A review of data analysis from the 2002 smolt trap program on the Nooksack River at Ferndale

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9/23/2003

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 2002 the smolt trap was operated from February 15th through to October 3rd. Initial sampling consisted of 6-hour sets conducted every 2 – 3 days. Starting on the 8th of May, these were supplemented by a series of 14 '24-hour' sets, which consisted of multiple 2-hour sets conducted sequentially. The actual length of these '24-hour' sets varied from as low as 16 hours up to 26 hours. The last of these '24-hour' sets was conducted on July 24th and the sampling intensity was reduced to one 6-hour set conducted on a weekly basis from September onwards. A summary of the sampling program and overall results is provided in the appendices.

The addition of the 24-hour sets, broken into 2-hour increments, allowed for diurnal trends in fry and smolt capture to be analyzed, as well as for associations between high catch per unit time and certain physical parameters such as secchi disk depth (water visibility) and flow to be examined. Moreover, because the 24-hour sets allowed within-day variation to be measured for the first time, this allowed an objective analysis of possible sampling periodicities to be made. This sampling periodicity analysis enables managers to better plan the field schedule to optimize the use of available resources.

This report aims to report the results of the sampling program in 2002, 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. In addition to the forementioned objectives, this report also seeks to outline an optimal sampling strategy for 2003 that would provide the most robust data for analysis of the 2003 production of Chinook fry and Coho smolts from the Nooksack River.

2002 Chinook 0+ Analysis

Summary

The first record of Chinook fry outmigration occurred on Feb 19th and the last record was on October 3rd, but the bulk of the outmigration occurred between mid-April and the end of July.

Smolt trap capture rates for marked and unmarked Chinook 0+ fry were used, along with secchi depth capture rate estimates, to estimate daily and seasonal production rates for marked and total fry production from Feb 15th to October 3rd 2002. This method has been used previously to calculate production estimates for other years and the results are presented here for comparison. The season-wide recapture rate of marked fish was also used to estimate total fry production for all Chinook fry caught. Equivalent estimates for other years are also presented for comparison. The first method estimated a total production of 1.5 million Chinook fry in 2002 and the second method estimated approximately 1 million Chinook fry outmigrated in 2002. The estimate of 1.5 million fry is within the range of estimates derived for other years using the same method. Since over 1.75 million fry were released from hatcheries, and wild fry were also present, it is apparent that mortality after release has to be an important consideration in production estimates for Chinook fry.

Daily modeling of marked and unmarked smolt populations in the river suggest that daily survivorship rates are high (98.5% and 91.1% for hatchery and wild fry respectively) but that residence times are potentially long (average residence time up to 38 days for one released group depending on the assumptions made). The combination of long residence times and low daily mortality rates still suggests that a significant proportion (~ 26%) of the hatchery-released fry do not live to outmigrate. More information on over-wintering rates of hatchery fry would help clarify what proportion if the estimated 'mortalities' may still be alive and simply waiting for the following spring. There is also a need for empirical data to test whether the estimates of daily mortality/survivorship are accurate.

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.

Results

Figure 1 shows the average catch of Chinook fry per hour for each week that was sampled in 2002. Table I outlines the timing, magnitude, and details of hatchery releases in 2002.

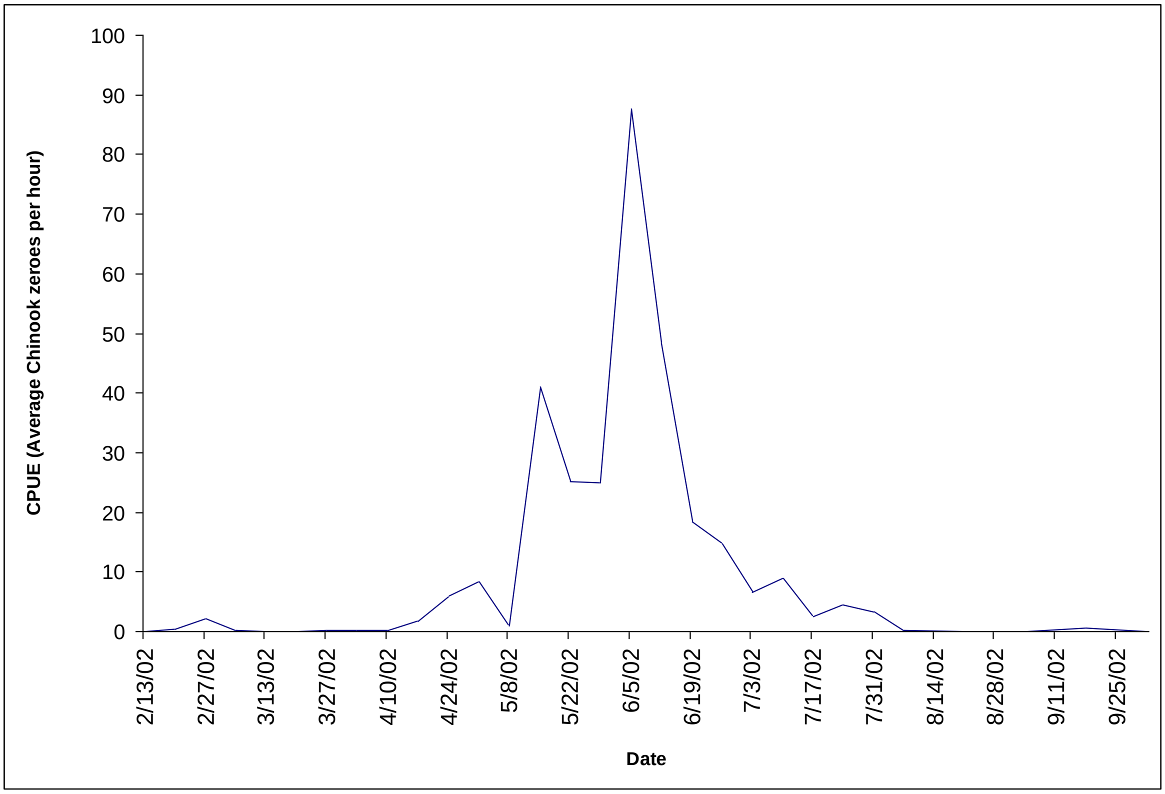

Figure 1. Average weekly catch per hour in 2002 for Chinook fry.

Table I. *Details of Hatchery releases of Chinook Fry in 2002*

Date	Site	Ad-clipped	Coded Wire Tagged	Total
4/11-4/22	Deadhorse Pond	0	0	217,400
4/27-5/6	Kidney Creek	0	0	194,000
4/27-4/30	Excelsior Trib	0	0	56,800
19-Apr	Kendall Creek	102,900	205,600	226,500
5/4-5/9	Deadhorse Pond	0	0	224,000
5/11-5-13	Excelsior Trib	0	0	54,900
5/5-5/8	Middle Fork	0	0	54,900
5/6-5/7	Middle Fork	0	0	168,000
5/21-5/31	Deadhorse Pond	0	0	227,300
5/22-5/24	Excelsior Trib	0	0	55,100
5/30-5/31	Excelsior Trib	0	0	50,300
6/1/02	Kendall Creek	102,600	205,000	216,500
		205,500	**410,600**	**1,745,700**

Chinook Production Estimates

Method 1. Estimating daily productions & interpolating between days

The average hourly catch rate for each sampled day was divided by the catchability factor to determined the average hourly production rate for that day. The catchability factor is obtained from the equation:

$$\text{Catchability} = 0.06138 * 1/x - 0.01682$$

…Where x represents the average, unlit secchi depth in feet. Minimum catchability was capped at 0.05% (1 twentieth of 1 percent) in order to avoid negative catchability and to avoid ridiculous multiplication factors of thousands. Typically catchability averaged 2.56% during the season but ranged from 0.05% up to 10.59%.

The average hourly production rate for each sampled day was then multiplied by the number of hours in the day (24) to obtain the daily production estimate for each sampled day.

Daily production estimates for days that were not sampled were estimated by linearly interpolating between sampled days. The daily production estimates for each day in the outmigration season were then summed in order to create a final estimate of the seasonal production.

Results

Table II (continued on 5 pages) shows the total daily production estimates during the season for all Chinook 0+ fry as well as just for the marked hatchery fish. Using this method, an estimated **1,505,645** Chinook 0+ fry are estimated to have outmigrated past the trap. Of these, 302,804 fry were marked hatchery fish.

When applied to data from the previous 3 years this method results in total Chinook fry production estimates of 1,428,903 for 1999, 7,036,072 for 2000, and 3,773,258 for 2001. The extremely high variability of these results suggest that the nature of the catch efficiency relationship is not well-enough understood and probably leads to inaccurate and occasionally unrealistic estimates (such as for 2000).

Method 2. Season-wide mark-recapture rates used to back calculate season-wide production.

Although the majority of hatchery fry are not visibly marked, two significant releases of fry were marked this year. The first release (April 19) consisted of ~ 102,900 adipose fin clipped fry and 205,600 coded-wire tagged fry. The second release (June 1st) consisted of 102,600 adipose fin clipped fry and 205,000 coded-wire tagged fry. Because these marked fish could be separated out from other fish in the smolt trap catch it is possible to track their capture rate over the season. Because we know how many were released into the Nooksack, and we know how many were caught at the smolt trap, it is possible to calculate a simple proportion that represents the catchability of these hatchery fry averaged over the length of the season. Since we know the catchability of this group of fish over the season, and we also caught a number of other fishes of unknown origin in the same sets, we could assume that the same catchability rate would apply to all fish caught in the trap during those sets. To determine how large a group the entire catch represents would therefore require dividing the total number of fry caught in the smolt trap during the season by the seasonal catchability factor.

