# An analysis of 2007 data from the Lummi smolt trap on the Nooksack Mainstem

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## Executive Summary

Total production estimates for Chinook fry outmigrating from the Nooksack River in 2005 ranged from 739,486 (ACRM/Peterson) to **649,218** (adjusted ACCE) individuals. 677,000 Chinook fry were released into the Nooksack between April 16 and May 31. Wild production estimates ranged from as high as 62,486 (ACRM/Peterson) to as low as **58,800** (adjusted ACCE). If hatchery-origin fry suffer significant mortality before reaching the trap site then these estimates are likely to be biased high. Wild-production in 2007 is the second lowest in the last 6 years and equivalent to only 12% of the production in the best year (trap year 2003) during that time.

Residence time modeling for Chinook fry in 2007 again supported the hypothesis that early release dates give rise to longer residence times prior to outmigration, although a significant flow event one week after the first release appeared to flush out most of the first group quickly.

The total production estimate for Coho smolts was **1,939,050** smolts (ACRM). 1,417,895 smolts were released from hatcheries between May 18 and May 24 of which **1,283,414** were adipose-fin clipped. These numbers include a small number of clipped Coho that appeared at the trap during the week prior to the first official release. The wild production estimate is therefore **521,155** smolts, assuming that no mortality occurs for hatchery-origin smolts prior to reaching the trap site. The effect of post-release mortality would be to inflate production estimates and the magnitude of the error incurred would be roughly proportional to the true mortality rate.

Residence time modeling for Coho smolts was not attempted in 2007 due to the presence of clipped Coho whose release dates and group size could not be determined.

# Contents

## Introduction

Lummi Natural Resources operates a rotary screw smolt trap on the Nooksack River in the lower mainstem, at Hovander Park 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 and South Fork stocks, but secondary objectives include stock assessment for other native salmonids such as Coho. Data analyses of data from the Lummi screwtrap have been previously conducted in 2002, 2003, 2004, 2005, and 2006 (Dolphin, 2002; 2003; 2004; 2005;2007a).

2007 was only the third year since trap operations began in 1994 that nearly 100% of hatchery-released age-zero Chinook were marked and could be reliably separated from wild-origin Chinook. However, WDFW estimates that up to 2,110 smolts were released that were externally 'unmarked' and may be mistaken for wild-origin smolts in the smolt trap data.

In 2007 the screwtrap was operated from December 12, 2006 through to August 24, 2007 and beyond, although sampling intensity was highest from early April through to mid July (Fig. 1). This report considers data collected from December 2006 through to August 24, 2006 and aims to report the results of the sampling program in 2007, summarize the main findings, and compare these results to previous data (where available) for Chinook fry (age 0+) and Coho smolts (age 1+). No analysis of the data for Chum, Pink, or Sockeye salmon has been made to date.

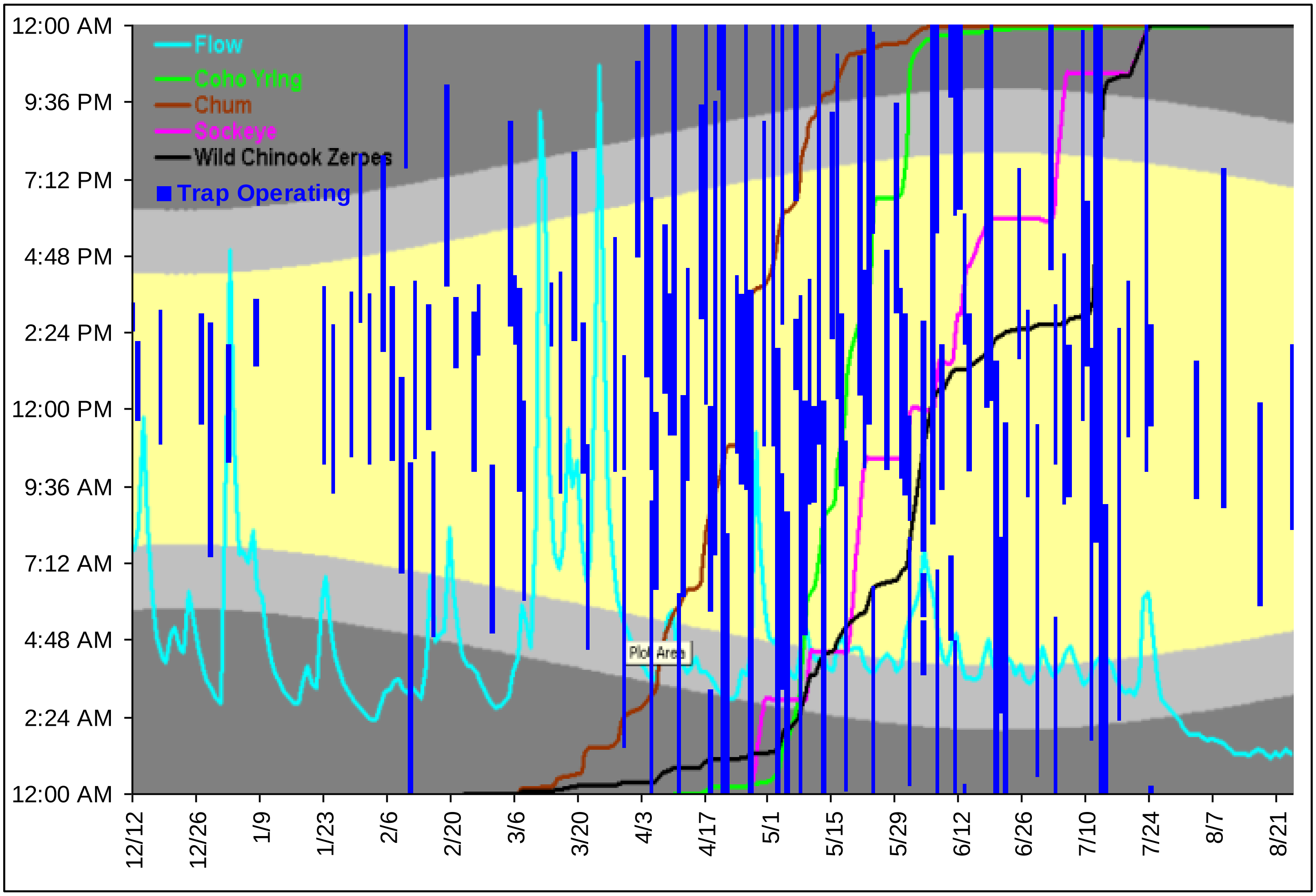


**Figure 1**. Daily sampling effort (Dark Blue) on the Lummi smolt trap in 2007 superimposed on a background of daylight (yellow), twilight (light gray), and night (dark gray) time periods, relative river flow at Ferndale (light blue), *cumulative production estimates* for unmarked Chinook zero-age smolts (black), and *cumulative catch curves* for Coho Yearling smolts (Green), Chum fry (Brown), and Sockeye fry (Pink). No Pink salmon fry were encountered in 2007.

## 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.

# Chinook

## Results

Figure 2 shows the average daily catch per hour for zero-age Chinook smolts based on trap data and linear interpolation between sample measurements. Table I outlines the timing, magnitude, and details of hatchery releases in 2007.

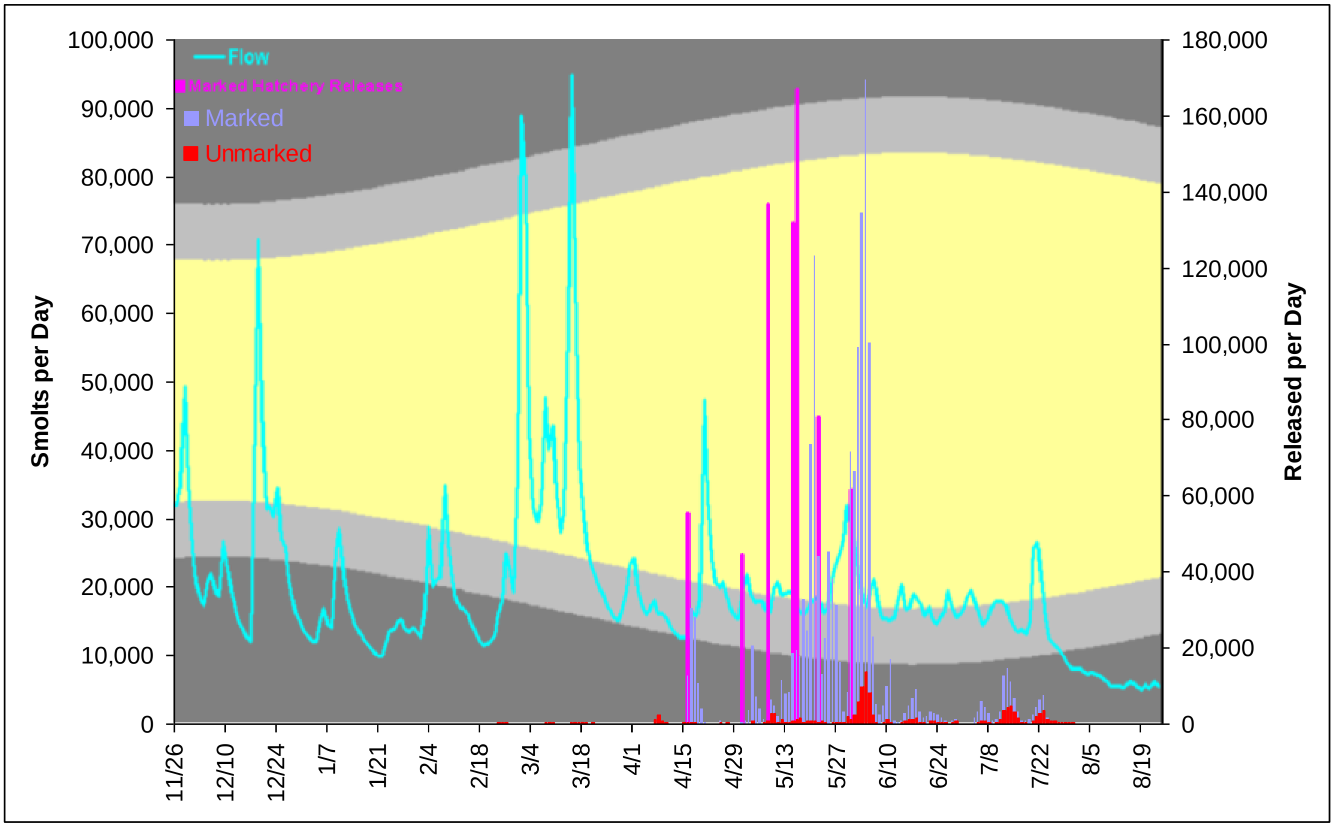


**Figure 2.** Average daily catch per hour for zero-age Chinook smolts in 2007. Hatchery releases are shown in the background along with relative river-flow at Ferndale, and approximate photoperiod (daylight is yellow, twilight is light gray, and night is dark gray).

| | | Ext. Marked | | | Unmarked | | |
|---|---|---|---|---|---|---|---|
| **Release Date** | **Release Site** | **Ad-Clip Only** | **Ad-Clip & CWT** | **CWT Only** | **No Clip. No Tag** | **Total Release (All)** | **Total Release (Ext. Marked)** |
| 4/16/2007 | Kendall Creek | 53,087 | 0 | 0 | 213 | 53,300 | **53,087** |
| 5/1/2007 | Kendall Creek | 44,023 | 0 | 0 | 177 | 44,200 | **44,023** |
| 5/8/2007 | North Fork Nooksack | 30,186 | 59,593 | 46,817 | 304 | 136,900 | **136,596** |
| 5/15/2007 | North Fork Nooksack | 20,710 | 51,507 | 59,268 | 315 | 131,800 | **131,485** |
| 5/16/2007 | Middle Fork | 166,332 | 0 | 0 | 668 | 167,000 | **166,332** |
| 5/22/2007 | North Fork Nooksack | 18,784 | 32,741 | 28,688 | 187 | 80,400 | **80,213** |
| 5/31/2007 | Kendall Creek | 61,154 | 0 | 0 | 246 | 61,400 | **61,154** |
| **Grand Total** | | **394,276** | **143,841** | **134,773** | **2,110** | **675,000** | **672,890** |

**Table I.** *Details of Hatchery releases of zero-age Chinook Fry in 2007*

## Chinook Production Estimate Methods

**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:

$$\hat{N}_P = \frac{N_2 N_1}{M_2} \qquad (1)$$

…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 recaptured is less than 10% of the number released ($M_2/N_1$), 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:

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

…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 were marked (either through an ad-clip, CWT, or both) and then released, as well as the number of marked smolts that were recaptured, and the total number of Chinook smolts captured in the same sampling program. If any marked hatchery fish die before reaching the trap site, or do not pass the trap site, then the final estimate of total production is likely to be too high because the true recapture rate will be higher than calculated in Table II.

