Terminal 90/91 (estuarine shoreline) indicate a lag in peak of about 15-20 days. Based on a mark-recapture study, Weitkamp and Schadt (1982) concluded that residence time in the Duwamish estuary was about two weeks.

The diet of these fish can be dominated by pelagic planktonic organisms (calanoids) but insects (chironomids) and some epibenthic copepods and crustaceans are taken (Weitkamp and Schadt 1982). That study examined the greatest number of chinook sampled in the Duwamish Waterway and included fish captured next to shore with a beach seine and in the middle of the waterway with a purse seine and the diets were similar. Few epibenthic prey were found in stomachs, nor were insects common. Meyer et al. (1981) found more differentiation in diet between chinook captured near shore by beach seine and those captured off shore by purse seine. In that study, epibenthic prey dominated in the beach seine caught fish and pelagic species dominated in the purse seine caught fish. Diet can vary depending upon the actual habitat occupied within the waterway. For example, fingerlings captured within the Terminal 108 mitigation site, an area with low-gradient shoreline habitat, were feeding on epibenthic prey and insects (chironomids) (Jones & Stokes Associates 1990). Similar results were reported for Kellogg Island (Williams 1990). Clearly, fingerlings have the capacity to occupy a range of habitat types and feed on a wide spectrum of prey within the Duwamish Waterway.

The diet of fingerlings in the estuarine shoreline habitat (Terminal 90/91) is dominated by fish although limited numbers of smaller pelagic prey and epibenthic prey are taken (Lipovsky 1985).

Yearlings

Yearling chinook do not appear to occur in the Green/Duwamish River other than as hatchery-produced fish (Warner and Fritz 1995). Hatchery yearlings are planted at Icy Creek and above Howard Hanson Dam. Their large size (140-175 mm) indicates that they should not be dependent upon the estuary for feeding or completion of their physiological transition to seawater. These fish have been captured in the estuary in mid-May but appear to move out of the estuary quickly (Warner and Fritz 1995).

Summary of Rearing Trajectories

The duration and season of use by each of the life history trajectories is presented in Table 1. The table presents the duration of use for individual chinook and the chinook population based on an interpretation of existing data. The relative abundance of the different trajectories is also presented. Based on existing data it can be concluded that the emergent fry and yearling life history trajectories are very rare.

Distinguishing the fry/fingerling trajectory and the fingerling trajectory is difficult due to the large numbers of hatchery chinook that are released into the system. Table 1 lists the fingerling component as being more abundant based on the catches in Figures 1 through 8. Data from the middle Green River and the estuary provide substantial information for chinook rearing at the upstream and downstream ends of the system. Based on that information substantial rearing would need to occur within the Green River downstream of RM 34 if the fingerling rearing trajectory is abundant within the system. No information on rearing is available below RM 34. Understanding rearing densities and habitat use within this reach would clarify the relative importance of these two trajectories.

Table 1. Green/Duwamish River Chinook Rearing Trajectories (WRIA 9).

Chinook Rearing Trajectory[1]	Abundance In Green/ Duwamish River[2]	Freshwater Rearing Duration[3]	Freshwater Rearing Season[4]	Estuarine Rearing Duration[3]	Estuarine Rearing Season[4]	Elliott Bay Shoreline Rearing Duration[3]	Elliott Bay Shoreline Rearing Season[4]
Emergent Fry (40<45 mm)	Uncommon	Days	Late February through March	Months	March to late May	Several Weeks to Months	May and June[5]
Fry/Fingerling (45-70 mm)	Present	Days to months	Late February to late April	Several days to months	Early April to late May	Several weeks to months	May and June[5]
Fingerling (>70 mm)	Abundant	Months	Late February to early June	Several days to two weeks	Late April to mid June	Several days to two weeks	May and June[5]
YEARLING	Uncommon	≈14 months	Year-round	Brief	—	—	—

[1] Defined based on timing of entrance to estuary.
[2] Based on Figures 1, 2, and 3.
[3] Individual residence.
[4] Population residence.
[5] Chinook are present in small numbers through July.