However, this procedure would be biased if CWT fry data were used because the smolt trap crew did not always ‘wand’ every fish—particularly during very intense catches when time was limiting. In other words the detection rate for CWT fish was below 100% whereas the detection rate of adipose fin clipped fish in the catch was probably very close to 100%. Consequently, I have limited my analysis of the seasonal catchability only to adipose fin clipped fishes.

Results

A total of approximately 1,475 adipose fin clipped Chinook fry were caught at the trap during the season. A total of 205,500 adipose fin clipped fry were released during the season. This is an overall recovery rate of 1,475/205,500, or 0.71776% of the known starting group.

If the recovery rate of marked hatchery fry were also typical for unmarked hatchery fry, and wild fry, then the total of 10,148 Chinook fry caught at the trap would be representative of a total of 1,413,840 fry in the upper river. This estimate is independent of the effects of natural mortality, and only represents the seasonal outmigration of fry if natural mortality during the season is zero. If the seasonal mortality of other fish were similar to the marked fish (~26% are assumed to have died or become resident upstream of the trap, Table III) then the outmigration estimate would be approximately **1,046,242** fry. When applied to data from the previous 3 years resulted in total Chinook fry production estimates of 1,989,794 for 1999, 1,023,513 for 2000, and 2,739,503 for 2001. Although these estimates remain highly variable they are probably more reliable than those derived using the alternative method given our present level of understanding. Interestingly, years with low wild-origin production appear to coincide with Pink salmon brood years.

Daily modeling of the Chinook stock in the Nooksack River

Table III (2 pages) shows the spreadsheet that was created using marked hatchery fry recapture data, and by assuming a constant natural mortality rate of 0.0149682 per day (i.e., survivorship = 98.50318% per day). This rate was determined through trial and error to balance the observed daily outmigration events with the assumption that no marked hatchery fish remain alive above the trap after the last date of capture. Figure 2 is based on the data in Table III and shows the cumulative proportion of the marked hatchery fry that outmigrate, remain above the trap, or that (presumably) die. Daily production estimates are also presented in Figure 2.

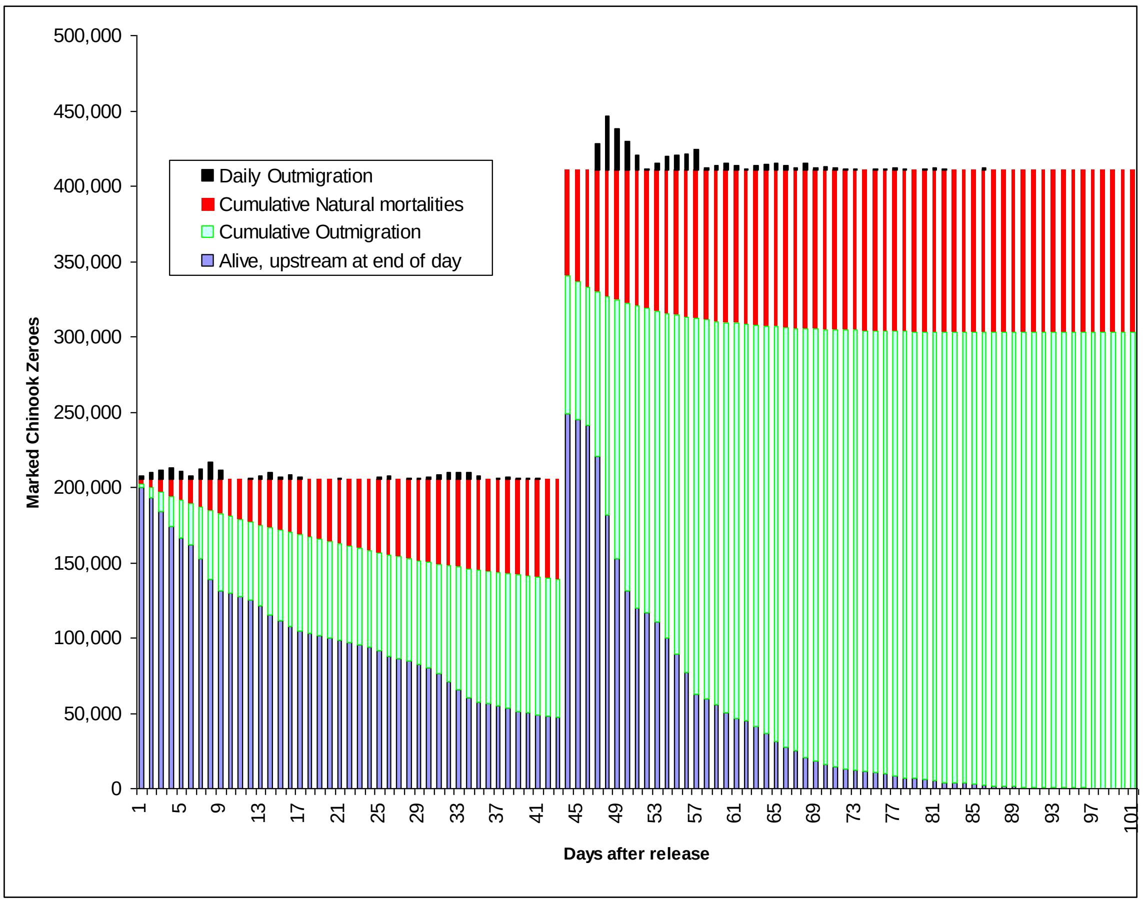

Figure 2. Cumulative fate based on daily modeling of two groups of marked hatchery fry, and daily outmigration estimates from Table III.

Table IV (5 pages) shows the spreadsheet calculated for the daily Chinook stock dynamics over the outmigration season. This assumes that all fry have departed or died by the end of the 3rd of October, and uses a constant daily natural mortality rate of 0.0149682 (taken from Table III).

Table IV indicates that at the time of the first hatchery release there were approximately 768,960 wild fry in the river, and outmigration data tells us that 47,080 wild fry had already outmigrated by this date. Because the mortality rate used to back-calculate the daily fry abundances in Table III was derived for marked-hatchery fry it may not apply as well to wild fry. Consequently, the hatchery derived mortality rate was not used for the purely wild stocks prior to April 11. Unfortunately, it is not possible to separate wild and hatchery stocks on a daily basis from April 11 onwards to more accurately estimate actual daily mortality rates. With more complete catch data on stock composition it may be possible to better refine daily mortality estimates that vary according to daily stock composition. Natural mortality rates used prior to April 11th were based on those indirectly calculated for wild salmon based on the data in Table V.

Table V summarizes information gleaned from Table IV, and uses the percentage of marked hatchery fish dying during the season (26.25%; Table III) to estimate how many hatchery fish died (or alternatively became resident) from all hatchery releases during the season. The difference between the hatchery mortalities estimated in this way, from the total mortalities estimated in Table IV from April 11 onwards, are assumed to represent wild mortalities during that time. The difference between the estimate of wild mortalities and the estimate of the number of wild fry present at the beginning of April 11th is assumed to be the number of wild fry outmigrating. Thus, the total production of wild Chinook fry is the total number of fry outmigrating prior to April 11th (estimated directly from smolt trap data), plus the indirectly estimated number of outmigrating wild fry from April 11th until October 3rd.

Table V. *Breakdown of fry data from the date of first hatchery release to last smolt trap sample Data in green is taken from Table IV. Data in yellow is derived using the season-wide estimate of percent mortality for marked hatchery fish (from Table II)*

From 4/11/02-10/03/02	Total Fish	Mortalities	Outmigrating
Total Fish	2,515,659	1,057,291	1,505,645
Wild Smolts	768,960	598,725	170,235
Hatchery Smolts	1,746,699	458,566	1,335,410

Therefore, the total production of wild Chinook fry from the Nooksack River is 47,080 + 170,235 = **217,315** fry between February 15th and October 3rd, 2002.

Wild fry mortality rates

Based on the data in Table V, and given that this data is for a period of 176 days (i.e., from April 11 to October 3), it is possible to derive a season-wide estimate of daily wild fry survival. This is calculated by the formula:

$$S = (\text{number outmigrating/starting number})^{1/176}$$
$$S = (170{,}235/768{,}960)^{1/176}$$

$$S = 0.991469$$

Since Daily Mortality = 1 - Daily Survivorship

$$M = 0.0085308$$

Consequently, Table IV was back calculated as far as February 15 using this estimate of wild fry survival for all dates prior to April 11. This suggests that there was a starting wild fry population of around 1.3 million wild fry in the Nooksack River on February 15th. At an average fecundity of 3,000 eggs per female, a minimum number of 430 females would be required to produce this number of eggs -- assuming that no mortality occurs between egg deposition and the fry life-stage that was present in mid February; a rather unlikely proposition!

Hatchery Fish Residence Times

Figure 2 demonstrates that the hatchery fish may remain in the river for a considerable length of time. The mean length of time spent in the river for the first group of marked hatchery fish was at least 24 days This assumes that all remaining individuals from the first group outmigrated on June 1st, when the second marked group was released, and is therefore a conservative estimate. If the holdovers from the first release were the first 47,000 fish leaving after June 1st, then the mean length of time for the first group increases to 38 days! The mean length of time that fish in the second marked group spent in the river was shorter than 24 days but is difficult to compute because holdover fish from the first group were also outmigrating along with the second group of marked fish. If all the fish remaining in the river on June 1st are considered to be 'new' then the mean residence time was 12 days. However, if the first 47,000 fish to outmigrate after June 1st were the holdover fish from the first release, then the average residence time for the second group of fish was 18 days.