**Table II.** Chinook clipped adipose fin smolts recapture rate details for 2007.

| | **2007** | |
|---|---|---|
| **Number of marked smolts released** | 672,890 | $N_1$ |
| **Number of marked smolts recaptured** | **3,688** | $M_2$ |
| **Marked Smolt Recapture Ratio** | 0.548% (3dp) | |
| **Total number of smolts caught** | **4,053** | $N_2$ |
| **Estimated Total production of Chinook smolts in 2007** | **739,486** | $N_P$ |
| **Upper 95% Confidence Limit** | 746,625 | |
| **Lower 95% Confidence Limit** | 732,346 | |

The results of using this method suggest that a total of **739,486** smolts migrated downstream past the Screwtrap in 2007. Since we know that 677,000 smolts were released from the hatchery, the difference (**62,486**) could be interpreted as wild-origin smolts. However, this does not incorporate any loss of hatchery fish due to mortality prior to their arrival at the trap site. The magnitude of any bias caused by wrongly assuming no mortality occurs when using the ACRM method is discussed further in the Coho production estimate results section but, generally, this error would lead to overly optimistic estimates for wild-origin Chinook production.

### Time-series based production estimate methods…

Other methods to estimate the annual production of Chinook smolts attempt to create a time series of catch-per-hour measurements for the entire outmigration period, and then convert this time-series into production (the number of fish passing the trap site per day) using a trap-specific catch efficiency estimate. Summing the daily production estimates over the entire outmigration period provides an estimate of total production. All of the methods that use this time series as a basis explicitly make predictions as to the magnitude and timing of outmigration past the trap site.

The time-series of catch-per-hour data for Chinook is created using trap catch rates stratified by dawn, day, dusk and night sampling periods. Measured data are extrapolated to a maximum of 24 hours after each sample based on relationships between cpue and set type for various times of the day. This relationship is derived from a scatter plot of cpue versus set type (dawn, day, dusk, night) with data gathered since 2003. For times beyond 24 hours from the last actual measurement, catch rates are interpolated linearly within sampling strata. As an example, if catch rates during the day on May 10$^{th}$ were 4 fry per hour, and catch rates during the day on May 12$^{th}$ were 2 fry per hour, then the rate used for daytime on May 11$^{th}$ would be 3 fry per hour.

The rules for interpolation used to analyze the 2007 data are summed up as follows:

1. Extrapolate from actual data within a 24 hour period of the last known sample, based on strongest predictive relationship between sample types (dawn, day, dusk, or night)
2. Secondarily, use linear interpolation to obtain values between actual and extrapolated data points
3. Do not linearly interpolate between data values that occur immediately before and after a hatchery release, instead assume that the last sample before the release is true for all subsequent dates prior to release, and that the first sample after the release is true for all previous dates from the time of release.

The third rule was deemed necessary because field staff actively try to catch the leading edge of any released smolts that outmigrate immediately following release. Since the sample timing is therefore non-random with respect to release timing it was necessary to avoid inadvertently overestimating the hatchery releases by linearly interpolating during a period in which hatchery fish that have not yet been released could not possibly be passing the trap site.

Three methods have been used historically to derive estimates for the trap's catch efficiency.

**Method 2. *Secchi-Depth – Catch Efficiency Relationship Method***

This method used a secchi-depth reading to estimate the trap's catch efficiency during each sampling period. However, application of this method in previous years has proven to provide very poor results. Moreover, the original secchi-depth-catch efficiency relationship was based on recaptures of newly released Chinook smolts and the behavior of smolts in the 24 hours after release is unlikely to be like that of smolts that have been at liberty for more than 24 hours. Furthermore, the relationship between secchi depth and trap catch efficiency began to break down as more release trials were done. Consequently, *this method has been abandoned* because it was not representative of the behavior of smolts acclimated to riverine conditions and because no dependable relationship could be found. Nonetheless, workers on the trap continue to believe that water clarity is an important factor in the trap's catch efficiency and if some method can be found to measure catch efficiency versus secchi depth for river acclimated smolts then this method may provide a significant improvement in our daily production estimates.

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

The percentage of marked smolts recaptured is a function of trap catch efficiencies that may vary from day-to-day and within day, fish migration timing, sample timing, and overall hours fished. To measure catch efficiency it is necessary to isolate catch efficiency from sample timing and amount of effort. Because we cannot measure the actual numbers of fish moving past the trap site we cannot directly measure catch efficiencies on a within day or day-to-day basis, so the most we can do is to estimate 'average' catch efficiency for the whole season. One indirect measure of the average instantaneous trap efficiency in a season can be obtained using the percentage of marked hatchery Chinook that were recaptured, along with the proportion of time that was spent sampling during the time when those marked fish were passing the trap site.

For this 'average' seasonal value to be useful for converting catch per hour values into production per hour values, it is necessary to assume that trap catch efficiencies are constant throughout the diurnal cycle, and throughout the sampling season. Since we do not see consistent differences in catch per hour between day and night sampling times, it is likely that trap catch efficiency is similar for both time periods. However, catch rates do appear to be slightly higher around dawn and dusk which may indicate either higher catch efficiency during these times, or else higher outmigration rates at these times. Any error created by failing to differentiate sampling efficiencies for these time periods is likely to be reduced by the comparatively short time (4 hrs a day total) involved for these sampling periods.

We know that if the trap were not operated at all (effort = zero hours) then no fish would have been recaptured at all. We also know that we caught a certain percentage of the marked hatchery fish after sampling a known proportion of the total time possible (and the effort was spread throughout the season). Assuming that the number of marked fish recaptured 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 sampling effort is a large proportion of the overall time.

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

Figure 3 shows the relationship between the recapture rate of marked hatchery smolts, versus the proportion of time sampled during their outmigration period, for the past seven years. An analogous value is also shown based on an identical screwtrap operating in the 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, 2002, 2003, 2004, 2005, and 2006 show very similar average catch efficiencies (~2.3 - 3.3%) after extrapolating based on sampling effort, whereas recapture rates were below expectations in 1999 (1.46%), 2001 (1.73%), and 2007 (2.03%), and much higher in 2000 (7.3%).

To see if trends in monthly or seasonal river discharge influenced season wide recapture rates of marked Chinook smolts, correlations were performed between the year specific trap catch efficiency estimates and the difference between average river flow for that period of the year and the average river flow during that same period of the year across all years. No statistically significant relationship was found to exist for flow vs. catch efficiency in any month of the year, or any combination of months during the outmigration period for marked Chinook smolts. The strongest correlation coefficient was 0.47 (p>0.1) for flows in the month of April, perhaps suggesting that low flows in April might tend to reduce the season-wide trap catch efficiency.

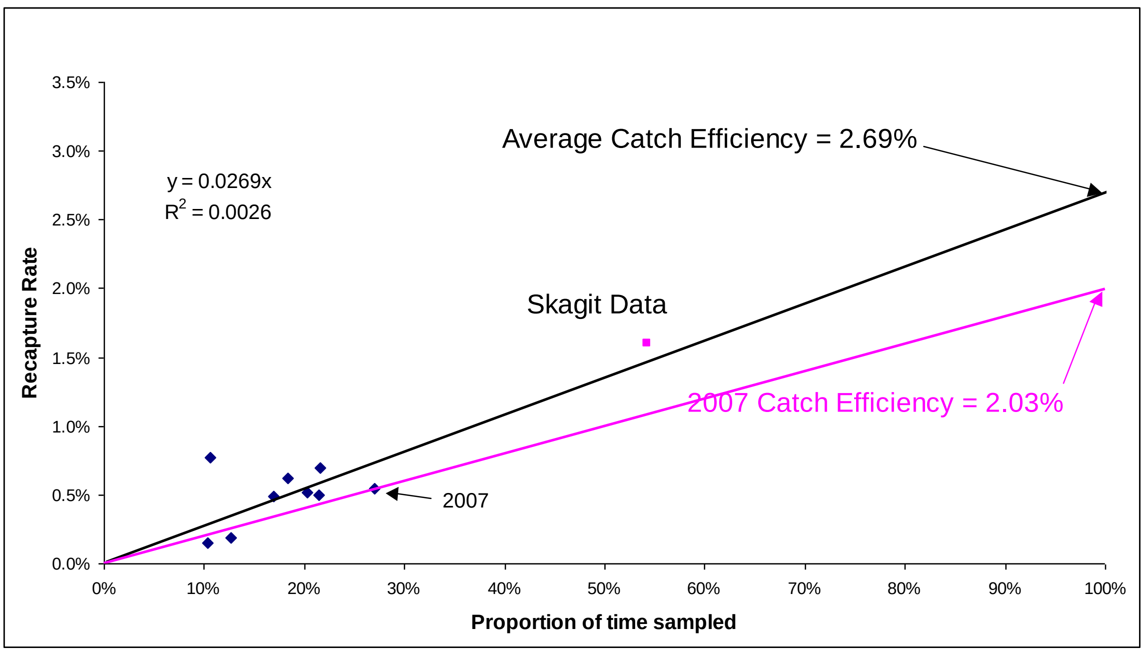


**Figure 3**. Season wide recapture rates of marked hatchery Chinook smolts versus the proportion of time sampled.

Based on the 2007 season catch efficiency of 2.03%, 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 4. The total number of zero-age Chinook smolts outmigrating past the trap-site was estimated to be 860,127 smolts. Of this estimate, 781,371 smolts are marked and the remainder, 68,277 smolts are unmarked. However, we know that the actual number of marked smolts released was only 672,890 in 2007 so it is apparent that the YCCE estimate overestimated the true production of marked smolts by 16.1%. Assuming that this bias is the same for unmarked smolts, then the number of unmarked smolts leaving the river in 2007 would be 58,798 smolts. Of this, we know that 2,110 unmarked smolts were released from the hatchery (Table I). Thus, the final estimate for wild-origin smolt production is **56,688** smolts using the YCCE estimate method and removing known bias.

It should be remembered that this estimate assumes that no mortality occurs between release and recapture for marked smolts. Mortality rates ought to be low, but if wrong then this assumption will tend to artificially reduce the catch efficiencies estimated in Figure 3. Underestimating the true catch efficiency of the trap would cause production estimates to be biased upward. This problem is compounded by the migratory behavior of the smolts where large fraction of the annual outmigration may pass the trap site in a relatively short period of time. The data in Figure 2 shows that large numbers of smolts were passing the trap site on a handful of days in late May and early June. If river conditions on those days meant that the trap was slightly more efficient than the season-wide average then it could cause an upward bias in the overall production estimate (or vice versa). This problem is inherent when using any constant value to represent trap catch efficiencies that are actually variable through time, and highlights the need to get accurate and reliable predictive relationships for actual trap catch efficiencies that are based on objective measurements of riverine conditions. Unfortunately, such an exercise is not logistically possible at the present time.

