Annual Report- 2008

Stillaguamish River Smolt Trapping Project

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Table of Contents

Index of Figures

Index of Tables

Acknowledgments

Funding to build the Stillaguamish smolt trap was provided through a Salmon Recovery Funding Board Early Action Grant. Funding to operate the trap during the 2008 season was provided through a combination of Hatchery Reform and Pacific Coastal Salmon grants.

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The 2008 trapping season was the result of much hard work by Stillaguamish Tribe Natural Resources Staff including Charlotte Scofield, Brian Wolfe, Robbie Hutton, Jen Sevigny, Jody Brown, Rick Rogers, Kip Killebrew, and Kevin Gladsjoe. Over the past several years, helpful advice on study design, and modifications to trapping equipment were provided by Marianna Alexsandersdottir of the Northwest Indian Fisheries Commission (NWIFC), Mike MacKay of the Lummi Tribe, and Dave Seiler (retired) of WDFW.

Introduction

Chinook returns to the Stillaguamish today are much reduced from the historic escapements of the mid to late 19th century. It is estimated that the historic Chinook population ranged from 9,700-13,321 returning adults as compared with average of 1080 seen within recent years (1996-2003, SIRC 2005). In the last few decades, the 12-year moving average for adult returns has been well below the 2,000 fish escapement goal agreed to by Washington Department of Fish and Wildlife, the Tulalip Tribes and the Stillaguamish Tribe (WDF 1977). Because of the depressed nature of the Chinook population in the Stillaguamish and other rivers in Puget Sound, these stocks were listed as threatened by the National Marine Fisheries Service (NMFS) in March 1999 under the Endangered Species Act (ESA). But even before the listing (and especially since), researchers in the Stillaguamish basin have focused on documenting the status of the Chinook stocks and have attempted to identify the factors contributing to their low abundance. Projects include redd mapping, adult carcass surveys, adult and juvenile snorkel surveys, estuary mapping, and research into the effects of scour and fine sediment on survival to emergence.

A key project in these ongoing research efforts has been the operation of a rotary screw smolt trap in the lower mainstem Stillaguamish River by the Stillaguamish Tribe Natural Resource Department. Two thousand and eight marked the completion of the eighth year of a long term monitoring project directed at measuring trends in the year-to-year production of Chinook smolts in the Stillaguamish. This is not the first time a smolt trap has operated on the Stillaguamish; the Washington Department of Fisheries operated an inclined plane trap near Haller Park in Arlington 1981-1983. However, no smolt data was collected between 1983 and the start of this effort in 2001. Measuring and understanding the interannual variation in run size of these various species is critical for managing harvest and prioritizing habitat restoration. Quantifying the number of smolts leaving the watershed is one of the few methods available that provides a direct measure of the year-to-year changes in freshwater survival and growth, free from the confounding influences of marine conditions. Smolt production data from this project can also be combined with adult escapement numbers to develop natural production potential estimates for the watershed, stock/recruit functions for each species of interest, and to better understand the major density-independent sources of interannual variation in freshwater survival.

The smolt trapping program can also be used to evaluate the effectiveness of the Stillaguamish Tribe hatchery program in meeting its goals. The tribal hatchery has undertaken a wild stock supplementation program since 1980 (with the exception of ’84, ’85) with the intent of rebuilding the North Fork Chinook population. This broodstocking program captures Chinook from the spawning grounds, spawns and rears the progeny, and releases the sub yearling smolts back into the upper North Fork Stillaguamish. One of the goals of the Stillaguamish hatchery is to produce juvenile Chinook that are indistinguishable from their wild spawned cousins in both timing and size at migration. Before release, all of the hatchery produced Chinook smolts are Coded Wire

Tagged (CWT), meaning hatchery and wild spawned Chinook can be differentiated and compared in a variety of ways. One of the concerns voiced by NMFS after the Chinook salmon listing, was the potential long-term genetic impact of the Stillaguamish program on the wild Chinook populations in the Stillaguamish. NMFS's main concern was that by taking a small percentage of the Chinook escapement and producing two hundred thousand hatchery smolts, the survival rates of wild smolts could be reduced through competition and genetic drift. The data collected by the Stillaguamish Smolt Trapping Project generates yearly estimates of the hatchery contribution to the Chinook smolt out-migration, along with monitoring timing and size at migration. Combining this monitoring with adult escapement estimates (broken into hatchery and wild components), differences in marine survival may become apparent, perhaps indicative of competition in the river, estuary, or nearshore.

The primary purpose of the Stillaguamish smolt trapping project is to develop a yearly production estimate for the Chinook salmon populations in the watershed and use this estimate to track egg-migrant survival. Two thousand and seven marked the fifth year where the trap fished seven days a week and, consequently, the fifth season that provided sufficient data to estimate the Chinook smolt production.

Study Site

The Stillaguamish Smolt Trap is located in the lower mainstem at approximately river mile 6, just downstream I-5 where the South Slough rejoins the main channel (Figure 1). This is an ideal location for a number of reasons: both sides of the river at the anchor locations are privately owned and limit public access (i.e. vandalism), the river constricts and increases velocity (the cone spins quickly enough at most flows), there is a wide sandbar on the left bank to facilitate easy set up and tear down of the trap, and the location is low enough in the watershed to intercept most of the salmon emigrating from the various tributaries. The channel at this location is approximately 45 meters wide and 6.5 meters (maximum) deep under average flow conditions. As this site is located at a large bend in the river, the thalweg (area of fastest current) flows tight against the right bank. From work on other river systems (D. Seiler, WDFW ret., pers. comm.) catch per unit effort (CPUE, fish/hour) is maximized when the trap in positioned directly in the thalweg. As the area of fastest current varies with flow, we position the trap accordingly, depending on river stage.

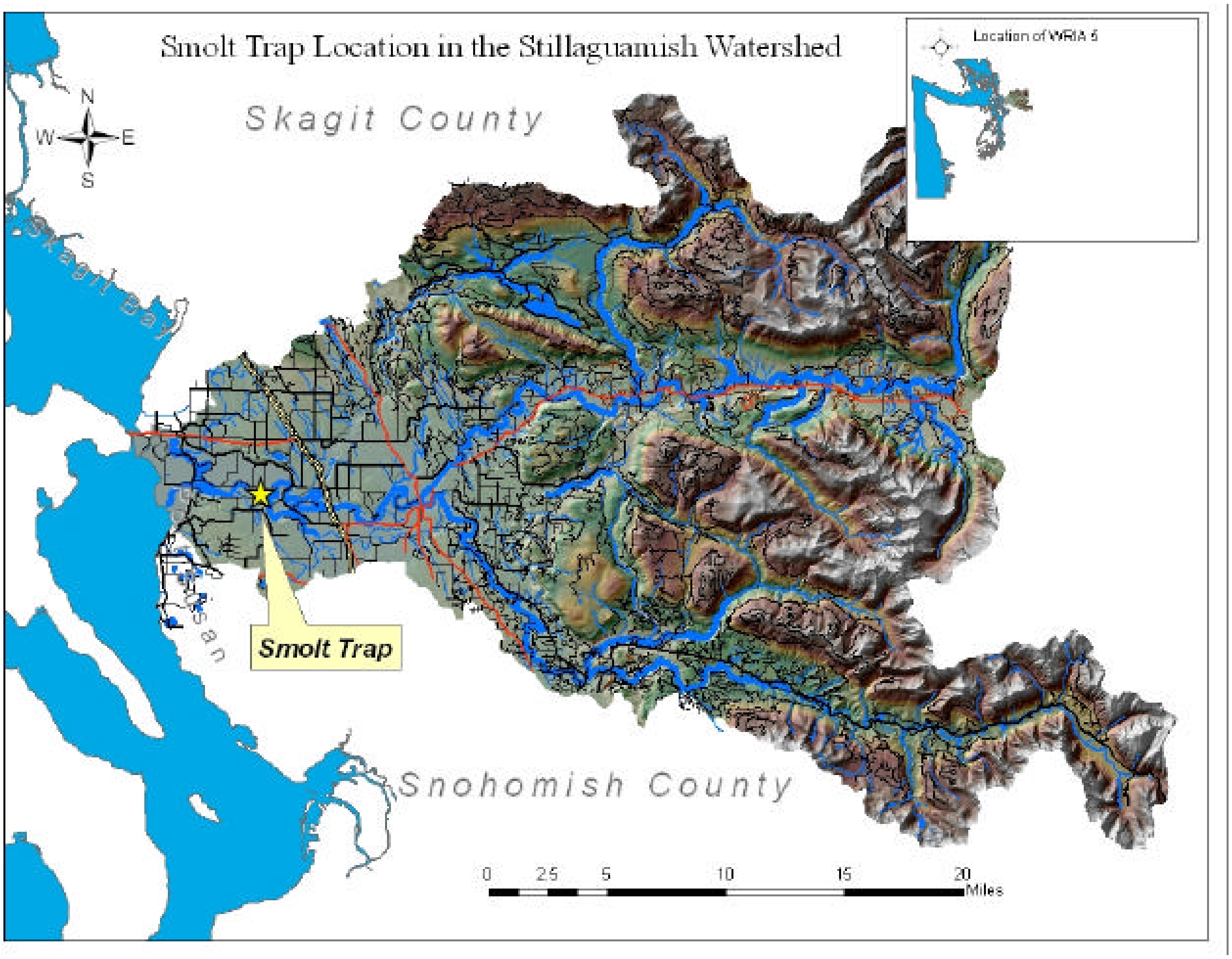

Figure 1. Location of the Stillaguamish Smolt Trap. T. 32N R 6E, Sect. 2

Smolt Trap Description

The Tribe purchased the smolt trap used in this project in 1999 (Figure 2). The cone and live box are manufactured by E.G. Solutions and are largely unmodified from the manufacturer, while the pontoons, walkways, and overhead supports are built from a design used by the Lummi Tribe Natural Resources Program Smolt Trapping project (Conrad and MacKay 2000). We have made minor changes to the design in order to strengthen the trap and add some features for comfort. These include: lights and a table on the stern of the trap, strengthening the winch platform channels with 1 cm steel plates, strengthening welds, along with many other small changes. All told, approximately $8000 has been spent in after-market additions.

