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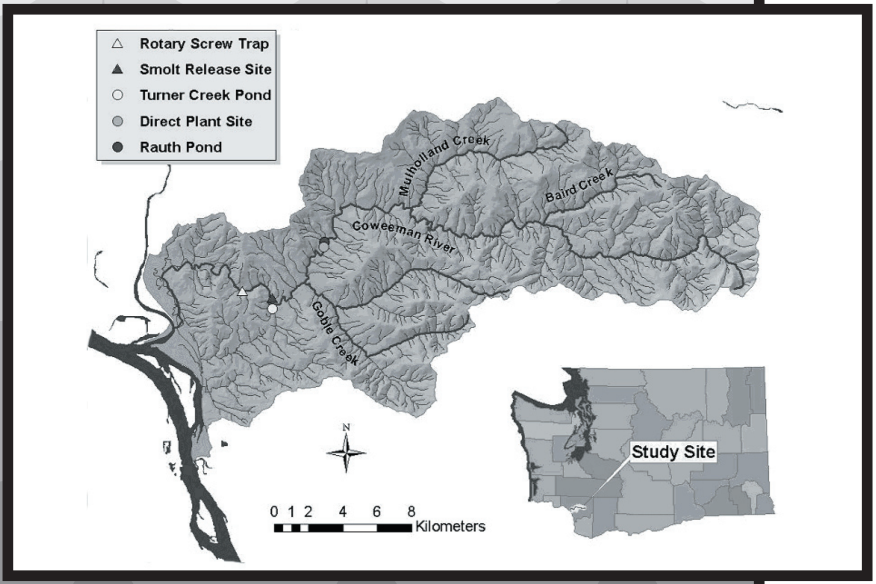
2005 Coweeman River Juvenile Salmonid Production Evaluation



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Washington Department of
FISH AND WILDLIFE
Fish Program
Science Division

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2005 Coweeman River Juvenile Salmonid Production Evaluation

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Executive Summary

- In 2005 Washington Department of Fish and Wildlife Conservation Biology Unit staff collaborated with Region 5 Fish Management staff to operate a rotary screw trap in the Coweeman watershed.

- The objectives of the work were to generate abundance estimates for juvenile salmonids emigrating from the Coweeman watershed including wild and hatchery winter-run steelhead, cutthroat, fall Chinook, and coho.

- Production estimates vary depending on the assumption made for the various analytical procedures but our best estimates for smolt and presmolt migrants past the trap between March 25 and August 8 2005 were approximately 20,000 wild winter-run steelhead, 1,500 wild cutthroat trout, 52,000 fall Chinook, and 17,000 wild coho.

- Approximately 16,000 hatchery winter-run steelhead trout out of approximately 19,000 planted successfully emigrated from the watershed.

Introduction

In the spring of 2005, WDFW Conservation Biology Unit staff collaborated with Region 5 Fish Management staff to operate a rotary screw trap in the Coweeman watershed. An ongoing project to determine the extent to which hatchery-origin steelhead smolts prey upon naturally produced fall Chinook fry (Sharpe et al. 2004, Sharpe et al., in prep) required that we identify basins that (1) receive hatchery steelhead smolts, (2) have substantial natural production by fall Chinook and (3) provide an opportunity to operate a migrant trap. The Coweeman watershed matched these criteria and, in addition, the need for operating a smolt trap in the basin afforded the opportunity to evaluate the natural production of the diverse other salmonids spawning there. The objectives of this report are to generate abundance estimates for juvenile salmonids emigrating from the Coweeman watershed including wild and hatchery winter-run steelhead, cutthroat, fall Chinook, and coho.

Study Site

The Coweeman is a third order tributary to the Columbia River located in Cowlitz County, WA (Figure 1). The Coweeman basin is a moderate gradient system with elevation ranging from near sea level to 846 meters at Coweeman Lake, the headwaters. The watershed is managed for timber production. No hatcheries or dams are present. This basin drains approximately 329 square kilometers. Anadromous salmonid species identified in the Coweeman include Chinook salmon, coho salmon, cutthroat trout, and steelhead. Small numbers of chum salmon may enter the lower basin (WDFW 2003). Hatchery smolt releases of winter-run steelhead occur annually through a cooperative effort with a local fishing club, the Cowlitz Game and Anglers, a private landowner, Pat Rauth, and WDFW. A small coho Remote Site Incubator (RSI; $\underset{\sim}{}$ 5,000 eggs/yr) program is also operated in the basin. A site for installing a rotary screw trap was identified at approximately Rkm 12. While the site is relatively high in the watershed, most of the lower 12 km is a tidally influenced slough and little spawning occurs there. In surveys conducted by the authors no steelhead spawning and only approximately 2.4% of Chinook redds were noted below the trapping location in 2004. The site had adequate constriction of the thalweg to ensure high trap efficiency, was easily accessible and was located on private property, providing some measure of security.