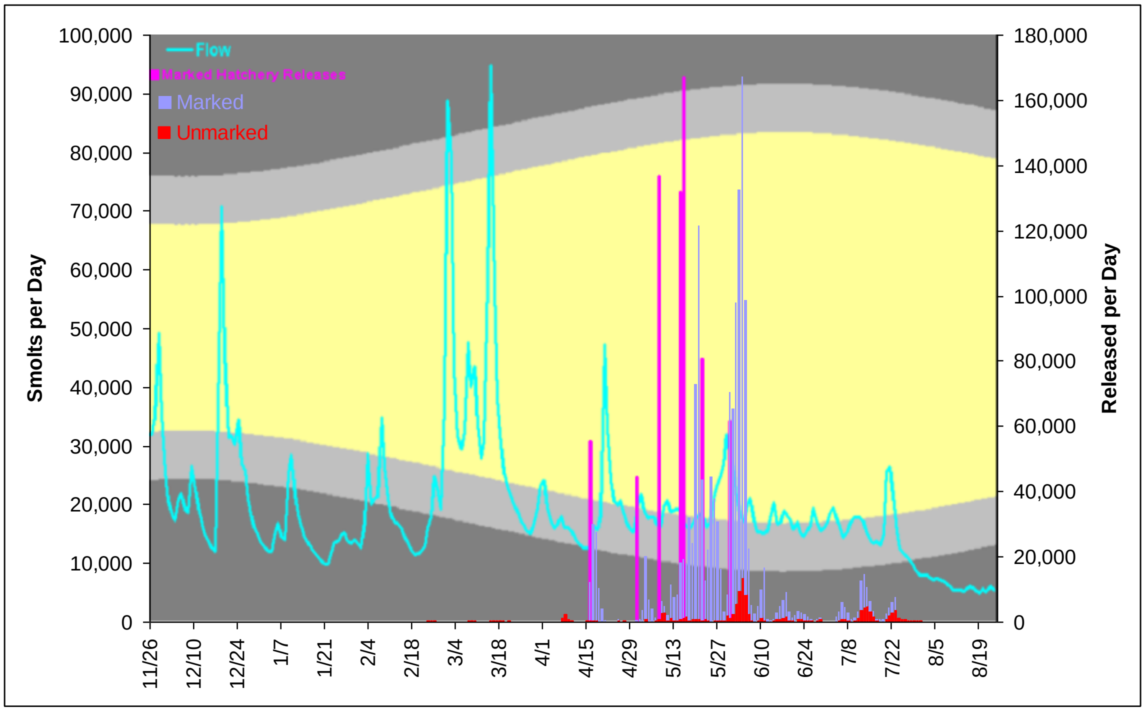


**Figure 4.** Daily production estimates in 2007 for zero-age Chinook smolts calculated from daily catch per hour and using a constant catch efficiency of 2.03% (YCCE).

### 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 3. Overall, the average catch efficiency for the Lummi screw trap is estimated to be 2.69% based on the past 9-year's data.

The results of this method for 2007 suggest that the total production of zero-age Chinook smolts was 649,218 smolts. Of this number, 589,778 smolts are marked and 51,537 smolts are unmarked. As with the YCCE estimate, the number of hatchery smolts passing the trap site predicted by this method differs from the known number of smolts released except that the ACCE underestimated the true number of marked smolts whereas the YCCE estimate overestimated the true number of marked smolts. The ACCE method, however, had a slightly smaller bias (12.4%) compared to the YCCE estimate (16.1%). By scaling the results to mach the known hatchery release of marked smolts, then the number of unmarked smolts passing the trap site is 58,800 smolts. Deducting the 2,110 unmarked hatchery-origin smolts released in 2007 gives a wild-origin estimate of **56,690** smolts.

This number is almost identical to the adjusted YCCE estimate because scaling the results to match the known hatchery release makes the two methods mathematically identical (except for rounding differences). The overall pattern of outmigration prior to scaling the results to match the known size of the hatchery release is shown in Figure 5.

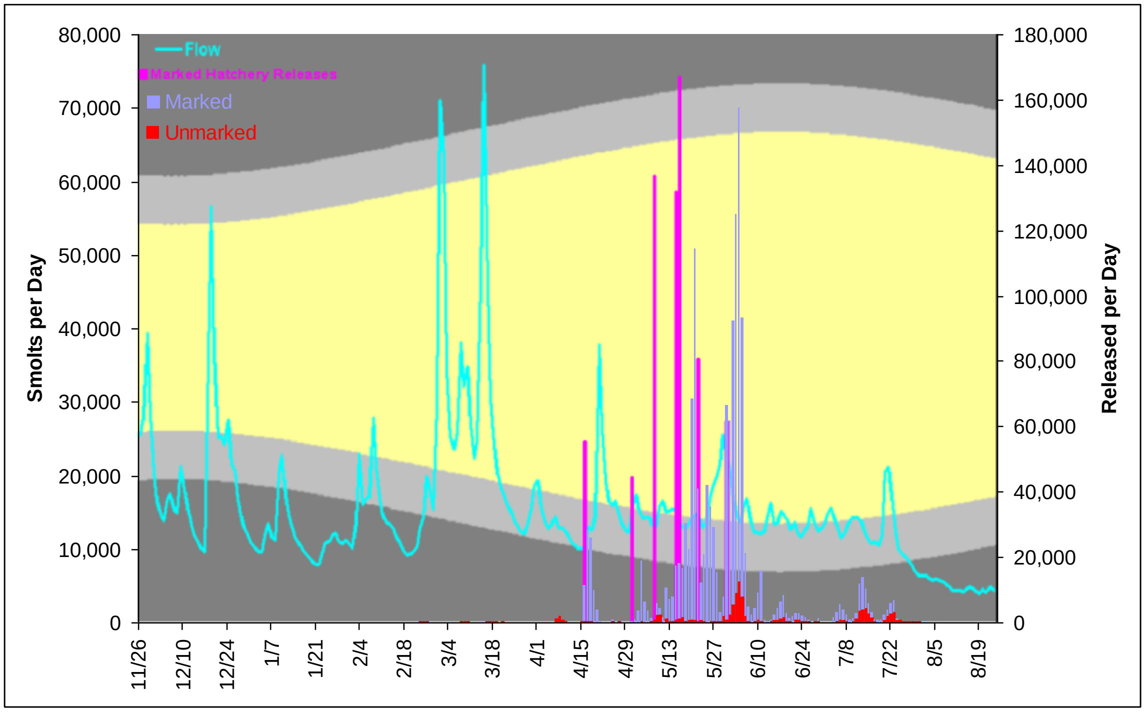


**Figure 5.** Daily production estimates in 2007 for zero-age Chinook smolts calculated from daily catch per hour and using a constant catch efficiency of 2.69% (ACCE)

## Comparison of the three production estimates

Results from 1999 – 2007 that were obtained using the three methods presented here are shown in Figure 6 and compared to the known hatchery releases in each year. Note that the absolute values in this graphic will differ slightly from those presented in earlier reports because the ACCE catch efficiency value has changed slightly with the inclusion of 2007 data in Figure 3.

For the third year in a row, the YCCE estimate has proved to introduce more bias for estimating the magnitude of the marked smolt outmigration than the ACCE estimate. Thus, early indications are that the ACCE estimate may have been a better predictor of actual production than the YCCE estimate in years where the bias could not be quantified (1999 – 2004). Relative performance of the ACCE estimates and ACRM estimates is more difficult to evaluate. Comparison of the estimates to known hatchery releases suggests that maybe the ACCE estimate is more 'realistic' in the majority of years, but the ACRM estimate makes more sense in 1999.

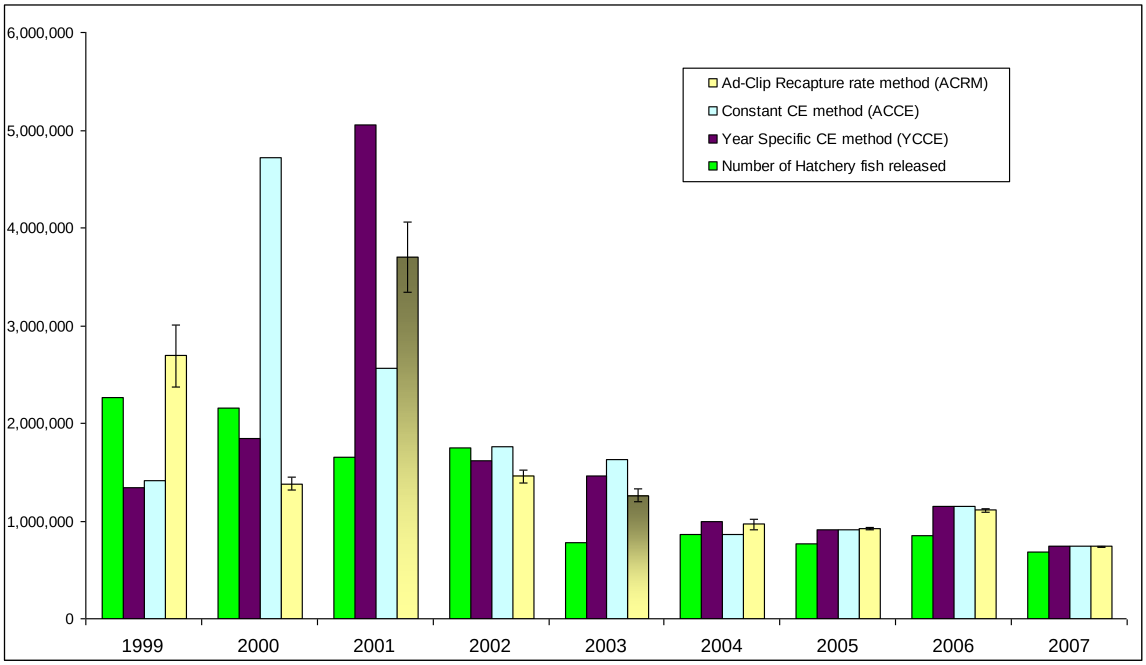


**Figure 6**. Three alternative production estimates for zero-age Chinook smolts outmigrating from the Nooksack River from 1999 – 2007, compared with the number of hatchery-origin smolts released in each year (green). Shading of the two ACRM bars in 2001 and 1999 indicates that many fewer marked hatchery smolts were caught relative to other years, and the ACRM estimate might be more prone to large error because of the increased scaling factors. This may also result from unusually high mortalities of marked hatchery smolts prior to recapture. ACCE estimates for 2005, 2006, & 2007 have been adjust to correct for known bias in estimating marked hatchery releases.

## 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 in the size range released. However, a large proportion (~99.4%) 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. 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 average 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; and there are several reasons for this difficulty.

Firstly, we are not intercepting all marked fish that are going down the river but instead are catching an unknown (and potentially variable) proportion on a daily basis. This problem can be resolved somewhat by making assumptions about the catch efficiency of the trap from day-to-day (that is, we can assume it is constant) but this itself can lead to inaccuracies if the trap's catch efficiency is not constant.

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 smolts are eventually driven from the pond. Sometimes this 'volitional release' period may last for as long as a week. This issue could be remedied for by counting smolts as they leave the pond but, unfortunately, no such counts are made for Chinook smolts. As a result, it becomes necessary to make some further assumptions regarding the rate of smolt departure from the holding ponds when volitional release is practiced. Fortunately, no volitional releases were made for Chinook smolts in 2007

A third problem arises when more than one group of marked smolts is 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 arriving in the trap that belong to each of the two (or more) groups of marked smolts that may be present in the river upstream.

A fourth problem arises when the summed daily production estimates for marked hatchery smolts do not tally with the number of marked smolts released. In some 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. However, if the summed daily production estimates exceed the known size of the release group then we are left with a major headache. The only solution to this problem is to scale all the daily estimates down so that their sum matches the size of the known hatchery release. This problem does not arise every year, and it is not the case in 2007. However, the advent of nearly 100% marking allows us to adjust for bias in either direction and avoid the issue altogether.

In 2007 several groups of ad-clipped Chinook smolts from Kendall Hatchery were released into the Nooksack River (Table I). The first group (52,911 smolts) was released on April 16. The last group (61,318 smolts) was released on May 31.

The first marked smolts (n=33) were caught at the screw trap just after noon on April 17. Figures 4 and 5 show that only a small fraction of the fish released in the early group left the river very soon after their liberty.

The last marked smolt (n=1) was caught at the trap site on July 24$^{th}$ which was 55 days after the last release of hatchery smolts and 100 days after the first release. Assuming that this smolt represents the last outmigrating hatchery fish, this suggests that the maximum residence time observed may be as high as 55 - 100 days (depending on which group this fish originally came from).