Habitat Conditions of the Green/Duwamish River Basin

Basin Description

The Duwamish drainage basin contains a single large river system, the Green/Duwamish River. The Green River originates at the Cascade Mountain crest near Stampede Pass and flows west and northwest through narrow valleys and generally steeply sloped terrain until it emerges from Green River Gorge near Flaming Geyser Park. At Auburn, the Green River turns northward and flows over the more gentle gradient of the broad valley floor, ultimately flowing into Elliott Bay. The lower 10 miles, between Tukwila and Elliott Bay, is known as the Duwamish River . The river banks in the lower reaches are contained by extensive diking and channelization, and the surrounding area is heavily urbanized.

Historically, the White, Green, Black, and Cedar rivers flowed into the Duwamish River, and the system drained an area of over 1600 square miles. In the early 1900s, the White, Black, and Cedar rivers were diverted, reducing the Green/Duwamish drainage area to 483 square miles (Blomberg 1995).

Streamflows in the upper drainage are fed by rain and snowmelt, whereas flows in the lower drainage are fed by rain and groundwater. In the upper portion of the basin, the Green River receives tributary flow from Sunday, Sawmill, Champion, Smay, and Charlie creeks, as well as from the North Fork Green River. The major tributaries in the lower basin include Coal, Newaukum, and Soos creeks.

Development in the watershed began in the mid-1800s with the building of settlements and homesteads near the present-day towns of Tukwila and Kent. In the 1870s through the 1890s, major rail lines were constructed in the Green River valley. The Green/Duwamish basin was one of the first areas west of the Cascades to be logged, and the majority of logging in the lowlands occurred between 1870 and 1910.

Major flooding occurred on the White and Green Rivers in 1906, and the U.S. Army Corps of Engineers developed plans to divert the White River to the Puyallup River. That diversion was completed in 1911. Diversion of the White River reduced flows at the mouth of the Duwamish from an estimated 2,500 – 9,000 cubic feet per second (cfs) to a mean annual flow of 1,700 cfs (Fuerstenberg et al., in prep.).

In 1916, completion of the Lake Washington Ship Canal diverted the Cedar River into Lake Washington and eliminated the Black River. The diversion of the White, Black, and Cedar Rivers reduced the size of the Green River watershed to about 30 percent of its original area. Figure 10 illustrates the configuration of the Green/Duwamish drainage before 1900 and after the diversions were completed in 1916.

Development in the Duwamish River estuary accelerated in the late 1800s. Excavation of the Duwamish Waterway through the estuary was begun in 1895 and completed in 1917. Construction of the Duwamish Waterway converted approximately 17.5 linear miles of meandering, distributary channel to 10 miles of deep, uniform channel with a substantial hardened shoreline (Blomberg 1995). Material excavated during construction of the waterway was used to fill adjacent intertidal shallows and wetlands. Based on historic maps, the pre-development estuary included approximately 1,230 acres of tidal freshwater marshes, 1,270 acres of tidal marshes, and 1,450 acres of intertidal mudflats and shallows. Essentially all of the estuary's shallows, flats, marshes, and swamps were converted by 1940 to filled, flat land suitable for industrial development.

The City of Tacoma constructed a diversion dam near the town of Palmer in 1913, completely blocking fish migration to the upper river and tributaries. In 1963, the Howard Hanson Dam was built by the Corps of Engineers in the Eagle Gorge of the upper Green River. The main purpose of the dam is flood control, with water supply and fisheries conservation as additional authorized purposes. No fish passage facilities are incorporated into this dam.

One result of changes in the basin was the reduction in the length of river accessible to anadromous fish from some 1,900 linear miles to 125 linear miles. Despite the alterations in the watershed and estuary, the Green/Duwamish system continues to support important fisheries and represents a valuable resource to be protected and enhanced.

Streamflows

Flows in the upper drainage can change rapidly from relatively low flows to flood levels within 24 to 36 hours (Grette and Salo 1986). Flows in the mainstem below River Mile (RM) 64.5 are controlled by releases from Howard Hanson Dam. Three miles below Howard Hanson Dam, the City of Tacoma operates the Palmer Diversion, withdrawing approximately 100 cfs for municipal use.

For the 1963 to 1985 period of record, mean annual flow at the gage located at RM 60.4 adjacent to the City of Tacoma water purification facility was about 986 cfs (Grette and Salo 1986). Mean annual flow in the Green River at Auburn is 1,366 cfs. Relatively high flows (monthly mean > 1,600 cfs) occur from November through May, with flood events generally occurring from November through March. The Howard Hanson Dam provides flood protection for the lower Green River Valley up to approximately the 100-year flood event. Streamflows at Auburn rarely exceed the regulated high flow of 12,000 cfs, and the mean of annual peak discharges recorded at the Auburn gage is 8,800 cfs. The high-flow season in the lower basin tributaries is somewhat shorter than in the mainstem, as these tributary streams are not fed by snowmelt. Flows in the lower elevation tributaries generally exhibit a steady decline from March and through the summer until the fall rains begin.