Figure 2. Photo of the Stillaguamish smolt trap.

At the sampling location, a 1.6 cm Spectra line (hereafter referred to as the highline) is strung across the width of the channel (~130 m). On the right bank, it is anchored to a large western red cedar approximately 4-5 meters off the ground, and is backed up to two large cottonwoods located further from the river. On the left bank, the highline is attached to four concrete ecology blocks. The trap is positioned in the river using hand winches (spooled with 1 cm Spectra Line) located on either side of the trap. The Spectra line used on the winches and on the highline have an advantage over steel cable in that while having a similar working load per diameter, it is significantly lighter. This reduces the amount of sag in the span over the river and decreases the likelihood of injuring unsuspecting boaters. A small shed/cabin is located on site to serve as a crew base when the trap is fishing, and a skiff (3 m) is used for accessing the trap once it is positioned in the thalweg.

The opening of the cone is 2.43 m (8 ft.) in diameter giving a sampling depth of 1.2 meters when lowered into the water for fishing. The cone and live box are connected together by a steel frame that allows the entire assembly to be winched easily into and out of the water. This steel frame is suspended from overhead supports that span the two pontoons and is raised and lowered using two hand winches mounted on the supports. The cone works like an Archimedes screw, with vanes in the interior of the trap forcing the cone to spin in the current, funneling fish to the live box located aft of the cone. The live box has a trash rack mounted on the stern on the box that removes a portion of the small debris that enters the live box.

Methods

Sampling Design

The sampling design utilized in 2008 was the same one used since the 2003 season; the primary objective is to fish seven days a week through the entire season (February to July). Each day the trap was fished for a six-hour shift (0000-0600, 0600-1200, 1200-1800, 1800-2400), with the shift rotating based on the day of the week. Thursday through Monday, the shifts were varied but the same week to week (i.e., every Friday was 0000-0600, every Saturday 0600-1200, etc.), with Tuesday and Wednesday's shifts rotated to evenly distribute the effort over the four different time slots (this is an artifact of attempting to fish 4 shifts twice during a seven day week). Traps operated on less turbid systems (Skagit, Snohomish) fish mostly at night, as catches of Chinook during daylight hours are sparse. In the Stillaguamish however, data collected over the last six years indicates Chinook CPUE does not differ significantly between day and night periods (Figures 12 & 13). Outmigration appears mostly influenced by flow and water clarity, variables randomized by nature (Griffith et al. 2001, 2005).

Our season of operation is based on the estimated timing of the Chinook out-migration in the Stillaguamish watershed. During the last eight years, we have installed the trap in the river in mid to late February, began fishing in late February/early March, and ceased fishing in late June/early July. From the number and timing of the Chinook catches, this seems to be an adequate window of operation to intercept a large majority of the Chinook out-migration. In 2008, we started fishing on February 12th and finished for the season on July 2nd. Since Chinook emigrate over such a broad time frame, this trapping season is also sufficient to capture the entire coho out-migration along with a significant portion of the chum and pink salmon smolt emigration. There were rare deviations from this sampling schedule, mainly for efficiency trials (more about these in following sections), and sometimes when the river was too high or full of debris to fish safely.

Trap Operation

Each sampling shift is termed a "set" and is the sum of all the time the cone is in the water fishing. Before the start of each set, the smolt trap is positioned in the thalweg of the river using the hand winches mounted to each pontoon. The live box assembly is lowered into the river and when the cone shaft touches the water the "start time" is noted on our data sheets. Similarly, the "stop time" is noted on the data sheet when the cone shaft leaves the surface of the water. The cone and live box are raised from the water, and the frame is raised in such a way as to lift the cone out of the water while still leaving a small amount of water in the live box. The live box is completely raised from the water after the last of the fish are cleared from the box.

After getting the trap fishing and recording this starting data, typically the crew will leave the trap and check in on it on a regular basis (usually every 1-2 hours) throughout the set. However, when catches are large or debris abundant, the crew might have to stay on the trap for the duration of the set and work continuously. Occasionally a log or stick will stop the cone from rotating and it will have to be raised for cleaning. During these instances, the time lost from fishing is noted on the data sheet.

Environmental Variables

At the start of every set, a visibility measurement is taken off the bow of the trap using a secchi disc attached to a long steel pole. This involves lowering the 21cm black and white disc into the water until it is no longer visible, and recording the depth. During the hours of darkness, the measurement is taken with the aid of a powerful flashlight. In addition, a water sample is collected to measure the turbidity of the waters passing through the trap. Further data collected at the start of the set included: the rotational speed of the cone (how many seconds per rotation), water color, water temperature, type and amount of river and live box debris, and weather conditions (cloud cover, wind speed and direction, and any precipitation).
At the end of the set, another secchi measurement is taken along with weather observations and a turbidity sample.

Catch Processing

Fish are dip netted out of the live box, and transferred to a small anesthetizing tank set into the table on the stern of the trap. Instead of the common anesthetizing agent, tricane methanesulfonate (MS-222), we use clove oil to sedate the fish. Clove oil has several advantages over MS-222 including much lower cost (1/40th the cost per dose) and no toxicity for humans. From research on coho and Chinook salmon, the optimal dosage is 25 mg/l, resulting in fast knockout and recovery times and no mortalities (Taylor and Roberts 1999).

Once the fish are anesthetized, they are identified to species, individually counted, and a sub sample measured. The first twenty of all salmonid species (other than Chinook) are measured (for length, nearest mm), and the rest enumerated. Every fifth Chinook is measured and all Chinook are wanded with a coded wire tag detector (since the tribal hatchery reared Chinook are not adipose fin-clipped, this is the only way of detecting them).

Processed fish are allowed to fully recover in a tank of clean river water for 5-10 minutes before they are released back into the river to resume their seaward journey.

Estimation of Smolt Trap Capture Efficiency

Capture efficiency is defined at the instantaneous percentage of smolts passing the trap that are captured by the gear. The capture efficiency of the smolt trap is the most important variable to quantify because it is needed to expand the catches at the smolt trap and estimate of Chinook outmigration for the entire river on a given day. It is also important to be able to relate capture efficiency to some environmental parameter in order to create a relationship that predicts efficiency over the broad range of conditions experienced over the course of the trapping season. Other trapping operations around the state have shown that capture efficiency can be affected by: water velocity, time of day (daylight or nighttime), species and life stage, river stage, origin of fish (hatchery or wild), trap placement within the channel, and water clarity (Conrad and MacKay

2000, Seiler et al. 2001). For a turbid river system (the Nooksack), the Lummi trapping operation has found Secchi depth to be the best predictor of trap efficiency (Conrad and MacKay 2000).

Capture efficiency experiments were performed by releasing a known number of marked, hatchery reared Chinook smolts upstream of the trap and then enumerating the number of marked fish recaptured on the trap. In 2008, the two groups were released about 2.5 kilometers upstream of the smolt trap, one group into each fork of the Stillaguamish below the I-5 bridge (Figure 3). Both release groups were marked with Bismark Brown dye and ad-clipped, with one group doubly marked with an upper caudal fin clip. These are the same release locations used since 2002; releases above where the river forks (2001) did not produce efficiencies in line with what has been reported from others using similar gear in neighboring rivers (Seiler et. al. 2002, Nelson et. al 2003). Unfortunately, this has meant that two large (3000-4000 fish) groups are released into each channel for each efficiency trial, not only to measure the efficiency of the trap over a range of environmental conditions, but also to test for differences in the ability of the trap to capture fish traveling down either channel (Figure 3). It is not known what percentage of juvenile salmonids travel down each of the channels immediately above the smolt trap, therefore it is important to make sure that the recapture rate for both groups, no matter which channel they are released into, are not significantly different.

All fish used in our capture efficiency trials were from the Stillaguamish Tribal hatchery. Catches of wild Chinook were not high enough to create an adequate sample size for paired releases (less than 1200 wild Chinook were captured during the entire season). The hatchery fish used in the efficiency trials were clipped a few weeks prior to the first release and portioned into raceways by their mark. Just before release, two groups of approximately (the exact numbers varied from trial to trial, see Table 1.) 3000-4000 fish were loaded into both tanks of a large hatchery truck. Bismark brown dye was added to the tanks at the manufactures recommendation of one gram for every 57 liters of water and was kept oxygenated using bottled O_2 and an air stone. From the time the fish were loaded into the tote to release was usually one hour. In our experience, this was a sufficient amount of time for the stain to take effect and dye the Chinook an obvious gold color.

The fish were driven to the two bridges indicated in Figure 3 and given a quick release. A 10cm hose was attached to the drain of the tank and all dyed fish were spread across the thalweg in the span of about a minute. The fish reached terminal velocity quickly, splashed into the river and swam away immediately, appearing unharmed. This release procedure was repeated soon after at the other fork of the river so both groups were always released within one half hour of each other.

During the release process, the smolt trap was either in operation or being deployed. The release site was far enough upstream so that fish never reached the trap until it had been fishing for close to one hour. During the efficiency trials, secchi measurements were taken every 2-3 hours and a water sample was taken for turbidity every 6 hours. The trap was fished continuously for at least 24 hours after marked fish were released, and usually until three hours elapsed without catching any marked fish.