To estimate the average residence time for hatchery fish it is necessary to model each group of released fish 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. If volitional releases are practiced, all smolts leave the holding pens on the first day of their volitional release period. This may result in overestimating the actual residence times if smolts entered the river at a later date. Unfortunately, no end dates for volitional release were reported by the hatcheries in some years. This assumption is not necessary for 2006 data.

2. Daily survival/mortality is fixed and constant throughout the season. If summed daily production estimates are lower than the known hatchery release then this variable can be manipulated until model output matches daily production estimates for marked hatchery smolts. If summed daily production estimate exceed known hatchery releases mortality is set to zero and daily production estimates are uniformly scaled so that the sum of these estimate equals the size of the known hatchery releases.

3. The number of fish from one group that is caught 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. Adjusted ACCE daily production estimates for marked smolts are a good indicator of relative daily production (outmigration) rates.

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

The first column for each group of smolts 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 April 14, 1 day after release if they were caught on April 15, and so on.

The second column records the numbers of fish in that group that are alive and still 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 (if applicable).

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 that a group of fish represents of all marked fish in the river above the trap site, at the beginning of each day.

The sum of all group's daily outmigrant columns must equal the ACCE daily production estimate for marked smolts. The only variable that can be altered is the daily mortality rate (a constant). If necessary, an iterative process varies the mortality rate until the model output exactly matches the ACCE daily production estimate and all remaining fish are accounted for by mortality.

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.

The results for 2007 are shown in Figure 7.

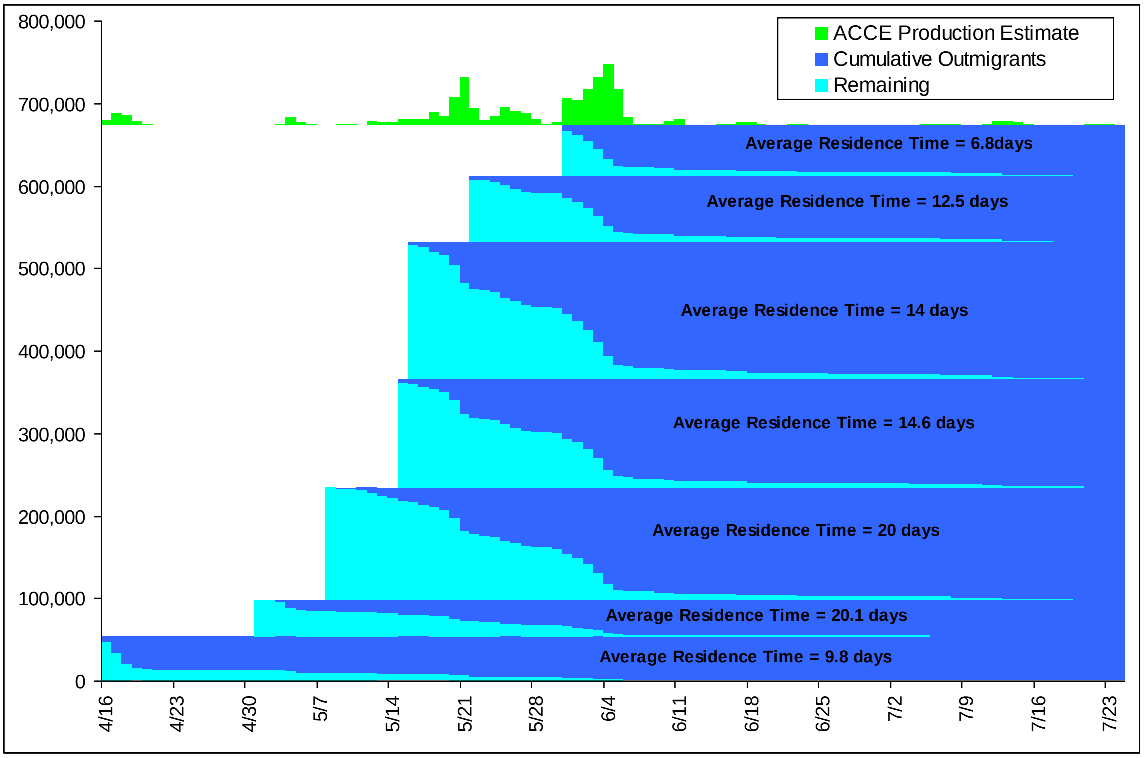


**Figure 7**. Model output showing cumulative outmigration, mortality, and adjusted-ACCE daily production estimates for seven groups of ad-clipped hatchery-origin Chinook smolts in 2007.

Similar modeling was also conducted using historical data for 2006, 2005, 2004, 2003, 2002, 2001, and 1999. Modeling could not be conducted for 2000 data because ACCE production estimates for marked fish in 2000 was nearly double that of the number of marked fish that were released. The reason for this large discrepancy is not known at this time, but one potential explanation could be that hatchery records may be erroneous for that year. Alternatively, low sampling effort combined with poor survival of marked hatchery fish may have strongly affected the measured recapture rate for ad-clipped fish in 2000. 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.

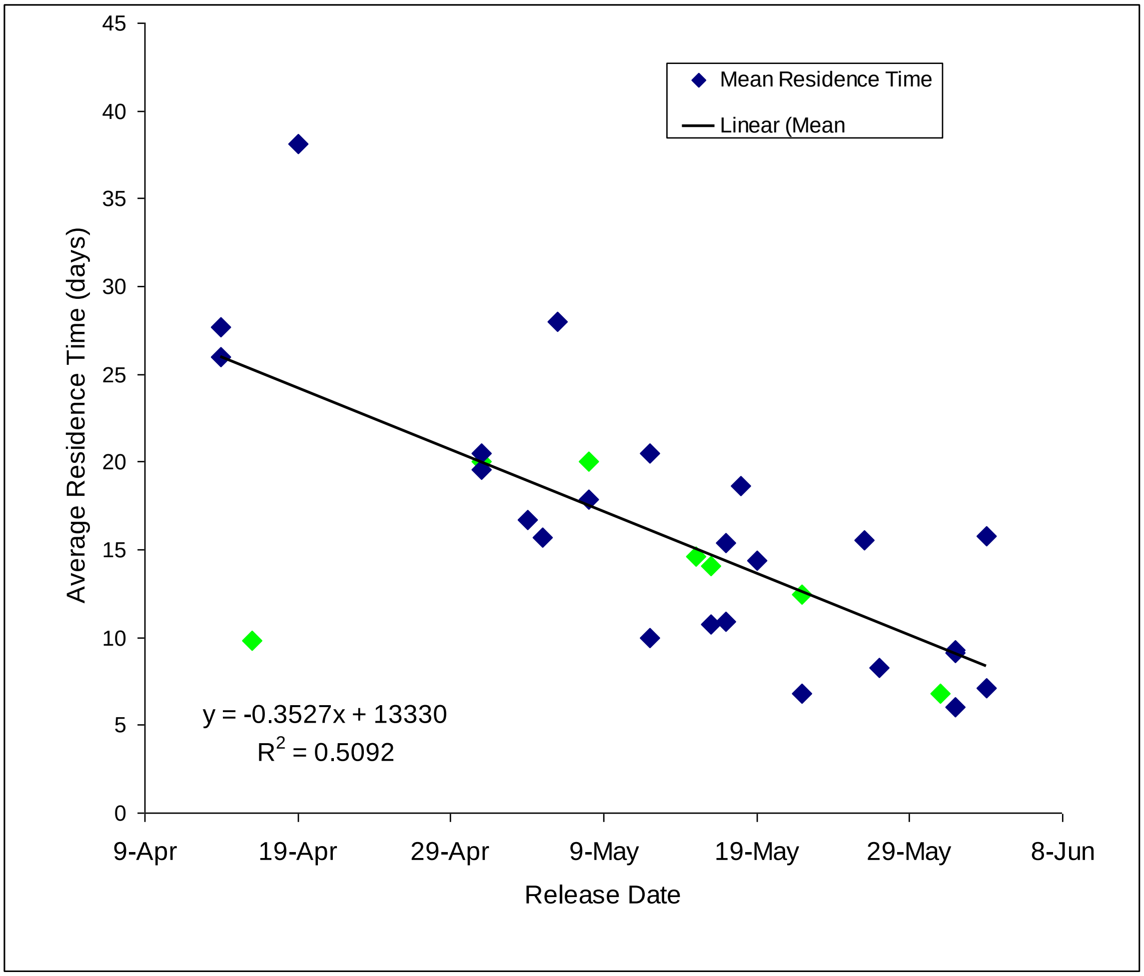


**Figure 8.** Modeled average residence time versus group release date for individually-modeled groups of marked hatchery Chinook smolts released in 1999, 2001, 2002, 2003, 2004, 2005, 2006, (navy) & 2007 (green).

Figure 8 shows the group residence times versus the release date based on historical trap data. Unfortunately, multiple groups being released into the river at different times confound the data from 2002, 2003, 2004, 2005, 2006, & 2007.

Although there appears to be a relationship between the timing of release and the modeled length of time that hatchery-origin smolts take to reach the trap site after release, the very first group released in 2007 did exhibit a fairly short residence time (9.8 days). This difference can be explained by a significant flow event that peaked at 11,800 cfs on 4/27/07 which undoubtedly flushed many of the released smolts downstream. Such events at the time of year are fairly rare: the last one occurring in 2000.

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 the system, 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.

**Wild-Origin Stock Composition**

Ultimately we are interested in estimating what the annual production of Spring Chinook smolts is from the Nooksack River. Unfortunately, in previous years we have had no direct means of counting these, as they were indistinguishable from wild-origin Fall Chinook or unmarked hatchery-origin Chinook. Consequently, we previously needed 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. However, beginning in 2005, almost 100% of the hatchery-origin smolts have been marked before release enabling us to directly separate hatchery smolts caught in the trap from wild-origin smolts (Figure 5).

Unfortunately, there is still no way to separate wild-origin Spring smolts and wild-origin Fall smolts from each other, save by comprehensive DNA analysis (to ascertain stock). With the advent of comprehensive marking of hatchery smolts we can now sample wild-origin smolts exclusively, thereby reducing the number (and therefore the cost) of DNA tests. Unfortunately, this kind of analysis is still prohibitively expensive. Nonetheless, DNA samples from a large percentage of wild-origin smolts has been collected from the 2005, 2006, & 2007 seasons in hopes that funding becomes available to allow the samples to be analyzed.

# Chinook Discussion

### Comparison of Production Estimate Methods over Time

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

The only confidence interval available for any of the estimates is the ACRM (= Peterson mark-recapture) method. In 2007, 2006, 2005, 2004, 2003, 2002, and 2000 the confidence intervals were remarkably tight (<5%) around the estimate. The estimates for 1999 and 2001 had worse confidence intervals, but they remained relatively 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 for each stock. That is, not all fish may have had an equal chance of being sampled. Consequently, the ACRM estimate and the associated confidence intervals should be considered with appropriate 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 assume that, historically, the number of wild-origin smolts wouldn't be high relative to the number of hatchery-produced smolts because we have observed that wild-origin adults have usually been a small proportion of the total adult return. (Because nearly 100% of hatchery smolts have been marked since 2005, this assumption has now been validated empirically by our trap data: 83%, 76%, and 91% of all smolts caught in the trap were definitely hatchery-origin in 2005, 2006 and 2007 respectively.)

Figure 6 shows the production estimates for the last 9 years that were derived using each of the three 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, and/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. Supporting this contention, both the YCCE and ACCE methods estimate a number that is approximately one half of the known hatchery release in 1999.

Unless the hatchery releases were subject to drastic mortality (disease perhaps?), these numbers are unlikely to be realistic.

Since 1999, the proportion of sampling effort conducted at night has increased considerably, particularly from 2002 – 2007. The ACRM, YCCE, and ACCE methods all agree closely for 2004, 2005, 2006, & 2007, and slightly less closely for 2002 & 2003. However, the three methods provide far less consistency prior to 2002, when the ACRM and YCCE methods produced estimates that were reasonably similar in magnitude but the ACCE method differed strongly. Why does the ACCE method diverge from the other two methods during 2000 and 2001?