Low flows in the mainstem generally occur in August, September, and October. The lowest flow recorded at Auburn was 81 cfs in September, 1952 (Fuerstenberg et al., in prep.). Historically, flows upstream of the Palmer Diversion fell below 150 cfs every other year on average, and below 100 cfs every nine years on average. Completion of the Howard A. Hansen Dam and implementation of a regulated flow regime has reduced the frequency of low flows less than 150 cfs to approximately once in six years on average, and flows below 100 cfs to less than once in 50 years on average.

Water and Sediment Quality

Poor water quality conditions exist where low summer flows result in high water temperatures. These conditions occur in the lower reaches of the Green River into the Duwamish, where high water temperatures and reduced levels of dissolved oxygen occur regularly during the summer. The contribution of recent logging activities to downstream water temperature problems is probably quite small. However, removal of vegetation in the Newaukum Creek and Big Soos Creek drainages may have caused increases in downstream water temperatures many years ago when these areas were first logged (Grette and Salo 1986).

The saltwater wedge, created by tidal intrusion into the dredged Duwamish Waterway, varies with tidal cycles and contributes to the low oxygen condition. Overall, water quality in the Duwamish estuary was probably poorest in the early 1960s. Since the early 1980s, however, water quality impacts from the discharge of industrial and domestic waste have been significantly reduced as a result of increased surveillance monitoring and the construction of wastewater treatment facilities.

The most significant overall water quality improvements resulted from removing a sewage treatment plant outfall in the Green River. Since that time, ammonia and phosphorous concentrations in the Green River have decreased dramatically. Temperature, turbidity, and nitrate levels have decreased significantly, and dissolved oxygen and pH have increased (Puget Sound Water Quality Authority 1993).

Low summer flows also occur in the tributary streams, both naturally and as a result of diversion of water for agriculture. Heavy siltation due to farming, logging, gravel mining, and other development affects tributary streams and the lower and middle reaches of the Green River.

Decades of discharges of dissolved and particulate contaminants into the Duwamish River and Elliott Bay from point and non-point sources led to the accumulation of a variety of contaminants in sediments over extended areas. A series of studies begun in the 1980s (e.g., Urban Bay Action Program) has been conducted to delineate the extent of contamination and changes in sediment characteristics over time. These studies have documented extensive areas where sediments exceed applicable state standards.

Remediation by dredging or capping of contaminated areas has been accomplished at several locations in Elliott Bay and the Duwamish River as a result of regulatory actions under the state Model Toxics Control Act and Sediment Management Standards. Other areas have been effectively remediated in the course of dredging to provide needed navigation depths at berths and in the federal navigation channel in the Duwamish River.

Overall sediment quality is expected to continue on an improving trend as a result of reductions in contaminant discharges, natural accretion of uncontaminated fine sediments, and active remediation of identified areas of contamination. Sediments adjacent to several of the large stormwater outfalls have been remediated and the remainder are under investigation for remedial actions in the near future. PCB-contaminated areas of the Duwamish River in the vicinity of the 16th Avenue bridge will be removed and capped in the next two yeas, and plans are underway to remediate other contaminated areas in the Duwamish River and around Harbor Island. The long-term efficacy of the remediation efforts depends upon the successful implementation of control of pollutant sources.

Habitats in the Upper Drainage (RM 64.5 to Headwaters)

Upstream of the Sunday Creek confluence at RM 84.2, the Green River and its tributaries are steep, and substrates are dominated by bedrock and boulders. There are few pools, and cascades and rapids are the dominant instream habitat types. The channel is quite narrow, generally ranging from 2 to 5 yards in width. Logging has occurred in this area, and the upland vegetation is a checkerboard of old-growth, second-growth, and recently logged areas. Sunday Creek offers moderate gradient stream conditions over its lower reaches. Most of the other tributaries in this portion of the basin exhibit mountain-type character, with very steep gradients, narrow channels, and boulder-rubble stream bottoms (Reference).