Trends observed in Chinook fry capture rates versus environmental factors

Diurnal Trends

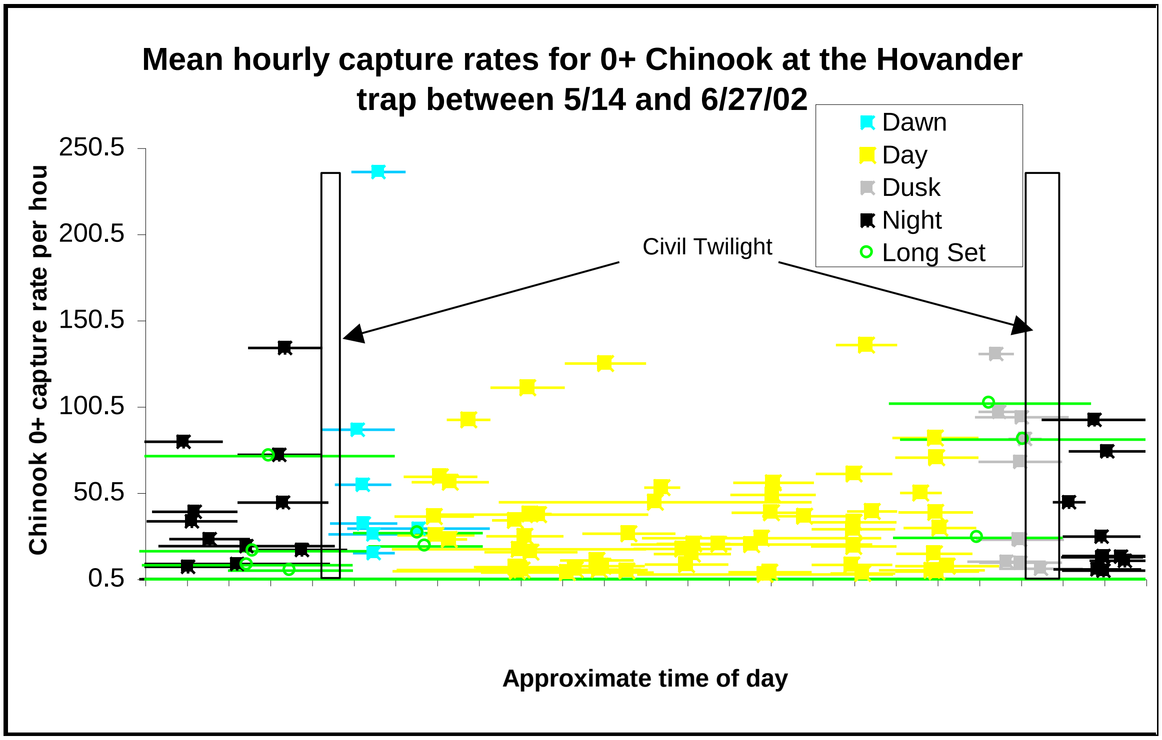

Figure 3. Individual subset catch per hour of Chinook fry versus time of day during the peak outmigration period.

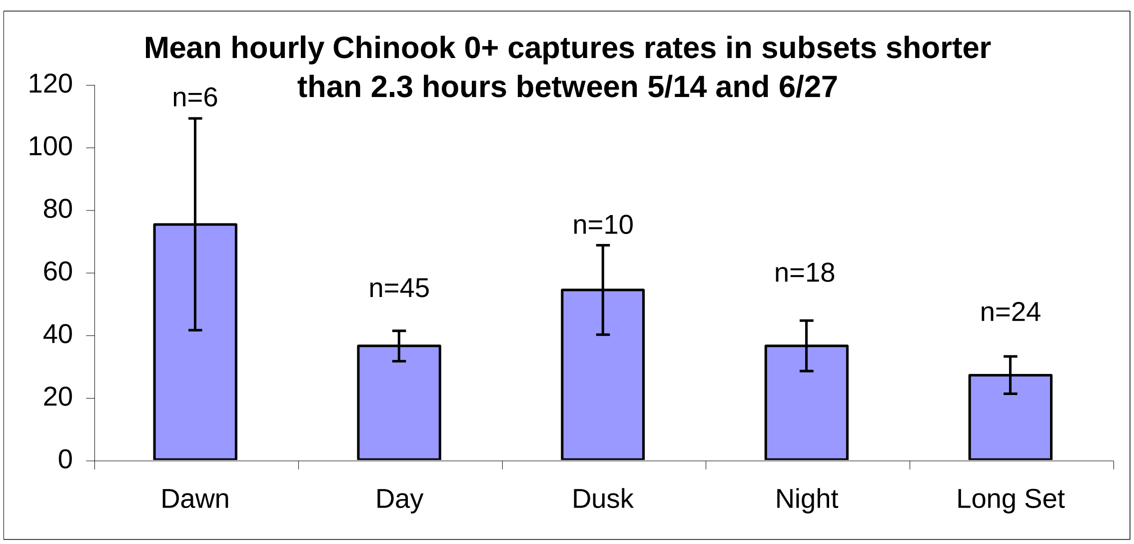

Figure 4. Average catch per hour of Chinook fry classified by light status where set timing and length permits such a classification (Error bars ± 1SE).

Overall there appeared to be no consistent trend between the time of day and the catchability of Chinook fry (Figures 3 & 4). There is some slight suggestion that catches may be slightly elevated around the dawn and dusk twilight periods, but these differences are not statistically significant. Also, the dawn dataset is strongly leveraged by one observation due to the low number of observations in this category.

Trends with Water clarity/visibility

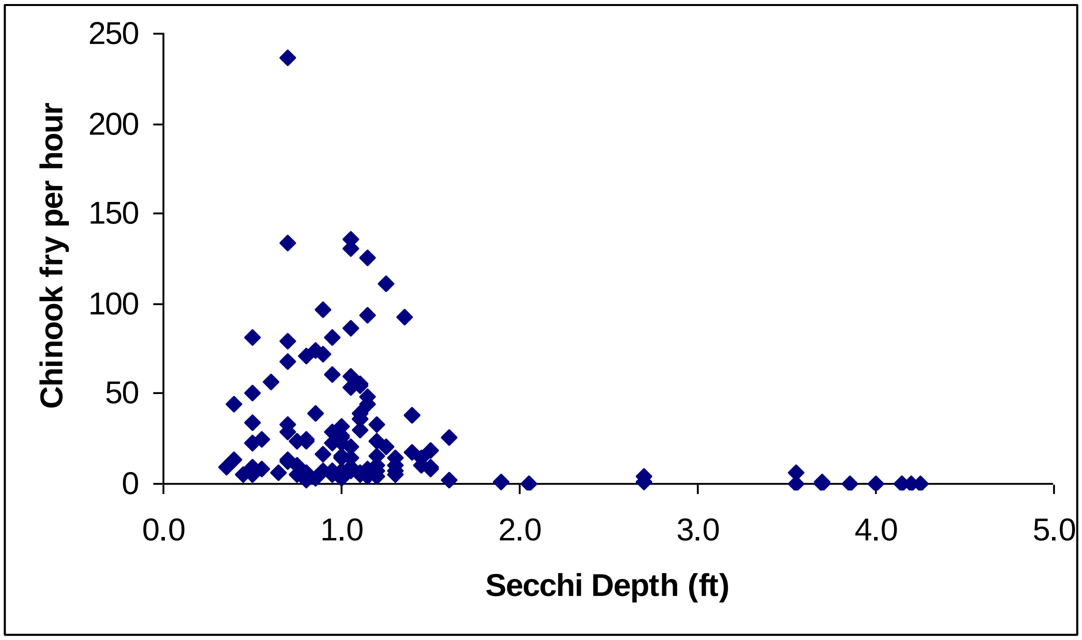

Figure 5. Chinook fry catch per hour versus secchi depth (visibility) for sets between 5/14 and 6/27/02.

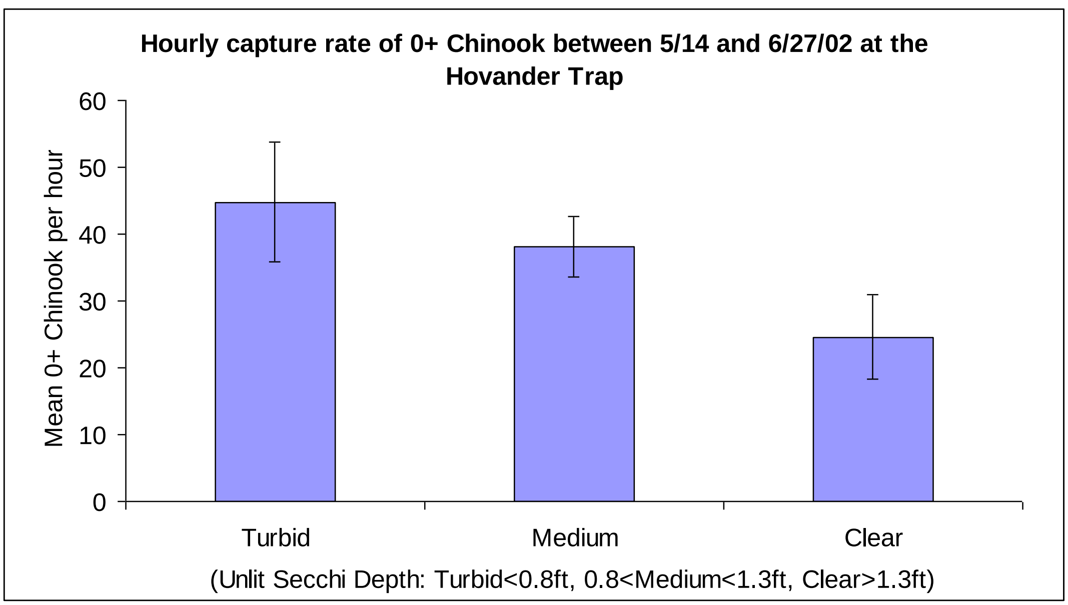

Figure 6. Average Chinook fry catch versus water clarity category for sets between 5/14 and 6/27/02 (Error bars ± 1 SE).