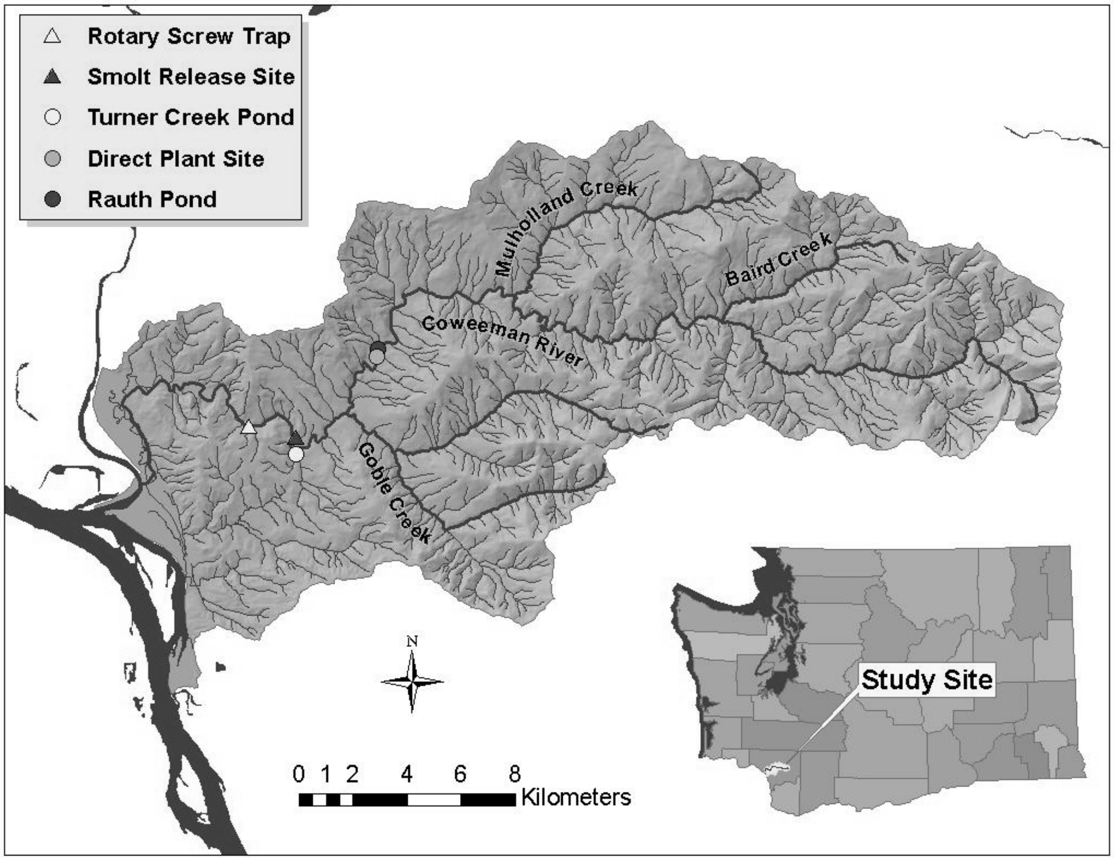


Figure 1. Coweeman watershed.

Monitoring and Management History

The first records of stream surveys for adult salmonids in the Coweeman watershed were from the late 1930's and early 1940's (LCFRB 2004a; WDFW unpublished stream survey card data). These were primarily "spot" surveys to identify the presence/absence of salmonids and provide minimum counts. They do not represent total escapements. In 1964, a 9.6 km index area was established for fall Chinook stream surveys. Index counts were expanded into estimates of total escapement in 1980 using peak count expansion with an expansion factor of two (WDFW unpublished memorandum from G. Krietman and D. McIssac, 10 June 1981). Use of this method to estimate escapement continued through 2001. In 2002 –04, an adult fall Chinook population monitoring project was conducted to develop improved escapement estimates (Glaser and Rawding, in prep.). Wild winter run steelhead escapement estimates have been generated using redd count expansion following standard WDFW protocols (Dan Rawding, WDFW, pers. comm.) since 1987. A few (<5) surveys to determine the presence/absence of chum salmon have been conducted since 1998 (J. Hymer, WDFW, pers. comm., WDFW unpublished stream survey card data). Coho salmon have been enumerated and sampled during fall spawning ground surveys, but estimates of total escapement have not been generated. Currently, one of us (BG) is involved in a project to estimate total escapement for 2005/06 late fall run coho. No history of monitoring or abundance data exists for cutthroat trout.