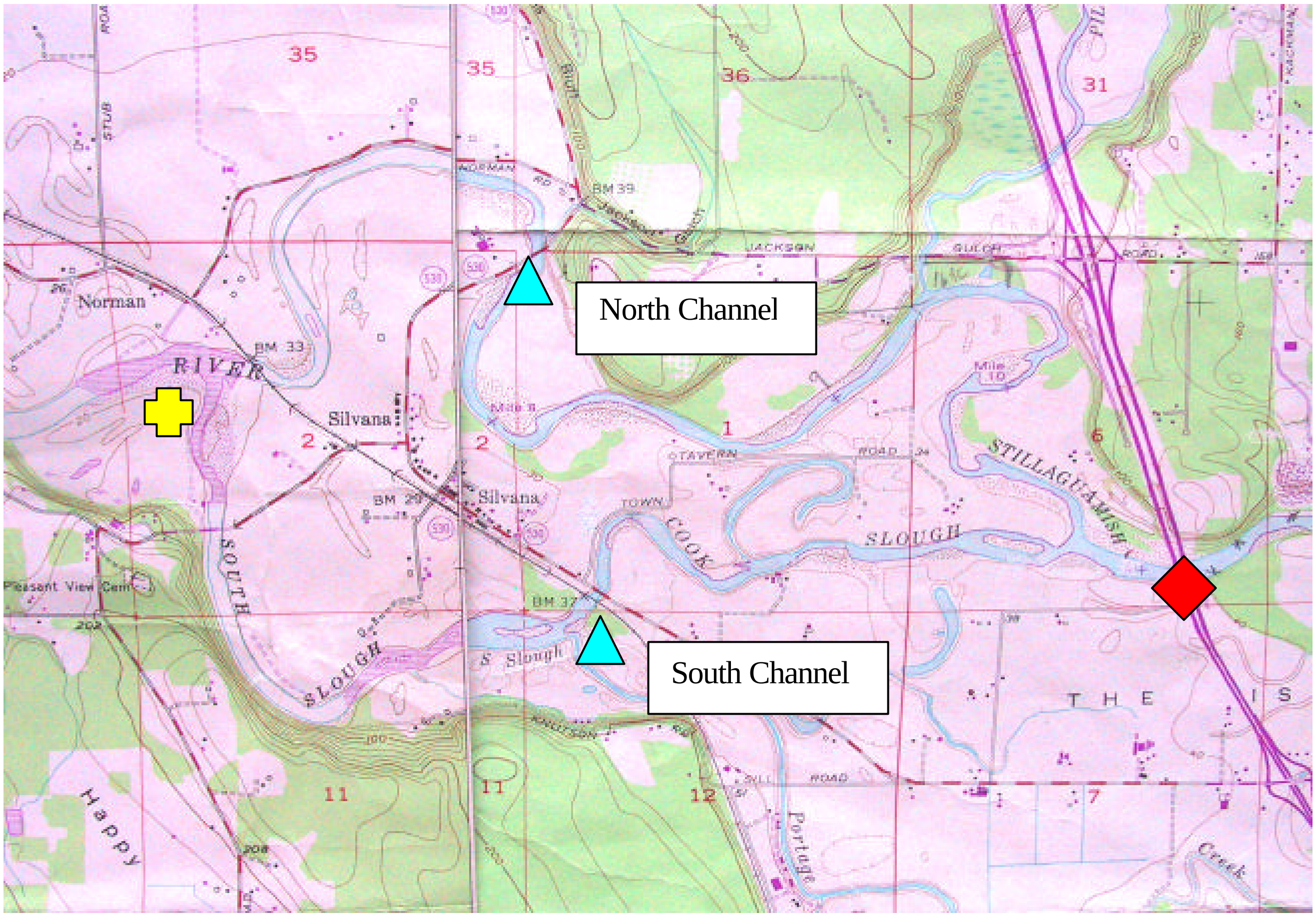

Figure 3. Map of the lower mainstem Stillaguamish, with locations of efficiency releases.

✚ Indicates smolt trap location. ▲ Indicates the release locations used in 2002-2006.

◆ Indicates release location used in 2001.

Estimation of Chinook Smolt Outmigration.

There are several steps in the estimation of the annual Chinook smolt outmigration from the Stillaguamish:

1. Run trap efficiency trials and estimate percent efficiency for each trial.
2. Estimate relationship between environmental variables and percent efficiency using data for all years from 2002 onward.
3. Sample 6-hour period each day, chosen in a systematic random manner.
4. Estimate catch per hour fished for natural origin and hatchery origin smolts from sampling data.
5. If a day's sampling is missing, estimate the day's CPUE from surrounding fishing dates.
6. Use trap efficiency relationship to expand to total out migration per hour for the period.
7. Expand 6-hour period to total day
8. Sum up days out migration for total production migrating past the trap site.

The Efficiency Trials.

Smolts are marked and released above the trap in two channels, the north and the south (the channels rejoin a couple of hundred meters above the smolt trap). Trap efficiency is estimated as the number recaptured in the trap over the number released above the trap. At the same time, several environmental variables are measured and are available for analysis: secchi disk reading, turbidity and flow.

Three paired releases were made in 2008, adding to the 24 trials run between 2002 and 2007; efficiencies calculated for each release and channel (Appendix A) Estimates of efficiency ranged from 0.4%-3.1% during the 2008 trials (Figure 4). While there were individual trials (in 2004, 2006, 2008) where recapture rates have been significantly different between the forks, there has not been a consistent significant difference ($a=0.05$, $p>0.05$) in recapture rates or timing between the forks when looking at an entire season or combining seasons (Figure 4). Therefore, the efficiency data has been pooled for both forks in generating a regression relating capture efficiency to an environmental variable. For further discussion of our methods of testing differences in timing and rate of recovery for efficiency groups please see the 2004 Stillaguamish River Smolt Trapping Project Report (Griffith et al. 2005).

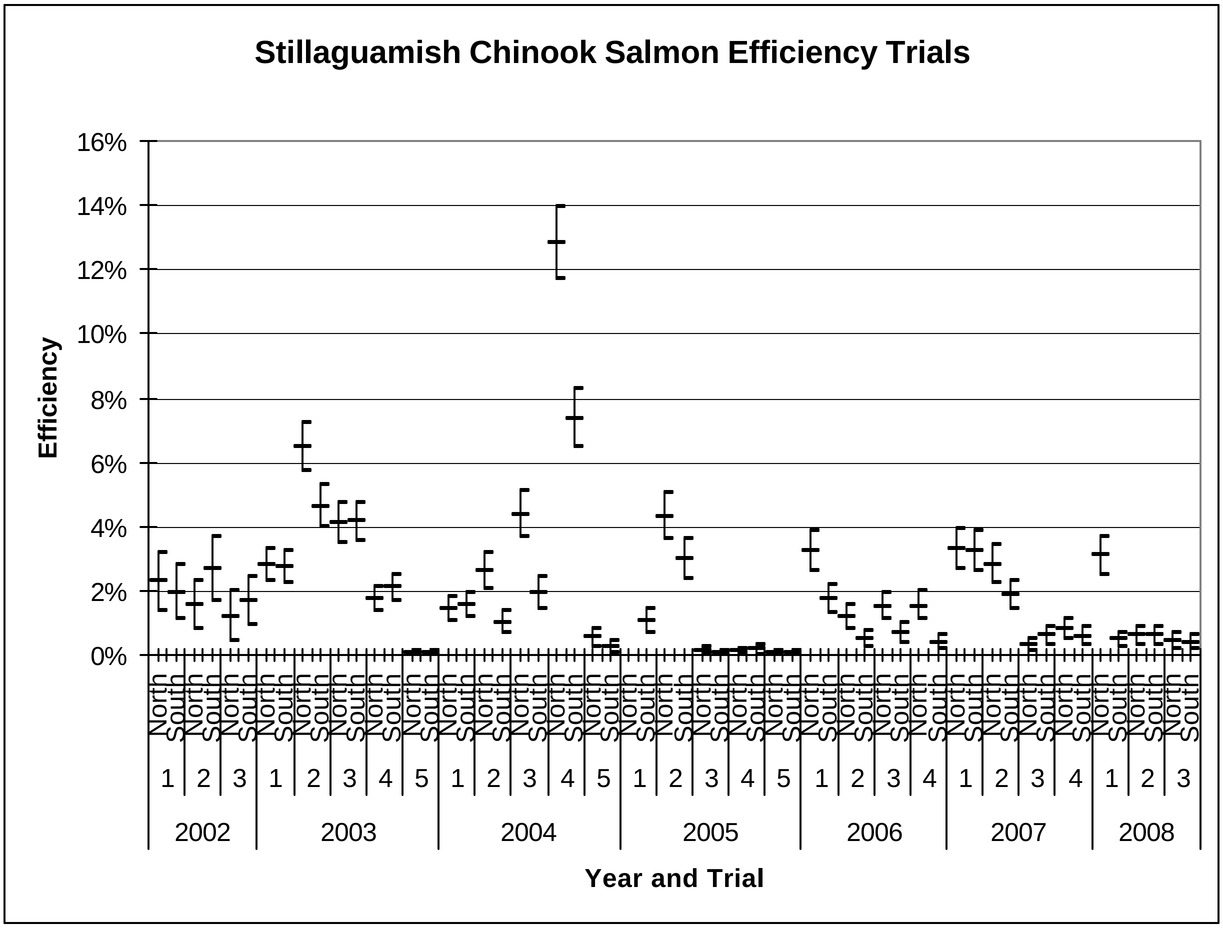

Figure 4. Estimates of trap efficiency as a percentage of release (recovered/released * 100) by trial, year, and channel of release for Stillaguamish Chinook salmon. Error bars represent 95% confidence intervals surrounding the estimate.

There are several choices for using the efficiency estimates for expanding catch per hour at the trap to total out migration per hour past the trap for any single day. These would include, estimating a mean efficiency over all trials, or estimating a relationship between the efficiencies and environmental variables that can be measure on a daily basis. The average secchi disk reading has been the best predictor of trapping efficiency for all of the years the Stillaguamish Trap has operated (Figure 5); an exponential function provides an estimate of the relationship:

$$\boldsymbol{E_i} = a\boldsymbol{e}^{b \cdot \boldsymbol{SDR_i}} \qquad \text{Equation 1}$$

where $\boldsymbol{E_i}$ is the efficiency for period i and $\boldsymbol{SDR_i}$ is the average secchi disk reading for period i.

The data for the three years were combined and a non-linear regression used to estimate the relationship between efficiency and average secchi disk readings (Figure 4). The estimate for efficiency combining data from all years and both release channels is shown in Table 2. Both parameters are significant at a<0.05. In this relationship one point is very influential, that on 6/11/03, when the secchi disk reading was 7.10 and efficiency estimated at 0.04%.

Table 1. Results for regression estimating relationship between efficiency and secchi disk readings (see equation 1) using non-linear regression methods.