During the main outmigration period it appears that there is a trend for increased Chinook fry catchability during sets with low water visibility, although this trend is not statistically significant.

Interaction between Visibility and Diurnal trends

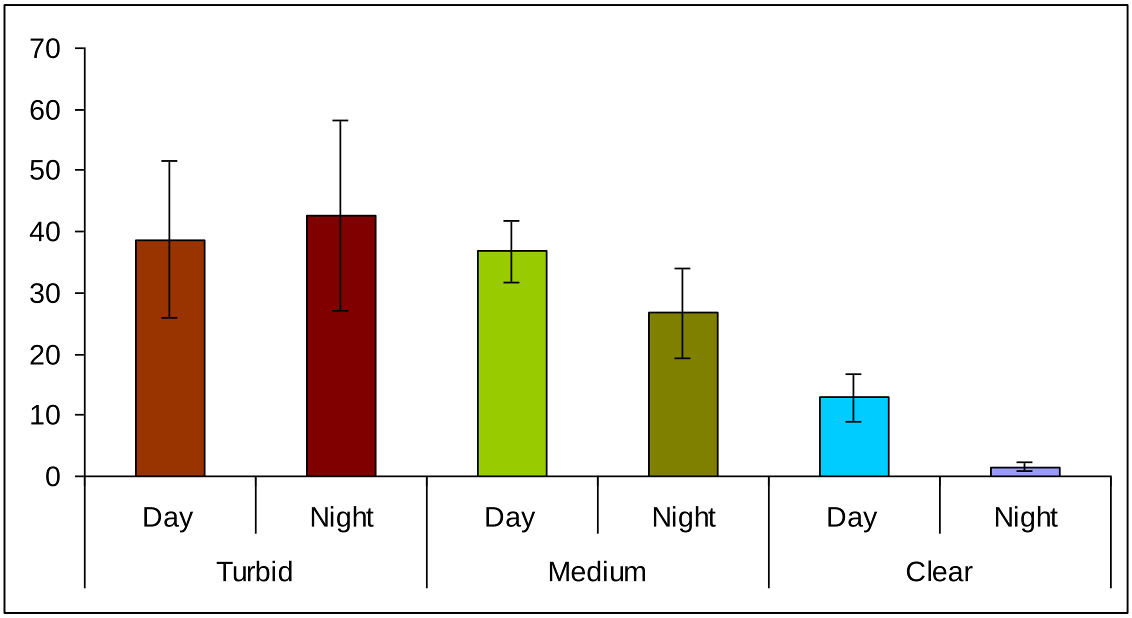

Figure 7. Trends in Chinook fry catchability in varying water visibility categories broken into night versus day. (Error bars ± 1SE)

Overall, the general pattern of declining catchability with increasing water visibility is still evident when the data is broken into night and day sets (Figure 7). Interestingly, there is a suggestion that daytime catchability is higher in clear conditions than nighttime catchability. One explanation for this may be that fry are attracted to the trap during the day as a possible refuge from visual predators.

Sampling Efficiency for Chinook Fry

A 3-level nested ANOVA was performed using data for the 24-hour sets and grouping this within months, within weeks within months, and within days within weeks within months. Prior to use, the data was transformed using the natural logarithm to reduce heteroscedasticity and normality. However, the transformation could not completely remove all kurtosis from the data and the transformed data remained somewhat heteroscedastic. The resulting ANOVA table is presented in Table VI.

Table VI. ANOVA table for 3-level nested ANOVA with unequal replication.

ANOVA Table

Source of Variation	*df*	SS	MS	Fs	F's	*df'*	Critical Value		
Between Months	2	64.74	32.37	1.33	1.13	8.91	3.22	Significant?	No
Between Weeks	9	218.51	24.28	27.69	27.69	5.76	3.58	Significant?	Yes
Between Days	8	7.01	0.88	1.21			2.01	Significant?	No
Within Days	127	91.81	0.72						
Total	146	382.07							

Based on the results in the ANOVA table, it appears that despite the likely existence of short term (< week) outmigration events there appears little added value in sampling either very extensively for fewer days of the week, or sampling less extensively on more days of a week. Instead it appears that the most important temporal unit to focus sample effort is within each week. That is, the more hours sampled each week the better: regardless of how they are distributed on a between or within day temporal scale. Using the procedure outlined in Sokal & Rohlf (1981) or optimizing sample design based on the variances calculated for each level of nested ANOVAs, a table of relative sampling efficiencies was calculated for the possible sampling permutations that could occur using 2-hour sets within a week. The table of relative sampling efficiencies is presented in Table VII, and all values shown are relative to a sampling schedule of 6 hours sampled every 48 hours (the schedule used for the last few years of sampling).

Table VII. *Relative efficiency of potential sampling programs based on variances calculated during the 3-level nested ANOVA*

	N° of 2-3 hour Samples taken per day											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
7 days per week	71%	138%	200%	259%	314%	367%	416%	463%	507%	550%	590%	628%
6 days per week	61%	118%	171%	222%	269%	314%	357%	397%	435%	471%	505%	538%
5 days per week	51%	98%	143%	185%	224%	262%	297%	331%	362%	393%	421%	449%
4 days per week	41%	79%	114%	148%	180%	209%	238%	265%	290%	314%	337%	359%
Every other day	35%	69%	100%	129%	157%	183%	208%	231%	254%	275%	295%	314%
3 days per week	30%	59%	86%	111%	135%	157%	178%	198%	217%	236%	253%	269%
2 days per week	20%	39%	57%	74%	90%	105%	119%	132%	145%	157%	168%	179%
One day per week	10%	20%	29%	37%	45%	52%	59%	66%	72%	79%	84%	90%

Discussion of Chinook Results

While this report presents preliminary estimates of daily mortality for hatchery and wild origin Chinook smolts, I wish to reiterate that these were not derived from empirical data, but were obtained instead by an exercise in modeling daily production and by making assumptions about daily catchability rates, constant daily mortality, and also that no marked smolts remained alive upstream after the last marked fish was caught in the trap. These estimates of daily mortality should therefore be treated with extreme caution until such time as independent data is available to confirm or refute either the assumptions, or the mortality estimates themselves. One assumption that is undoubtedly flawed is that of a constant mortality rate for each day of the season. Skalski (1998) showed that daily survivorship rates in the Snake River fluctuated between 40% and 99.1% per day although typically they were very close to the average of 87.3% (SE=0.5%). Given the relatively small standard error in Skalski's results I do not expect that the assumption of a constant mortality rate will introduce a large error when averaged across the season. Unfortunately, no other estimates of daily or seasonal mortality for Nooksack River smolts are presently available for direct comparison.

On the face of it both estimates of total production appear to be too low given that, during the course of the season, around 1.75 million hatchery fry were released into the Nooksack, and approximately 50 thousand wild fry had already outmigrated prior to their introduction. The first method used to estimate the seasonal production indicated that approximately 1.5 million Chinook fry passed the trap site. This is within the range of estimates for other years that were derived using the same methodology (Robert Conrad, pers. comm.) The alternative method used in this report, using season-wide recapture rates of marked fish, estimated that only slightly over one million fry outmigrated past the trap site once the mortality of the marked hatchery fish group was also applied to the unmarked fish. Although these estimates differ by a substantial amount (half a million fish, or 50% of the smaller estimate) they are at least in the same order of magnitude. Given the enormous potential for orders-of-magnitude extrapolation error when converting catchability to productivity, it is encouraging that an alternative methodology that is not reliant on the daily estimates of catchability confirms that the final result is at least in the right ballpark, at least for 2002. Despite this, the number of fry released and the number of fry outmigrating clearly do not add up unless mortality reduces the number of fry before they reach the trap. Consequently, I have used the only estimates of mortality available to me in analyzing the trap data.

Until recently, mortality of hatchery fish after release has not been explicitly incorporated into production estimates for the Nooksack River even though experience elsewhere has shown that daily mortality rates can be significant for outmigrating hatchery salmon. For example, daily survival rates averaged 87.3% for hatchery released Chinook fry in the highly regulated Snake River during the main part of the outmigration season (Skalski, 1998). The Nooksack River might be expected to provide better survival rates than the Snake River because it doesn't have several large dams and impoundments, or their associated additional mortality for outmigrating fry. The estimated season-wide daily survival rate of 98.5% for hatchery fry, and 99.1% for wild fry in the Nooksack River agrees with that expectation. The higher daily survival rate for wild smolt might be expected if hatchery fish take time to adjust to life outside of captivity. The survival rate for wild fry was calculated for the period of time when both wild and hatchery fry coexisted in the river and it is possible that survival rates outside of this time differ even if these estimates are valid for the time they coexist. Unfortunately, it is not possible to estimate daily survival rates for wild fry prior to hatchery releases with the available data.

Even though daily survival rates for Chinook fry in the Nooksack appear to be relatively high, the cumulative effect of this during the season can be significant because the residence time for the fry appears to be surprisingly long. The modeling exercise summarized in Table III and Figure 2 suggests that, depending on the assumptions made and the timing of release, the *average* residence time for released groups of marked hatchery fish ranged from 12 to 38 days. Presumably because of the relatively long period time spent in the river, approximately 26% of the marked fish are estimated to have died during that time. This value is highly similar to the estimate of 20% mortality used in production estimates of Chinook fry in the Skagit River system (Seiler *et al*., 2000) suggesting it is not an unreasonable figure. However, it is also possible that some of these 'mortalities' may, in fact, be fish that have decided to over winter in the river or else outmigrated after the end of the time considered in this report. It is apparent that there is a need to better understand mortality rates, residence times, and outmigration strategies for both hatchery and wild fry.