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 given the amount of sampling effort). 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 estimate (ACCE) may be more realistic for the 2000 season. Also, although the sampling effort in 2000 was higher than 1999, it was still short of the effort expended in the following seasons. Consequently, large gaps in the sampling record may have resulted in pulses of fish being missed altogether as they migrated downstream.

In 1999 (ACRM only), 2001, 2003, 2004 (barely), 2005, 2006, & 2007 both the ACRM and YCCE methods estimated that the total production of Chinook fry from the river exceeded the number of hatchery-origin fry that were released. However, in 2000 and 2002 both of these methods estimated that the total production of fry from the river was *lower* than the number of hatchery-origin fry that were released. If true, then the production estimates for 2000 and 2002 are surprising, since we had assumed that hatchery-origin fry would have a fairly short stay in the river and experience only minimal mortality. Also, there ought to be at least *some* wild-origin fry outmigrating as well. This raises some serious questions about the assumptions used, or about the accuracy of the production estimates.

Obviously, the first question is whether these estimates are even in the right ballpark. Until now, we have attempted to answer this question by looking for consistency in the results in comparison to known hatchery releases. However, such an analysis is confounded when you are extrapolating from a small fraction of marked fish to estimate the seasonal hatchery production. Because we now have 100% marking, we are more accurately able to measure the bias in the ACCE and YCCE models. In 2005 the ACCE model overestimated the hatchery production by c. 27.53% while the YCCE method overestimated by c. 32.5%. In 2006 the ACCE model overestimated the hatchery production by 12.6% and the YCCE overestimated by 40.8%. In 2007, the ACCE model underestimated the hatchery production by 12.3% while the YCCE estimate overestimated this value by 16.1%.

Based on these numbers, it seems that the ACCE estimate generally exhibits a lower magnitude of bias compared to the YCCE estimate and should probably be preferred in years where the ACRM method is considered suspect. In 2005, 2006, and 2007, the adjusted ACCE estimate fell within the 95% confidence limit for the ACRM estimate.

The relatively close agreement between the ACRM and the ACCE & YCCE methods from 2002 onwards contrasts strongly with the wildly differing estimates that the three methods produced from 1999 – 2001. This validates the change in sampling protocols since 2002 that has increased the overall effort, begun to stratify sampling by dawn, day, dusk, and night periods, and aimed to minimize the length of the gaps in the sampling time-series to avoid missing pulses of fish moving downstream. It seems likely that these methods are producing results that are in the correct ballpark.

Leaving aside the question as to the accuracy of the production estimates, is it possible that some of the assumptions made regarding residence times, mortality, or wild production are erroneous? Unfortunately, most of these assumptions are difficult to test directly.

Muir *et al.* (1999) showed that that daily survival rates for marked hatchery-origin Chinook fry (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. None of the methods used in this analysis explicitly allow for smolt mortality. Actual recapture rates of marked hatchery smolts will be slightly higher than we report because we are assuming that no smolts die before reaching the trap site. Consequently, our estimates of production may be slightly biased too high for hatchery smolts. At an average residence time of 16 days with a daily mortality rate of 0.9% (half of that calculated by Muir *et al.*, 1999) you would expect around 13.5% of the marked hatchery smolts would perish before passing the trap site. This would mean that our recapture rate for 2007 was actually 0.634% instead of 0.548%, and the YCCE instantaneous catch efficiency would change from 2.03% to 2.35% and the ACCE instantaneous catch efficiency would increase to 2.77%. It turn, this would change the bias of the YCCE and ACCE methods to 0.4% and 14.8% respectively. Although wild-origin estimates would not be affected by this change, (results from these two methods are adjusted for perceived bias), such a change would reduce ACRM estimate of wild-production to 54,050 smolts in 2007 (instead of 62,486). Thus, it seems that the ACRM estimate method is most sensitive to a faulty assumption of no mortality between release and recapture.

Another possible bias could arise if some of the hatchery-origin fish had not moved downstream past 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 or tagged yearling Chinook smolts have ever been caught in the screw trap (except when clipped/tagged yearlings were also released upstream 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 zero-age chinook then we may have an indication that some hatchery fish may over-winter either 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. No further information is available to evaluate the likelihood or proportion of hatchery fish that could be accounted for in this way.

The main assumption that seems to be causing problems during data analysis is the constant catch efficiency assumption. We strongly suspect that trap catch efficiency varies depending on environmental conditions (turbidity, noise due to fast rotations etc). When salmon move in short-duration pulses, the catch efficiency during that short time could be quite different than the average for the whole season leading to an erroneous production estimate for that time frame. Unfortunately, our attempt to resolve this problem (secchi depth – catch efficiency trials) proved to be far too unreliable: even for the specific groups of hatchery-origin fish being used.

We also assume that wild fish behave like river-acclimated hatchery fish, and that catch efficiencies prior to hatchery releases are similar to those after hatchery releases. With the advent of ~100% marking in 2005, we can now see that the majority of wild smolts do have a similar outmigration pattern to hatchery fish, and that relatively few wild smolts outmigrate before hatchery releases begin. Consequently, even if this assumption is faulty, it should have relatively little impact on the wild production estimates unless the difference in catch efficiency is very large.

**Hatchery Chinook Residence Times**

In 2007 the shortest residence time was 1 day, and the longest residence time observed may have been as long as 55 - 100 days. Modeling results suggest that the average residence time for the first group was around 9.8 days; with the following groups averaging 20+ days, with the average residence time eventually declining to around 7 days.

For most of the smolts released in 2007, these results are consistent with the relationship generated in previous years. This relationship suggests that 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 zero-age Chinook are not without precedent. Unlike data from previous years, however, the first group of smolts released had a quite short residence time. In most years, river flows towards the end of April are usually fairly low and settled. However, in 2007 a moderately large flow event occurred which undoubtedly helped flush out the smolts that had been released approximately one week earlier. This unusually timed flow event probably explains the unusually short residence time for the first release group in 2007 and consequently it should probably be treated as an outlier.

Residence time modeling has provided a consistent pattern of residence times versus release date over several years of data ($p < 0.01$). Better release rate information for years when volitional releases were practiced (in earlier years) would probably result in only minor adjustments to the model results. 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.

Modeled daily survival rates of zero-age Chinook smolts in 2001, 2002, 2003, and 2004 were 99.21%, 99.66%, 99.43% and 99.17% respectively. These survival rates are all better than those for outmigrating zero-age Chinook smolts in the Snake River (98.16% surviving per day; Muir *et al*., 1999). This is likely because zero-age Chinook outmigrating from the Nooksack River do not have to contend with predator-filled impoundments or additional mortality associated with hydroelectric schemes present on the Snake River (e.g., turbine damage, oxygen-super-saturation, spillway turbulence, etc). However, these results should be taken with a grain of salt as we now know that both un-adjusted ACCE and YCCE methods can be wrong by up to 40% and calculating survival in years where the estimate for hatchery smolts is lower than the known release size is likely to be more influenced by the problems with the analysis method than by the sampling results.

## Wild-origin Chinook Production Patterns

The wild-origin production estimate for 2007 varies from **56,690** (ACRM method) to **58,800** (adjusted ACCE method) smolts.

The level of wild production in 2007 (Figure 9) is the second-worst in the last six years but only marginally above that of the lowest outmigration (recorded in 2000). Table III indicates that river flows in fall 2006 exhibited a large flow event (31,800 cfs at Ferndale) in early November during early egg incubation, and a smaller, but still significant, event occurred in January 2007.

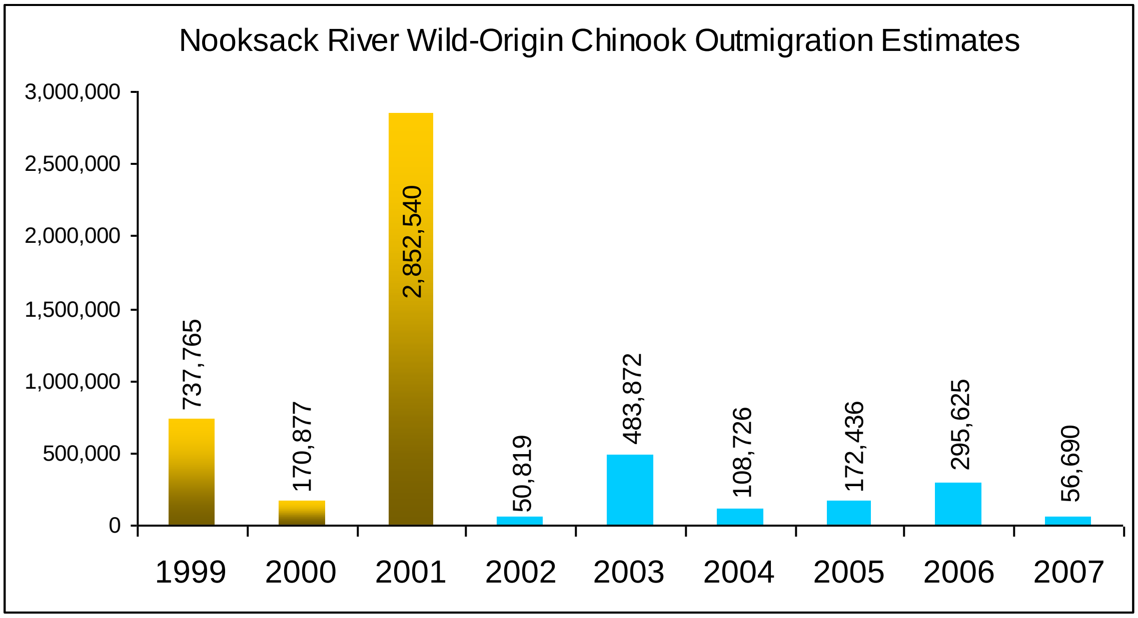


**Figure 9**. Wild-Origin Production Estimates from 1999 to 2007. Blue bars indicate estimates are probably reliable. Shaded-orange bars indicate data quality is not as good.

**Table III.** *Maximum monthly flows (cfs) in the Nooksack River at the Ferndale Gage Station. Red cells indicate severe flows that are most likely to cause scouring. Pink cells indicate years with spawning Pink Salmon. White cells indicate no pink salmon spawning occurred.*

| | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Max Jan | 23,200 | 10,300 | 14,300 | 4,890 | 7,640 | 24,100 | 13,900 | 11,700 | 29,000 | 16,000 | 17,700 |
| Max Feb | 8,470 | 5,680 | 9,500 | 5,160 | 2,900 | 27,500 | 8,210 | 6,700 | 5,480 | 9,510 | 8,710 |
| Max Mar | 33,700 | 8,160 | 7,180 | 5,860 | 5,810 | 5,760 | 16,200 | 6,970 | 6,400 | 2,850 | 23,700 |
| Max Apr | 10,100 | 5,730 | 5,730 | 13,800 | 5,100 | 15,700 | 7,740 | 4,040 | 10,400 | 5,340 | 11,800 |
| May May | 17,700 | 6,500 | 10,000 | 8,390 | 7,140 | 9,860 | 6,150 | 6,580 | 5,290 | 8,850 | 5,860 |
| Max Jun | 12,400 | 4,420 | 10,600 | 13,300 | 7,150 | 13,100 | 5,270 | 5,740 | 3,070 | 8,550 | 7,980 |
| Max Jul | 15,300 | 5,300 | 8,450 | 4,720 | 3,190 | 5,729 | 2,990 | 2,970 | 6,970 | 4,010 | 6,570 |
| Max Aug | 3,230 | 2,230 | 6,090 | 3,600 | 9,860 | 2,280 | 1,940 | 9,920 | 1,840 | 1,730 | 1,990 |
| Max Sep | 7,470 | 1,340 | 3,350 | 4,950 | 2,690 | 2,490 | 1,640 | 9,580 | 10,600 | 1,600 | 2,020 |
| Max Oct | 13,000 | 3,560 | 16,600 | 9,990 | 8,790 | 1,880 | 32,300 | 6,340 | 11,900 | 2,020 | 9,610 |
| Max Nov | 7,700 | 16,600 | 19,800 | 3,290 | 17,700 | 13,700 | 25,400 | 31,100 | 7,350 | 31,800 | 9,290 |
| Max Dec | 12,600 | 21,100 | 19,100 | 4,260 | 19,300 | 11,100 | 6,620 | 22,400 | 15,900 | 12,300 | 20,300 |
| | | Brood Year | | | | | | | | | |
| Wild Production Estimate (0+ Chinook Numbers) | | | 737,765 | 170,877 | 2,852,540 | 50,819 | 797,733 | 108,726 | 162,466 | 300,788 | 56,690 |
| | | | Zero-Age Migrants | | | | | | | | |
| Wild Catch / Hundred Hours (Yearling Chinook CPUE) Between 1/5 and 6/11 for yearlings | | | | 16.3 Yearling Migrants | 5.84 | 17.13 | 1.99 | 9.25 | 4.2 | 4.6 | 3.2 |

## Wild Chinook Outmigration Timing

The bulk of the wild outmigration in 2007 began with a small number of smolts detected during the descending limb of the hydrograph during some significant flow events in March. A slightly more pronounced pulse of smolts outmigrated in the second week of April, before the first release of hatchery smolts, but this declined to trickle for the following month when it began to pick up again and stayed consistent at low levels for another month. The wild outmigration peaked in early June immediately following a period of sustained higher flows. A trickle of wild fish continued to outmigrate right through to July when two more pulses of unmarked smolts occurred in mid and late July. Generally speaking, the outmigrant period for wild-origin smolts in 2007 was much less intense and more drawn out than in 2005 or 2006. It was especially notable how late in the season unmarked smolts continue to pass by the trap site this year.

