An analysis of 2003 smolt trap data from the Hovander smolt trap

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Executive Summary

Season-wide estimates of age zero Chinook smolts outmigrating from the Nooksack River were made using three methods of interpreting smolt trap data. The Ad-Clipped Recapture Ratio Method (ACRM) provided an estimate of 1,262,272 Chinook smolts outmigrating past the trap in 2003. The Year-Specific Constant Catch Efficiency method (YCCE) used a catch efficiency rating of 3.21% at estimated the season-wide production of Chinook smolts to be **1,498,710**. The Average Constant Catch Efficiency method (ACCE) used a constant catch efficiency rate of 3.42% to estimate that total production of age-zero Chinook smolts was 1,407,079. The Secchi Depth-Catch Efficiency method (SCE) predicted a total production of 1,868,072 Chinook smolts using secchi-depth related daily catch efficiencies. Of these four alternative analyses, the YCCE method is probably most robust, and the SCE method is probably the least dependable.

A total of 778,400 hatchery-produced Chinook smolts were released in 2003, but experience elsewhere, and trap data from previous years, suggests that some mortality occurs between the release site and the trap site. Modeling work on marked hatchery fish released in 2001, 2002, 2003, suggests that mortality amongst the hatchery fish might have reduced the number of hatchery-origin smolts reaching the trap site to 700,977 smolts. This means that the remaining 797,733 smolts were wild-origin.

Examination of historical data indicates that there may be a relationship between Fall-Winter river flows and wild-origin Chinook production in the following year; presumably due to redd scouring at high flows. Similarly, there may be a negative relationship between the arrival of adult Pink salmon and Chinook production the following year that may reflect redd superimposition behavior.

Residence time modeling suggests that the length of time taken for hatchery Chinook to reach the trap site is a function of release timing during the season. Average residence times vary between 6 and 37 days, depending on what date they are released. For the three groups of marked hatchery smolts released in 2003, the shortest average residence time was 8.4 days, and the longest was 20 days.

The ACRM method estimated total Coho yearling production to be **1,988,042** smolts, while the YCCE method, using a catch efficiency of 1.203% for yearling Coho smolts, estimated that 2,046,765 yearling smolts were produced. No secchi-depth – catch efficiency calibrations have been conducted for yearling Coho that would allow us to apply the SCE method to the data. A total of 1,403,100 hatchery-origin smolts were released in 2003. The YCCE method estimated that a total of 1,370,403 hatchery-origin and 676,361 wild-origin smolts outmigrated past the trap site in 2003. However, attempts to use the YCCE method on Coho data from earlier years did not work, and overestimated the known hatchery component in 2000, 2001, and 2002. Consequently, the ACRM method is the best method presently available for determining the total yearling Coho production.

Residence time modeling for yearling Coho suggested that hatchery Coho take between 2.4 and 2.9 days on average to reach the trap site from their release point.

Introduction

Lummi Natural Resources operates a rotary screw smolt trap on the Nooksack River in the lower mainstem, near Ferndale. The goals of the sampling program are to develop accurate estimates of the annual production of outmigrating wild-origin salmon fry and smolts. The emphasis of the program is to quantify wild Chinook production for the endangered North Fork stock but secondary objectives include stock assessment for other native salmonids such as Coho.

In 2003 the screwtrap was operated from January 7 through to August 16, although sampling intensity was highest from early March through to mid-July (Fig. 1).

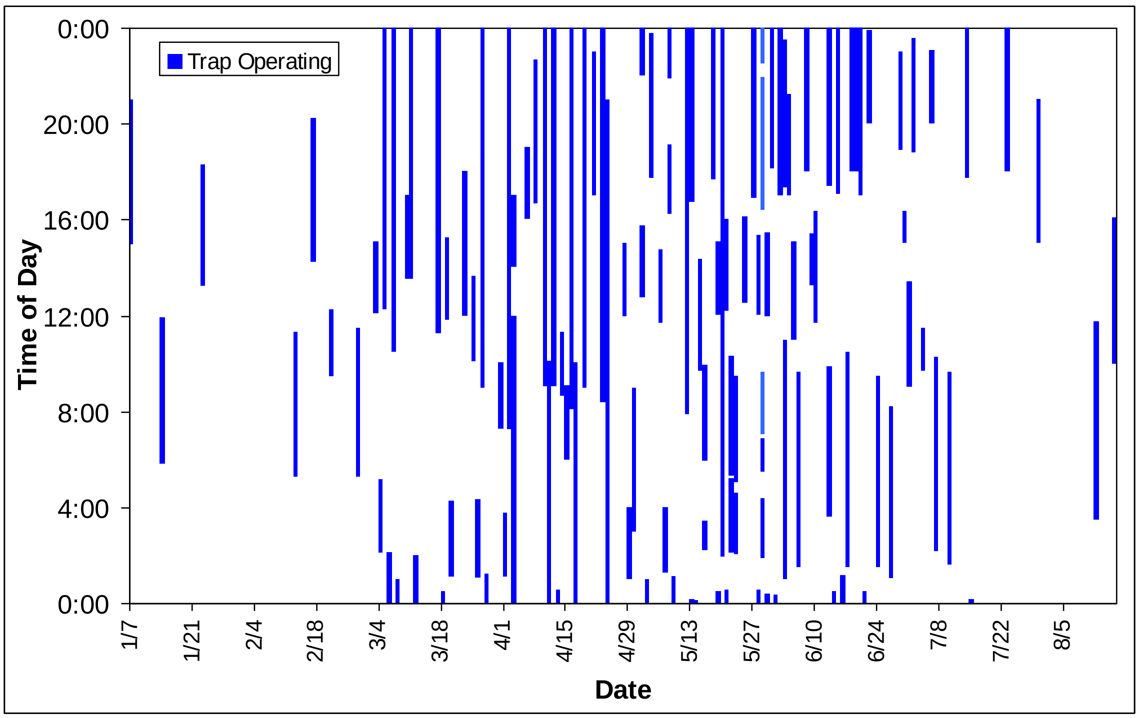

Figure 1. Daily sampling effort on the Lummi smolt trap in 2003.

This report aims to report the results of the sampling program in 2003, summarize the principle findings, and compare the results to previous data (where available) for Chinook fry (age 0+) and Coho smolts (age 1+). No analysis of the data for Chum or Pink salmon has been made to date.

Field Methods

The full methodology for the operation of the smolt trap is not given here but interested readers are referred to Conrad & MacKay (2000) for a full description of the site, sampling apparatus, and field protocols. A summary of the field data for each set and subset is provided in Appendix A.

Chinook

Results

Figure 2 shows the average daily catch per hour for age zero Chinook smolts based on trap data and linear interpolation between sample measurements. Table I outlines the timing, magnitude, and details of hatchery releases in 2003.

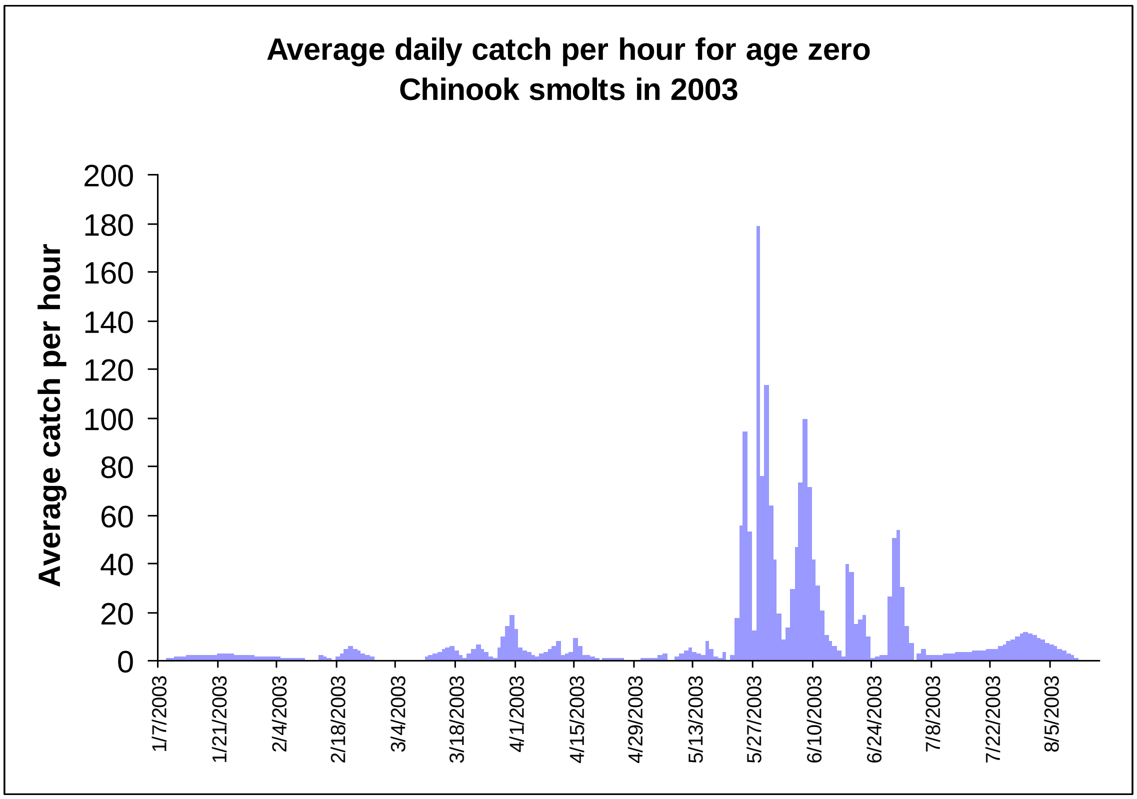

Figure 2. Average daily catch per hour for age-zero Chinook smolts in 2003

Table I. *Details of Hatchery releases of age-zero Chinook Fry in 2003*

Release Date	Release Site	Total Otolith Mark	Total Adipose Clip	Total CWT	Total Release	Volitional Release?
4/14/2003	**Kendall Creek**	51,300	0	0	51,300	No
4/30/2003	**Kendall Creek**	52,400	0	0	52,400	No
05/9-05/12	**DeadHorse Creek**	100,000	0	98,800	100,000	Yes
05/9-05/12	**DeadHorse Creek**	99,700	99,700	99,204	99,700	Yes
5/7/2003	**Middle Fork**	197,500	0	0	197,500	No
05/16-05/19	**DeadHorse Creek**	52,600	52,600	52,339	52,600	Yes
05/16-05/19	**DeadHorse Creek**	52,400	0	51,771	52,400	Yes
05/23-05/27	**DeadHorse Creek**	58,400	0	57,699	58,400	Yes
05/23-05/27	**DeadHorse Creek**	59,100	59,100	58,806	59,100	Yes
5/27/2003	**Kendall Creek**	55,000	0	0	55,000	No
Totals		778,400	211,400	418,619	778,400	

Chinook Production Estimates

Method 1. *Ad-Clipped Hatchery smolts recapture ratio method (ACRM)*

Traditional mark-recapture models use the ratio of marked individuals in the total catch, along with the original number of marked individuals that were released, to provide an estimate of how many individuals are represented by the catch. Several models have been developed for a range of scenarios where multiple releases of marked individuals and multiple catches are made. However, the simple Peterson estimate (single release, single recapture) is most appropriate in this case because outmigrating smolts are assumed to be catchable only once as they move out of the river. Assumptions made when making Peterson mark recapture estimates include the following:

1. The population under study should be both *geographically closed* and *demographically closed*.
2. Each member of the population has the same probability of being captured, and this capture probability does not change over time.
3. Marked and unmarked individuals randomly mix between samples.
4. Marks are permanent and always recognizable.

The formula used in the Peterson mark-recapture method is shown in 1 below:

$$\hat{N}_P = \frac{N_2 N_1}{M_2} \tag{1}$$

Where N_1 = the number of marked smolts released, N_2 is the total number of smolts caught during sampling, M_2 is the number of marked smolts caught at the trap during sampling, and N_P is the estimated size of the total population.