It was also interesting to find that the residence time for the first group of marked hatchery fish may have been longer than that of the second group of marked fish. While this difference may be an artifact of differences in flow or some other cues that stimulate outmigration behavior, it may also reflect changes in the perceived value of staying in the river for the fry. Fry that leave the river too quickly may miss out on an opportunity for freshwater growth preparatory to undergoing the transition to saltwater, and this could potentially worsen post-outmigration survival rates in the near-shore environment. Unfortunately we do not know anything about mortality rates for Chinook smolts in the estuarine/near-shore environment. Even though some fry leave almost immediately, it may be that they are better off staying in the river as long as possible, and only outmigrate when the riverine conditions deteriorate sufficiently to offset the potentially greater risks of life in saltwater.

Skalski (1998) suggested that daily survivorship rates for outmigrating smolt in the Snake River declined towards the end of the outmigration period. Although he did not suggest a mechanism for this phenomenon this could, perhaps, be due to changes in food availability, flow regimes, or changing predator efficiencies. This scenario would also help explain shorter residence times for hatchery fish released later in the season. For example, if the relatively large inputs of fish earlier in the season had resulted in scarcer food availability, then late arrivals may opt to leave sooner than they would have otherwise.

Future Sampling Effort

Since the majority of the Chinook outmigration occurs between mid May and early July I would suggest that sampling effort should be maximized during this time period in order to improve our understanding during the period when most fry are outmigrating. However, sufficient sampling effort needs to be conducted from April onwards since some wild-origin fry are outmigrating during this time.

The ANOVA results suggest that sampling effort should be strongly focused within the 'week' temporal scale, but makes little distinction regarding whether samples should be distributed more at within-day temporal scales (i.e., fewer days sampled more intensively) or between day temporal scales (i.e., more days sampled less intensively). However, logic suggests that it would be best to minimize the un-sampled intervals between samples so as to reduce the temporal scope of extrapolations based on samples. This would ideally suggest spreading out the effort evenly throughout the week. In practice, however, this may prove to be difficult and highly taxing on the trap crew. There is less travel and setup time required if short sets can be strung together and ultimately we may get more active sampling time by grouping sample blocks.

From the examination of diurnal and turbidity effects on Chinook fry catchability it seems that there is no strong day-night difference in catchability in the Nooksack River at the trap site. This contrasts with the pattern observed in the Skagit River where daytime catches are typically lower than nighttime catches, even though the daylight period is much longer (Seiler *et al*., 2000). The relationship between secchi depth and fry catchability in the Nooksack River is already known to exist, although the nature of the relationship is not yet fully understood. Until recently, data from a series of calibration experiments was used to estimate instantaneous catch efficiency based on secchi depth. However, re-examination of the calibration data suggests that there may be a significant confounding factor introduced by mixing results from stressed fry with those of de-stressed fry. This may have the consequence of overestimating catch efficiencies for wild and acclimatized fry that, presumably, behave more like de-stressed fry (Figure 8). Additionally, the most recent data points suggest that catchability may increase somewhat in very clear conditions, which is contrary to the simple relationship that was originally used (i.e., exponentially declining catchability with increasing visibility). This phenomenon requires further explanation and testing.

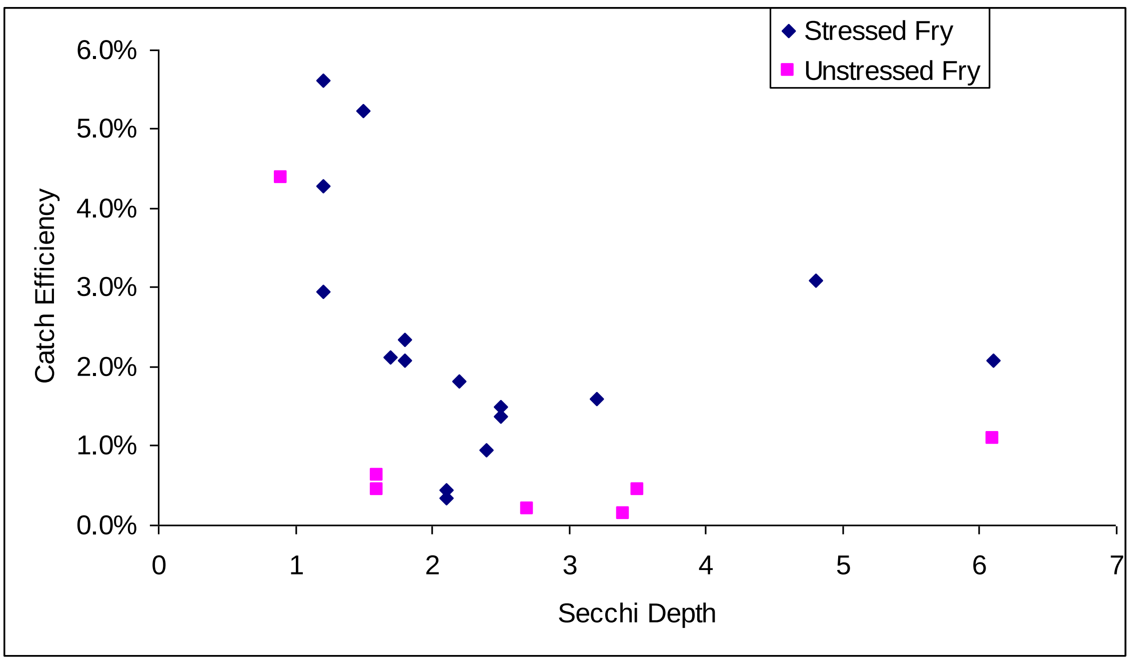

Figure 8. Comparison of catch efficiency determined for stressed and unstressed Chinook fry versus secchi depth.

One possible explanation for the rise in catchability in clear conditions may be that Chinook fry mistake the trap for cover during very clear conditions when they are at their most vulnerable to visual predators. In that light, the increase in catchability may simply reflect a switching of behavior from avoidance in moderate visibility conditions to attraction in very clear water.

Alternatively, or additionally, the phenomenon may reflect changed hydrological conditions at times when the water is very clear. Typically, very clear conditions happen because flows are very low. There is evidence that as flows increase at the trap site a bow-wave builds up in front of the trap and may deflect some of the fish arriving at the trap. At low flows/very clear water this bow-wave may not be present and its negative impact on catchability may be reduced such that catchability increases, despite the increased visibility of the trap to arriving fry.

We need to conduct more calibration experiments to better define the nature of the relationship between fry catchability and water clarity, particularly for de-stressed fry that are more likely to behave like wild and acclimated hatchery fish. I would also suggest examining how this relationship might change between day and night. To this end I include a summary outline of a trap calibration program for 2003 following the Coho section.

2002 Coho Yearling Analysis

Summary

Low numbers of wild-origin smolts began outmigrating in late April and continued until late July, but the majority of wild outmigrants left during the period of mid-May to mid-June. The outmigration period for hatchery smolts began in mid-May and lasted until mid-June, with a few isolated stragglers persisting until July 1st.

Total Coho smolt production in 2002 was estimated using the season-wide recapture rate of marked hatchery-origin smolts and applying this rate to the total catch of Coho smolts. Known hatchery releases in 2002 were subtracted from the total to estimate the wild-origin production. Overall production was estimated to be 2,077,633 Coho smolts in 2002. This is comprised of 772,802 wild-origin smolts and 1,304,831 hatchery-origin smolts. The production estimates assume that negligible mortality occurred between smolt release and smolt recapture at the trap site, and that capture rates of wild-origin smolts were comparable to the hatchery-origin smolts over the entire duration of the wild-origin outmigration.

Coho smolt production in 1999, 2000, & 2001 were also estimated using the same method as for 2002 applied to smolt trap data for those years. However, the recapture rate for 1999 was not in the same order of magnitude as the other years and would have led to a wildly unrealistic production estimate for that year. It is likely that a combination of lower sampling effort, a much smaller group of marked smolts, and inaccurate recording of the frequency of marked smolts in very large catches, contributed to this difference. Removing compromised data from several extremely large Coho catches in 1999 reduced the final estimate of wild-origin smolts to a comparable order of magnitude to the estimated production in the following three years, but the final estimate remained statistically much higher than the other years, and the revised recapture rate was not substantially improved. The production estimate for 1999 should therefore be viewed with skepticism.

Production estimates for wild-origin Coho smolts were **772,802** smolts in 2002; **992,066** smolts in 2001; **831,719** smolts in 2000; and (possibly) **1,971,071** smolts in 1999.

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.

Results

A total of 5,997 yearling smolts were captured during sampling in 2002. Figure 9 shows the average catch of Coho smolts per hour for each week that was sampled in 2002. The first Coho smolt (wild-origin) was caught on April 12th and the last on July 25th (wild-origin). The first hatchery-origin smolt was caught on May 18th and the last on July 1st. The majority of the outmigration occurred between mid-May and mid-June.