	Estimate	
	$Efficiency = ae^{ß(Secchi\ Reading)}$	
a ß	0.073 -0.7485	

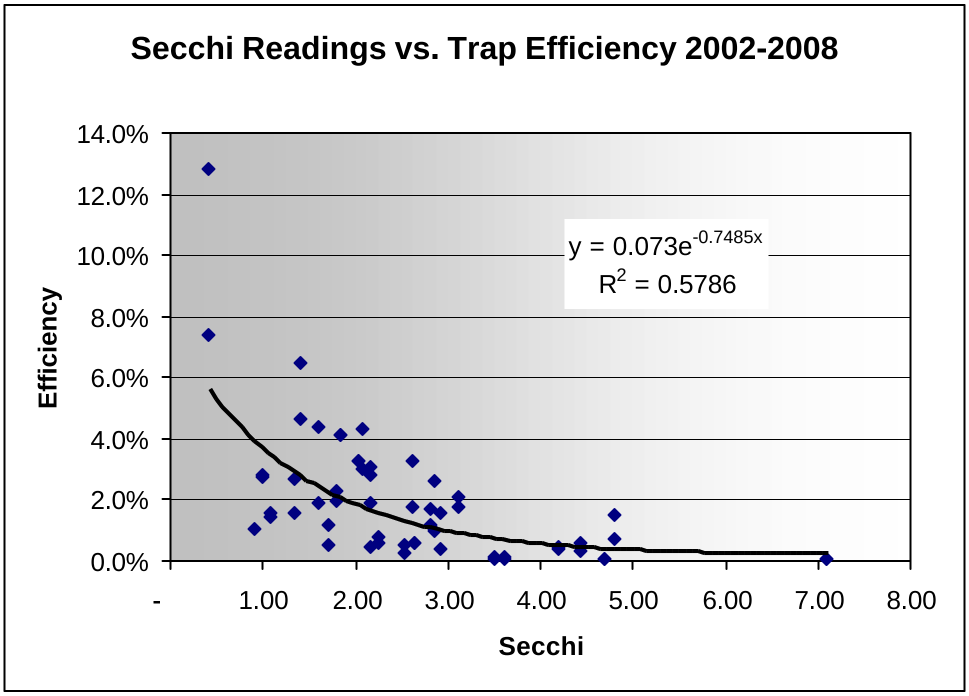

Figure 5. Regression relating capture efficiency of the Stillaguamish Smolt Trap to secchi depth measurements taken off the trap itself. Data depicted were collected in the 2002-2008 trapping seasons.

Estimation of out migrations of smolts.

The trap samples a single period each day and the total catch per hour by type (natural or hatchery origin) for each period is c_i. The migration per hour for period i is estimated as;

$$\hat{n}_i = \frac{c_i}{\hat{E}_i} \qquad \text{Equation 2}$$

and the variance is;

$$Var(\hat{n}_i) = \hat{n}_i^2 \frac{Var(\hat{E}_i)}{\hat{E}_i^2} \qquad \text{Equation 3}$$

The out migration per hour averaged over multiple sample periods within a day is;

$$\bar{n}_d = \frac{\sum_{j=1}^{p} \hat{n}_j}{p} \tag{Equation 4}$$

and the variance among the periods is,

$$Var(\bar{n}_d) = \frac{\sum_{j=1}^{p} (\hat{n}_j - \bar{n}_d)^2}{(p-1)} \tag{Equation 5}$$

where p is the number of periods in a 24 hour day. As the migration for each period is an estimate, a variance within periods must also be accounted for, by:

$$V(\hat{\bar{n}}_d) = (1 - \frac{p}{P})\frac{Var(\bar{n}_d)}{p} + \frac{\sum_{j=1}^{p} Var(\hat{n}_j)}{p} \tag{Equation 6}$$

A total out migration (N_d) is estimated for the 24-hour day by expanding the mean out migration per hour by 24,

$$\hat{N}_d = H \ \hat{\bar{n}}_d \tag{Equation 7}$$

and the variance by,

$$V(\hat{N}_d) = H^2 Var(\bar{n}_d) \tag{Equation 8}$$

The variance equation in equation 6 has two variance components, variance among periods ($Var(\bar{n}_d)$) and variance within periods, ($Var(\hat{n}_i)$). The single sample period per day does provide an estimate of the variance within period, but does not allow an estimate of the variance among periods. Although the regular sampling schedule was to sample a single period, full 24-hour days were sampled when trap efficiency tests were being carried out. These data can be used to estimate a coefficient of variation among periods, which can then be used to estimate the first variance component in equation 6. The coefficient of variation is,

$$CV(\bar{n}_d) = \frac{\sqrt{Var(\bar{n}_d)}}{\bar{n}_d} \tag{Equation 9}$$

and so the variance of the average out migration per hour for day d can be estimated by,

$$Var(\bar{n}_d) = CV^2(\bar{n}_d)\ \bar{n}_d^2 \qquad \text{Equation 10}$$

In order to get a daily migration estimate for those days not fished, we needed to estimate what CPUE (numbers of Chinook per hour) would have been had the trap actually collected data (Equation 2). It was also necessary to estimate what the secchi measurement would have been if the trap would have been fishing (Equation 1). In such instances of high flows, the only environmental data available are flow measurements from the USGS gauge site on the North Fork Stillaguamish. Plotting CPUE values (two weeks before and after days missed) as a function of flow produced a regression that could be used to interpolate CPUE for those days not fished (Figure 6.). The relationship is quite weak, however, underscoring the difficulty of estimating migration on days missed.

Similarly, a regression relating flow to Secchi measurements (Figure 7) was used to estimate what the secchi measurement would have been, had the trap actually been fishing. The interpolated values for both efficiency and CPUE were subsequently used in Equation 2 to estimate daily migration for Chinook.

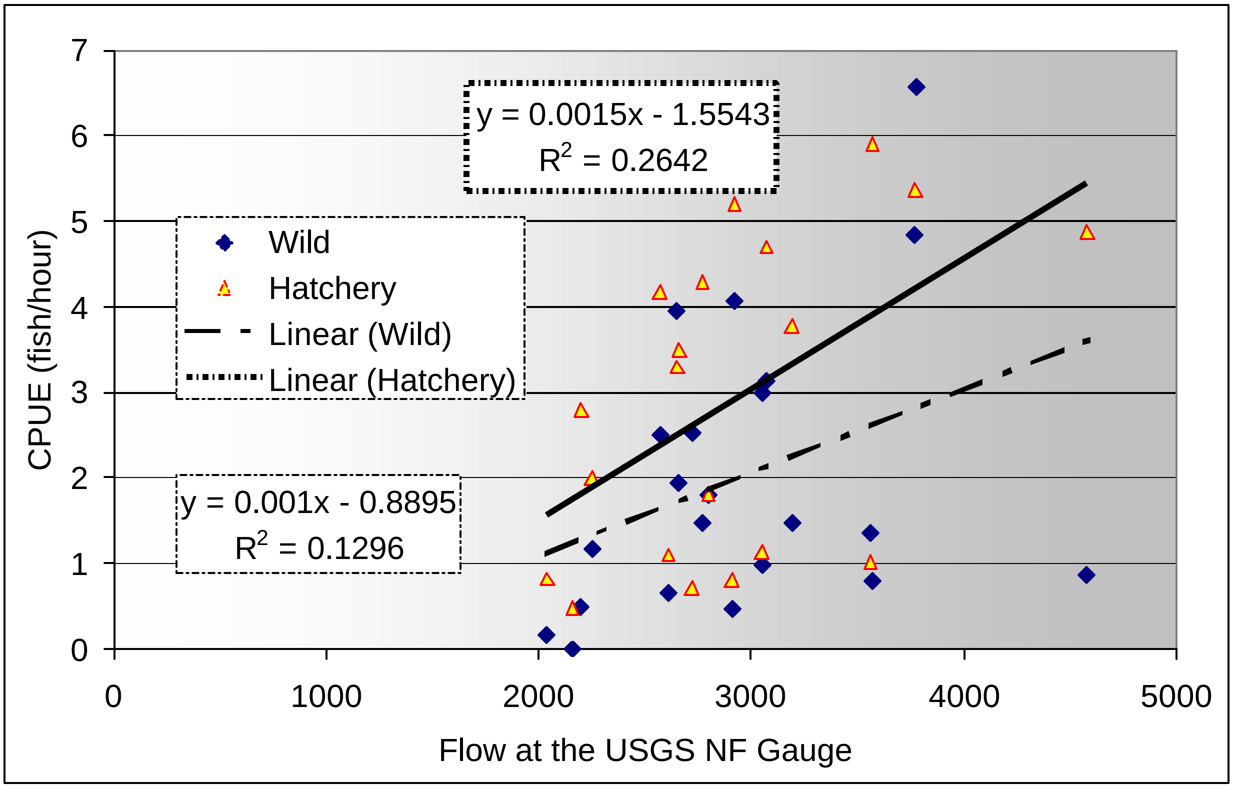

Figure 6. Regression relating CPUE to flow surrounding the May missed fishing days.