95% confidence intervals for N_P can be calculated using a variety of probability distributions. However, when the percent of marked individuals (M_2/N_1) is less than 10%, and the number of recaptures, M_2, is greater than or equal to 50, a confidence interval based on the Normal distribution is the most appropriate method. Consequently, confidence intervals for the ACRM method are calculated using equation 2:

$$N_P \pm 1.96 * \sqrt{Var(N)} \qquad (2)$$

…where N_P is the population estimate, and the variance of N_P is determined using equation 3.

$$Var(N_P) = \frac{(N_1+1)(N_2+1)(N_1-M_2)(N_2-M_2)}{(M_2+1)^2(M_2+2)} \qquad (3)$$

Table II shows the total number of hatchery Chinook that had their adipose fins clipped and were released, as well as the number of adipose fin clipped smolts that were recaptured, and the total number of Chinook smolts captured in the same sampling program. Hatchery-origin fish with coded wire tags are not similarly used to estimate recapture rates because of the possibility that detection rates are lower than for adipose fin clipped, thereby artificially lowering the recapture ratio and biasing the final estimate too high.

Table II. Chinook clipped adipose fin smolts recapture rate details for 2003.

	2003	
Number of Adipose fin-clipped smolts released	211,400	N_1
Number of Adipose fin-clipped smolts recaptured	1,311	M_2
Marked Smolt Recapture Ratio	0.62%	
Total number of smolts caught	7,828	N_2
Estimated Total production of Chinook smolts in 2003	**1,262,272**	N_P
Upper 95% Confidence Limit	1,324,334	
Lower 95% Confidence Limit	1,200,211	

Method 2. ***Summed daily production estimates – Secchi-depth catch efficiency method (SCE)***

Previously, daily production estimates were based on estimating catch per hour for days that were sampled, multiplied by 24 hours, and then divided by a secchi-depth related catch efficiency (determined earlier by a series of independent calibration experiments) to arrive at a figure for the total number of smolts migrating downstream past the trap site. Previous results determined using this method have proved to be unsatisfactory, and typically result in estimates that are unrealistically large. In an effort to further refine the data underpinning this method two major modifications were employed this year.

The first of these was to deliberately sample in shorter blocks of approximately 2 hours duration. These blocks were randomly determined within daytime periods, nighttime periods, or dawn and dusk twilight periods. This was done to better understand diurnal catchability patterns for Chinook and Coho in the Nooksack river with the hope that this would better explain high catch per hour data and allow for more representative 'daily average catch per hour' values to be used.

Secondly, previous calibration data used highly stressed hatchery fish released only a mile or so above the trap site and oftentimes the resulting catch efficiencies were considerably lower than 1%. Recapture rates of groups of marked hatchery smolts are typically considerably higher than this (when adjusted for hours sampled), which suggests that the fish used in the calibrations behave differently than hatchery fish that have been resident in the river for a few days. Consequently, new calibration experiments were undertaken that were identical to previous experiments except that experimental fish were held in a net pen in the river for several hours prior to release. Moreover, because we wished to apply the most relevant catch efficiency relationship possible to the differentiated day and night samples, the calibration experiments consisted of a daytime recapture rate (for smolts released just after dawn) and a nighttime recapture rate for smolts released after dusk. A single data point from a 2002 calibration experiment was also included to add to the data set at the low end of the secchi depths observed. This data point also used 'de-stressed' fish and was conducted during daylight hours.

Results from these calibration experiments are shown in Figure 3. Although more data are needed, there appears to be no clear relationship between catch-efficiency and secchi-depth at night. Moreover, the daytime relationship requires further exploration since it suggests that catch efficiencies are increased at very low turbidity and high visibility, but is considerably lower at intermediate turbidities.

Catch efficiencies for nighttime, dawn, and dusk samples were fitted to a linear trendline with the equation CE (catch efficiency) = -0.0021*S.D. (secchi depth) + 0.0355. Similarly, daytime samples used a stepwise relationship where catch efficiencies for secchi depths lower than 0.89 were capped at 4.38%. Secchi depths over 3.5 resulted in catch efficiencies of 5.38%. Catch efficiencies for secchi depths between 0.89 and 3.5 feet were calculated using the following polynomial trendline (Fig. 3):

$$CE = 0.0184*S.D.^4 - 0.164*S.D.^3 + 0.5331*S.D.^2 - 0.7461*S.D. + 0.3909$$

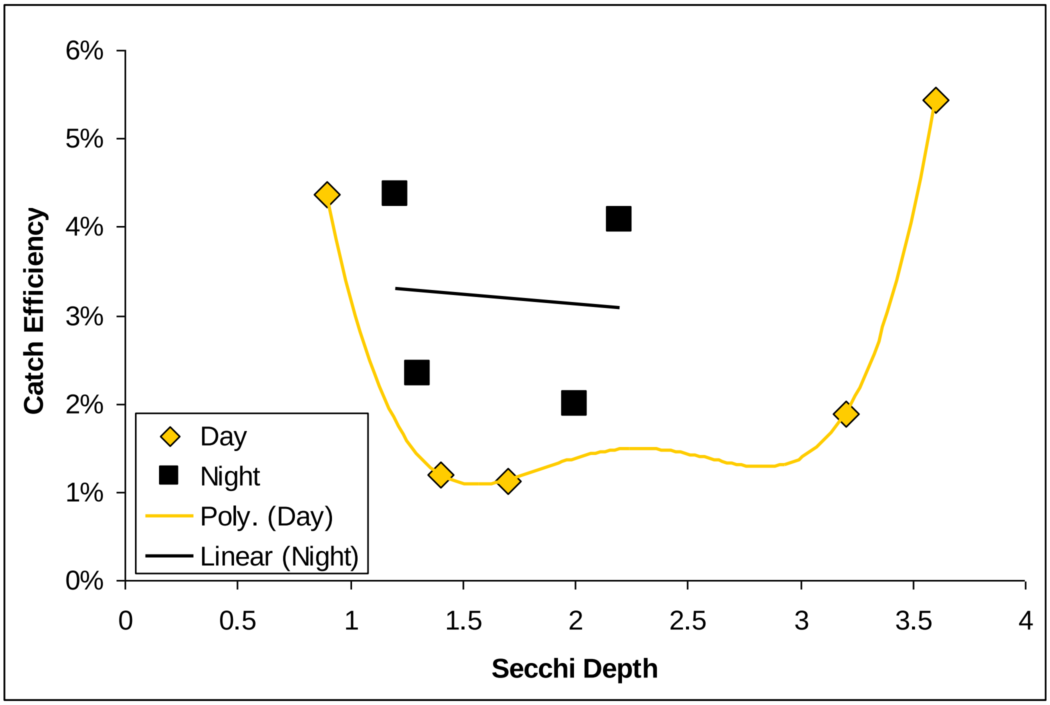

Figure 3. Secchi-depth versus trap catch efficiencies for 'de-stressed' hatchery smolts released 1 mile above the trap site.

The resulting catch efficiencies tended to be higher than many of the values obtained with 'stressed' hatchery fish but still underestimated the average catch efficiency of the trap during the period when marked hatchery fish were in the river (Average of 3% between May 15 and July 1 compared to the estimated average catch efficiency of 3.7% for fully acclimated, marked hatchery smolts caught during the same time period).

Each calendar date was split into 4 time periods: dawn, day, dusk, and night. Dawn and Dusk periods were each 2 hours in length and occur immediately following the morning civil twilight and before the evening civil twilight respectively. Photoperiods for each calendar date were then calculated and 2 hours subtracted to determine the day length in hours (1 hour each were subtracted from day to allow for half of the dawn and dusk times). Similarly, the length of each night was determined as 24 hours minus the day length and the dawn and dusk time period.

Because all four time-periods were not sampled each day, it was first necessary to attempt to extrapolate from one or more of the time periods that were sampled on that day. For example, if day samples and night samples were taken on a given day, it was necessary to predict catch per hour values for dawn and dusk based on the available day and night data. To do this, paired samples from each time were correlated against the other times. Sampling times that gave the highest correlation coefficient were preferentially used to predict values for missing data. That is, if nighttime were a better predictor of dusk values than daytime, then nighttime samples would be preferentially used to estimate dusk values where possible. If a nighttime sample were not available, then the next best predictor would be used in preference to the worst predictor. In some cases, only one time period was sampled on a calendar data and this would necessarily be used to calculate values for the remaining time periods.

Once catch-per-hour values for all four time periods in each sampled day were determined, the catch-per-hour values for non-sampled days were calculated using linear interpolation for each time period. That is, dawn catch per hour data was used to interpolate dawn values for non-sampled days, day data used to interpolate day values etc.

A similar process was undertaken to provide a complete matrix of secchi-depth values for each time period on each day.

Finally, the number of smolts produced for each time period was determined by multiplying the catch per hour for each time period (i.e., dawn, day, dusk, night), multiplying it by the length of time of that time period, and dividing it by the estimated catch efficiency for that time period (based on the secchi depth value). The daily production was the sum of the four time periods on each calendar date.

Figure 4 summarizes the results of this analysis. Overall, the summed daily production estimates that a total of **2,122,182** Chinook smolts migrated past the trap site in 2003.

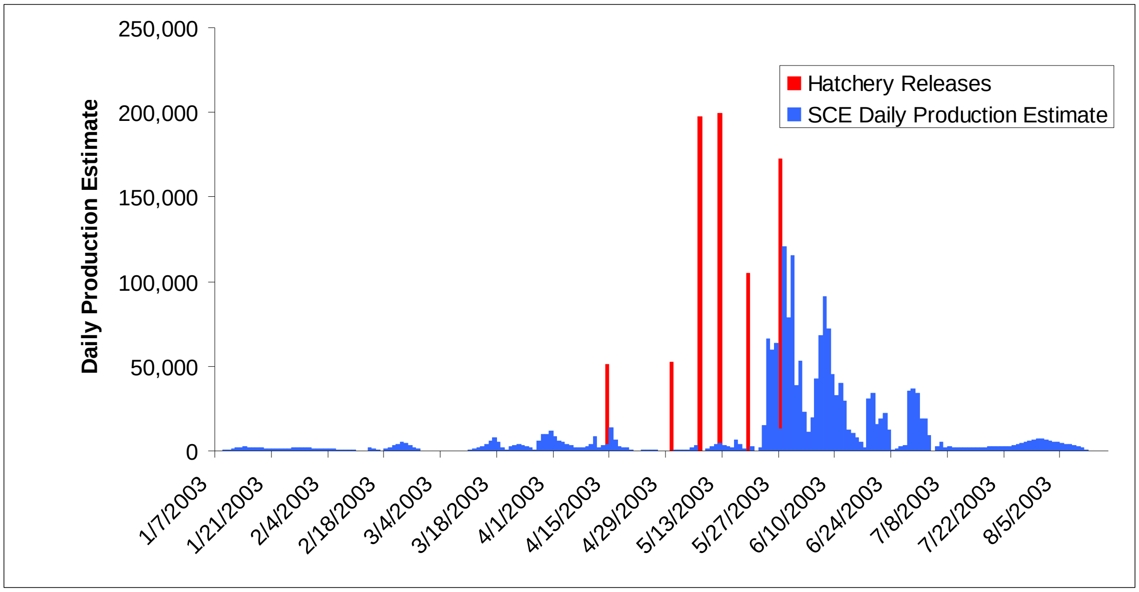

Figure 4. SCE Daily Production Estimates for age-zero Chinook smolts

Method 3. ***Summed Daily Production Estimates – Year-Specific Constant Catch Efficiency method (YCCE)***

Ideally, determining trap efficiency involves measuring it directly for one group of representative smolts, and then applying this rate to all smolts that are outmigrating at the same time. Unfortunately, it is nearly impossible to do this directly and so we are forced to use alternative means.

One indirect measure of trap efficiency can be obtained using the proportion of marked hatchery Chinook that are recaptured during sampling. This proportion is a function of trap catch efficiencies that vary from day-to-day, sample timing, and overall hours fished. We wish to isolate catch efficiency from sample timing and amount of effort. Because we cannot measure actual numbers of fish moving past the trap site we cannot measure catch efficiencies on a day-to-day basis, so the best we can hope to do is to estimate an 'average' catch efficiency for the whole season. We know that if the trap were not operated at all (effort = zero hours) then no fish would have been recaptured. We also know that we caught a certain proportion of the fish after sampling a particular proportion of the total time possible (spread throughout the season). Assuming that fish recapture is linearly related to hours of effort, then the slope of the line joining these two points is the average trap catch efficiency during that sampling season. Clearly, this extrapolation will be most convincing when the actual sample effort is a large proportion of the overall time.