Unlike recent years, no group of wild fish was detected at the trap site between Christmas 2006 and early February 2007. However, the presence of a small group of fish at this time of year is difficult to measure for a number of reasons. Firstly, sampling effort at this time of year is much lower than during the peak of the outmigration season. Secondly, the relative size of this group is thought to be quite small compared to the rest of the outmigrant population and they maybe unlikely to be encountered in a year with very low numbers of smolts.

# Coho

## 2007 Hatchery Releases

Table IV shows the data of release, hatchery, and numbers of hatchery-origin Coho yearling smolts released in the Nooksack River upstream from the screw trap location.

**Table IV.** *Coho Yearling Smolts released in 2007. Green columns indicate 'marked' Coho for the purposes of this report.*

| | Ad. Clip – CWT | Ad. Clip only | CWT only | No Clip – No CWT | Source |
|---|---|---|---|---|---|
| 18-May | 7,513 | 169,806 | 616 | 14,156 | Skookum Ck |
| 19-May | 5,146 | 116,308 | 422 | 9,696 | Skookum Ck |
| 20-May | 9,678 | 218,729 | 793 | 18,235 | Skookum Ck |
| 21-May | 7,608 | 171,947 | 624 | 14,335 | Skookum Ck |
| 22-May | 4,656 | 105,234 | 382 | 8,773 | Skookum Ck |
| 23-May | 49,701 | 226,333 | 49,402 | 1,764 | Kendall Ck |
| 23-May | 4,418 | 99,843 | 362 | 8,324 | Skookum Ck |
| 24-May | 3,356 | 75,855 | 275 | 6,324 | Skookum Ck |
| **Total** | 92,077 | 1,184,054 | 52,875 | 81,606 | |

## Coho Production Estimate Methods

There are four potential methods for quantifying Coho production based on smolt trap data.

### Adipose-fin Clipped Recapture Method (ACRM)

The first method is to use the percentage of marked (adipose fin-clipped) hatchery smolts that were captured in the trap after being released upstream, to convert the number of all smolts that were caught in the trap to an estimated total production assuming that the recapture rate is the same for marked and unmarked smolts. The calculations and assumptions underlying this method have been previously described in the Chinook methodology section. Using this method allows you to calculate a total production estimate but does not provide any information on the timing of migration during the season. Hatchery Coho with coded wire tags that are not also fin-clipped are not considered 'marked' because field crew at the trap do not use the detector wand on all Coho due to time constraints and the large quantities of Coho they encounter. This differs from Chinook because all Chinook are wanded.

In 2007 the first adipose-fin clipped Coho was detected on May 16$^{th}$, with several others being detected between May 16$^{th}$ and May 18$^{th}$: all prior to the first official release date provided by the two hatcheries. Based on historical trap catch efficiencies for marked Coho, and the proportion of time that was actively sampled during this pre-release period, it is likely that 7,283 marked Coho smolts passed by the trap site in the two days prior to the first release of marked Coho.

This information makes the mark-recapture calculation prone to bias if these additional fish are not added to the 'official' release numbers. However, it is difficult to know whether more Coho from this unofficial release might still remain upstream of the trap on May 18th when the first official release occurred. Consequently, even adding this estimated group magnitude is likely to result in an underestimate of the true number of marked fish released, which will mean an overestimate of the true recapture rate in 2007, and this in turn will cause a bias in the final estimate of unmarked Coho passing the trap site.

**Time-series based production estimate methods…**

The remaining three methods attempt to create a time series of catch-per-hour measurements for the entire outmigration period, and then convert this time-series into production (all fish passing the trap site) per hour using a trap-specific catch efficiency estimate that is derived in different ways. Summing the hourly production estimates over the entire outmigration period provides an estimate of total production. All of the methods that use this time series as a basis explicitly make predictions as to the magnitude and timing of outmigration past the trap site.

The time-series of catch per hour data for Coho is created using trap catch rates stratified by day versus night sampling periods. Intervals between sampling periods are assumed to be related primarily to catch rates during other portions of the same 24-hour period. That is, if night time sampling data is available for a particular 24-hour period, then the day time value is assumed to be a function of the night time sample. This relationship is derived from a regression of a scatter plot of day versus night catch rates. For days in which no sampling data is available at all, catch rates are interpolated linearly within sampling strata between known days for which data is available. As an example, if catch rates during the day on May 12th were 4 smolts per hour, and catch rates during the day on May 14th were 2 smolts per hour, then the rate used for daytime on May 13th would be 3 smolts per hour.

**Year-Specific Constant Catch Efficiency Method (YCCE)**

Marked fish that are caught in the trap either have their adipose-fin clipped, or they have a coded wire tag implanted, or both, and are released from hatcheries in the upper watershed. The number of these released, marked fish are known and reported by the hatchery. Consequently, it is possible to determine what percentages of the released fish are recaptured at the trap over the period of the outmigration season. However, because the fish do not all go past the trap en-masse this value is unlikely to represent the true catch efficiency of the trap. Moreover, the trap does not operate 24-7 during the entire outmigration period and, consequently, many individuals that would have been caught if the trap were operating are never captured at all. Obviously, the actual recapture rate results from a combination of instantaneous trap catch efficiencies, the timing of outmigration, and the duration and timing of the trap sampling activities during the outmigration period. However, we do know exactly when the trap was operating and it is therefore possible to estimate the *average* instantaneous catch efficiency of the trap during the outmigration season.

- We know that if we did no sampling at all while the fish were outmigrating then we would have caught no fish.
- We know that we sampled a certain percentage of the possible time during the period when the marked smolts were outmigrating past the trap site (this period defined as beginning on the day that the first marked smolt is caught and ending on the day that the last marked smolt is caught).
- We also know what percentage of the marked fish was recaptured during the outmigration period.
- Generally we assume that the timing of sampling within the outmigration period is not important but it would be better to sample evenly throughout the outmigration period for this number to be realistic.

By assuming that the number of fish captured is a linear function of how much time is spent sampling during the outmigration period, we can plot a line on a chart showing recapture rate versus the proportion of the outmigration period that was sampled. One end of the line would be at the origin (0% recaptured, 0 time sampled) and the other end of the line would be the actual recapture rate at the known proportion of time sampled. The slope of the line represents the average instantaneous catch efficiency of the trap for that year's outmigration period.

This value is calculated separately for each year's results, and then used to transform catch per hour data into production-per-day data separately for each year.

**Average Constant Catch Efficiency Method (ACCE)**

One of the problems of the YCCE method is that the timing of Coho outmigration appears to be typically rapid for the majority of the hatchery production (2 - 6 days) with a few stragglers outmigrating in low numbers for the remainder of the outmigration period. If environmental conditions during that short period of high-intensity outmigration are unusual, or if the trap operating hours within that time period are greatly different than for the remainder of the outmigration period, then it is possible that the catch efficiency determined by the YCCE method could be unrealistic, and thus greatly distort the production estimate for that year.

One way to avoid year-specific problems with the timing and magnitude of sampling effort within the outmigration period would be to standardize effort at the highest level for the entire outmigration period. Unfortunately, that is logistically beyond our means. One alternative approach would be to step back from year-specific predictions of catch efficiency and use the average catch efficiency calculated from data collected over several years (YCCE method catch efficiencies). This can be done by plotting several years observed recapture percentage versus the proportion of the outmigration period sampled in each year. Since we also know that no effort equals no fish, we regress the data points using a line that passes through the origin. This time, the slope of the regression is the estimated average constant catch efficiency (ACCE) of the trap over a period of years.

This single catch efficiency value can then be used to transform catch per hour data for all years into production per hour data, and therefore total production estimates also. Obviously, with each new year's data, the average value will change and the production estimates for each year will then need to be recalculated.

The risk to this approach is that if actual trap catch efficiencies are non-average during the peak outmigration period then using an average catch efficiency calculated across several years could strongly bias the resulting production estimates. The only way to remove this risk, and to simultaneously avoid the risk of differential sampling effort within the outmigration period, would be to use the YCCE method, but maintain consistent relative effort throughout the entire outmigration period. Of necessity, the amount of effort should be as high as possible.

Another serious issue with both the ACCE and YCCE methodologies is that Coho smolts are known to migrate primarily at night, and move closer to the surface at night which ought to mean that the trap should have a higher catch efficiency for Coho at night than it does during the day. Unfortunately, there is presently no way to reliably separate out the trap catch efficiencies for day vs night sampling for Coho because we have no way to independently and accurately measure the number of fish moving past the trap site in each time period. Any attempt to use the trap catch rates to estimate the numbers of Coho passing the trap at night versus day is hopeless because the trap catch rate is a function of both the number of fish moving downstream and the instantaneous catch efficiency of the trap. You cannot measure one factor without knowing the other. Moreover, yearling smolts are more competent at evading capture than zero-age smolts/fry and, consequently, the catch efficiency for yearling smolts will be much lower than for zero-age fish. This, in turn, means that expansion factors will be larger and any error is likely to be magnified by a similar degree.

Nonetheless, when we plot separate scatterplots of actual recapture percentage versus the proportion of the outmigration period that was actually sampled at night and at dawn/day/dusk time strata we find that night sampling is a better predictor of Coho catch rates and generally results in higher estimates of trap catch efficiency than day sampling rates. This is consistent with the hypothesis that Coho smolts are more likely to be caught by the trap at night. However, because we cannot separate the actual recapture rate for day and night sampling, the scatterplots are likely to underestimate Coho catch efficiencies at night and over estimate catch efficiencies during the day. Since Coho are known to move downstream primarily at night, this problem is most likely to result in an overestimate of the Coho production rate.