Below Sunday Creek, the Green River broadens to a width of 5 to 18 yards, and the overall gradient moderates to 0.6 – 0.7% (Grette and Salo 1986). Sunday Creek marks the beginning of a narrow floodplain, and wetlands occur on the floodplain adjacent to the river in the flatter areas. The substrate in this reach is generally cobble and gravel, and is low in fines. The pool:riffle ratio in this area is relatively good (Reference).

From the Champion Creek confluence at RM 78.1 to Howard Hanson Dam, the Green River averages from 8 to 20 yards in width, with a good pool:riffle ratio. Substrates are dominated by gravel and cobble. This reach is sediment rich and the mainstem river braids across the valley floor upstream of the dam pool. The extent of the reservoir fluctuates considerably, reflecting seasonal variations in water supply.

Habitats in the Green River Gorge (Howard Hanson Dam to RM 46.5)

Below Howard Hanson Dam, the Green River maintains mountain stream characteristics, descending 7 miles to the town of Kanasket. The stream gradient in this section averages 0.7%, and the substrate is dominated by cobble and boulders (Grette and Salo 1986). There is little recruitment of gravel in this reach (Reference). This condition is likely aggravated by the dams, which trap sediment from over 50 percent of the watershed. The river banks in this reach are well-defined and brush and timber grow down to the high water mark. Tributaries entering this stretch of the river drain the slopes of the adjacent hills and provide little habitat accessible to anadromous fish.

The Green River Gorge begins near RM 58.0 and continues 12 miles downstream. This section of the river represents the upper limit of anadromous fish utilization. In this reach, the stream has cut through glacial deposits and bedrock, creating a narrow channel over 300 feet deep. The channel width varies from 100 to 200 feet. The substrate is dominated by boulders and large rubble, with some spawning habitat provided by interspersed gravel patches. The stream gradient in this reach averages about 1.5%. High quality pool habitat occurs in the gorge reach from about RM 50.8 to RM 50.1 (Fuerstenberg et al., in prep.). There is little cover found along the streambanks in the gorge, with only scattered patches of brush growing along the high water fringe. Much of the stream is deeply shaded by the high canyon walls.

Coal Creek and Deep Creek occur in the lower gorge area. These streams are not directly tributary to the main river, but instead flow into small lakes. It is believed that they drain into the Green River via springs and seeps (Williams et al. 1975).

Habitats in the Middle and Lower Green River (RM 46.5 to RM 11.0)

Middle Reach

From the lower end of the Green River Gorge (RM 46.5) the river meanders through the upper Green Valley to Auburn (RM 30.5). The valley broadens as it proceeds downstream. The gradient through this reach averages about 0.1% with a predominantly gravel substrate. The channel width varies from 50 to 200 feet, and some braiding occurs, primarily in the Metzler-O'Grady Park area. Natural streambanks end near RM 38, below which the channel has been widened, and the banks are diked or protected by revetments in several locations. The upper levees in Flaming Geyser State Park were constructed between 1950 and 1959. The levees located between Flaming Geyser State Park and Metzler-O'Grady Park were built in the mid-1930s. Downstream of Metzler-O'Grady Park, levees were constructed between 1960 and 1964. The Ross revetment (RM 36.6) was constructed in 1988.

Good quality pool habitat occurs at the downstream end of Flaming Geyser State Park from RM 42.8 to RM 42.3. The reach downstream of Metlzer-O'Grady State Park from RM 39.6 to RM 36.0 contains the longest continuous stretch of pool habitat in the middle Green River, although pool quality in this area is lower than that upstream near Flaming Geyser State Park (Fuerstenberg et al., in prep.)

Deciduous trees comprise slightly more than 38 percent of the riparian zone along the middle reach (Fuerstenberg et al, in prep). Paved surfaces, buildings, pasture and bare ground occur on 30 percent of the area adjacent to the river, and "mixed trees", including deciduous and coniferous species, comprise approximately 11 percent. Shrubs account for just under 6 percent of the total riparian zone acreage. Conifers, crops, forbs, and grasses account for the remaining area.