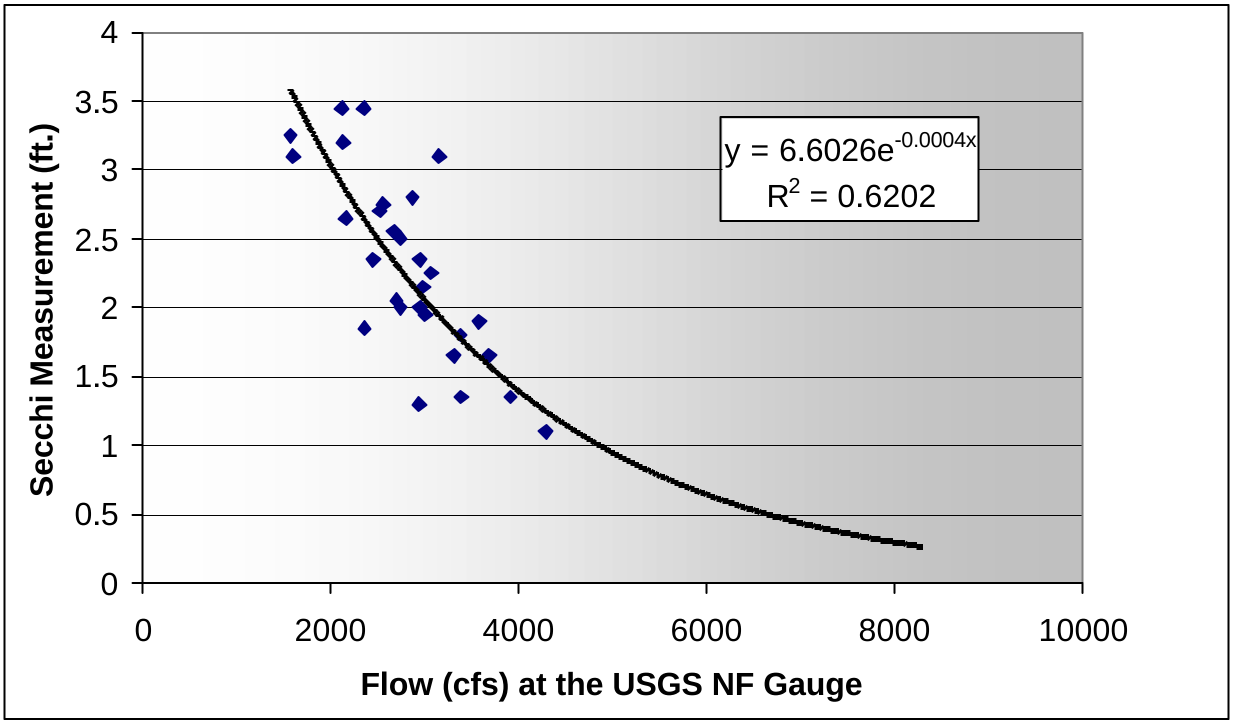

Figure 7. Regression relating Secchi measurements at the trap to flow measurements at the USGS North Fork Gauge for the two weeks surrounding missed fishing days.

Egg to Migrant Survival

Once total Chinook production is estimated for a particular brood year, it is straightforward to estimate survival from egg deposition to smolt outmigration. Following from Seiler et al. (2002):

Egg-to-migrant survival for brood year i, S_i is estimated by:

$$S_i = \frac{M_{i+1}}{R_{si} F_i} \qquad \text{Equation 11}$$

Where: M_{i+1} = *estimated age 0+ Chinook migration in year i+1*

R_{si} = Numbers of Females estimated to have spawned in year i.

F_i = estimated Chinook fecundity in year i.

R_{si} is estimated from the yearly WDFW Chinook redd counts on the Stillaguamish (assuming one female/redd). F_i is estimated using fecundity data from the Stillaguamish Tribe's Chinook broodstocking program.

Results

Smolt trap effort and trapping season

In 2008, the Stillaguamish Smolt Trap fished on 128 days for a total of 803 hours. The trap was fished on a systematic random sampling design (per as described earlier), seven days a week, from February 12th to July 2nd. Most sets were six hours, except during the three efficiency trials. During efficiency trials, the trap was fished varying amounts depending on the number of recaptures of marked fish (times ranged from 22-26 hours). Two thousand and eight was one of the most challenging years to fish in the history of our trapping effort, with twelve days lost due to high flows. These days were lost in 7 and 5 day blocks during the peak outmigration period in mid to late May (5/15-24, 25-29). During flood events, the speed of the river and the volume of debris (logs, sticks, car tires, etc.) make trap operation unsafe for both crew and fish. There were no days lost to mechanical or staffing problems.

Wild Chinook Catches

Over the entire season, 634 wild smolts were captured and released (Figure 8), including nine mortalities (1.4%). Most wild Chinook captured were in the 40-70 mm range, most likely 0+ smolts. Most years, a few large (>90 mm, presumable 1+ smolts) Chinook are captured early in the year, however no fish fitting this life history profile were captured during the 2008 sampling season. The trap is capable of catching fish in this size range, however; more than 1700 coho, averaging 98 mm were captured during the 2008 season, in addition to over 500 larger (>150mm) steelhead and cutthroat trout. Wild Chinook were captured as soon as the trap started fishing in mid February; the 50% migration date was May 8 for wild Chinook (Figures 8 & 10). Catch per unit effort (CPUE, hours) for wild Chinook exhibited a predominately uni-modal distribution with the broad peak in CPUE (>5 fish/hour, Figure 8) occurring in mid-late May. The mean daily discharge at the USGS North Fork gauge has been added on a second axis (log scale); illustrating that most peaks in CPUE are related to spikes in the hydrograph (Figure 8). Some interpolation is needed to see that the period when the trap was not fishing was likely the period of peak outmigration for wild Chinook smolts.

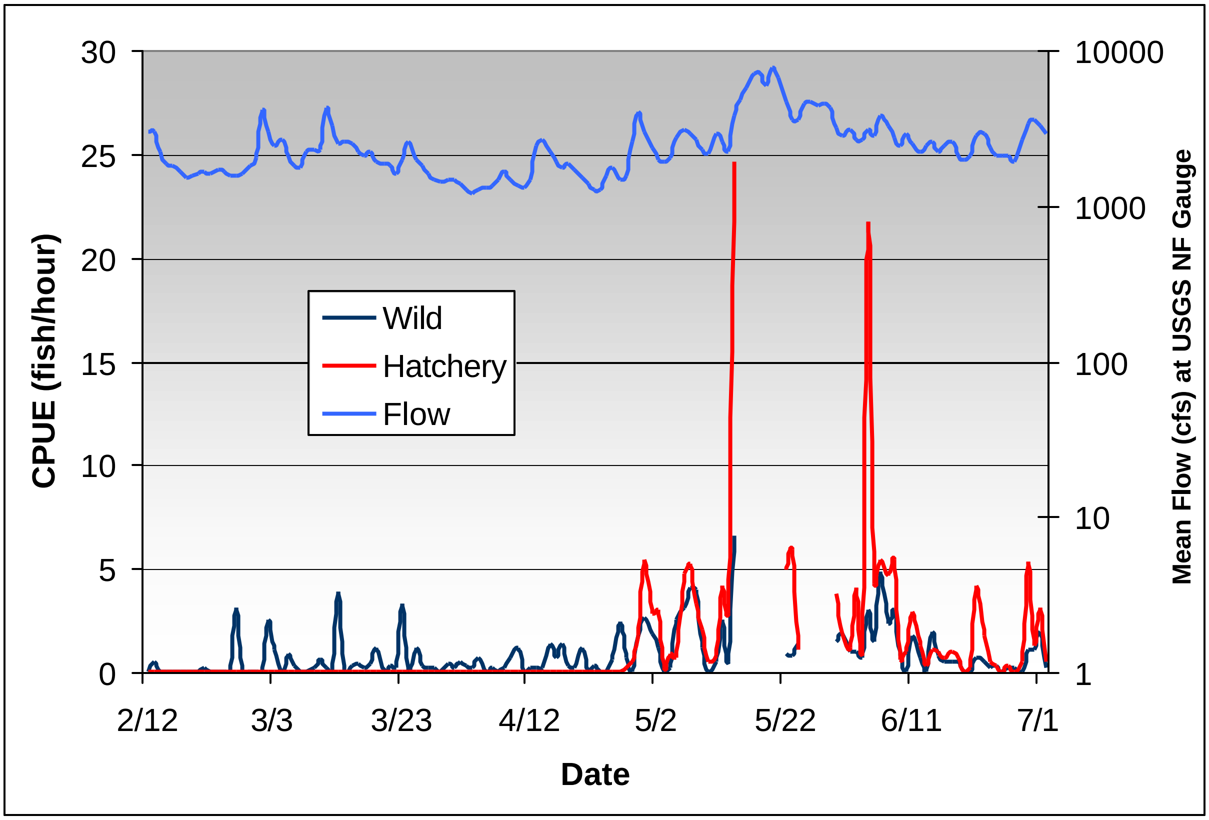

Figure 8. Wild Chinook and Hatchery CPUE over the 2008 trapping season along with mean daily discharge (cfs). Discontinuity in the CPUE lines indicate days that the trap could not fish due to high flows.

Hatchery & Wild Chinook- Migration Timing and Size

During the 2008 season, 926 hatchery Chinook were captured and released from the trap. All of the hatchery Chinook are doubly marked with coded wire tags (CWTs) and adipose clips, allowing hatchery fish to be differentiated from wild spawned smolts. Hatchery fish were significantly (p<.01) larger during all weeks sampled (usually ~15-20 mm) as compared with wild Chinook (Figure 9). While exhibiting similar timing of migration in relation to rain events (Figure 8), hatchery fish migrated predominately during the latter half of the wild outmigration, with a 50% migration date of 6/1 as opposed to 5/8 for wild smolts (Fig. 10).