If we assume that conditions/trap efficiencies during the outmigration period of the marked fish are also representative of the remainder of the outmigration season, then the estimate of average trap catch efficiency for marked hatchery fish can be extrapolated to unmarked hatchery fish, and possibly wild-origin smolts also.

Given that marked hatchery smolts spend several days in the river prior to reaching the trap, it is more likely that their behavior is similar to wild-origin fish compared to newly released hatchery fish that have been used in the secchi-catch efficiency calibration experiments. Consequently, catch efficiencies calculated from these fish are probably more similar to the unknown catch efficiencies of wild-origin fish.

Figure 4 shows the relationship between the recapture rate of marked hatchery smolts, and the proportion of time between May 15 and July 1 sampled for the past five years. A similar value is also shown based on an identical screwtrap operating in the larger Skagit River mainstem. Based on the larger volume of water in the Skagit you would expect that the Skagit trap would have a lower catch efficiency rate. Overall, 1999, 2002, and 2003 show highly similar average catch efficiencies (~3 - 3.2%), whereas recapture rates in 2001 were below expectations (1.73%) while 2000 showed a much higher recapture rate (7.3%). Flows in 2001 were quite low, possibly explaining the reduced catch efficiency, but no such explanation is known for the 2000 data when river flows and secchi depth were moderate.

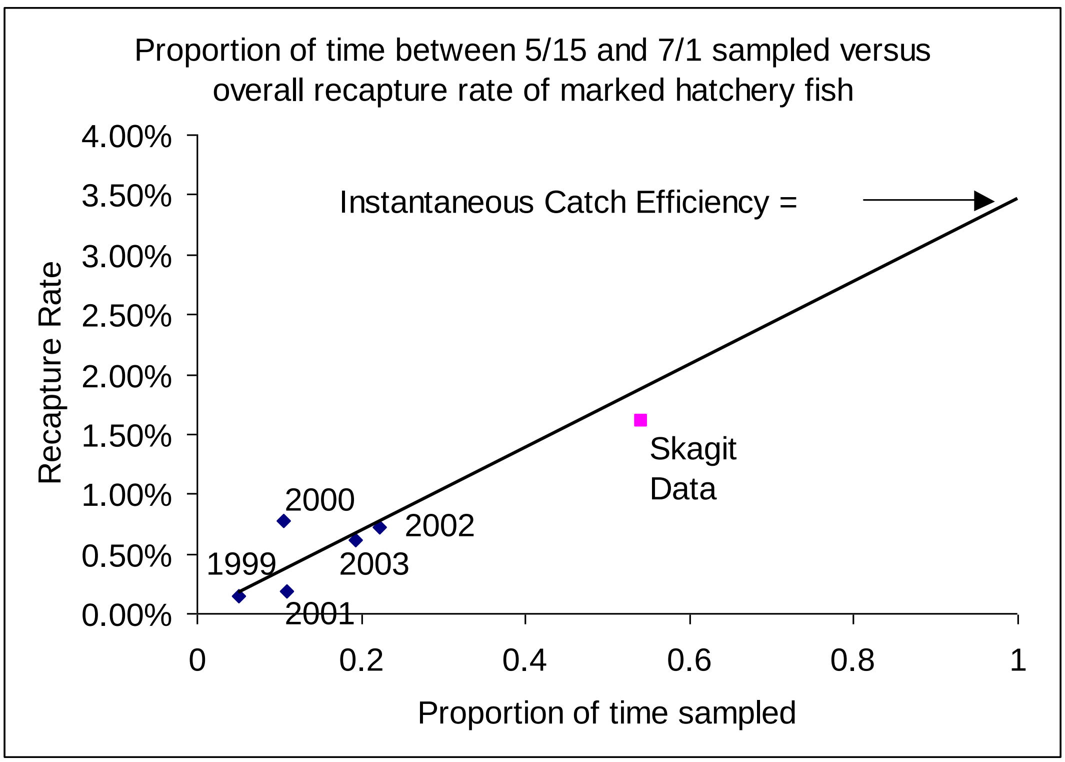

Figure 5. Season wide recapture rates of marked hatchery Chinook smolts versus the proportion of time sampled between May 15 and July 1.

Based on the 2003 season catch efficiency of 3.21%, daily production estimates were derived using the interpolated daily catch-per-hour data shown in Fig. 2. The results of this analysis are shown in Figure 6. Based on this, the total number of age zero Chinook smolts outmigrating past the trap-site was estimated to be **1,498,710** smolts.

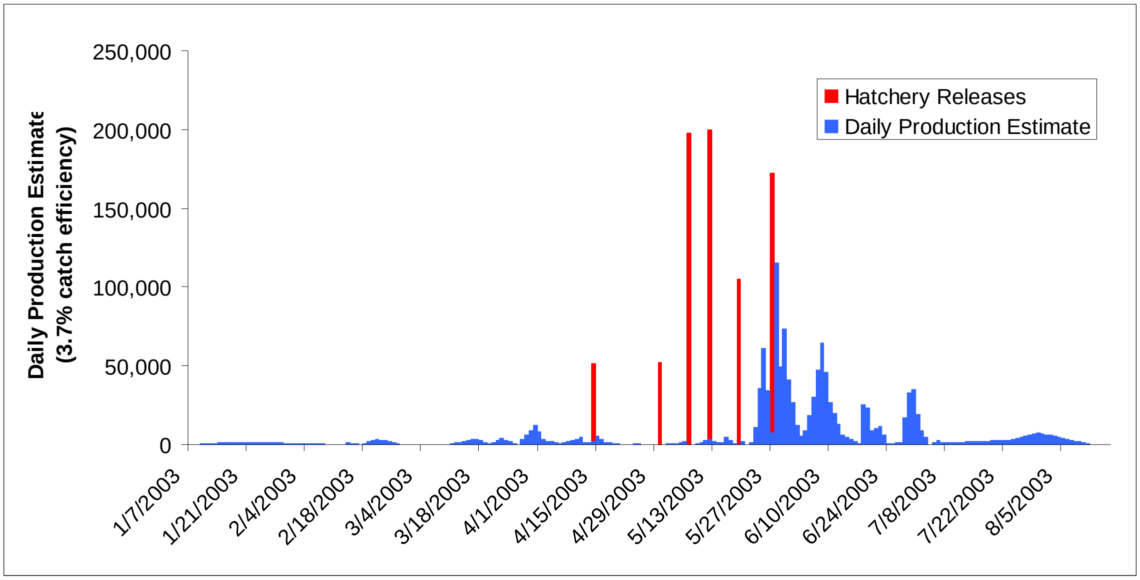

Figure 6. YCCE Daily Production Estimates for age-zero Chinook smolts

Method 4. *Summed Daily Production Estimates – Average Constant Catch Efficiency method (ACCE)*

This method is identical to the year-specific constant catch efficiency method except that, instead of using different constant catch efficiencies for each outmigration season, the long-term average catch efficiency across all seasons is used. This long-term average catch efficiency is represented as the slope of the trendline shown in Figure 5. Overall, the average catch efficiency for the Nooksack screw trap is estimated to be 3.42% based on the past 5-year's data.

The results of this method for 2003 suggest that the total production of age-zero Chinook smolts was 1,407,079 smolts. The overall pattern of outmigration is proportional to that shown in Figure 6.

The results from each of the four methods from 1999 – 2003 are each presented in Figure 7 and compared to the known hatchery releases in each year.

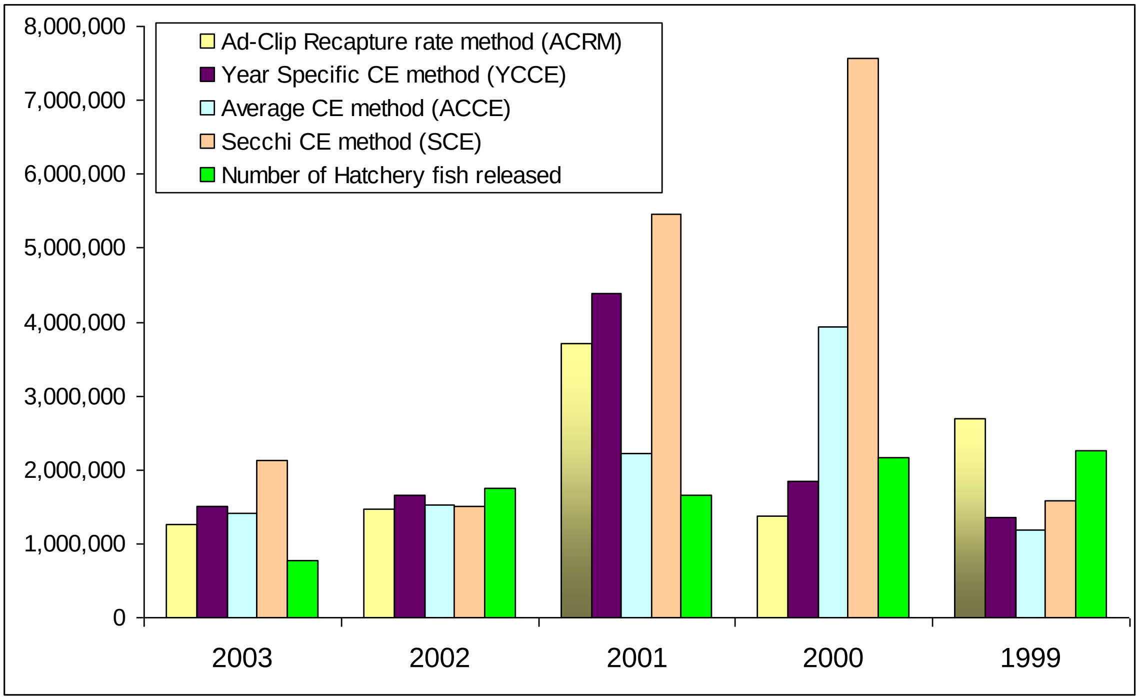

Figure 7. Four alternative production estimates for age zero Chinook smolts outmigrating from the Nooksack River from 1999 – 2003, compared with the number of hatchery-origin smolts released in each year. Shading of the two ACRM bars in 2001 and 1999 indicates that many fewer marked hatchery smolts were caught, and the ACRM estimate might be more prone to large error because of the increased scaling factors.

Marked Hatchery Chinook Residence Time Modeling

One of the concerns associated with a hatchery program releasing smolts into the upper watershed of a river system is whether the presence of hatchery fish might have adverse impacts on wild-origin Chinook smolts. Such impacts could, hypothetically, come about through predation (i.e., large hatchery smolts eating small wild-origin smolts), competition for food (e.g., aquatic stages of stream insects, drift of aerial insects, etc), competition for space (e.g., prime holding habitat, flood refugia, etc), and possibly transmission of diseases from hatchery-origin smolts to wild smolts. To evaluate the likelihood of predatory and competitive interactions, as well as the potential for disease transmission, it is necessary to understand the behavior of hatchery smolts after their release. Logically, there is less opportunity for competitive/predatory interactions if hatchery smolts head downstream until they reach the estuary immediately upon release. Conversely, if hatchery-origin smolts prefer to spend long periods of time in the upper watershed they will have to eat suitable food and spend time in suitable micro-habitats that afford predator protection, foraging opportunities, and refuge from flood water velocities. Obviously this strategy increases the potential for interaction between hatchery and wild-origin smolts.

It is not possible to directly observe the behavior of individual hatchery smolts after release because radio/acoustic tagging is not presently possible with Chinook smolts that are in the size range being released. However, a small proportion of the hatchery smolts are marked in one of two ways. Some hatchery smolts have a coded wire tag (CWT) inserted into their snout, some have their adipose fin clipped (this fin does not re-grow), and some have both CWT and the adipose clip. In theory, we know when and where the marked smolts are released, and we can identify marked smolts amongst the smolts caught in the trap. Essentially, we ought to be able to measure the length of time taken for the marked fish to leave their release site and reach the trap (i.e., the residence time). This information should provide an indication of hatchery fish residence times in general if you assume that marked hatchery fish behave in the same way as unmarked hatchery fish.