An inventory of large woody debris indicates that there are three moderately stable to stable log jams in the reach between RM 43.7 to RM 38.6 (Fuerstenberg et al., in prep.). At Flaming Geyser State Park (RM 43.7), a log jam containing 10 to 12 pieces of large woody debris occurs at the head of a right bank side channel. This log jam is located on the outside of a tight bend and appears to be quite stable. A second jam containing 9 pieces of large woody debris guards the entrance to a side channel at Metzler State Park (RM 40.0). The third jam in this reach, located at RM 38.6, spans the width of the river and contained 9 visible pieces of large woody debris. In general, however, there is a shortage of large wood in the river, and most of the debris is deciduous, with a relatively short in-stream life.

Considerable side-channel habitat occurs in the Metlzer-O'Grady Park area between RM 36.9 and RM 40.6. Fuerstenberg et al. (in prep.) identified 28 side channels in this area. Eight of these side channels are cut off from the main channel by levees, roads, and other barriers.

Important tributaries entering the Green River in this reach are Newaukum Creek and Big Soos Creek. Newaukum Creek originates on Grass Mountain, dropping rapidly down broad gulleys to a plateau at the 700-foot elevation near Enumclaw. From there, it flows at a low gradient approximately 6 miles through farmlands and then enters a steep-walled ravine, where the gradient increases to 11%. It enters the Green River on the left bank at RM 40.7. Substrates in Newaukum Creek are dominated by gravel above RM 3.0, and coarser material predominates below that point. Shade is lacking in many areas where Newaukum Creek flows through farmland.

Big Soos Creek originates in springs near Renton and flows southerly approximately 14 miles to meet the Green River at RM 33.7. There are 25 tributaries feeding into Big Soos Creek, and the system provides over 60 miles of stream habitat. Big Soos Creek contains some long riffles and rapids below RM 5.0 where the tributaries converge and provide additional flows (Williams et al. 1975). Good pool-riffle-glide sections are found in the lower section of the stream. Low summer flows affect habitat quality in both the Newaukum and Big Soos creek drainages, and development has contributed heavy silt loads in the lower drainages.

Ten smaller tributaries enter the Green River between the lower end of the gorge and Auburn. Together, the tributaries in this section total 47 miles in length.

Lower Reach

Below Auburn, the Green River flows through a broad, glacially-carved valley that has been filled with fluvial deposits (Grette and Salo 1986). The gradient is low and the river meanders in a deep channel that is confined by dikes to a width of 100 to 200 feet. Fuerstenberg et al. (in prep.) calculate that approximately 80 percent of the river between RM 33 and RM 17 has either a levee or revetment on at least one bank. Substrates in the lower reach are fine, with gravel giving way to silt near RM 24.0. The bottom composition downstream of Kent at RM 14.0 is heavy silt and mud compacted in large boulders (Williams et al. 1975).

Much of the area adjacent to the river is developed, and there is little shade along the streambanks. Where vegetation occurs, deciduous trees and shrubs dominate the vegetation community.

The major tributaries in the lower Green River are Spring Brook Creek (via the remnant channel of the Black River) and Mill Creek. A dam and pumping station were constructed at the mouth of Spring Brook Creek in 1971. Both upstream and downstream fish collection and passage systems were incorporated into this facility. Seventeen smaller tributaries enter the Green in this reach; together, there are a total of 84 miles of tributary streams in this section. Fish passage on many of the smaller tributaries is blocked by culverts and flood control flapgates.