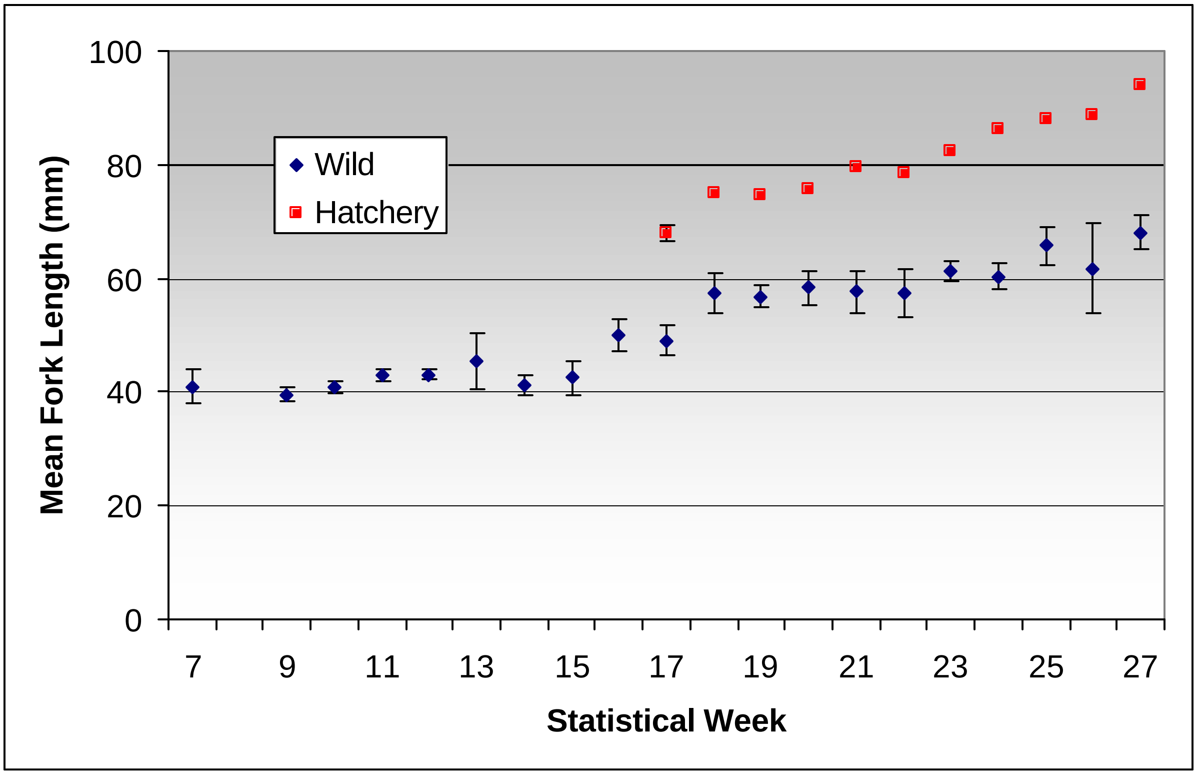

Figure 9. Weekly mean size (mm) of hatchery and wild fish. Error bars depict the 95% confidence interval surrounding the mean, bars on Hatchery are too small to be seen.

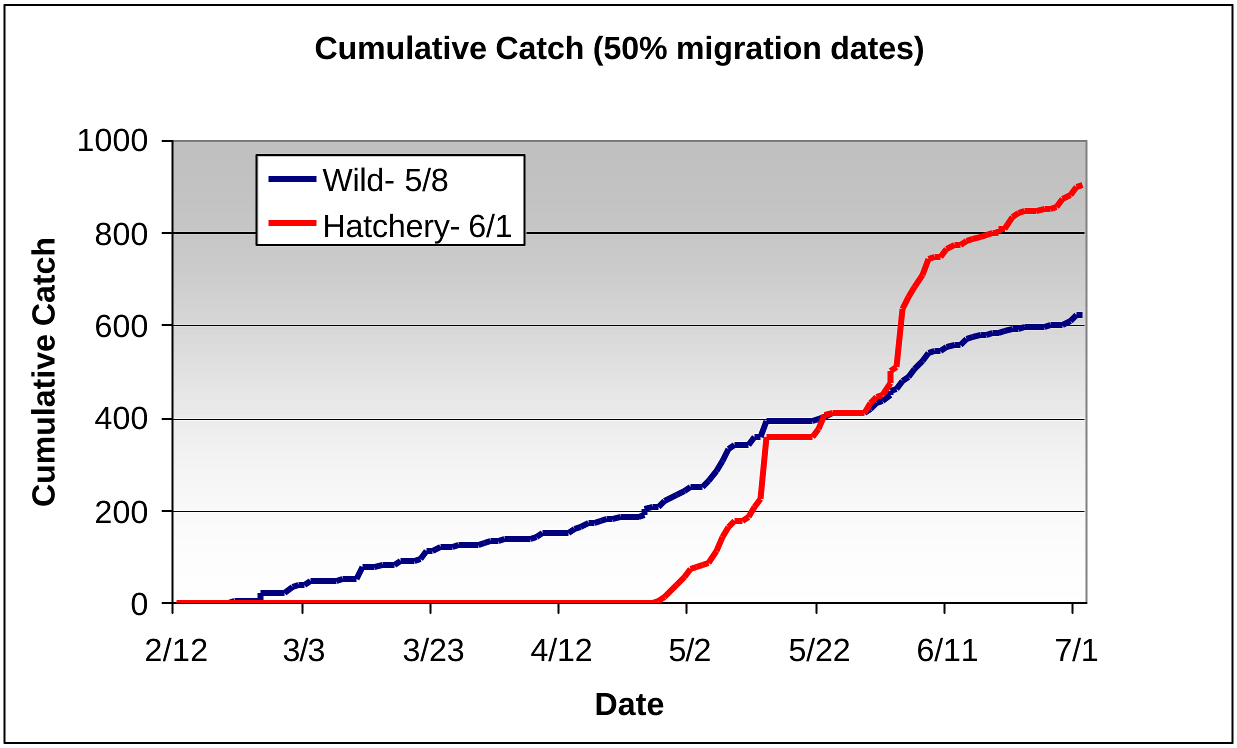

Figure 10. Hatchery and wild cumulative catches of Chinook salmon on the smolt trap 2008. 50% migration dates were 6/1 for hatchery and 5/8 for wild Chinook smolts.

Outmigration Estimates for NOR and HOR smolts-

Utilizing the equations detailed in the Methods section, a total of 186,115 natural origin smolts and 277,019 hatchery origin smolts were estimated to have passed the trap location over the sampling period. The outmigration is summarized below in Table 3. May and June were the peak months of outmigration for wild and hatchery Chinook smolts, respectively (Table 3, Figure 11). Combining the wild smolt production estimate with adult escapement estimates and fecundity for the 2007 brood (Equation 11) yields an egg-migrant survival estimate of 13.9%.

Table 2. Estimated average daily out migration of smolts from Stillaguamish for 2006 and total out migration for the season. Pooled Standard Error: PSE = $\frac{\sqrt{Variance}}{Estimate}100$

Average Out Migration Per Day				
	Natural Origin		Hatchery Origin	
Month	**Estimate**	**Avg. PSE**	**Estimate**	**Avg. PSE**
February	116	12%	0	0%
March	707	58%	0	0%
April	844	56%	400	10%
May	2782	66%	4146	79%
June	2437	70%	13504	75%
Total Out Migration for 2008				
Total	**186,115**	52%	**277,019**	55%
Lower 95% CI	151,201		204,875	
Upper 95% CI	221,028		349,163	

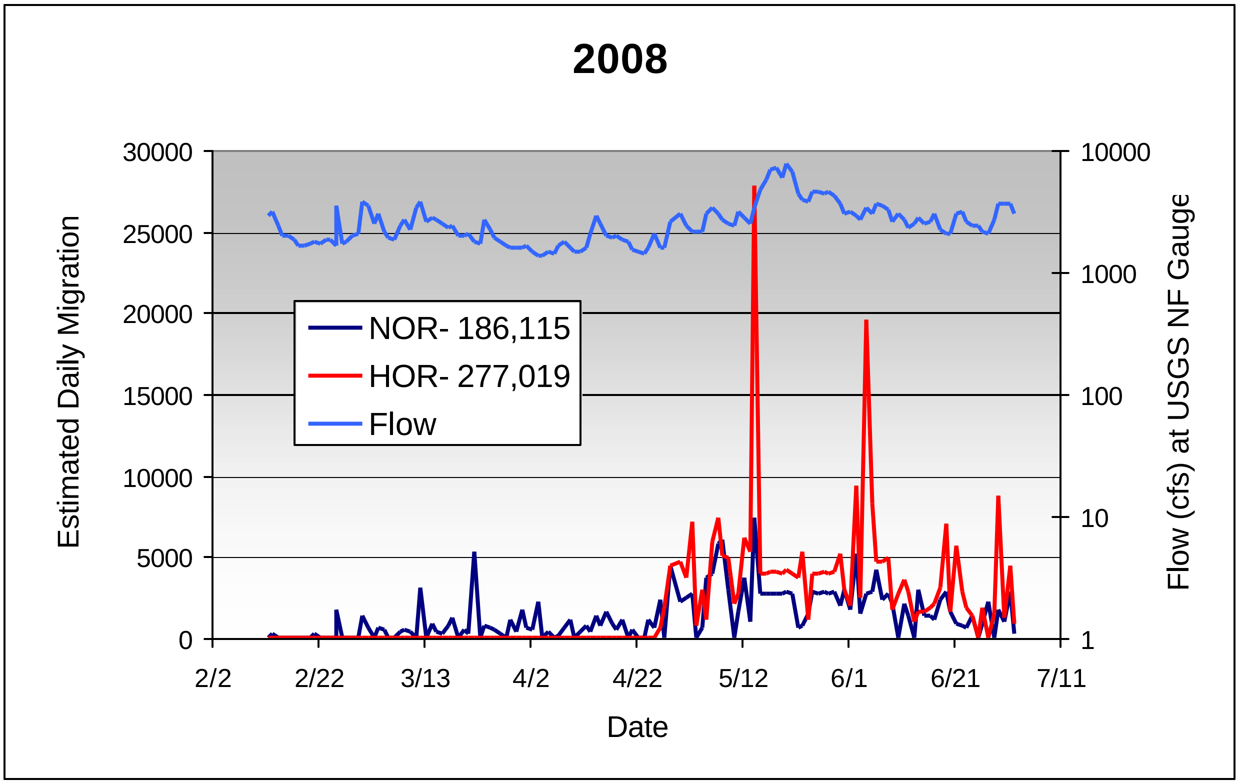

Figure 11. Estimated daily migration for natural origin (NOR) and hatchery origin (HOR) Chinook smolts. Flow (cfs) as measured at the USGS North Fork Gauge is added on a secondary axis.

The sample design required that the trap be fished daily, however we were not able to fish on twelve days in May. In order to provide estimates of the daily passage for the missed days, a linear regression relating CPUE to flow at the USGS North Fork gauge was calculated using the two weeks prior to and after the days with no fishing (Figure 6). A non-linear regression was used to estimate what the secchi measurement would have been had the trap fished (Figure 7). The estimated CPUE and Secchi values were then used in equations 1&2 to calculate migration on those days we did not fish. The total out migration for the missed days was estimated to be 32,961 wild and 47,788 hatchery origin Chinook smolts, representing 17.7% and 17.2% of the total natural and hatchery origin Chinook outmigration, respectively.