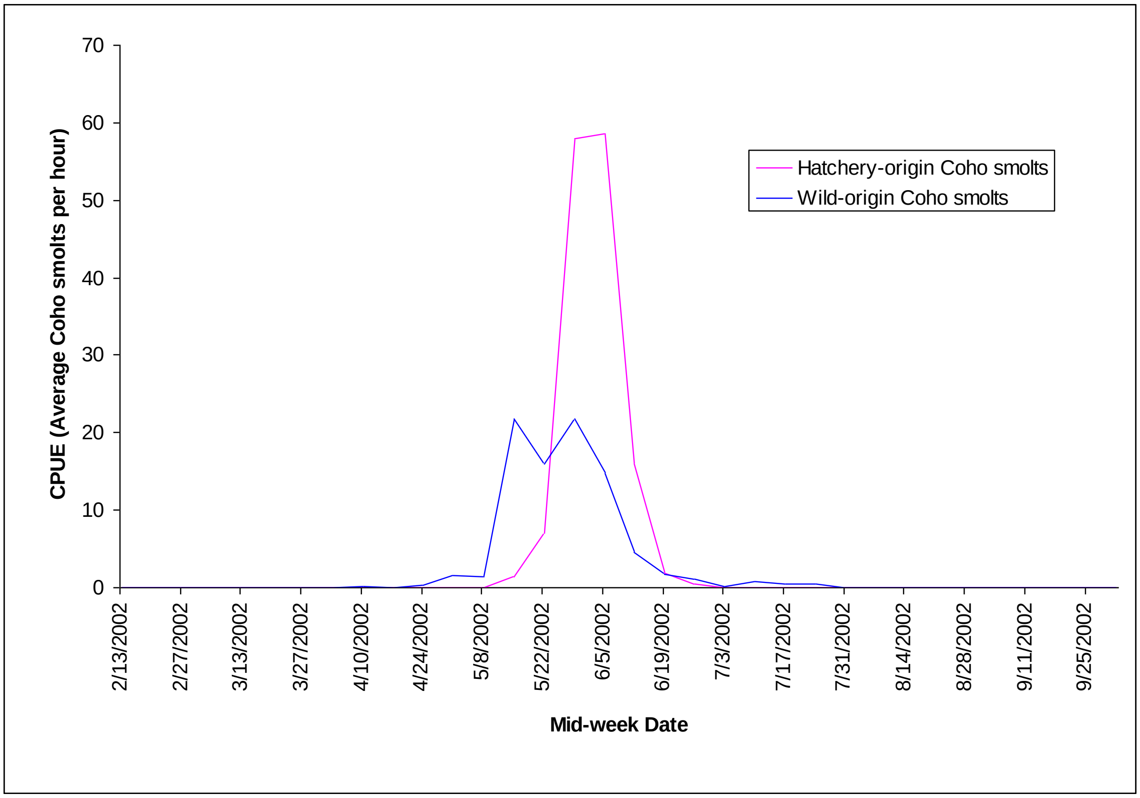

Figure 9. Average weekly catch per hour in 2002 for Coho smolts.

Table VIII summarizes smolt trap results and the magnitude of hatchery releases of Coho smolts from 1999 - 2002.

Table VIII. *Smolt trap results and hatchery releases of Coho smolts from 1999 – 2000.*

	1999	**2000**	**2001**	**2002**
Total # of Hatchery Smolts Released	2,669,737	1,429,200	1,170,747	1,304,831
Marked # of Hatchery Smolts Released	**320,465**	**1,365,635**	**1,170,747**	**1,225,031**
Total # of smolts caught in sampling	782	2,937	3,946	5,997
Unmarked smolts caught	728	1,163	1,810	2,461
Marked smolts caught	**54**	**1,774**	**2,136**	**3,536**
Recapture rate of marked smolts	**0.02%**	**0.13%**	**0.18%**	**0.29%**
Hours sampled between 5/15 and 7/1	58	122	127	256

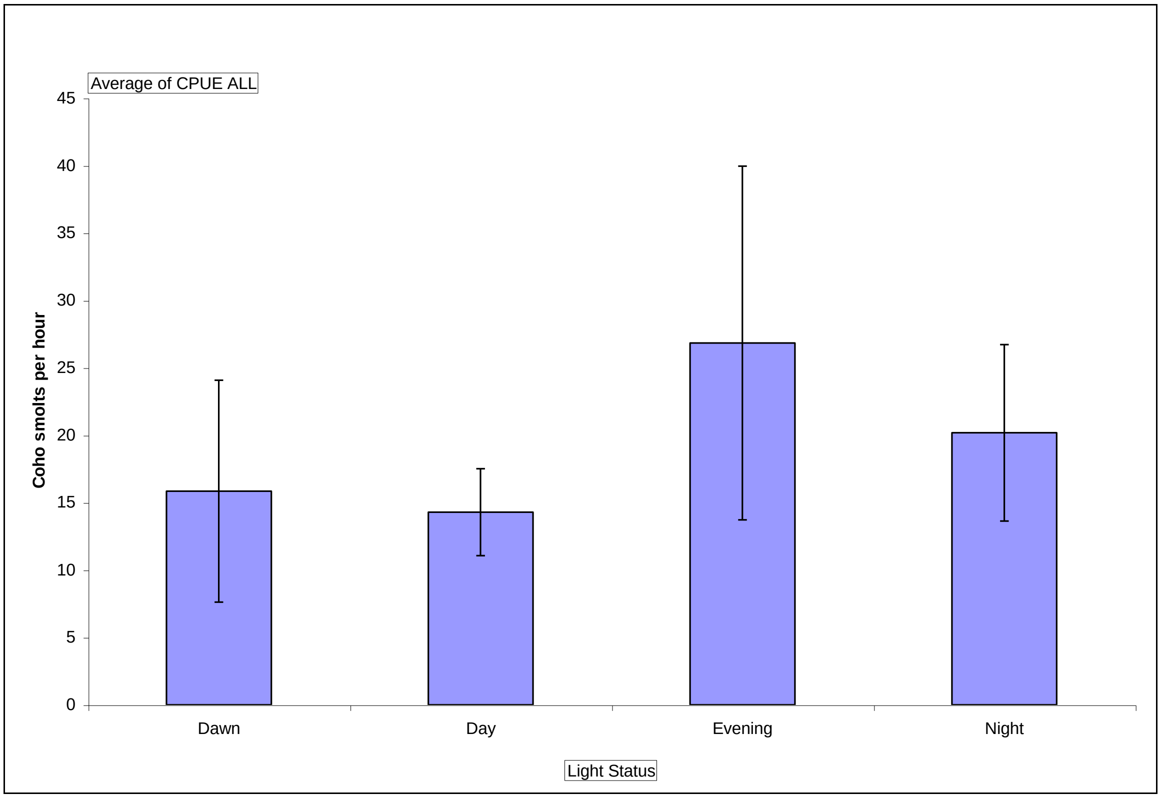

Figure 10. Diurnal pattern of Coho smolt capture rates.

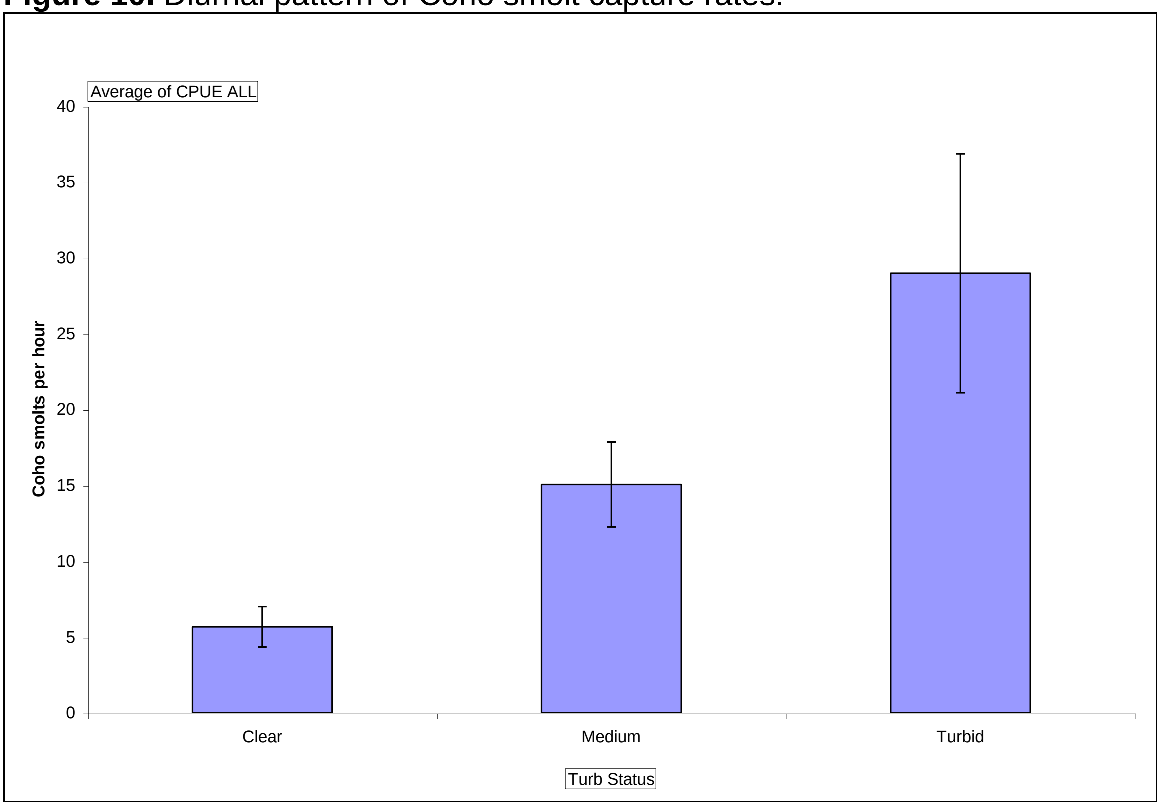

Figure 11. Pattern of Coho capture rates in different water visibility categories (Unlit secchi depth: Turbid<0.8ft; 0.8<Medium<1.3ft; Clear >1.3ft)