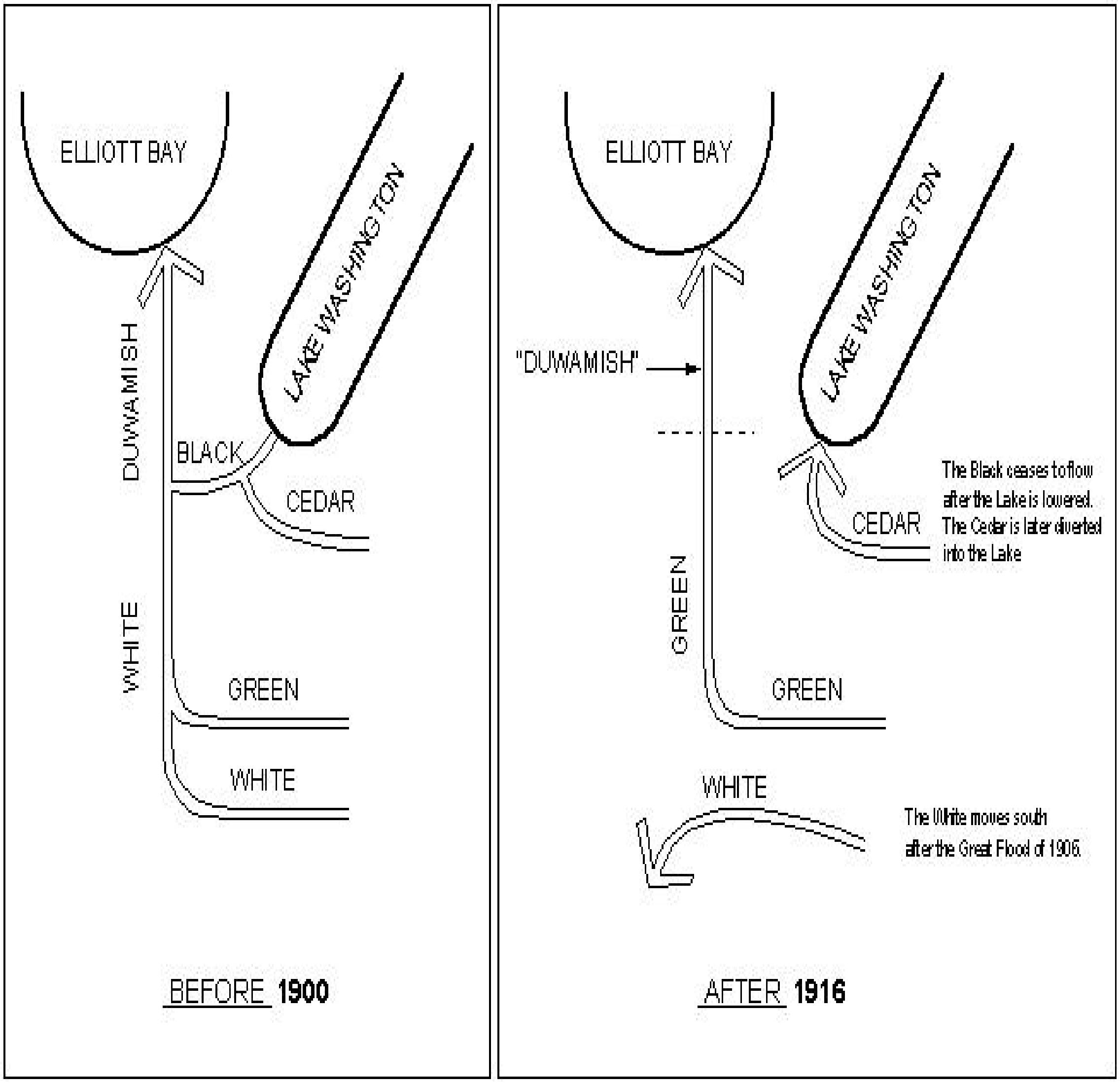
Habitats in the Duwamish River and Estuary (RM 11.0 to Mouth)

From the former confluence of the Black River at RM 11.0 to Elliott Bay, the stream is called the Duwamish River. From RM 11.0 to RM 5.2, the river is contained within a hardened shoreline consisting of bulkheads, riprap, and docks; below RM 5.2, the river has been dredged, affording navigation for ships and barges. The banks are typically hardened in this reach. The Duwamish River varies in width from 500 to 1000 feet in the lower 5.2 miles and from 150 feet to 200 feet upstream to RM 11.0. Below RM 11.0 the river is under tidal influence and the dredged section allows salt water to penetrate farther upstream than historically. The salt water wedge extends 8.7 miles upstream at high tide and is confined to the dredged section at low tide (Grette and Salo 1986).

The adjacent area includes nearly 5,200 acres of industrial land, and the area represents the primary industrial core in the City of Seattle. Less than 2 percent of the estuary's pre-development mud and sandflats and intertidal wetlands remain in small margin areas of the Duwamish Waterway. The largest single are of intertidal habitat remaining is located adjacent to Kellogg Island (RM 1.25). As noted earlier, most of the filling in the estuary occurred by 1940.

The Duwamish provides transportation and rearing habitat for anadromous fish, and the lower estuary is vital to salmonids as a transition area for adaptation to salinity changes (Williams et al. 1975). Existing Tribal and recreational fisheries continue to be important assets in the area.