Unfortunately, this is not as simple in practice as in theory. This is due to a number of reasons. Firstly, we are not intercepting all marked fish that are going down the river but instead are catching an unknown proportion on a daily basis. This can be resolved by making assumptions about the catch efficiency of the trap from day-to-day. Secondly, the timing of hatchery smolt release is sometimes complicated by an extended volitional release strategy. This is where the smolts are kept in a holding pond and an opening is made between the pond and the river itself, and the smolts allowed to emerge from the pond at their leisure. At some point, the last fish are eventually driven from the pond in some way. Sometimes the volitional release period may last as long as a week. This could be accounted for by counting smolts as they leave the pond but, unfortunately, no such counts are made. In this case, it is necessary to make another assumption regarding the rate of smolt departure from the holding ponds. A third problem arises when more than one group of marked smolts are released into the river at different times/locations. This is especially problematic when marked smolts from one group are still arriving at the screw trap when another marked group is released somewhere upstream. Once you have two groups of identically marked smolts in the river above the trap it is impossible to know whether a marked fish arriving at the trap has been in the river for a short time (second release group) or a long time (first release group). Consequently, it becomes necessary to make assumptions about the proportion of marked fish that belong to each of the two (or more) groups of marked smolts. The fourth and final problem arises when the summed daily production estimates for marked hatchery smolts do not tally with the number of marked smolts released. In all but one case, these discrepancies suggest that fewer marked fish are moving downstream past the trap site than were originally released. This problem can be overcome by assuming that a number of marked hatchery fish die (or else decide to outmigrate as yearlings the following year). Skalski (1998) suggested that survival of marked hatchery smolts in the Snake River remained relatively constant throughout the outmigration period. Consequently, a constant daily survival rate may be a reasonable solution, although it is likely that survival would also depend on fluctuations in the environmental conditions experienced by the smolts.

In 2003 three groups of marked Chinook smolts from Kendall Hatchery were released into the upper Nooksack watershed at Deadhorse Creek (Table I). The first group (99,700 smolts) was volitionally released between May 9 and May 12. The second group (52,600 smolts) was volitionally released between May 16 and May 19. The last group (59,100 smolts) was volitionally released between May 23 and May 27. The first marked smolts (n=3) were caught at the screw trap on the night of May 12 (see Appendix A). No marked smolts were caught during the daytime set on May 12. I am assuming that these represent the first smolts reaching the trap site, but the trap was not operated on May 9th, 10th, or 11th, so it is possible that some earlier outmigrants may have gone past the trap prior to May 12. The last marked smolts (n=2) were caught at the trap site on July 7. Assuming that these represent the last outmigrating marked smolts, this suggests that the minimum residence time is between 0 and 3 days) and the maximum residence time observed may be as high as 44-60 days (depending on which group these last 2 fish originally came from).

To estimate the average residence time for hatchery fish it is necessary to model the three groups individually and make some assumptions regarding their actual release times, daily mortality rate, and what proportion of the fish from mixed groups arriving at the trap belong to each group.

Critical assumptions used in residence time models

1. All smolts waited until the last day of their volitional release period before entering the river itself. This may result in underestimating the actual residence times if smolts immediately entered the river at the first opportunity.
2. Daily survival/mortality is fixed and constant throughout the season. This is a variable that can be manipulated until model output matches daily production estimates for marked hatchery smolts.
3. The number of fish from one group in the screw trap catch is assumed to be directly proportional to the percentage of the total marked fish population made up by that group at the start of the day. That is, if 30% of all marked fish upstream from the trap belong to ‘Group 1’, then 30% of the fish caught in the trap that day are assumed to be from ‘Group 1’. If this number exceeds the total number of smolts remaining in that group, then the actual number remaining is used and the remainders of the captured smolts are split proportionally amongst any remaining groups.
4. YCCE daily production estimates for marked smolts are representative of marked smolt outmigration timing.

In essence, the model works by establishing 6 columns for each group of marked hatchery fish that were released, with a separate column containing the YCCE daily production estimates for each calendar date (rows).

The first column for each group of smolts simply records the number of days since that group was released. For example, The first group of marked smolts that were released were considered to be caught 0 days after release if they were caught on May 12, 1 day after release if they were caught on May 13, and so on.

The second column records the number of fish in that group alive and upstream from the trap site at the beginning of the day. This value corresponds exactly to the number remaining alive in the river at the end of the previous day, except for day 0 when this is the number of smolts released (another column elsewhere in the spreadsheet).

The third column indicates how many of those smolts will die that day. This is simply the number of smolts alive at the start of the day, multiplied by a constant mortality rate.

The fourth column is the estimated number of marked smolts *from that group* that outmigrate past the trap site during that day. This is a function of the total daily production estimate for that day, multiplied by the proportion of all marked fish, that are alive and upstream of the trap, that belong to that group at the start of that day (calculated in column 6).

The fifth column is the number of fish remaining alive and upstream from the trap site at the end of the day (= number alive at start of day, minus the number dying, minus the number outmigrating.)

The last column calculates what proportion of all marked fish in the river above the trap site, at the beginning of each day, that group of fish represents.

The sum of each groups outmigrant column must equal the YCCE daily production estimate for marked smolts. The only variable that can be altered is the daily mortality rate. An iterative process varies the mortality rate until the model output exactly matches the YCCE daily production estimate.

Now we have an approximation of the daily outmigration and mortalities for each group of marked fish. The average residence time is calculated by multiplying the combined mortalities and outmigrants for each day, by the number of days that have passed since release (the first column for each group). These values are summed for each group and then divided by the number of smolts in that group that were originally released.

Overall group survival (to the trap site) can also be estimated by summing the total number of modeled outmigrants for that group and dividing this by the number of smolts that were originally released.

A summary of the table showing the final model for marked hatchery smolts in 2003 is presented in Appendix B. The results for 2003 are shown in Figure 8.

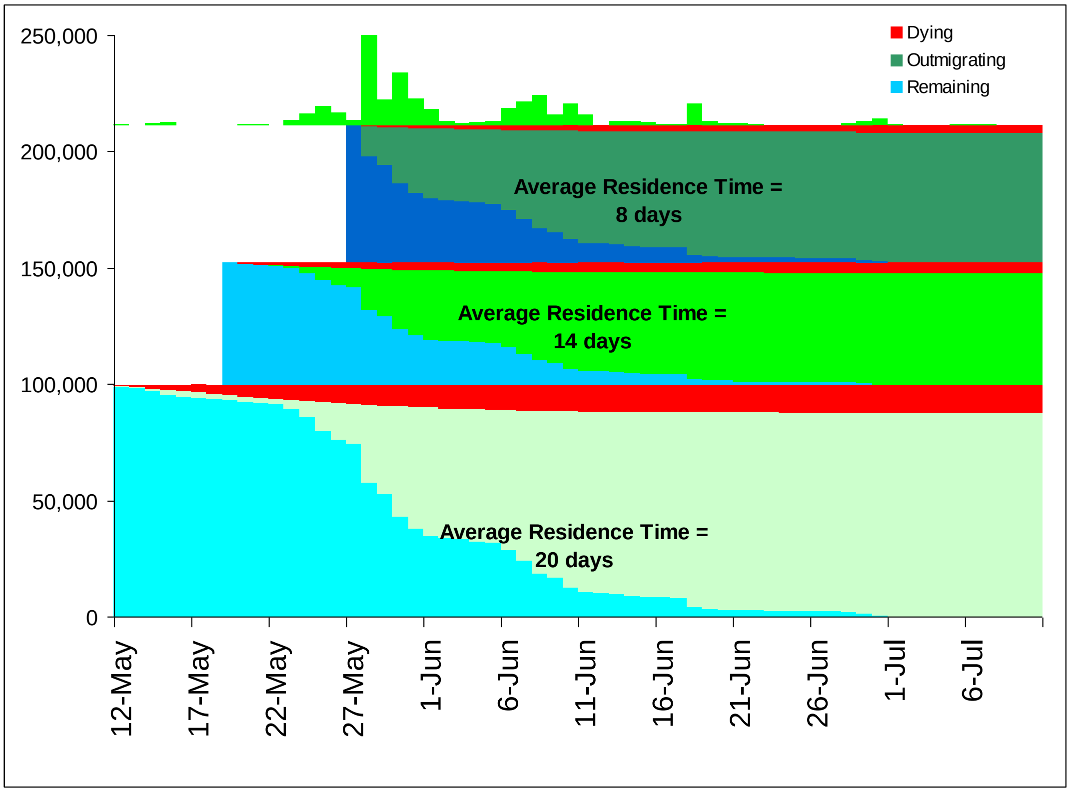

Figure 8. Model output showing cumulative outmigration, mortality, and YCCE daily production estimates (lime green bars at top of chart) for three groups of marked hatchery-origin Chinook smolts in 2003.

Similar modeling was also conducted using historical data for 2002, 2001, and 1999. Modeling could not be conducted for 2000 data because YCCE production estimates for marked fish in 2000 was nearly double that of the number of marked fish that were released. The reason for this discrepancy is not known at this time, but one potential explanation could be that hatchery records may be erroneous for that year. The results of the model for 1999 differ markedly from those of 2001 – 2003 but this may be a result of the poor sampling effort in 1999, which is discussed further in the section comparing the three methods of determining production estimates.

Two groups of marked fish were released in 2002, and one group only was released in 2001. Model results for 2002 and 2001 are shown in Figures 9 and 10 respectively.

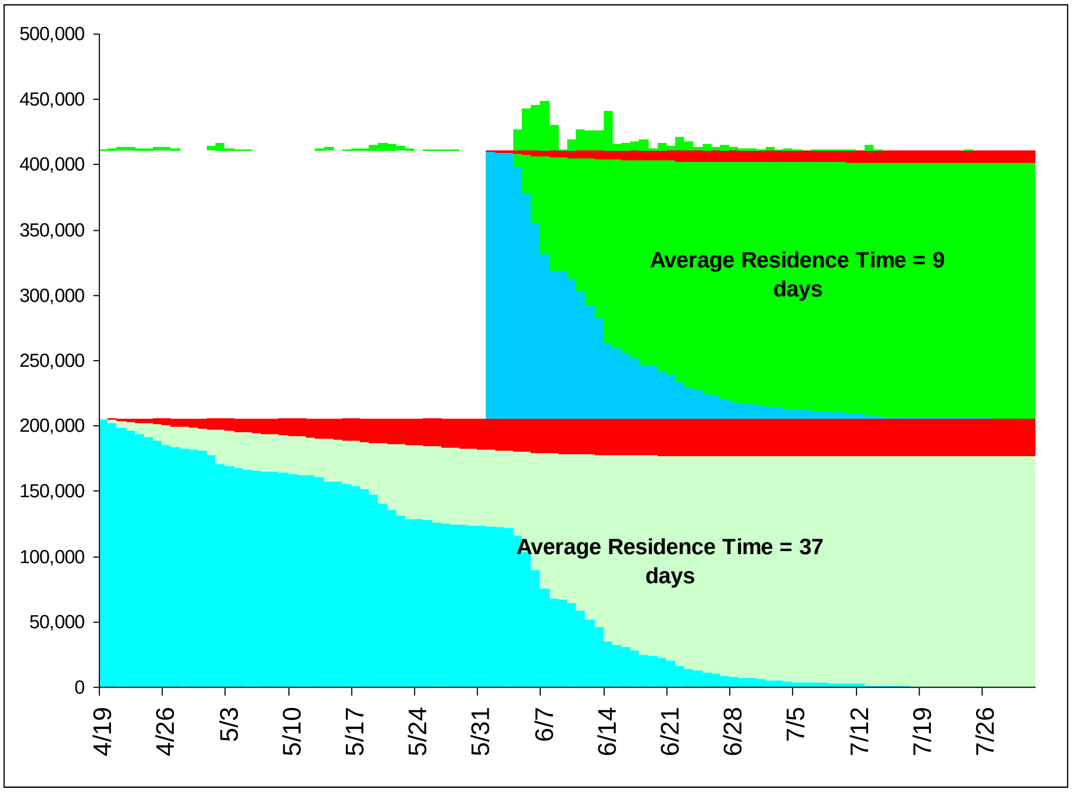

Figure 9. Model output showing cumulative outmigration, mortality, and YCCE daily production estimates (lime green bars at top of chart) for two groups of marked hatchery-origin Chinook smolts in 2002.