## Coho Production Estimate Results

### Adipose-fin Clipped Recapture Method (ACRM)

**Table V** *Results obtained using the ACRM method for smolt trap data from 1999 to 2007.*

| Year | 2007 | 2006 | 2005 | 2004 | 2003 | 2002 | 2001 | 2000 | 1999 |
|---|---|---|---|---|---|---|---|---|---|
| Total Production Estimate ($N_P$) | **1,939,050** | **2,082,277** | **2,280,573** | **2,693,075** | **1,988,042** | **2,077,633** | **2,162,813** | **2,260,919** | **4,640,808** |
| Known Hatchery Releases (H) | **1,417,895** | **1,316,788** | **1,245,234** | **1,241,005** | **1,403,100** | **1,304,831** | **1,230,747** | **1,429,200** | **2,669,737** |
| Wild Production ($N_P$-H) | **521,155** | **765,489** | **1,035,339** | **1,452,070** | **584,942** | **772,802** | **932,066** | **831,719** | **1,971,071** |
| Ad-Clips Released ($N_1$) | 1,283,414 | 1,170,806 | 1,198,134 | 1,193,205 | 1,353,300 | 1,225,031 | 1,170,747 | 1,365,635 | 320,465 |
| Total Coho Caught ($N_2$) | 2,993 | 4,384 | 3,489 | 2,898 | 4,056 | 5,997 | 3,946 | 2,937 | 782 |
| Ad Clips Recaptured ($M_2$) | 1,981 | 2,465 | 1,833 | 1,284 | 2,761 | 3,536 | 2,136 | 1,774 | 54 |
| Observed Recapture Rate ($M_2$/$N_1$) | 0.15% | 0.21% | 0.15% | 0.11% | 0.20% | 0.29% | 0.18% | 0.13% | 0.02% |
| Variance ($N_P$) | 639,683,736 | 767,262,913 | 1,342,138,235 | 3,133,772,188 | 455,562,613 | 499,032,987 | 1,001,065,168 | 1,137,357,243 | 345,516,755,075 |
| 95% Confidence Interval Width | 49,572 | 54,291 | 71,805 | 109,721 | 41,834 | 43,785 | 62,014 | 66,100 | 1,152,101 |

Table V shows the parameters and results obtained using the ACRM/Peterson's Mark-Recapture method for smolt trap data in 2007 and earlier seasons. The magnitudes of ad-clip Released Coho and Known Hatchery Releases that are shown in Table V include 7,283 additional marked smolts that are estimated to have passed the trap site between May 16$^{th}$ and May 18$^{th}$ (before the first official release). The production estimates are also presented graphically in Figure 10.

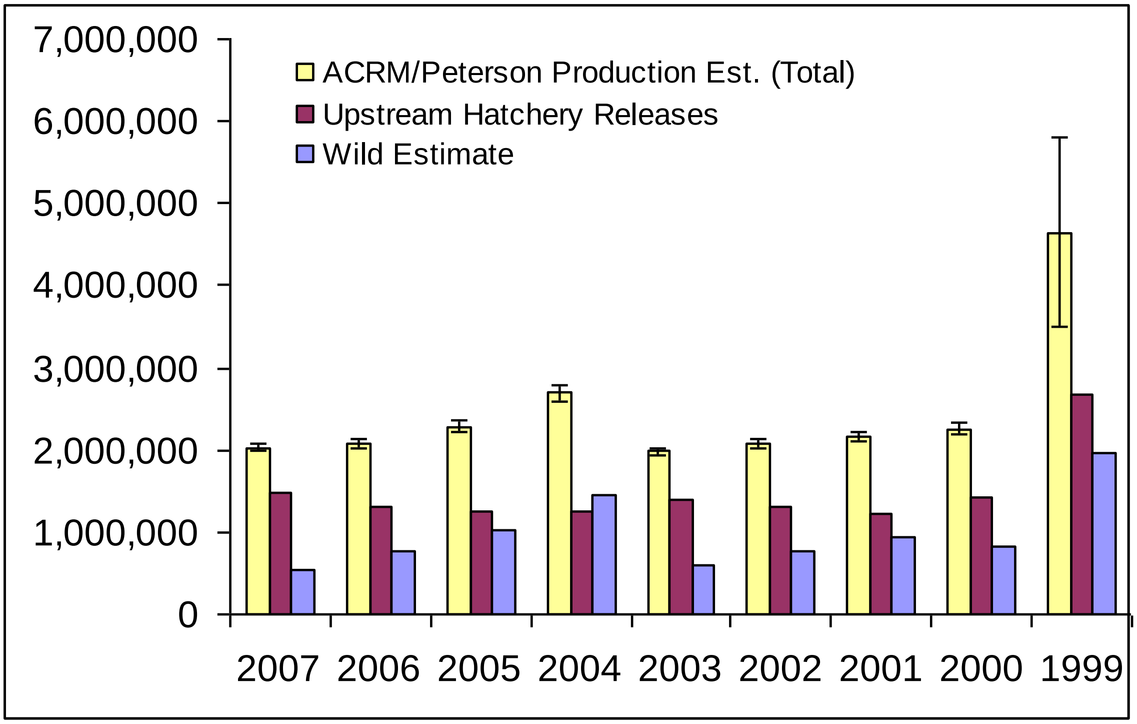


**Figure 10.** ACRM / Peterson Mark-Recapture Production Estimates for Coho Yearling smolts outmigrating from the Nooksack River (+/- 95% CL).

Based on the data in Table V it appears that c.1.9 million Coho smolts outmigrated in 2007. We know that 1.41 million smolts were released from hatcheries above the trap-site, and this suggests that the difference is comprised of wild-origin smolts (~**0.52 million**). However, it is important to remember that one of the primary assumptions in this estimate is that the population is demographically closed: that is, no mortality occurs between release and recapture of the marked fish. Unfortunately we have no means to measure post-release mortality of marked hatchery fish in the river.

In other river systems daily mortality rates of hatchery-released smolts are very low in unobstructed stretches of river. If this is true for the Nooksack River also, then it is likely that overall mortality of the fish is also low…especially since we are confident that their residence time is only a few days. However, it is likely that the measured recapture rate is probably biased slightly lower than the true recapture rate. This will have the effect of artificially biasing the final production estimate slightly too high which will artificially inflate the wild production estimate by an unknown amount. On the other hand, when we subtract the total hatchery release from the (presumably slightly too high) ACRM production estimate we do not factor in this mortality of hatchery-released smolts either. This would have the effect of artificially reducing the wild-production estimate by an amount directly related to the actual mortality of hatchery-released smolts. So, on one hand the faulty assumption of nil mortality would increase the wild-production estimate, and simultaneously it would decrease it by a different amount. To quantify which 'bias' would dominate requires a good understanding of daily mortality rates for hatchery-origin smolts as well as a thorough knowledge of residence times. Lacking specific knowledge of true mortality rates, it is instead possible to model different scenarios to determine how sensitive the estimate is to varying levels of mortality. Accordingly, I have constructed a theoretical plot (Figure 11) showing the overall effect on the ACRM estimate when mortality ranges from 0% (no mortality) to 25% (25% of all hatchery-released smolts die before reaching the trap site).

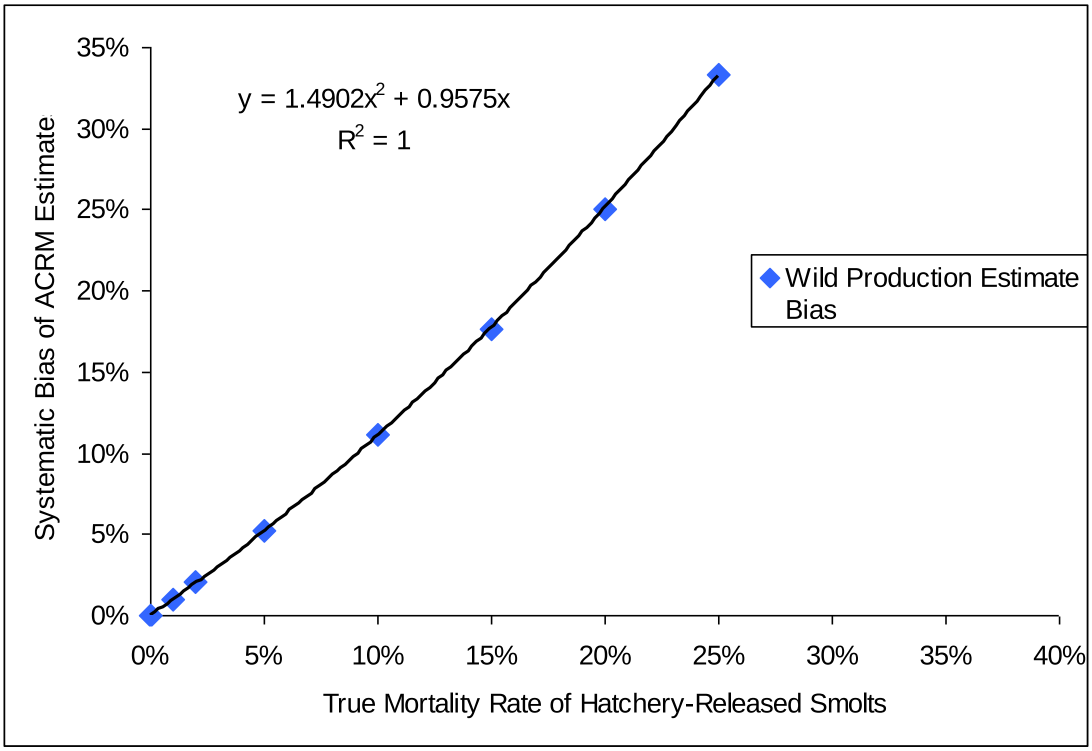


**Figure 11.** Plot of modeled ACRM bias magnitude compared to theoretical group mortality rates for hatchery-origin smolts prior to reaching the trap site.

Based on the modeling of hatchery-origin smolt group mortality rates, it appears that the ACRM estimate tends to over-estimate the true outmigration by a percentage that can be described by the equation $y = 1.49*M^2 + 0.96*M$; where *y* is the percentage bias, and *M* is the group mortality (%) of hatchery-origin smolts. This relationship also describes the bias of ACRM estimates for total Coho, hatchery Coho, and Chinook fry estimates as well. Consequently, if 5% of all hatchery smolts that are released were to die before reaching the trap (or else become resident upstream until after sampling ceases), then the overall ACRM production estimates for hatchery and wild-origin smolts would both be

$$\begin{aligned} \text{Bias} &= 1.49 * 0.05^2 + 0.96 * 0.05 \\ &= 0.052 \text{ (3dp)} \\ &= 5.2\% \end{aligned}$$

This modeling does not factor in any bias introduced by the presence of an unknown number of marked Coho that were present in the river a week prior to the first official release.

**YCCE/ACCE Method Results**

Figures 11 and 12 show scatter plots of the season-wide recapture rate of hatchery Coho smolts plotted against the proportion of the nighttime hatchery outmigration period that was sampled, and against the proportion of the dawn/day/dusk outmigration period that was sampled respectively.