During efficiency trials the trap is fished continuously for 24 hours or more. During these experiments, the data is collected using the same six hour time periods (0000-0600, 0600-1200, 1200-1800, 1800-2400) as a normal fishing day. This allows the variability among periods to be estimated for a given fishing season. For the 2008 data, the average CV measuring variability among periods was estimated as 75.3%. This CV estimate was used in Equations 9 and 10 to estimate the variance component in Equation 6.

All periods within the day had a chance of being sampled, although for most days only one period was sampled. The mean CPUE for wild Chinook by fishing shift is plotted in Figure 12 along with the 95% confidence intervals for the means; there was not a significant) difference between the four shifts (ANOVA, ∝ 0.05, p= 0.10). There were significant differences in hatchery

Chinook CPUE among the four fishing shifts (ANOVA, ∝ 0.05, p= 0.02, Figure 13), however these differences were driven by two outliers in the 6am fishing shift data. Removing these outliers from the analysis, yields insignificant differences between the fishing shifts.

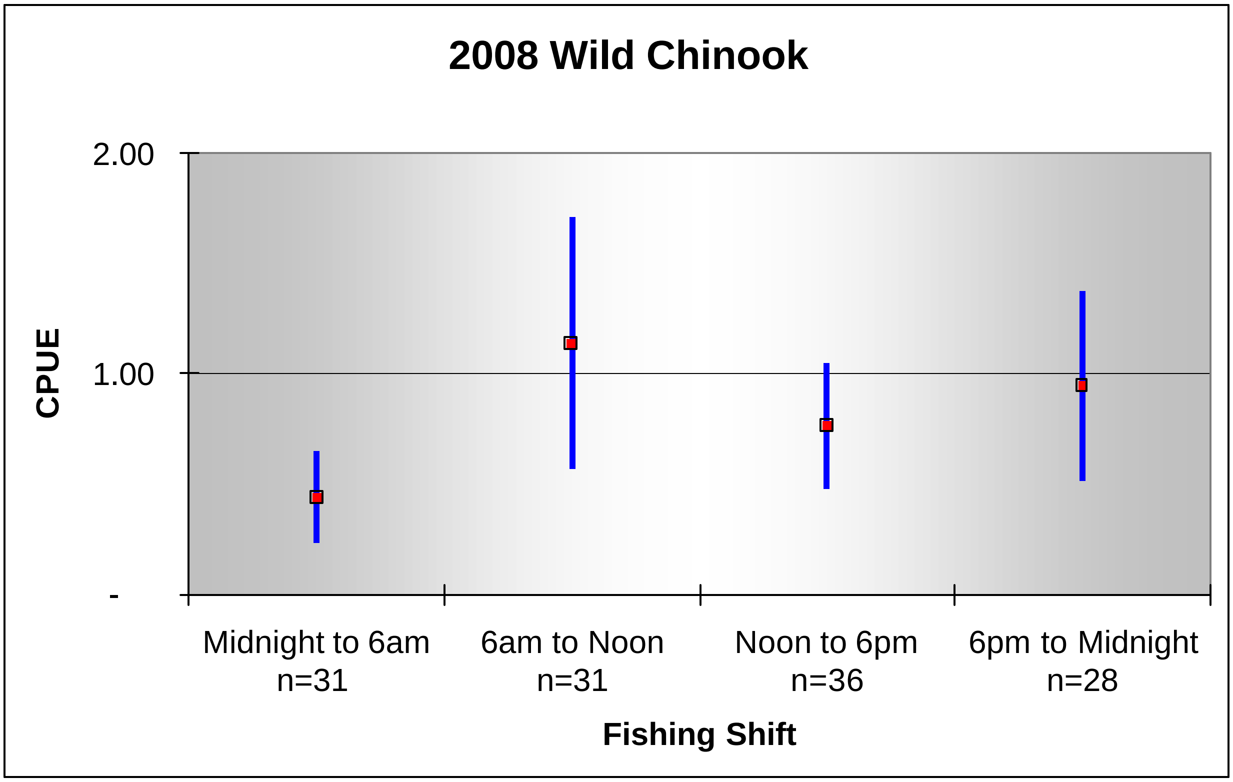

Figure 12. Mean wild Chinook CPUE (boxes) along with 95% confidence intervals (bars) by fishing shift for the Stillaguamish smolt trap in 2007.

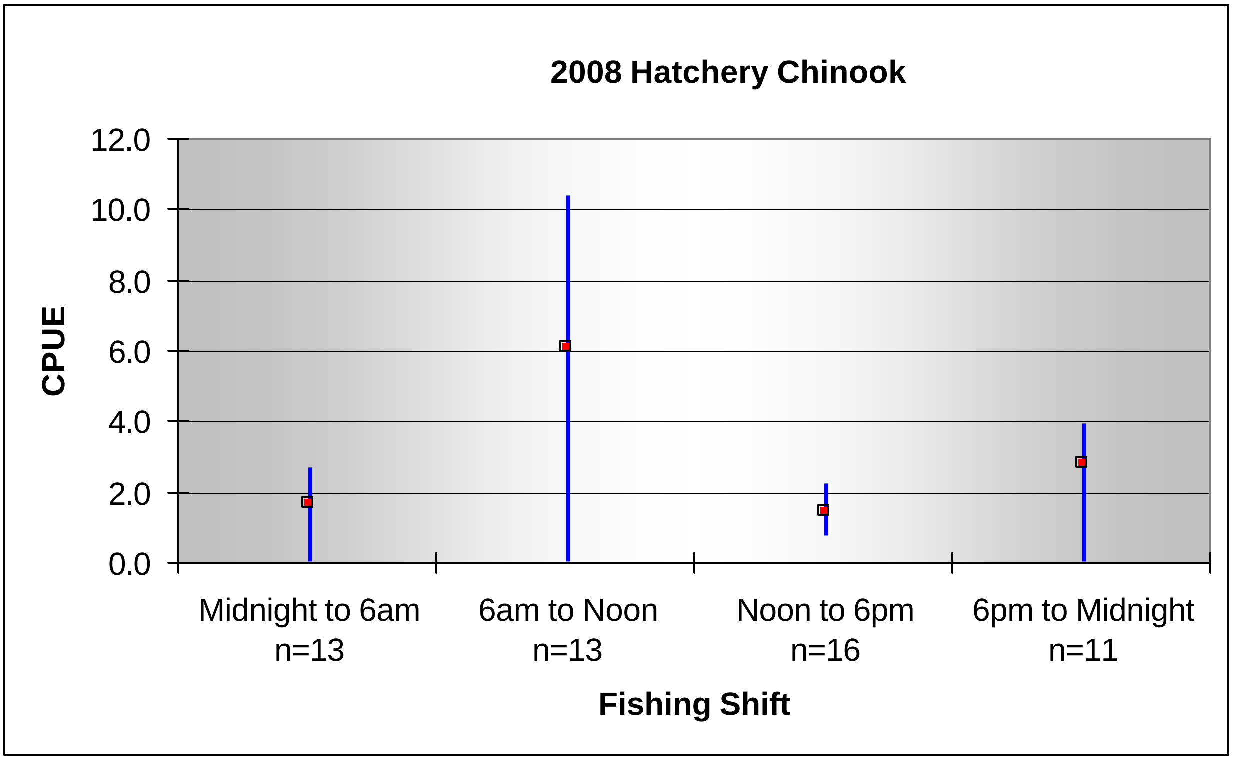

Figure 13. Mean hatchery Chinook CPUE (boxes) along with 95% confidence intervals (bars) by fishing shift for the Stillaguamish smolt trap in 2007.

Discussion

The primary goal of the Stillaguamish smolt trapping operation is to estimate the number of Chinook smolts produced by the system each year; this is the sixth year where production estimates have been made. We estimated that 186,115 (PSE=52%) natural origin smolts and 277,019 (PSE=55%) hatchery origin Chinook migrated past the trap from mid February to early July. While there is evidence that some fish migrated before and after the trap fished, we did not attempt to determine numbers in the pre and post fishing season tails.

Relatively moderate flows allowed the trap to operate most days, except for a period in May where twelve days were lost to high flows. During these missed fishing days, 17.7% (32,961) of the season's wild production total was estimated to have passed the trap. This is concerning, as the relationship relating flow and CPUE was extremely weak in 2008 (Figure 6), indicating that there is limited confidence in the estimates from missed fishing days. The estimates from missed days likely affected the overall accuracy of the production estimates as evidenced by the calculated hatchery production estimate. While we estimated that 277K hatchery fish migrated past the trap, only 216K were released 40 miles upstream. Although the 95% confidence interval around the hatchery estimate encompasses the number released upstream, we have observed in prior years that only ~ 67% of fish released survive to reach the trap (est. at 144,890 in 2008, putting it outside of the confidence interval). Part of the discrepancy could be attributed to two hatchery CPUE outliers; on these days alone (5/14, 6/4), 47K hatchery Chinook were estimated to have passed the trap. It is possible that on these days, changes in migration behavior (fish swimming more in the thalweg, shallower, etc.) resulted in higher efficiencies than is predicted by the regression relationship (Figure 5.). Outliers were not observed in the catch rates of wild Chinook, therefore is not as likely that the wild production estimate is biased high.

Combining the 2008 wild smolt production estimate with 2007 adult escapement estimates yields an estimate of the egg-migrant survival rate, calculated at 13.9% for the 2007 brood. This estimate is at the upper end of what has been observed in the past eight years (but still falls near the regression line) and is a reflection of the incubation conditions experienced during the fall and winter of 2007. Peak flows typically result in gravel scour and sediment deposition, processes that (depending on the severity of event-Figure 14) can kill a large number of the eggs deposited, either by suffocation or displacement from the gravel (Healy 1991). As the Stillaguamish smolt trapping project continues, refining the relationship between egg-migrant survival and environmental variables continues to be an important component in understanding the limiting factors affecting Chinook populations. In recovery planning for the watershed, understanding the variables affecting production is important for prioritizing limited restoration funds.