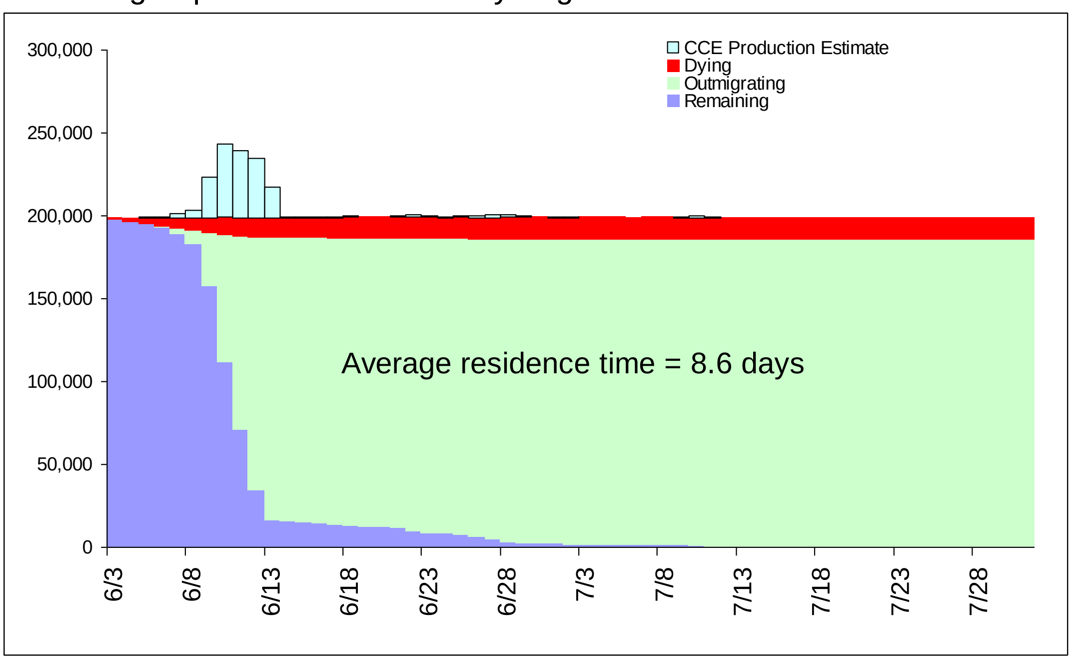

Figure 10. Model output showing cumulative outmigration, mortality, and YCCE daily production estimates (light blue bars at top of chart) for one group of marked hatchery-origin Chinook smolts in 2001.

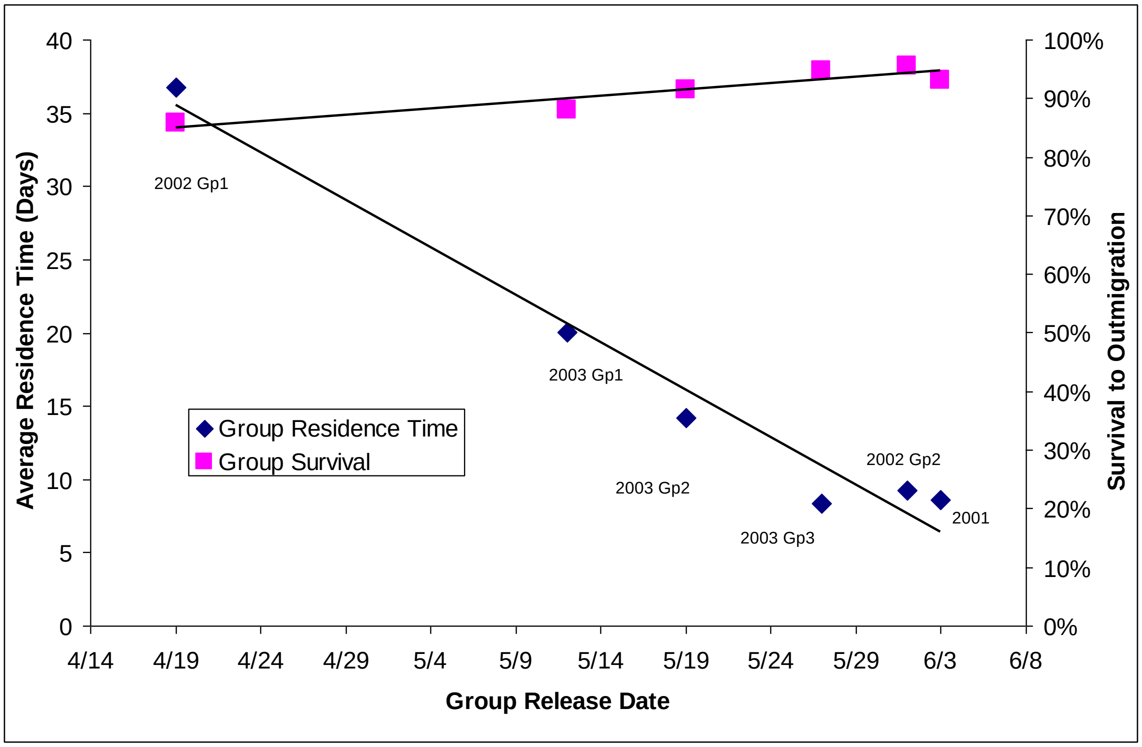

Figure 11. Modeled average residence time and group survival versus group release date for groups of marked hatchery Chinook smolts released in 2001, 2002, and 2003.

Figure 11 shows the group residence times and survival rate versus the release date based on the data shown in figures 7 – 9. Clearly there appears to be a relationship between the timing of release and the length of time that hatchery-origin smolts take to reach the trap site after release. This also appears to affect the number of marked fish surviving to reach the trap site. Unfortunately, multiple groups being released into the river at different times confound the data from 2002 and 2003.

If you were to assume that all fish caught in the trap were from the first group released, regardless of other groups being introduced before the first group had cleared, then the average residence time for the first group would be shortened, but the average residence time for subsequent groups would increase commensurately. However, this would be an unlikely scenario because fish from the second or third groups would probably not delay their outmigration solely because of the lingering presence of some fish from the first group.

Modeling hatchery introductions in 2003 using parameters developed in the 2003 residence time model

Ultimately we are interested in estimating what the annual production of Spring Chinook smolts is from the Nooksack River. Unfortunately, we currently have no direct means of counting these, as they are indistinguishable from wild-origin Fall Chinook and unmarked hatchery-origin Chinook in screw trap operations. Consequently, we need to devise some means of indirectly separating wild-origin from hatchery-origin smolts, and then further subdividing the wild-origin component into the Spring and Fall stocks. At the present time there is no way to separate wild-origin Spring smolts, unmarked hatchery-origin Spring smolts, and wild-origin Fall smolts from each other, save by comprehensive DNA analysis (to ascertain stock) and Otolith examination (to determine wild or hatchery origin) for each unmarked Chinook smolt that is caught in the trap. Unfortunately, this kind of analysis would be prohibitively expensive.

An indirect means of separating hatchery-origin from wild-origin smolts can be made by and modeling the total Chinook smolt population to match two parameters. The first parameter is the YCCE daily production estimates for all Chinook smolts combined (measured from trap data). The second parameter is the estimated daily mortality rate of marked hatchery Chinook smolts that was derived in the residence time modeling section above. If we assume that the last Chinook smolt caught in the trap represents the last day of outmigration, then we assume that the number of smolts remaining alive upstream from the trap site is zero at the end of that last day. We have an estimate of how many fish outmigrated on the last day, and we know what the daily mortality rate is, so we can back-calculate the number of fish that must have been alive upstream of the trap that morning. The number alive at the start of the last day is also the number alive at the end of the penultimate day. In the same way as for the last day, we can then estimate how many must have been alive at the start of the penultimate day by factoring in that day's outmigrants and allowing for mortality once again. Essentially we can back calculate the entire outmigration season, remembering to deduct hatchery groups from the modeled starting population on the dates that they were released.

We know that all outmigrants prior to the first release of hatchery smolts are wild-origin. If we assume that the proportion of hatchery smolts in the trap catch is identical to the proportion of hatchery fish in the total pool of smolts alive and upstream of trap site, then we can split the hatchery-origin and wild-origin components out of the total daily production estimate based on the relative proportion of each group alive and upstream of the trap at the start of each day. Modeling hatchery fish separately from the main model can be done because we know their relative proportion in the main model's population and we know their daily mortality rate. Consequently, we can subtract the modeled daily production of hatchery-origin fish from the total production of all Chinook smolts combined, to finally arrive at a modeled daily production estimate for wild-origin smolt throughout the season.

Once again there are some critical assumptions in arriving at the daily production estimate of wild-origin smolts. These assumptions are essentially the same as those in the residence time model section above except that the YCCE daily production estimates are not exclusive to marked hatchery fish, and there is the further assumption that unmarked hatchery fish exhibit the same mortality rate as marked hatchery fish. One final assumption also exists. This is that modeled mortality rate of marked hatchery smolts is also true for wild-origin smolts.

Appendix C details the results of the model for each day of the outmigration season. The breakdown of daily production estimates generated from the model are presented in Figure 12. Overall, this model predicts that 618,674 hatchery-origin smolts outmigrated past the trap site and 880,036 wild-origin smolts outmigrated past the trap site.

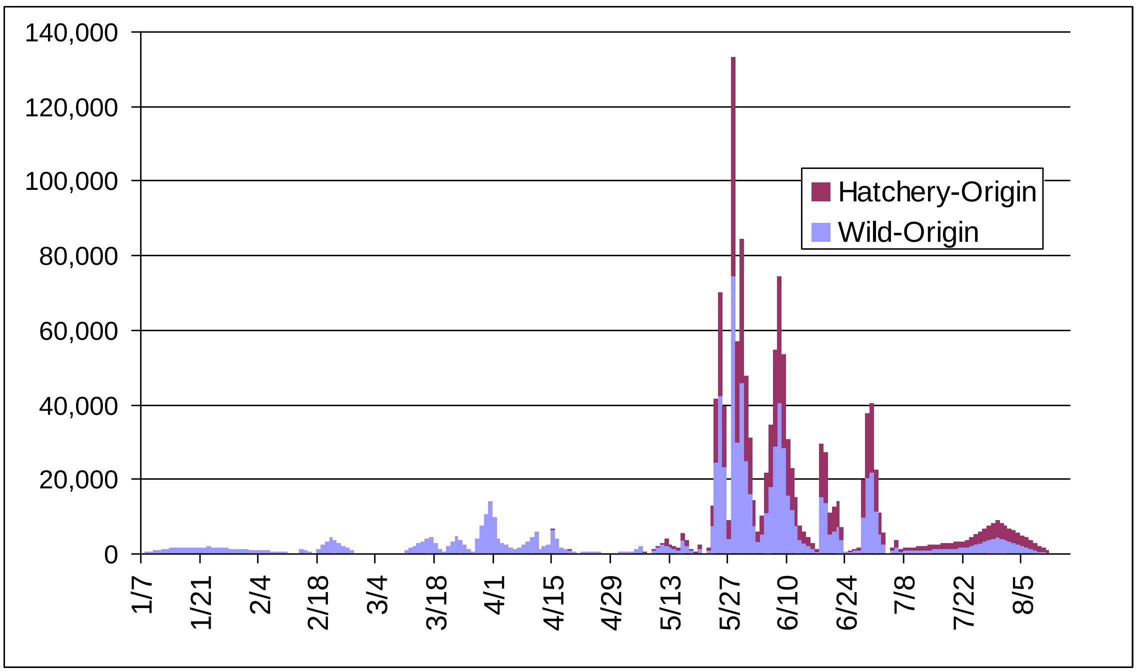

Figure 12. Hatchery-origin and wild-origin daily production estimates derived from daily modeling using daily mortality rates from the 2003 residence time model.

Another approach to splitting overall Chinook smolt production into the hatchery and wild-origin components may be offered by the relationship shown in Figure 11. This relationship relates the overall survivorship of each group of marked hatchery smolts to the timing of release, based on the modeled survival of groups of marked smolts released at various times of the season from 2001 onwards. To do this, we simply assign a group survival rate to each group of hatchery-origin smolts that were released in 2003, based solely on the timing of release. The predicted numbers of survivors are then summed for all groups, and this value is then subtracted from the YCCE production estimate for the season to determine how many wild-origin smolts outmigrated past the trap site. Results from this process indicate that 700,977 hatchery-origin smolts and 797,733 wild-origin smolts would be expected to survive and outmigrate past the trap site in 2003. This process does not, however, make any predictions about the timing of wild-smolt outmigration and only provides a point estimate for the season. Figure 13 shows the results of this process if applied to the last 5 years of data (except for using the ACRM production estimate in 1999).