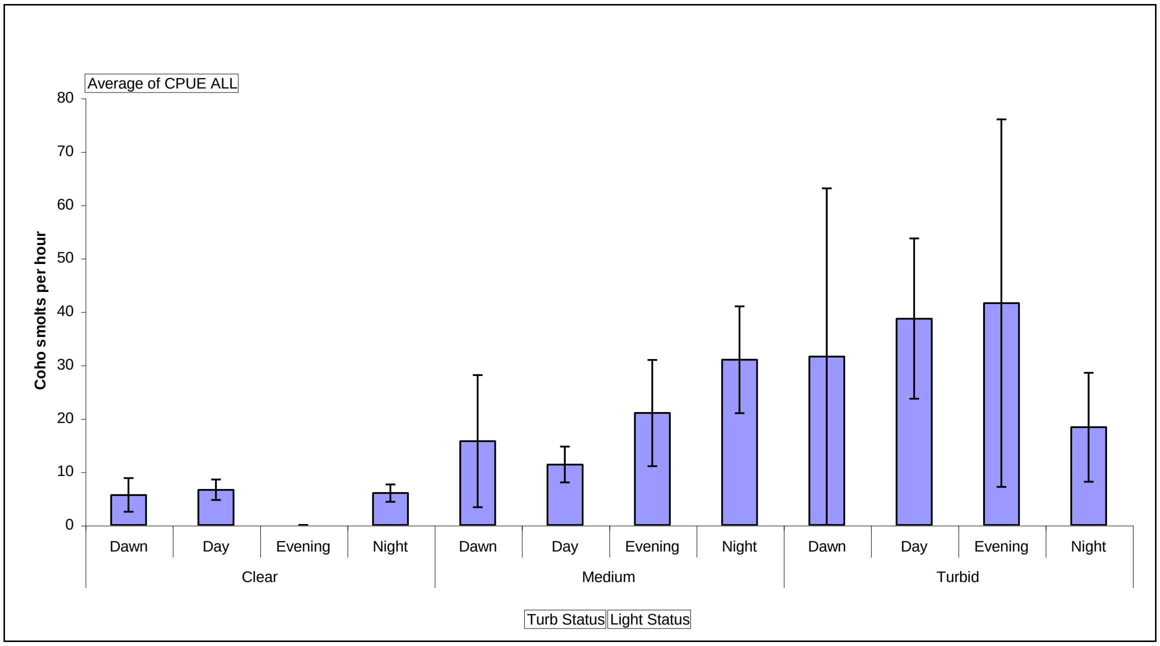

Figure 12. Trends in Coho smolt catchability in varying water visibility categories broken into night versus day. (Error bars ± 1SE)

Coho Production Estimates

Methods

Because the primary objective of the trapping program is to quantify Chinook fry production, there has been little effort directed at determining trap catch efficiencies for Coho smolts. Consequently, it is not possible to convert daily trap CPUE to daily outmigration rates. However, on a longer-term temporal scale (season-wide) it is possible to estimate the 'season-wide' catch efficiency of the trapping program by using the seasonal recapture rate of marked hatchery-produced smolts. This statistic integrates the instantaneous catch efficiency of the trap across the range of physical parameters that occurred during sampling as well as the level of sampling effort used within that portion of the season. Assuming that the instantaneous catch efficiencies and sampling effort are also representative of the rest of the outmigration season, then this statistic can be used to estimate the abundance of smolts by applying it to the total catch of Coho smolts. Because physical parameters, catch efficiencies, sample timing, and the level of effort can vary from year to year it is necessary to recalculate the recapture rate for each year that an estimate is required.

Assuming that no significant mortality occurs between release and recapture, and that the recapture rate of hatchery fish is also true for wild fish, then the starting size of the wild smolt population can be calculated by dividing the total number of smolts caught by the recapture rate (marked-hatchery smolts), and then subtracting the known hatchery release for that year from this resulting number.

Results

Table VIII summarizes the details of hatchery releases; trap catches of marked and unmarked Coho smolts; marked smolt releases; recapture rates; and sampling effort for 1999, 2000, 2001, and 2002. The catch data for 1999 excludes data taken during a week of sampling in the peak of the outmigration. This exclusion was necessary because unusually large catches overwhelmed the processing capacity of the trap crew. Because the crew had to prioritize their processing time to get Chinook fry data they were unable to sort marked and unmarked Coho smolts, and consequently the inclusion of data from the affected sets would vastly underestimate the true recapture rate.

Table IX shows the total production of Coho estimated using the total catch divided by the season-wide recapture rate, as well as the known hatchery release and the difference between the total and the hatchery fish is assumed to be wild-origin fish.

Table IX. *Production estimates derived using recapture rates of marked hatchery smolts and known abundances of released hatchery smolts.*

	1999	**2000**	**2001**	**2002**
Total Production	4,640,808	2,260,919	2,162,813	2,077,633
Hatchery Production	2,669,737	1,429,200	1,170,747	1,304,831
Wild-Origin Production	**1,971,071**	**831,719**	**992,066**	**772,802**

Between 2000 and 2002 the wild-origin Coho production has ranged from 772,802 to 992,066 smolts (Figure 13). The production estimate for 1999 is based on incomplete data and a much lower recapture rate from a smaller group of marked hatchery smolts that were released in 1999. Given that the production estimate for 1999 is statistically much higher than the estimates for the following three years ($p<0.05$), and there are significant potential problems with it, the 1999 estimate of wild production is probably flawed.

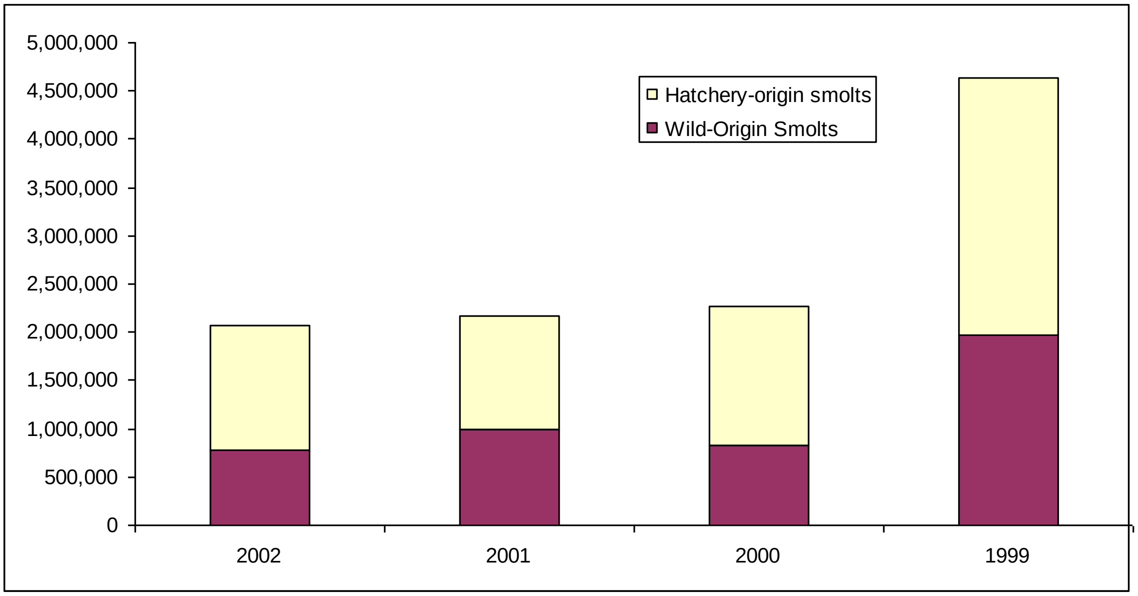

Figure 13. Breakdown of production of Coho smolts from the Nooksack River from 1999 to 2002. All estimates assume zero mortality between release and the trap site.

Season-wide recapture rates are a function both of instantaneous catch efficiencies and the amount of sampling effort expended during the season. In other words, the longer you fish during the season, the more marked fish you are likely to recapture. We know that no marked fish will be recaptured if no sampling at all is done, and that the season-wide recapture rate should increase linearly in proportion to the time spent sampling. If the season-wide recapture rate of marked fish is plotted against the number of hours fished, a trendline can be fitted to the data that has an intercept at zero (Figure 14). When the trendline is extrapolated from the data to the hypothetical situation where the trap would be in operation for 24 hours a day for the whole season, the trendline should provide an approximation of the average instantaneous catch efficiency for the trap. Based on the data in Figure 2 the average instantaneous catch efficiency for the trap would be approximately 1.29%.