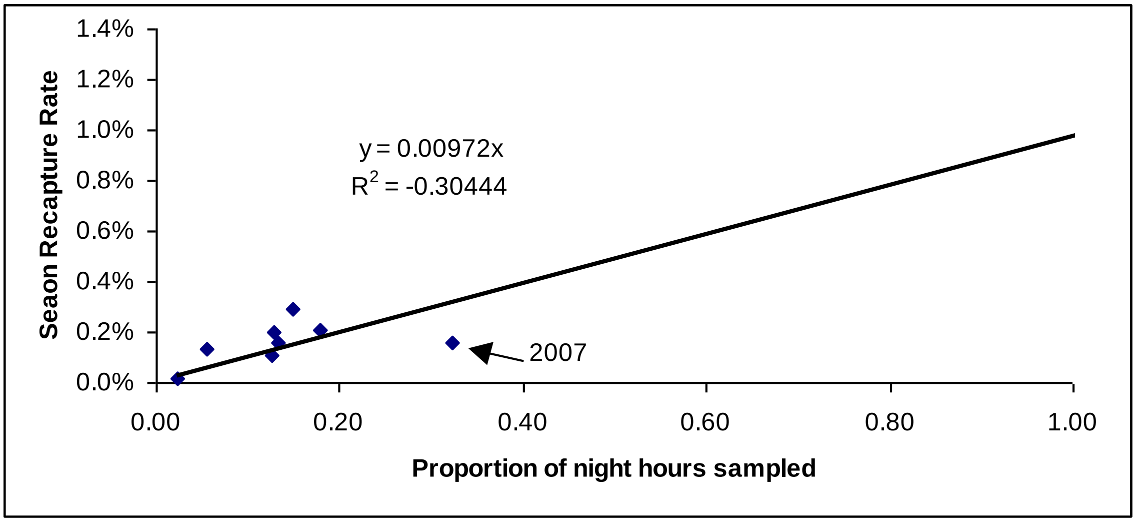


Figure 11. Coho recapture rate versus proportion of nighttime sampled during the outmigration period

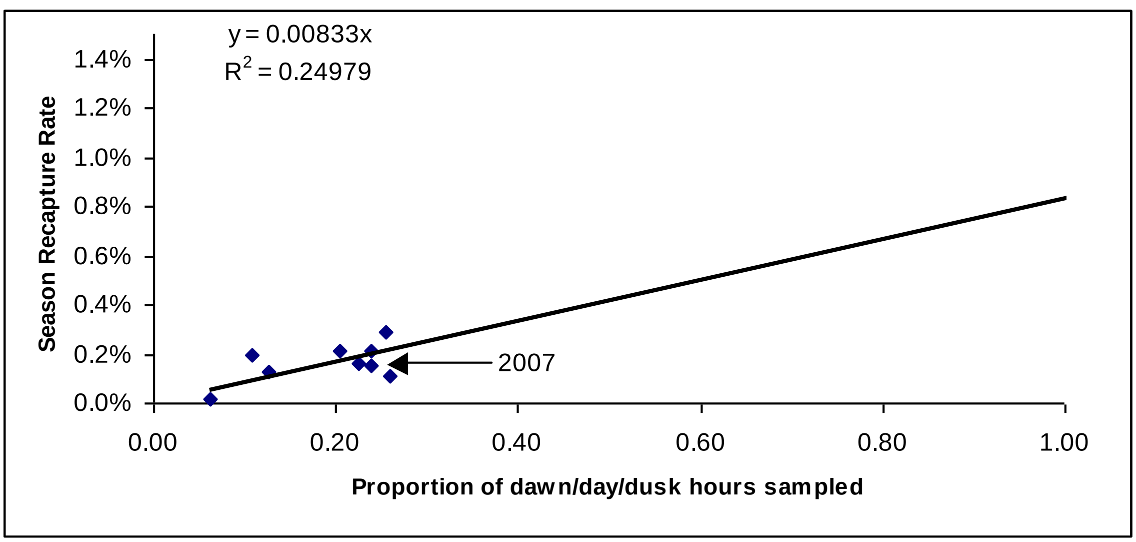


Figure 12. Coho recapture rate versus proportion of the hatchery outmigration period sampled at dawn, day, and dusk times

The YCCE estimate for nighttime catch efficiency was 0.48% and for the daytime was 0.88%. The ACCE estimate for nighttime catch efficiency was 0.972% and for the daytime was 0.832% (overall ACCE was 0.907%).

Both methods use the interpolated trap catch per day data (summarized in Figure 13) to extrapolate catch data based on constant catch efficiencies but stratified by sampling time (i.e., night vs. day).

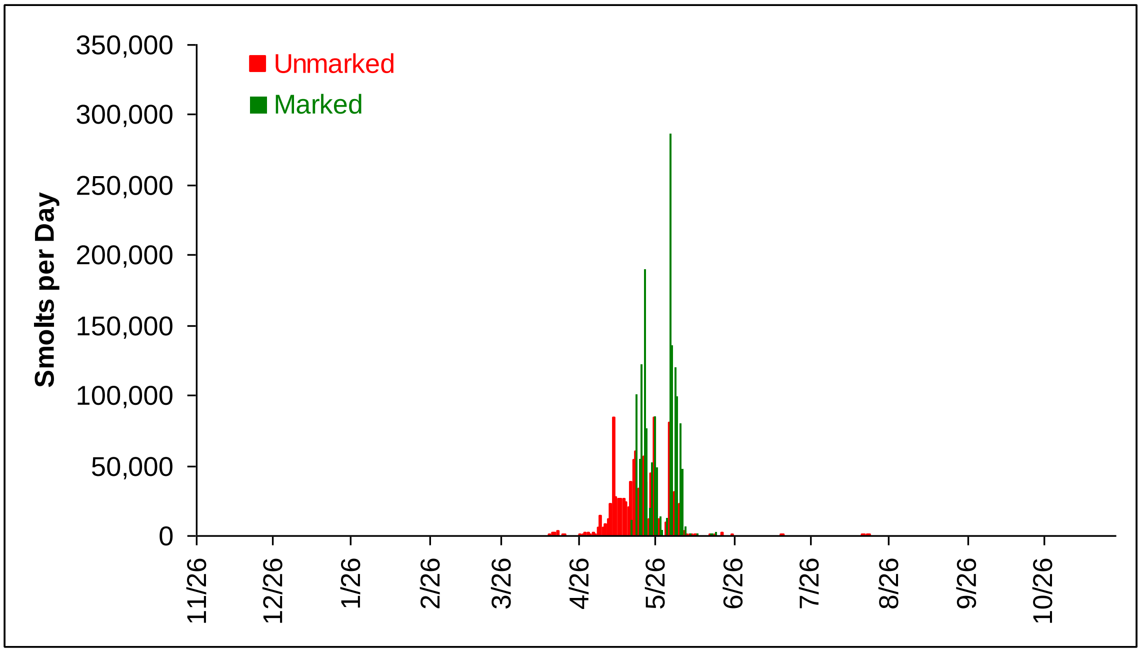


**Figure 13.** Average daily catch rates for adipose fin-clipped and non clipped Coho yearlings in 2007.

As we have seen previously, hatchery fin-clipped Coho smolts outmigrate over a relatively short time span, en-masse. Un-clipped (presumably wild) Coho yearlings tend to outmigrate over a longer time period. This probably indicates that ACCE and YCCE production estimates for hatchery smolts are likely to be more adversely affected by an erroneous assumption of constant trap catch efficiencies than wild Coho. Both groups are still likely to be affected by an underestimation of nighttime catch efficiencies though since wild and hatchery origin smolts swim closer to the surface at night and the true number of marked smolts passing the trap site during the night and during daylight is unknown.

Using the overall ACCE catch efficiencies the total production of ad-clipped Coho yearlings for 2007 is 985,011 smolts and the total production of un-clipped smolts is 697,727 smolts. Using the YCCE catch efficiencies, the clipped production would be 1,567,376 clipped smolts and 1,110,241 unclipped smolts. However, we know that 1,283,414 clipped smolts were released in 2007 making the ACCE estimate 23.3% too low for clipped hatchery smolts, and the YCCE estimate 22.1% too high.

Adjusting the ACCE and YCCE estimates for unclipped Coho to account for this bias would result in an estimate of ~ 909,098 unmarked Coho smolts passing the trap site in 2007. Of these, we know that around 134,481 were unclipped hatchery-origin smolts. Thus, a wild production estimate for 2007 derived using the ACCE or YCCE estimation methods would be **774,618** wild-origin smolts.

**Residence Time Modeling for Coho**

Residence times were not modeled for 2007 due to the presence of adipose-clipped yearling Coho in the river prior to the fist official release. Since it is not possible to accurately estimate the date of release or the true magnitude of the released group of clipped Coho, there is no way to quantify the residence times in 2007 without making assumptions that will directly influence the results of the modeling. However, the general pattern of outmigration in 2007 does appear to follow the pattern of previous years whereby hatchery Coho move rapidly out of the river within a few days after they have been released.

## Screwtrap Sampling Mortality Results

Table VI shows the total number of individuals handled during screwtrap operations in 2007 grouped into species, life-stage, and mark status (marked means an Adipose fin clip, coded wire tag, or both were present), and split into those individuals that were released alive and those that were not released alive (morts). The causes of mortality were generally related to inundation of the trap by debris, but also include individuals that were thought to be dead on arrival or deliberately sacrificed for DNA analysis.

***Table VI**. Summary of Individuals Released Alive vs. Mortalies during Screwtrap operations in 2007 by Species, Lifestage, and Mark Status.*

| Species | Lifestage | IsMarked | Morts | Released Alive | Total | % Morts |
|---|---|---|---|---|---|---|
| Bass | Not Recorded | Unmarked | 0 | 279 | 279 | 0.0% |
| Bulltrout/Char | Not Recorded | Unmarked | 0 | 1 | 1 | 0.0% |
| **Chinook** | **Yearling** | **Unmarked** | **0** | **23** | **23** | **0.0%** |
| Chinook | Zero-Age | Marked | 61 | 3627 | 3688 | 1.7% |
| **Chinook** | **Zero-Age** | **Unmarked** | **3** | **362** | **365** | **0.8%** |
| Chum | Not Recorded | Unmarked | 42 | 8047 | 8089 | 0.5% |
| Chum | Mature Adult | Unmarked | 0 | 1 | 1 | 0.0% |
| Coho | Yearling | Marked | 56 | 1925 | 1981 | 2.8% |
| **Coho** | **Yearling** | **Unmarked** | **51** | **1582** | **1633** | **3.1%** |
| Coho | Zero-Age | Unmarked | 0 | 4 | 4 | 0.0% |
| Cutthroat | Not Recorded | Unmarked | 0 | 2 | 2 | 0.0% |
| Dace | Not Recorded | Unmarked | 0 | 114 | 114 | 0.0% |
| Lamprey (eyes) | Not Recorded | Unmarked | 0 | 393 | 393 | 0.0% |
| Lamprey (no eyes) | Not Recorded | Unmarked | 0 | 50 | 50 | 0.0% |
| Mountain Whitefish | Not Recorded | Unmarked | 0 | 9 | 9 | 0.0% |
| Polywog (Tadpole) | Not Recorded | Unmarked | 0 | 1 | 1 | 0.0% |
| Pumpkin Seed | Not Recorded | Unmarked | 0 | 5 | 5 | 0.0% |
| Sculpin | Not Recorded | Unmarked | 0 | 22 | 22 | 0.0% |
| Sockeye | Not Recorded | Unmarked | 0 | 16 | 16 | 0.0% |
| Steelhead | Not Recorded | Unmarked | 1 | 146 | 147 | 0.7% |
| Steelhead | Juvenile | Unmarked | 0 | 1 | 1 | 0.0% |
| Steelhead | Sub-Adult | Unmarked | 0 | 1 | 1 | 0.0% |
| Stickleback | Not Recorded | Unmarked | 0 | 299 | 299 | 0.0% |
| Sucker | Not Recorded | Unmarked | 0 | 1 | 1 | 0.0% |
| Trout - Indeterminate | Zero-Age | Unmarked | 0 | 17 | 17 | 0.0% |

Because summary tables in previous reports did not break down mortality totals by life-stage or mark status, the data from Table VI is also shown again in Table VII to enable a direct comparison with previous years.

***Table VII**. Summary of Individuals Released Alive vs. Mortalies during Screwtrap operations in 2007 by Species only.*

| Species | Morts | Total Handled | Percentage Mortality |
|---|---|---|---|
| Bass | 0 | 279 | 0.00% |
| Bulltrout/Char | 0 | 1 | 0.00% |
| Chinook | 64 | 4076 | 1.57% |
| Chum | 42 | 8090 | 0.52% |
| Coho | 107 | 3618 | 2.96% |
| Cutthroat | 0 | 2 | 0.00% |
| Dace | 0 | 114 | 0.00% |
| Lamprey (eyes) | 0 | 393 | 0.00% |
| Lamprey (no eyes) | 0 | 50 | 0.00% |
| Mountain Whitefish | 0 | 9 | 0.00% |
| Polywog (Tadpole) | 0 | 1 | 0.00% |
| Pumpkin Seed | 0 | 5 | 0.00% |
| Sculpin | 0 | 22 | 0.00% |
| Sockeye | 0 | 16 | 0.00% |
| Steelhead | 1 | 149 | 0.67% |
| Stickleback | 0 | 299 | 0.00% |
| Sucker | 0 | 1 | 0.00% |
| Trout - Indeterminate | 0 | 17 | 0.00% |

The majority of mortalities in 2007 originated from one set conducted on May 31 where 30 unmarked Coho, 74 marked Coho, 38 marked Chinook, 1 Chum, and 1 Steelhead were killed by an unexpectedly large amount of debris that collected in the cone of the trap.

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