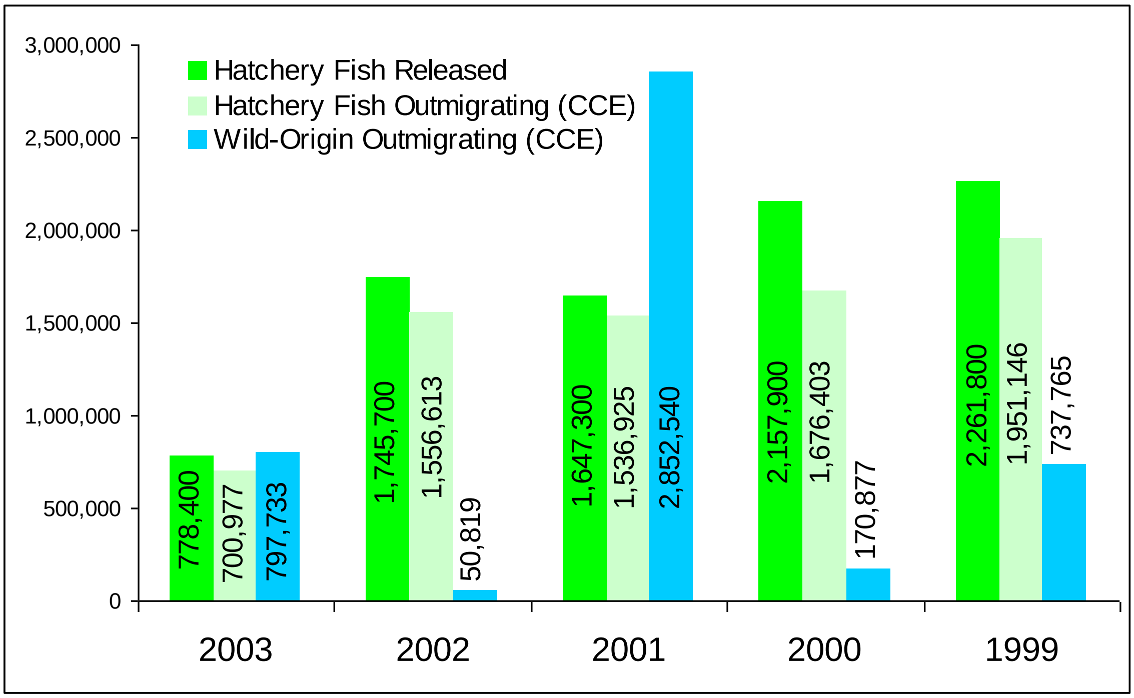

Figure 13. YCCE production estimates for age zero Chinook smolts between 1999 and 2003 showing hatchery-origin and wild-origin smolts based on hatchery-group release timing, and the number of hatchery smolts released into the upper watershed is also shown for comparison.

Chinook Discussion

Comparison of Production Estimate Methods over Time

It is difficult to assess the relative merits of each of the four estimation methods used to analyze the trap data without knowing the true number of smolts outmigrating in any given year, or the width of confidence intervals around each estimate.

The only confidence interval available for any of the estimates is the ACRM (Peterson) method. In 2003, 2002, and 2000 the confidence intervals were remarkably tight (<5%) around the estimate. The estimates for 1999 and 2001 had relatively worse intervals, but they remained surprisingly narrow (11% and 10% respectively). However, it should be remembered that this method makes some critical assumptions that could easily be violated in this application. For example, marked fish could not mix with fish that were caught prior to their release. Also, marked fish may not behave identically to unmarked hatchery fish, and hatchery fish overall may not behave like wild-origin fish, leading to differences in trap catch efficiency. That is, not all fish may have had an equal chance of being sampled. Consequently, I would treat the ACRM estimate and the associated confidence intervals with due caution.

The only reference value that we know with reasonable certainty is the number of hatchery fish that were released into the river. An unknown (but probably large) proportion of the hatchery-origin fish survive to reach the trap site, and an unknown number of wild-origin fish presumably also outmigrate past the trap site. Consequently, we would expect that a good production estimation method would not result in values markedly below the known release of hatchery smolts. We also believe that, historically, the number of wild-origin smolts wouldn't be all that high in relation to the hatchery-production since we believe that wild-origin adults have typically been a small proportion of the total adult return. Figure 6 shows the production estimates for the last 5 years that were derived by using each of the four methods detailed above, as well as the number of hatchery-origin smolts released each year.

Sampling effort in 1999 was much lower than other years, and featured very few nighttime samples. Inadequate nighttime sampling might considerably under-estimate the total number of fish if smolts are more likely to outmigrate, or be caught by the trap, at night. Consequently, it is likely that the most useful production estimate for the 1999 season will the Ad-Clip Recapture Ratio method.

Since 1999, the proportion of sampling effort conducted at night has increased considerably, particularly in 2002 and 2003. The ACRM, YCCE, and ACCE methods all agree fairly closely for both 2002 and 2003. The SCE (Secchi Depth-Catch Efficiency method) agreed well in 2002 but less well in 2003. Moreover, the SCE estimates for 2000 and possibly 2001 were implausibly large.

Consequently, I am disregarding the SCE method from further consideration until a more reliable understanding of the water-visibility-catch efficiency relationship can be determined. Although not presented in this paper, SCE production estimates have previously come up with numbers as high as c.9 million smolts (in 1998), and Bob Conrad (NWIFC) considered this method to be un-reliable (pers.com.)

In the past four years both the ACRM and YCCE methods have produced estimates similar in magnitude. By contrast, the ACCE method differs strongly in 2000 and 2001, while agreeing closely in 2002 and 2003. Focusing solely on the 2000 and 2001 outmigrations, why does the ACCE method diverge from the other two methods? River flows during the outmigration in 2001 were considerably lower than usual which could explain why the catch efficiency of the trap differed from ‘normal’ conditions during that season. Since there is an environmental explanation for unusual trap catch efficiency in 2001, it is likely that the ACRM and YCCE estimates are probably more reliable than the estimate based on long-term trap catch efficiencies because long term averages are most useful in ‘typical’ circumstances. However, river flows in 2000 were not unusually low, and secchi-depth readings didn’t deviate from the normal range either. There doesn’t appear to be an environmental explanation for the extremely high recapture rate of marked hatchery-origin smolts (nearly double what was expected). One possible explanation could be erroneous records of how many marked hatchery-origin fish were released in 2000. Given that there is no readily apparent environmental explanation, it may be that the long-term catch efficiency may be more realistic for the 2000 season.

In 2003 and especially in 2001, both the ACRM and YCCE methods estimated that the production of smolts from the river exceeded the number of hatchery-origin smolts that were released. However, in 2000 and 2002 both of these methods estimated that the total production of smolts from the river was *lower* than the number of hatchery-origin smolts released. In light of our expectations this is somewhat surprising since we had assumed that hatchery-origin smolts would have a fairly short stay in the river and only minimal mortality, and there ought to be at least some wild-origin smolts outmigrating as well. This raises some questions.

Obviously, the first question is whether these estimates are even in the right ballpark. As has been discussed, the ACCE method may prove to be a better method for estimating the production in 2000. In this case, production estimates exceed known release groups in 2000 (ACCE), 2001 (YCCE, ACRM), and 2003 (YCCE, ACRM). However, this still leaves a question mark over the 2002 estimate. There are a number of assumptions made in arriving at these estimates. Unfortunately, most of these assumptions are difficult to test directly. For example, measuring actual catch efficiencies on a day-to-day basis would be prohibitively expensive, and logistically challenging to say the least! One possible method may be to string a net across the whole river, just behind the trap, and count every fish caught in the big net every hour or so and compare these numbers to the numbers of smolts caught in the screw trap.

If the production estimates are right, how could they really be lower than the numbers of smolts that we know were released into the upper watershed?

One hypothesis might be that some of the released hatchery-origin smolts died prior to reaching the trap. Muir *et al.* (1999) showed that that daily survival rates for marked hatchery-origin Chinook smolts (c. 80mm FL) released into the Snake River was c. 98.2% per day. Although conditions in the Nooksack are probably less hostile than the highly regulated (i.e., dammed) Snake River, it is still reasonable to assume that some mortality occurs between release sites and the Lummi screw trap. Mortality of Chinook released into the Nooksack River might be due to handling stress, disease (perhaps exacerbated by stress), starvation, predation, or stranding in off-channel habitat when river waters drop suddenly after high-flow conditions.

Another possible reason for the production estimate being lower than the number of hatchery fish released in a year could simply be that some of the hatchery-origin fish had not moved down past to the trap site by the end of sampling. In other words, some hatchery fish might over-winter in the river and outmigrate as yearlings the following year. Arguing against this hypothesis is the fact that no ad-clipped yearling Chinook smolts have ever been caught in the screw trap (except when clipped yearlings were also released that same year). However, the number of yearling Chinook caught in the trap is typically very small (10-30 fish per year) so the chances of catching a marked yearling would be very low even if they were present in the river. Interestingly, two adipose-clipped yearling Chinook were caught in beach seines in the Nooksack Estuary in 2003. If these fish were released into the Nooksack as zeroes then we may have an indication that some hatchery fish may over-winter in the river (or in the estuary). However, the possibility also exists that these yearling Chinook could have been released elsewhere and were simply migrating along the shore from their release site, and happened to be caught as they passed the Nooksack estuary. No further information is available to evaluate the likelihood or proportion of hatchery fish that could be accounted for in this way.

Based on the preceding, and with the exception of the 1999 and possibly 2000 estimates, it seems that the most plausible production estimators currently available are the YCCE and ACRM methods. Of these, the YCCE method provides the most information so it is to be preferred. However, the ACCE estimate probably provides a 'ballpark' comparison that is useful for corroboration. If the ACCE and YCCE results disagree by a large margin there ought to be a close examination of the data to explain how the difference arose and which method is likely to be at fault. A good example is 2001 where unusually low flows probably invalidate the longer-term average (ACCE) method. Similarly, the ACRM method provides a good control with the YCCE method. Where these two methods differ strongly there ought to be a close examination of the data to determine why. In 1999, for example, inadequacies in the sampling program probably lead to underestimation of the number of outmigrating smolts using daily catch-per-hour values obtained almost solely during daylight sets. This probably means that the ACRM method performed better than the YCCE method in 1999.

Hatchery Chinook Residence Times

In 2003 the shortest residence time may have been as short as 0 - 3 days, and the longest residence time observed may have been as long as 60 days. Modeling results suggest that the average residence time for the first group was around 20 days, the second group averaged 14 days, and the last group averaged somewhere around 8 days. These results are consistent with the trend in the 2002 and 2001 data where early-release groups tend to stay in the upper watershed for a longer time than those released later in the season. This behavioral difference has also been noted in the Snake River, albeit for yearling Chinook smolts (Smith *et al.*, 2002), so the modeling results for age-zero Chinook are within the realm of possibility. If the model findings are true, then there are obviously implications for the scheduling of hatchery releases. Delaying hatchery releases until the start of June should minimize whatever interactions exist between hatchery-origin and wild-origin smolts.

Residence time modeling has provided a consistent pattern of residence times over several years of data. Better release rate information (i.e., for extended volitional releases etc) would probably result in minor adjustments to the model results. This would likely result in an increase of the estimated residence time by a day or two. Significant changes to the model output will probably only arise if day-by-day trap catch efficiency information becomes available so that changes in environmental conditions are ***reliably*** taken into account (e.g., secchi depth, flow patterns, etc) each day.

Daily survival rates of age-zero Chinook smolts determined by modeling in 2001, 2002, and 2003 were 99.21%, 99.66%, 99.43% respectively. These survival rates are better than those for outmigrating age-zero Chinook smolts in the Snake River (98.16% surviving per day; Muir *et al*., 1999). This is likely because age-zero Chinook outmigrating from the Nooksack River do not have to contend with predator-filled impoundments and additional mortality associated with hydroelectric schemes present on the Snake River (e.g., turbine damage, oxygen-super-saturation, spillway turbulence, etc).

Modeling Wild-origin Chinook production

Two approaches were used to try to split the overall YCCE production estimate into wild-origin and hatchery-origin components.

The first method attempts to reconstruct the daily population dynamics occurring upstream from the trap site, based on daily YCCE production estimates, hatchery release timing, and the constant daily mortality rate derived from the residence time modeling. Then it makes assumptions regarding the proportion of the two components (wild vs. hatchery) in the screw trap catch, based on the relative proportions of the two population components that remain upstream. Based on all of the above, it then constructs a model of the hatchery outmigration. The difference between the hatchery-only model and the total Chinook model is assumed to represent the daily wild-origin outmigration.