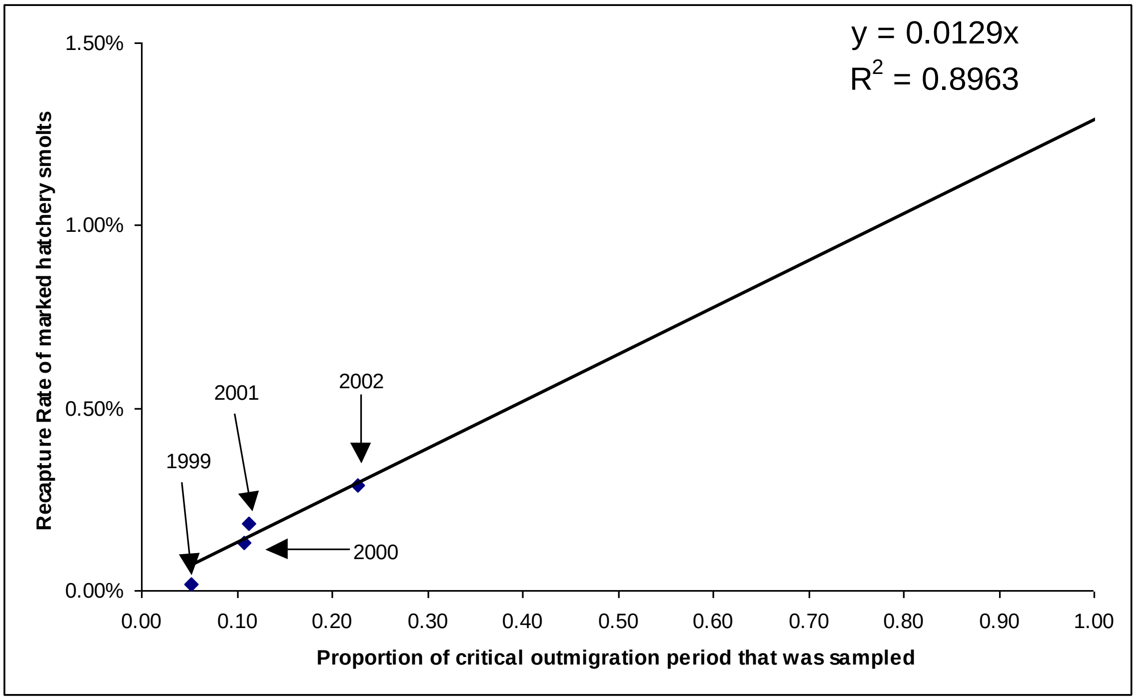

Figure 14. Plot of season-wide recapture rates versus the proportion of the Coho outmigration season (May 15 - July 1) that was sampled each year.

Discussion of Coho Results

Assuming that no mortality occurs during the outmigration period, the estimates in Table IX indicate that wild Coho production in the Nooksack River averages ~865,500 smolts per year (since 2000). In reality, however, it is likely that the unknown effects of mortality probably bias the final production estimates too high. As an example, if a mortality rate of 10% affected released hatchery fish prior to their arrival at the trap, then the final production estimate would be 10% too high (i.e., 86,000 smolts too high on average). If the mortality rate were 5% then the bias would be 5% (43,000 smolts on average).

Unfortunately we have no information regarding mortality rates of yearling Coho in the Nooksack River. It is likely that mortality rates for yearling Coho are considerably lower than those estimated for Chinook fry (e.g., 26%) because survival is typically higher for larger fish. Also, hatchery smolts appear to have a relatively rapid dispersal out to sea after their release from the hatchery ponds. The average residence time for Coho smolt may be only a few days in length, which contrasts significantly with the longer residence times of Chinook fry. Workers on the Skagit River, who do not adjust their Coho estimates to account for mortality, also consider a very low mortality rate for Coho smolts to be likely (Seiler *et al.,* 2000). So it is probable that the magnitude of any bias caused by this assumption is likely to be small because natural mortality is likely to be relatively minor for Coho smolts, perhaps as low as 5-10%.

Problems in calculating the Coho recapture rate in 1999 points up some logistical problems associated with manning the smolt trap during peak outmigration events. The fact that the best estimate of the 1999-recapture rate doesn't fit with the other data in Figure 14, and the statistically much higher final estimate for wild-origin smolts in 1999 suggests that the data for 1999 is not accurate and should not be used in further analysis.

The estimated average catch efficiency of 1.27% for Coho smolts derived from Figure 14 does not allow us to make daily estimates of the number of outmigrating smolts based on daily catches in the smolt trap. It could, however, provide a baseline for comparison of any calibration data that may be generated in future. Clearly, the estimate of average catch efficiency would be much improved if season-wide recapture rates were known for sampling programs that operate for a much larger proportion of the season. I would hope that we can aim to sample somewhere between 30 and 40% of the critical May 15th to July 1st interval in 2003 although this would be difficult to achieve given staffing constraints.

The approach used in this report to estimate the Coho production for the Nooksack River is a very broad-brush method that makes no predictions about salmon smolt behavior under varying environmental stimuli. As a consequence it does not risk introducing orders-of-magnitude scale error by using potentially weak or inaccurate relationships between smolt catchability and measurable environmental conditions. On the other hand, this method provides only a point estimate for each season and does little to advance our understanding of salmon ethology (behavior) or ecology in the river within each season. Such an understanding is crucial to identify limiting factors in the salmonid life cycle and to develop restoration strategies that target the critical bottlenecks in production. Consequently, there is still need to develop accurate and meaningful relationships between smolt trap catch efficiencies and environmental conditions for all species and life stages of salmonids for which production estimates are desired. At the very least these estimates should provide an independent verification of the production estimates derived in this paper. More importantly perhaps, such information could reveal information about residence times in the upper reaches of the Nooksack River and what rate of mortality occurs there. In turn, this information will help drive other studies into habitat use and migratory cues by salmon fry and smolts. For salmonids that use the riverine environment extensively during their early life history, this information may be critical to ensuring the long-term sustainability of the stock.

2003 Calibration Experiments

To advance our understanding of the early life history strategy and limiting factors for Chinook and Coho in the Nooksack River it is imperative that we develop a robust relationship between catch efficiency and one or more controlling environmental parameters. Although we have some direct data showing that secchi depth is one such controlling factor for Chinook fry (Figures 5-8), and Coho smolts (Figures 11 & 12), the relationship is confounded by differences in the stress levels of the groups of fry used in the calibration trials. Moreover, the majority of fry used were still highly stressed from their transport to the river meaning that the relationship used to estimate daily production for Chinook may not be applicable to more relaxed fry such as wild-origin or acclimated hatchery fry. Another potentially confounding factor is that behavior of fish may change from day to night. Even though there appears to be no difference in catches between night and day for Chinook or Coho (Figures 4 & 10), this does not necessarily mean there are no differences in production between night and day. For example, if daytime catchability increases (for example, if fry come to the surface to feed during the day) but overall outmigration rates are lower in daylight then the interaction of the two could be masked when looking solely at the resulting catch.

Consequently I believe we need to expand the calibration dataset and control for both stress levels and night versus day catchability. Given a group of 7,000 Chinook fry I would divide these into 10 groups of 700. All groups of fish would be allowed to recover in in-river net pens for several hours after transport to the river so that they behave as similarly to acclimated fish as possible. 5 of these groups would be released as daylight groups and 5 as nighttime groups following the previously used protocol of distributing them across the channel. Although this handling will create a short-term stress factor it will hopefully be of short enough duration so that ‘normal’ fish behavior can re-establish itself prior to passing the trap. On 5 days during the season, across as large a range of water clarity conditions as possible, one daytime group will be released just after dawn and one nighttime group will be released just after dusk. All fish from the dawn release will be assumed to have passed the trap by dusk, and likewise for nighttime released fish when dawn occurs. Should any daytime fish be caught after dusk, that proportion of all the marked fry would be assumed to represent the proportion of the released fish remaining above the trap at dusk. Likewise for any nighttime fish caught after dawn the following day. Because nighttime fish may still be caught after dawn (although previous calibration data suggests otherwise) it will be necessary to continue smolt trap operations for longer than a single 24 hour period. I would want to sample at least a few more hours to detect any stragglers. Depending on the conditions, it may be possible to work the calibration experiments around previously scheduled 24-hour sampling efforts so as to reduce the additional effort placed on the trap crew.

The calibration schedule described above would give two datasets of 5 points showing catch efficiency versus secchi depth during daylight and nighttime conditions. If there is no difference in catch efficiency in daytime versus nighttime the results may be pooled. On their own these 5 points will probably not provide a convincing relationship and they will undoubtedly require additional calibration experiments to improve or reduce our confidence in any relationship that we observe. However, I do not feel that group sizes of less than 700 will be adequate given the low recapture rates observed in some of the previous calibration experiments. In fact, I would be more comfortable with larger release groups than 700 fish…say 1,000 – 2,000 fish but that would result in many fewer data points, and a time lag of several years before a workable relationship could be obtained, unless many more Chinook fry were available for use in calibration experiments.

Other than the number of Chinook fry available, the major constraint on calibration experiments is the very long period of time that the trap must operate continuously to determine the catchability of the released group. Consequently, it makes sense that whenever a calibration experiment is being undertaken for Chinook fry it would be sensible to simultaneously undertake releases of marked yearling Coho and Chum fry so that calibration curves can also be determined for these species without adding much additional effort on the smolt trap crew. Of course, there would be additional effort and resources required to obtain, mark, transport, and hold in temporary net pens the other salmon groups. I would recommend using group sizes of 2,000 Coho yearlings per release (due to their potentially lower recapture rate) and approximately 1,000 Chum fry per release.

References

Conrad, R.H. & MacKay, M. T. 2000 *Use of a rotary screwtrap to monitor the out-migration of Chinook salmon smolts from the Nooksack River: 1994-1998*. Northwest Fishery Resource Bulletin. Project Report Series 10.120pp.

Seiler, D.; Kishimoto,L.; & Neuhauser, S. 2000. *1999 Skagit River Wild 0+ Chinook Production Evaluation*. Washington Department of Fish & Wildlife Annual Report.

Skalski, J.R. 1998 *Estimating season-wide survival rates of outmigrating salmon smolt in the Snake River, Washington.* Can.J.Fish.Aquat.Sci. **55**: 761-769.

Sokal, R.R. & Rohlf, F.J. (1981) *Biometry*. 2^{nd} Edition. W.H Freeman & Company, New York. 859pp.