Since the mid to late 1970s, increased application of the provisions of Section 404 of the Clean Water Act and the State Hydraulic Code has resulted in compensation for aquatic habitat losses from development projects. In the past decade, efforts undertaken by the Port of Seattle have resulted in the restoration of approximately 3.6 acres of intertidal habitat at five sites in the estuary. Approximately 12.4 acres of subtidal reef were constructed during this same period (Blomberg 1995). In addition, long-range planning for aquatic habitat improvements (e.g., Elliott Bay cooperative study, Corps ecosystem restoration study, and Port of Seattle long-range facility development plan) are expected to continue the trend toward increasing availability and quality of nearshore habitats in the estuary.



BEFORE 1900

AFTER 1916

The Black ceases to flow after the Lake is lowered. The Cedar is later diverted into the Lake

The White moves south after the Great Flood of 1906.

Figure 10. Configuration of the Duwamish drainage prior to 1900 and after 1916 (Source: Dunne and Dietrich 1978).

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Glossary

Adaptive management
Monitoring or assessing the progress toward meeting objectives and incorporating what is learned into future management plans.

Adfluvial
Life history strategy in which adult fish spawn and juveniles subsequently rear in streams but migrate to lakes for feeding as subadults and adults. Compare fluvial.

Anadromous
Life history strategy in fish hatch in freshwater, mature in saltwater, and return to freshwater to spawn.

Anadromous fish
A fish that originates from a specific watershed as a smolt and generally returns to its birth stream to spawn as an adult.

Aquifer
Water-bearing rock formation or other subsurface layer.

Basin flow
Portion of stream discharge derived from such natural storage sources as groundwater, large lakes, and swamps; does not include direct runoff or flow from stream regulation, water diversion, or other human activities.

Bioengineering
Combining structural, biological, and ecological concepts to construct living structures for erosion, sediment, or flood control.

Biological Diversity (biodiversity)
Variety and variability among living organisms and the ecological complexes in which they occur; encompasses different ecosystems, species, and genes.

Biotic Integrity
Capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable

to that of natural habitat of the region; a system's ability to generate and maintain adaptive biotic elements through natural evolutionary processes.

Biological oxygen demand
Amount of dissolved oxygen required by decomposition of organic matter.

Braided stream
Stream that forms an interlacing network of branching and recombining channels separated by branch islands or channel bars.

Carrying capacity
Maximum average number or biomass of organisms that can be sustained in a habitat over the long term. Usually refers to a particular species, but can be applied to more than one.

Channelization
Straightening the meanders of a river; often accompanied by placing riprap or concrete along banks to stabilize the system.

Channel Stability
Tendency of a stream channel to remain within its existing location and alignment.

Check dams
Series of small dams placed in gullies or small streams in an effort to control erosion.

Confluence
Joining.

Critical Stock
A stock of fish experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred.

Depressed Stock
A stock of fish whose production is below expected levels based on available habitat and natural variations in survival levels, but above the level where permanent damage to the stock is likely.

Distributaries
Divergent channels of a stream occurring in a delta or estuary.

Diversity
Variation that occurs in plant and animal taxa (i.e., species composition), habitats, or ecosystems. See *species richness.*

Ecological restoration
Involves replacing lost or damaged biological elements (populations, species) and reestablishing ecological processes (dispersal, succession) at historical rates.

Ecosystem

Biological community together with the chemical and physical environment with which it interacts.

Ecosystem management
Management that integrates ecological relationships with sociopolitical values toward the general goal of protecting or returning ecosystem integrity over the long term.

Endangered Species Act
A 1973 Act of Congress that mandated that endangered and threatened species of fish, wildlife and plants be protected and restored.

Endangered Species
means any species which is in endanger of extinction throughout all or a significant portion of its range (other than a species of the Class Insecta) determined by the Secretary to constitute a pest whose protection under would provide an overwhelming and overriding risk to man.

Escapement
Those fish that have survived their marine rearing phase and all fisheries to return to their natal stream.

Estuary
A partly enclosed coastal body of water that has free connection to open sea, and within which seawater is measurably diluted by fresh river water.

Eutrophic
A water body rich in dissolved nutrients, photosynthetically productive, and often deficient in oxygen during warm periods. Compare *oligotrophic*.

Evolutionary Significant Unit (ESU)
A definition of a species used by National Marine Fisheries Service (NMFS) in administering the Endangered Species Act. An ESU is a population (or group of populations) that is reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species.

Floodplain
Lowland areas that are periodically inundated by the lateral overflow of streams or rivers.