The second method uses the relationship shown in Figure 11 to predict the survival of groups of released smolts, based on residence time modeling for 3 years of data. This process results in a point estimate of how many hatchery smolts outmigrate each year, and the difference between this value and the total YCCE production estimate is assumed to be the number of wild-origin smolts outmigrating. This approach provides less information than the other method, but also requires less detailed information and, consequently, has (relatively) less risk of going astray.

The two methods respectively provide estimates of 880,036 and **797,733** wild-origin smolts outmigrating in 2003. I believe that the second method is more defensible since it requires fewer steps away from the 'real' data. However, there may yet be some value in the former approach, simply by providing a basis for comparison with screw trap data from the South Fork. This method at least provides some basis for speculation, and thereby the development of testable hypotheses.

Figure 13 shows the output of the second method and raises some interesting questions. Was 2001 really such a stellar year for wild-origin smolt production? If so, why? Similarly, why was 2002 such a bad year? Preliminary investigation of flow data shows that river flows during the critical October-December period of 2000 were unique in the last 5 years by having no notable (>10,000 cfs) flows at the Ferndale gage. In contrast, flows in October-December of 2001 were quite severe, with major flow events occurring almost every month through the critical period and also throughout the remainder of the winter. Another potential pattern that could be seen is that Chinook production is relatively low in years following the annual return of adult pink salmon, but higher in the same year as the pink return. This might indicate that redd superimposition by Pinks could be adversely impacting Chinook production. However, confounding the issue is the confusion as to whether the YCCE estimate or the ACCE estimate is the best estimate to use.

Since we suspect that the ACCE estimate may be more appropriate for the 2000 season, then we would expect the wild production in 2000 to change from a lowly 170,877 smolts to a whopping 2,271,084 wild-origin smolts! This figure is nearly as big as the 2001 wild-origin production but without apparent environmental explanation since flow events toward the end of 1999 included events up to 21,000 cfs. Also contradicting this high level of wild production in the 2000 season is the relatively low production of yearling Chinook in 2001 (~5.5 per 100 hours sampling effort vs. 15.5 in 2002). If the proportion of age-zero Chinook remaining in the river over winter were constant, then you would expect that yearling catch-per-hour would be high for the year following a strong year class. This doesn't appear to be the case following the 2000 season so perhaps the ACRM and YCCE estimates perform better in 2000 after all?

Coho

Results

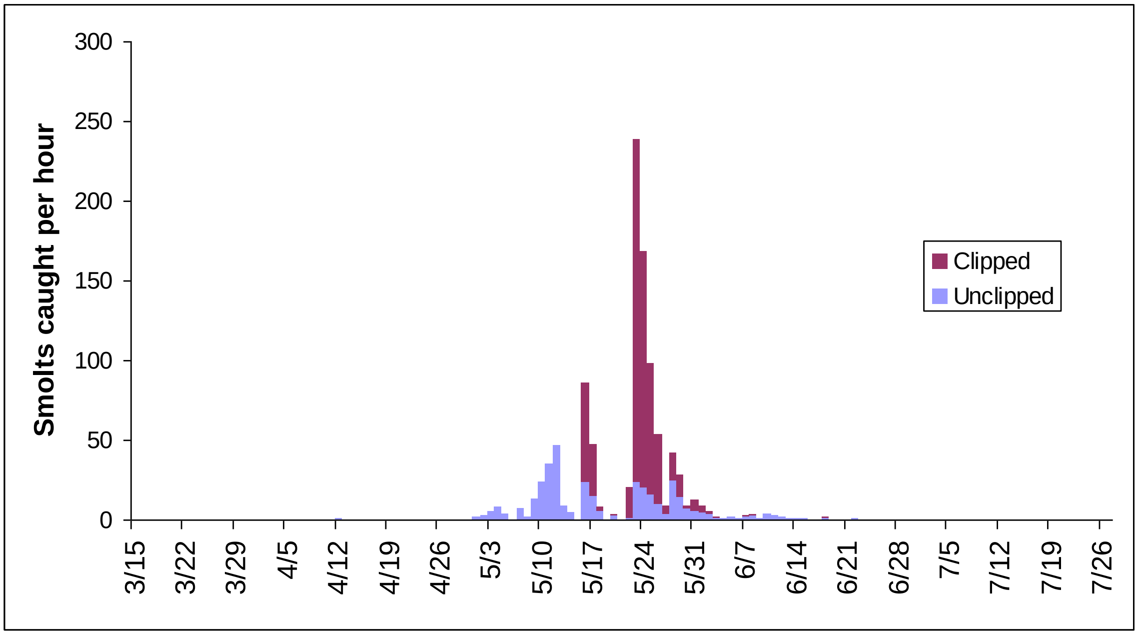

Figure 14. Average daily trap catch-per-hour for Coho yearlings through the sampling season.

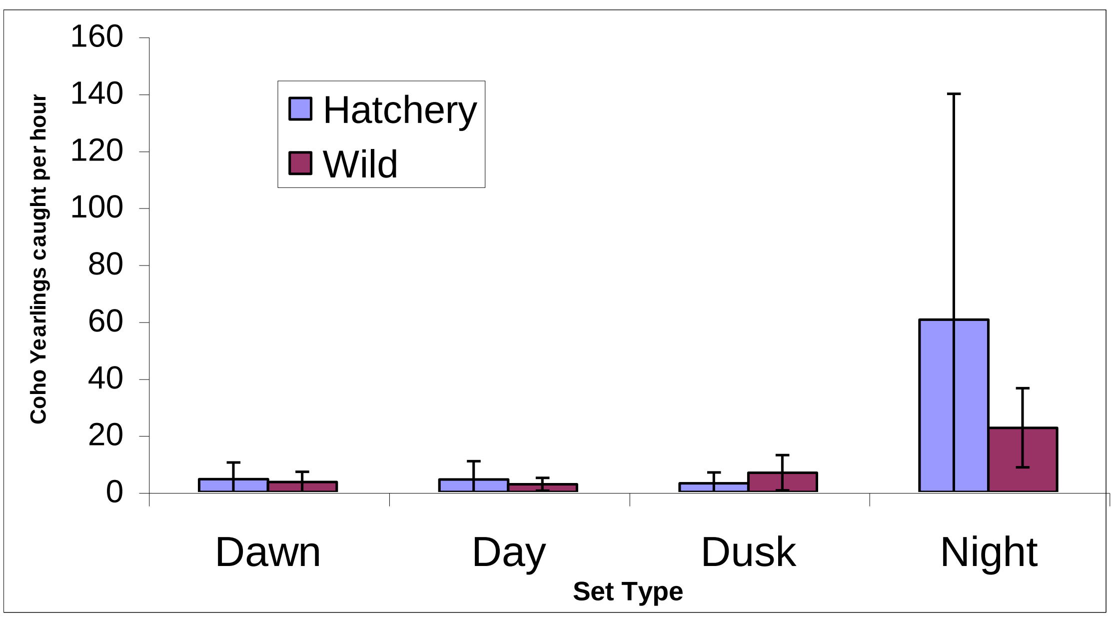

Figure 15. Average Coho yearling catch-per-hour values at different times of day between 5/15 and 7/1/2003.

Yearling Coho smolts began appearing near the start of May and continued through to mid June (Figure 14). Typically, catch rates were much higher at night than during dawn, dusk, or day sets (Figure 15).

Coho Yearling Production Estimates

Method 1. Ad-Clipped Recapture Ratio Method (ACRM)

Table III shows the total numbers, and marking strategies used, for hatchery Coho that were released in 2003, as well as the number of adipose fin clipped smolts that were recaptured, and the total number of Coho smolts captured in the same sampling program.

Table III. *Adipose-clipped recapture rate parameters used in the 2003 ACRM Coho production estimate.*

	2003
Number of Adipose fin-clipped smolts released	1,353,300
Number of Adipose fin-clipped smolts recaptured	2,761
Marked Smolt Recapture Ratio	0.204%
Total number of smolts caught	4,056
Estimated Total production of Coho smolts in 2003	**1,968,359**

A further 49,800 hatchery-origin Coho smolts were released that had no adipose fin clip. Assuming no mortality occurs between the release site and the screw trap, this means that 1,403,100 hatchery origin smolts and 565,259 wild-origin Coho smolts were produced in 2003.

Figure 16 shows the ACRM production estimates for wild-origin yearling Coho smolts and hatchery releases from 1999 to present.

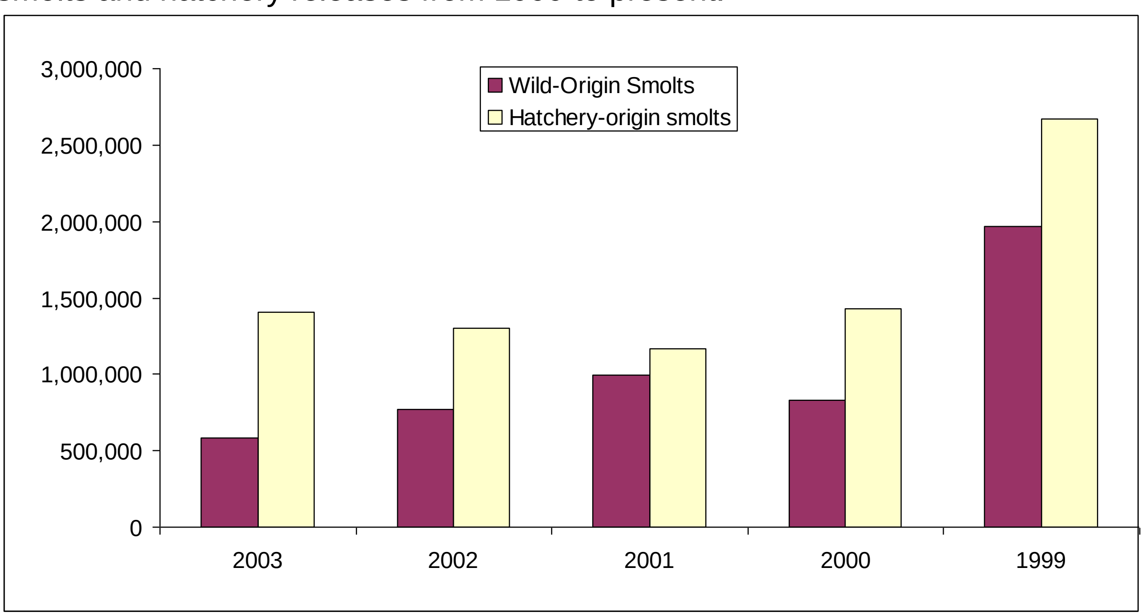

Figure 16. Annual hatchery releases of yearling Coho and ACRM production estimates for yearling Coho smolts from 1999 – 2003.

Method 2. Constant Catch Efficiency Method (YCCE)

Figure 17 shows the relationship between the recapture rate of marked hatchery Coho smolts, and the proportion of time between May 15 and July 1 sampled for the past five years. Overall, the average catch efficiency for the Nooksack screw trap is estimated to be 1.2% based on the past 5-year's data.