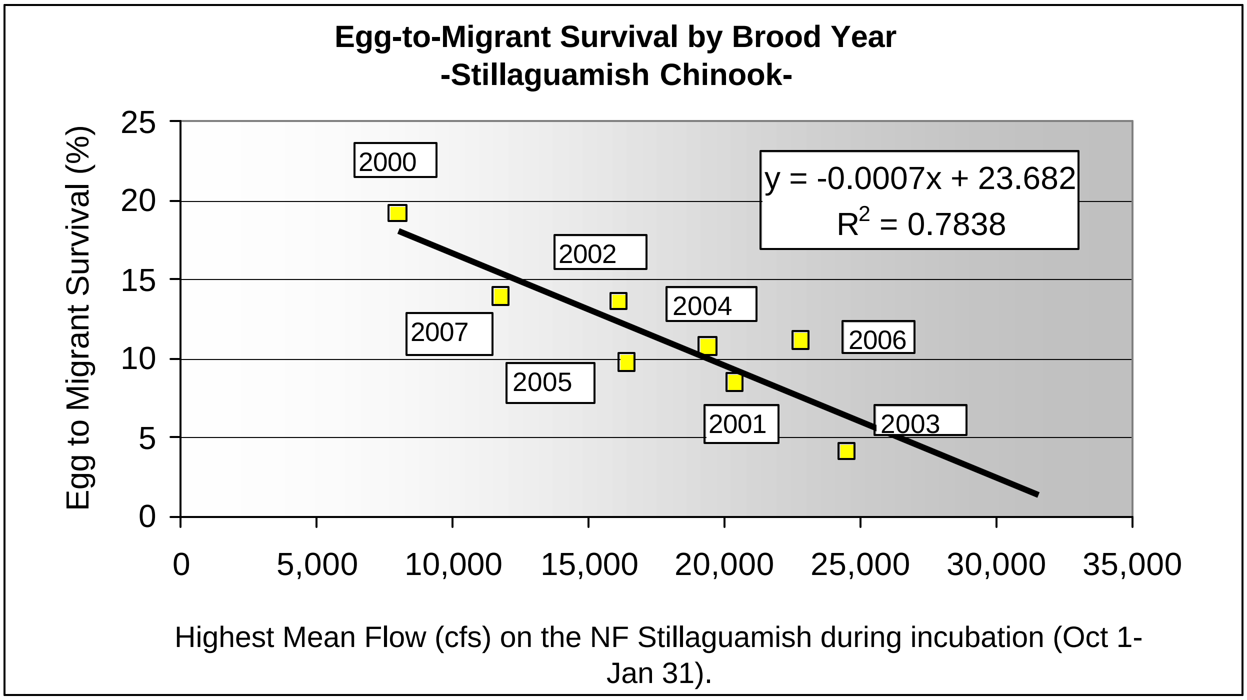

Figure 14. Egg-Migrant Survival by Brood Year for Stillaguamish Chinook.

One of the advantages of this project is that the catches can be used to compare migration timing and size at migration between hatchery and wild spawned Chinook. In all the years of trapping thus far (including 2008), wild origin Chinook were smaller and migrated earlier than hatchery origin Chinook smolts (Figures 9 & 10). Because the Stillaguamish Hatchery program is an Integrated Recovery type operation (designed to help recover the endangered Chinook populations on the Stillaguamish), it is important that hatchery releases as closely as possible mimic their wild counterparts in size and timing of migration. The goal is to produce hatchery fish that are subject to the same selective pressures as their wild cousins, thereby minimizing genetic differences. Already, based on the last five years data, hatchery feeding rates/release timing have been adjusted to better produce smolts that more closely resemble their wild spawned cousins (one of the goals of the Stillaguamish Hatchery Genetic Management Plan). As is evidence by the 2008 data, however, there is still more work to do to match the timing and size of the wild Chinook. The Stillaguamish Tribal hatchery is on stream water that is significantly warmer than the water experienced by the wild Chinook in the upriver spawning gravels. Since water temperature regulates growth rates, we have found it difficult to match the wild fishes' size without starving the hatchery fish. In addition, the hatchery Chinook have to be a certain size before they can be coded wire tagged and adipose clipped. This means that the earliest the hatchery fish are ready for release is usually early/mid-April, approximately one month after the wild fish have already begun their seaward migration. We are investigating the feasibility of chilling the hatchery water supply to more closely match the rearing environment experience in the wild.

In order to make inferences about migration timing and to estimate daily and total migration, the efficiency of the trap has to be estimated over a range of flows and environmental conditions. Efficiency is the key variable that allows for catch expansion and production estimation. As is evidenced by the last six years of capture efficiency trials, trap efficiency is not a constant; it varies with respect to flow, turbidity, and perhaps most importantly, visibility. Since the smolt trapping program's inception, variation in capture efficiency has been best explained by the visibility at the trapping site (Figure 5; Griffith et al. 2001, 2003, 2005). Visibility likely influences the ability of the fish to avoid the trap but perhaps also the depth at which the fish migrate. The cone of the trap only strains the top 1.25 meters of the water column, while the river underneath is more than 4 meters deep, allowing ample room to migrate at a deeper depth then the trap can fish. The accuracy and precision of our yearly Chinook production estimate leans heavily on our ability to estimate the instantaneous efficiency of the trap. As is evidenced by the biased hatchery production estimate in 2008, the equations that estimate efficiencies are not perfect and have room for improvement. We will seek to refine these relationships in upcoming years. Aside from the challenges experienced during the 2008 season, the efficiencies measured (0.4 – 3.1%) are similar to those reported from other river systems (Conrad and MacKay 2000; Seiler et al. 2000).

On relatively clear river systems like the Skykomish and Skagit, there is evidence that daylight has a negative influence on migration or capture by rotary type screw traps. In these systems, catch rates are reported to decrease during daylight hours (Seiler et al. 2001, Nelson et al. 2003.). On more turbid systems such as the Nooksack, catch rates during the night and day are not significantly different (Conrad and MacKay 2000). During the 2008 season, as in the previous seven years, catch rates of wild Chinook did not vary significantly between "day" and "night" time periods (Figure 12). The Stillaguamish is so turbid during much of the migration period that, from a predation perspective, it may not matter if Chinook migrate during the day or night, but rather when the flows are most conducive for a rapid move down into the estuary. There were differences in catch rates of hatchery Chinook among the four shifts in 2008 (the first time this has been observed in the history of the project), however these differences disappear when outliers are removed from the analysis. Future years of trapping will continue to test for differences between time periods and analysis methods adjusted accordingly.

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Appendix A: Efficiency Trial Data 2002-2008

Trial	Date	Average		North Channel				South Channel			
		Secchi	Flow	Rel.	Rec.	Effic.	SE	Rel.	Rec.	Effic.	SE
1	4/22/2002	1.79	2280	1047	24	2.29%	0.46%	1024	20	1.95%	0.43%
2	5/1/2002	1.35	2560	1031	16	1.55%	0.38%	1014	27	2.66%	0.51%
3	5/16/2002	2.80	1719	1168	14	1.20%	0.39%	1188	20	1.68%	0.37%
1	3/26/2003	0.99	2365	4020	113	2.81%	0.26%	4202	116	2.76%	0.25%
2	4/23/2003	1.40	1661	4016	260	6.47%	0.39%	4071	188	4.62%	0.33%
3	5/7/2003	1.83	1100	4079	167	4.10%	0.31%	4122	171	4.15%	0.31%
4	5/28/2003	3.11	1364	4601	80	1.74%	0.19%	4615	97	2.10%	0.21%
5	6/11/2003	7.10	889	2631	1	0.04%	0.04%	2625	1	0.04%	0.04%
1	3/30/2004	1.08	3130	4194	60	1.43%	0.18%	4390	68	1.55%	0.19%
2	4/28/2004	2.86	1750	3062	80	2.61%	0.28%	3168	32	1.01%	0.18%
3	5/5/2004	1.61	1910	3127	137	4.38%	0.36%	3032	58	1.91%	0.25%
4	5/27/2004	0.40	2120	3314	425	12.82%	0.58%	3216	237	7.37%	0.46%
5	6/18/2004	2.54	1320	2542	14	0.55%	0.14%	2699	7	0.26%	0.10%
1	3/21/2005	0.90	2,260	-	-	-	-	2,706	29	1.07%	0.20%
2	4/19/2005	2.08	2,260	3,005	130	4.33%	0.37%	3,085	92	2.98%	0.31%
3	5/4/2005	3.62	1,200	3,000	4	0.13%	0.07%	3,293	2	0.06%	0.04%
4	5/11/2005	3.50	1,100	3,156	3	0.10%	0.05%	3,149	5	0.16%	0.07%
5	5/26/2005	4.69	1,100	2,000	1	0.05%	0.05%	1,981	1	0.05%	0.05%
1	3/30/2006	2.61	1554	3105	101	3.25%	0.32%	3102	54	1.74%	0.23%
2	4/17/2006	1.71	2077	3180	38	1.19%	0.19%	3224	16	0.50%	0.12%
3	5/4/2006	4.79	1595	3304	50	1.51%	0.21%	3020	21	0.70%	0.15%
4	5/22/2006	2.93	2270	3000	47	1.57%	0.23%	3001	12	0.40%	0.12%
1	4/19/2007	2.03	1778	3068	101	3.29%	0.32%	3128	102	3.26%	0.32%
2	4/30/2007	2.15	2078	3288	93	2.83%	0.29%	3426	64	1.87%	0.23%
3	5/14/2007	4.43	1573	3195	10	0.31%	0.10%	3019	18	0.60%	0.14%
4	6/4/2007	2.25	1943	2878	23	0.80%	0.17%	3100	18	0.58%	0.14%

1	4/24/2008	2.17	1925	3319	103	3.10%	0.30%	3185	15	0.47%	0.12%
2	6/2/2008	2.63	2760	3068	19	0.62%	0.14%	3008	18	0.60%	0.14%
3	6/19/2008	4.20	2135	3107	14	0.45%	0.12%	3071	12	0.39%	0.11%