Flow regime
Characteristics of stream discharge over time. Natural flow regime is the regime that occurred historically.

Fluvial
Pertaining to streams or rivers; also, organisms that migrate between main rivers and tributaries. Compare *adfluvial*.

Gabion

Wire basket filled with stones, used to stabilize streambanks, control erosion, and divert stream flow.

Geomorphology
Study of the form and origins of surface features of the Earth.

Glides
Stream habitat having a slow, relatively shallow run of water with little or no surface turbulence.

Healthy Stock
A stock of fish experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock.

Hydrograph
Chart of water levels or flow over time.

Hydrology
Study of the properties, distribution, and effects of water on the Earth's surface, subsurface, and atmosphere.

Intermittent stream
Stream that has interrupted flow or does not flow continuously. Compare *perennial stream*.

Intraspecific interactions
Interactions within a species.

Limiting Factor
Single factor that limits a system or population from reaching its highest potential.

Macroinvertebrates
Invertebrates large enough to be seen with the naked eye (e.g., most aquatic insects, snails, and amphipods).

Native
Occurring naturally in a habitat or region; not introduced by humans.

Non-Point Source Pollution
Polluted runoff from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, agriculture, and livestock grazing.

Parr
Young trout or salmon actively feeding in freshwater; usually refers to young anadromous salmonids before they migrate to the sea. See *smolt*.

Plunge pool
Basin scoured out by vertically falling water.

Redd
Nest made in gravel (particularly by salmonids); consisting of a depression that is created and then covered.

Riffle
Stream habitat having a broken or choppy surface (white water), moderate or swift current, and shallow depth.

Riparian
Type of wetland transition zone between aquatic habitats and upland areas. Typically, lush vegetation along a stream or river.

Riprap
Large rocks, broken concrete, or other structure used to stabilize streambanks and other slopes.

Rootwad
Exposed root system of an uprooted or washed-out tree.

SASSI
Salmon and Steelhead inventory.

SSHIAP
A salmon, steelhead, habitat inventory and assessment program directed by the Northwest Indian Fisheries Commission.

Salmonid
Fish of the Family Salmonidae, including salmon, trout, chars, and bull trout.

Salmon
Includes all species of the genus Oncorhynchus except for steelhead and cutthroat trout.

Sinuosity
Degree to which a stream channel curves or meanders laterally across the land surface.

Smolt
Juvenile salmon migrating seaward; a young anadromous trout, salmon, or char undergoing physiological changes that will allow it to change from life in freshwater to life in the sea. The smolt stage follows the parr state. See *parr*.

Stock
Group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction. Generally, a local population of fish. More specifically, a local population – especially that of salmon, steelhead (rainbow trout), or other

Stream order

Classification system for streams based on the number of tributaries it has. The smallest unbranched tributary in a watershed is designated order 1. A stream formed by the confluence of 2 order 1 streams is designated as order 2. A stream formed by the confluence of 2 order 2 streams is designated order 3, and so on.

Stream reach
Section of a stream between two points.

Sub Watershed
One of the smaller watersheds that combine to form a larger watershed.

Thalweg
Portion of a stream or river with deepest water and greatest flow.

Trajectories
Juvenile salmon life history patterns.

Watershed
Entire area that contributes both surface and underground water to a particular lake or river.

Watershed rehabilitation
Used primarily to indicate improvement of watershed condition or certain habitats within the watershed. Compare *watershed restoration*.

Watershed restoration
Reestablishing the structure and function of an ecosystem, including its natural diversity; a comprehensive, long-term program to return watershed health, riparian ecosystems, and fish habitats to a close approximation of their condition prior to human disturbance.

Watershed-scale approach
Consideration of the entire watershed in a project or plan.

Weir
Device across a stream to divert fish into a trap or to raise the water level or divert its flow. Also a notch or depression in a dam or other water barrier through which the flow of water is measured or regulated.

Wild Stock
A stock that is sustained by natural spawning and rearing in the natural habitat, regardless of parentage. *Reference: SASSI*

Wild Stock
A stock that is sustained by natural spawning and rearing in the natural habitat regardless of parentage. *Reference: Conservation Commission*

Wild Stock

A stock that is sustained by natural spawning and rearing in the natural habitat, regardless of parentage (including native). *Reference: Wild Salmonid Policy - FEIS*