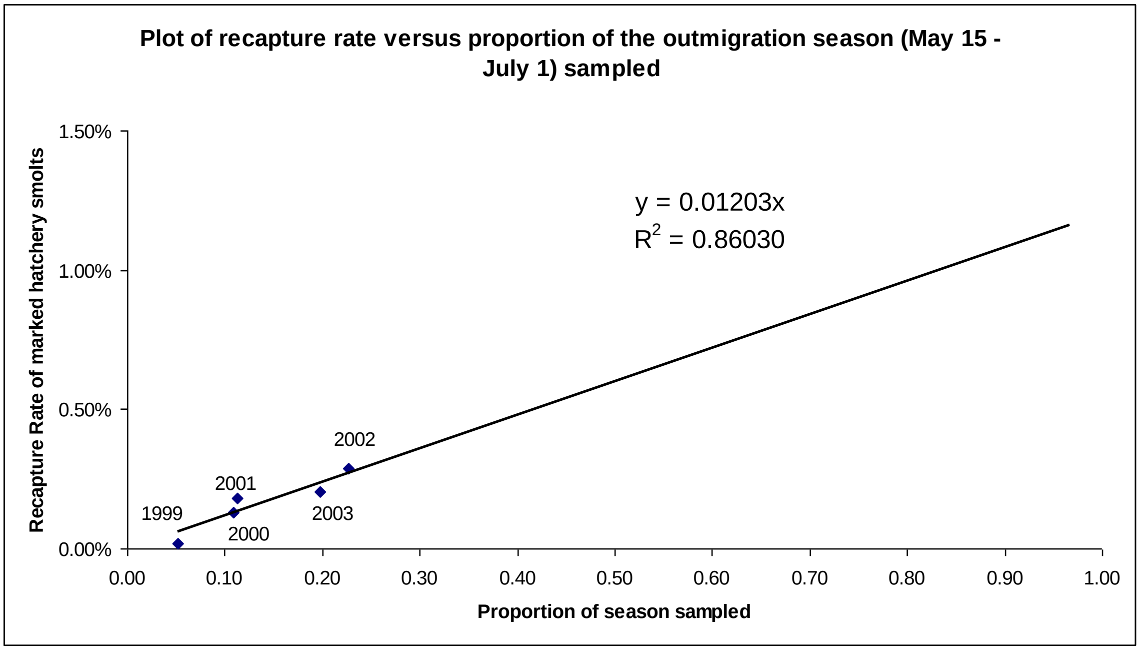

Figure 17. Plot of recapture rate versus proportion of the outmigration season (May 15 - July 1) sampled from 199 – 2003.

Based on the data shown in Figure 17, the average catch efficiency during 2003 was calculated to be 1.03%. The same methodology used to determine the YCCE estimate for Chinook was used for Coho, using the value of 1.03% instead of 3.21% for the trap's catch efficiency. The YCCE daily production estimates are presented in Figure 18 for ad-clipped and non-ad-clipped Coho yearlings, along with known releases of Coho smolts. The total YCCE production estimate for 2003 was 2,046,765 smolts. Of these, 1,320,603 smolts were marked and 726,161 were unmarked. We know that 49,800 unmarked smolts were of hatchery origin, so this provides a wild-origin estimate of 676,361 Coho yearling smolts.

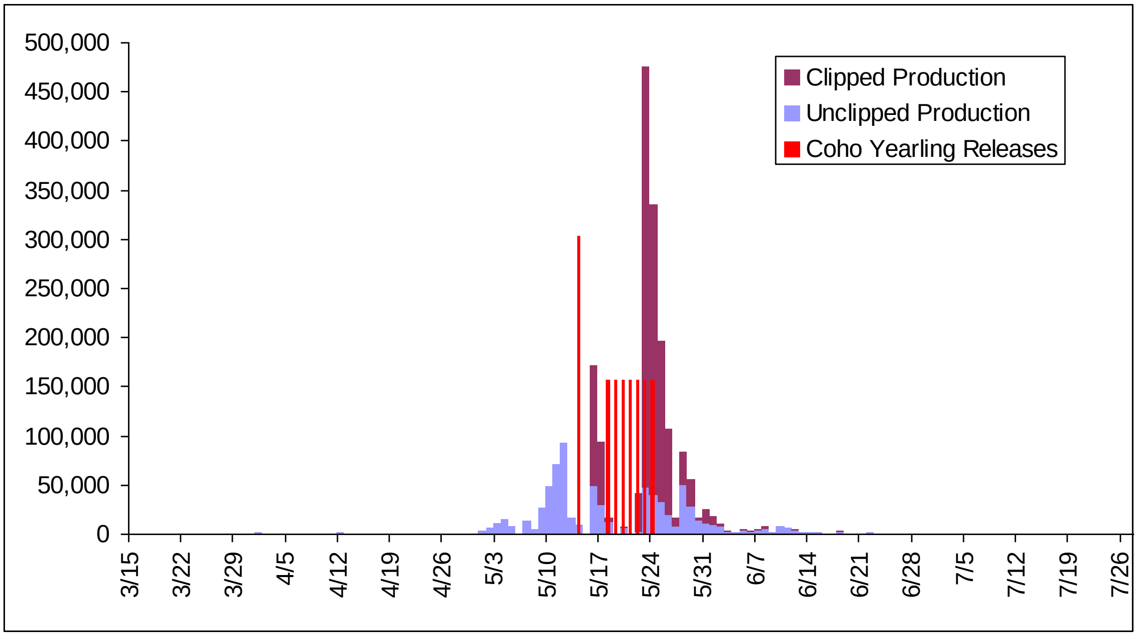

Figure 18. YCCE daily production estimates for Coho yearlings in 2003 plotted along with hatchery released groups. The second group had an extended volitional release period between 5/19 and 5/25. This assumes that equal numbers of smolts left the pond each day during the volitional release period.

Modeling Coho Residence Times

The same general procedure was followed for Coho as is described for Chinook earlier in this paper. The one difference was that it was not possible to assume that all Coho left the volitional release pond on the last day possible. This was because numbers of smolts arriving at the trap before the end of the volitional release period were too high for this scenario to be possible. Consequently, the movement of the smolts out of the volitional release pond was assumed to be distributed evenly across the whole release period (as illustrated in Figure 17). A daily summary of the data produced by the model is presented in Appendix B, and shown in Figure 19. The model predicted that the daily mortality rate for yearling Coho was 99.32% per day in 2003.

Overall, the average residence time for Coho yearlings was typically between 2.5 and 3 days, which is consistent with results from 2002.

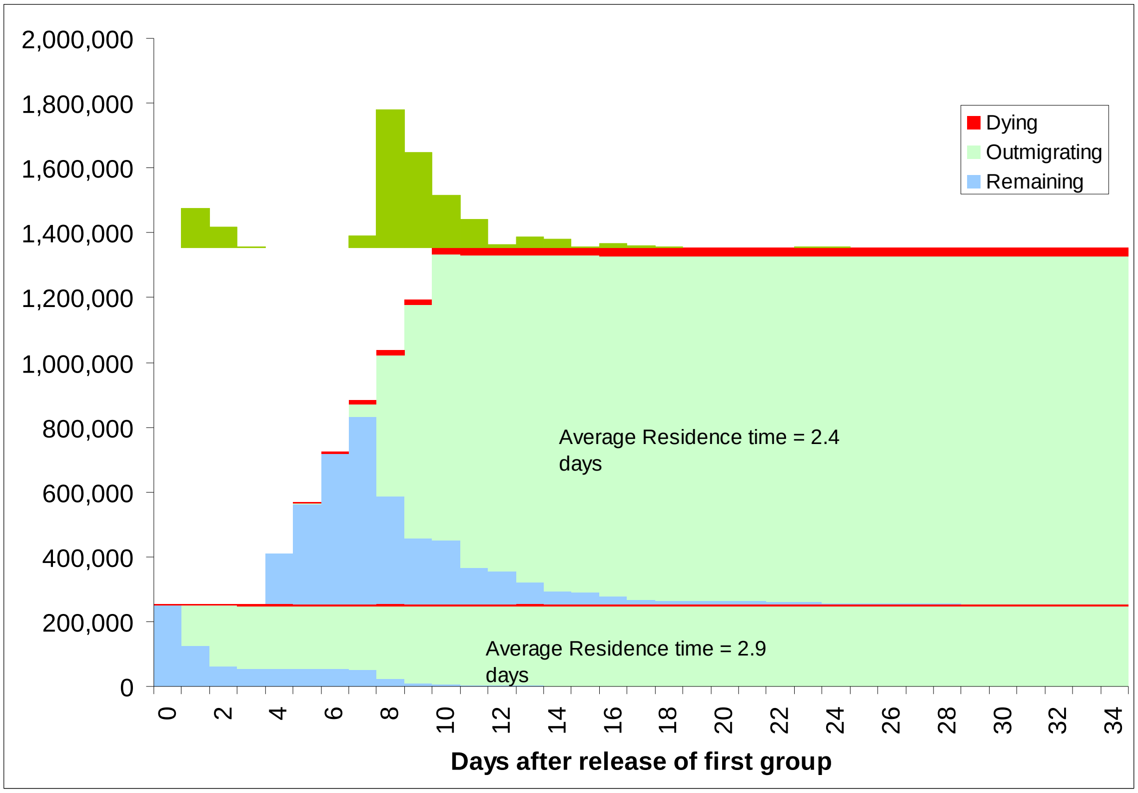

Figure 19. Model of marked hatchery-origin Coho yearling behavior after release into the river, showing cumulative outmigration, mortality, and the number remaining upstream from the trap for each group of smolts.

Coho Discussion

Both methods of estimating the total production of yearling Coho provided an estimate close to 2-million smolts. Depending whether or not you assume negligible mortality of the released hatchery smolts, this translates to a wild-origin production estimate between 584,942 and 676,361 smolts. The catch efficiency/sampling effort relationship shown in Figure 17 seems to be more stable from year-to-year than the equivalent relationship for Chinook, suggesting that catch efficiency is lower but less variable from year-to-year for Coho yearlings that it is for age-zero Chinook smolts. This may be a reflection of the strong preference for nighttime outmigration by Coho yearlings, because the relative visibility of the trap is probably also less variable at night.

The point that deviates most from the trend line in Fig. 17 is from the 1999 season. This deviation can readily be explained by the much lower proportion of sampling conducted at night in 1999. Since Coho yearlings are primarily caught at night, the strong daytime sampling bias in 1999 resulted in a much lower than expected recapture rate.

Modeling of the 2003 YCCE data suggests that Coho yearlings only remain in the River system for 2 – 3 days on average. The distance from the

Skookum hatchery to the trap site is c. 72 km, and the distance from the Kendall hatchery to the trap site is 66 km. The average outmigration rate of the Kendall (first) release group was 23 km/day, and the average rate for the Skookum release group (second) was 30 km/day. These rates are intermediate relative to some reported movement rates for yearling Coho smolts in other rivers. Dawley *et al*. (2000) reported average movement rates of 40 km per day between the Dalles Dam and the Bonneville Dam in 1999, while Dawley *et al*. (1984) found that migration rates from hatchery release sites to the lower Columbia River (Jones Beach) averaged between 14 and 19 km per day over three years.

However, YCCE estimates for clipped yearling Coho production from 2000 to 2002 all exceed the known release of Coho yearlings. Consequently, I suspect that the YCCE production estimate method is presently not a reliable indicator of daily production for yearling Coho, even if it fortuitously ‘worked’ for 2003. This means that modeling based on the YCCE method will also be unreliable and the daily mortality rate estimated in the modeling process is probably wrong. Regardless, the method used to generate the mean residence/travel time is based on catch-per-hour modified by a constant catch-efficiency, and the actual value of the constant catch efficiency will not alter the mean of the original catch-per-hour distribution at all. Therefore, the daily survival rate should be viewed with skepticism, but the average residence/travel time is probably realistic.

I do not yet understand why the YCCE method doesn’t work for yearling Coho. It may be that the time period used (May 15 to July 1) is too long to use for the much briefer outmigration period of Coho and a more narrowly defined time window needs to be used in relation to the Coho release dates. More work may help clarify this situation.

Although the modeled Coho daily survival rate is probably wrong, it would be interesting to compare it with daily survival rates from other rivers. The daily modeling of the Nooksack Coho outmigration in 2003 estimated that 1,370,403 of the original 1,403,100 hatchery origin smolts survived to outmigrate past the trap site. This is an overall mortality rate of just 2.3%, which translates to 99.32% per day. I am unable to find any information relating to the daily survival rates of hatchery-origin Coho yearlings in other river systems. However, Skalski (1998) showed that hatchery-origin yearling *Chinook* smolts released from Lower Granite Dam had an overall survival of ~87% by the time they reached Little Goose Dam on the Snake River, 5 –10 days after release. If the average passage time was 7 days between the dams, then this translates to a daily survival rate of around 98% per day. If you assume that yearling Coho and Chinook have similar survival characteristics, then the higher survival rate predicted by the 2003 Coho residence time model (99.32%) is entirely plausible, because the Snake River is a more hostile environment; with large, predator-filled impoundments, and other perils associated with hydroelectric development.

Because there is likely to be at least some mortality associated with hatchery Coho before reaching the trap, the wild-origin Coho production estimates shown in Figure 16 are likely to underestimate wild Coho production. This is because the total number of smolts released is subtracted from the total ACRM production estimate. In reality, 2 - 3% of hatchery Coho may not reach the trap site at all.

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