To our knowledge, basin-wide juvenile production has never been monitored in the watershed. Monitoring of juvenile fish within the subbasin has been minimal and limited to electrofishing in a Baird Creek index established for juvenile coho stock assessment. Surveys were conducted in 1977 – 79, 1985 - 86 and 1994 - 95 (Campbell et al. 1994, Heitz 1997).

Some modeling of potential productivity in the watershed has been done. The Ecosystem Diagnosis and Treatment model (EDT; Mobrand Biometrics Inc. 1999, 2002) is a habitat-based model that assesses ecosystem performance using indicator species. The model links salmonid performance to both current and historical environmental conditions. Within the model, salmonid performance is estimated by examining the productivity, capacity, and life history diversity of the indicator species in relation to the environmental attributes of its habitat, in this case the Coweeman watershed. Habitat assessment and monitoring completed within the basin includes: a baseline inventory of large woody debris (Volkhardt 1999), temperature monitoring (Sullivan et al. 1990, Cowltz/Wahkiakum Conservation District unpublished data), flow monitoring (USGS 2004), habitat surveys conducted for EDT (S. VanderPloeg, WDFW, Pers. Comm.), and a salmonid limiting factors analysis (Wade 2000). A complete description of all data used in the Coweeman EDT model is presented in the EDT documentation (LCFRB 2004b).

Historically, hatchery plants of fall Chinook occurred between 1951 and 1979, plants of coho occurred before 1987, and plants of cutthroat trout occurred between 1989 and 1993. Hatchery winter run steelhead plants have occurred since 1957 (WDFW Hatchery plant unpublished records, Catie Mains; LCFRB 2004a). Current hatchery plants consist of ~20,000 winter-run steelhead smolts, and ~5000 coho eggs for use in remote site incubators in the watershed.

The Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan (LCFRB 2004a) Volume IIE outlines the most current management and recovery strategy for the Coweeman subbasin, and provides a detailed synopsis of salmonid distribution, life history, diversity, abundance, productivity, hatchery plants and harvest within the subbasin.

Hatchery Steelhead Plant

Winter-run hatchery steelhead are planted as yearlings in the Coweeman from the Elochoman Hatchery. The fish are of the Beaver Creek stock, a Chambers Creek (Puget Sound) derivative in use in southwest Washington since the late 1950's (Crawford 1979). Steelhead are planted both from acclimation ponds and by trucking directly from the Elochoman Hatchery. Two acclimation ponds are in use: one on Turner Creek (Figure 1: Turner Creek Pond; TP), entering the Coweeman at Rkm 15 and one on an unnamed creek entering the Coweeman at Rkm 21 (Figure 1: Rauth Pond: RP). The acclimation ponds are less than 1 km from the mainstem Coweeman. The direct plant was off a bridge crossing at Rkm 21.

Methods

Trap Operation

On March 25, 2005 a 1.5 meter rotary screw trap was installed at Rkm 12 (Figure 1). The trap was fished until at or near the end of the smolt migration on August 8, 2005. The trap was located near the head of a pool, just below a riffle of fast turbulent flowing water. The trap was positioned so that stream flow entered in a straight line. Water velocities at this site produced cone revolutions of between 7 and 14 revolutions per minute (rpm). The trap was fished 24 hours/day throughout the smolt outmigration period. We did not fish the trap for 3 days (March 27, March 28, and April 4) because of high flows and equipment failure. Since this was prior to the start of significant spring migration, we assumed that missing those days had a negligible effect on the production estimates.

Fish Handling

For most of the trapping season, the trap was checked and emptied of fish once daily in the morning. Initially, fish removed from the livebox onboard the trap were placed in 19 L buckets when small numbers of fish were being processed and in perforated live boxes anchored in a flowing side channel near the trap when large numbers of fish had to be processed. Later, to improve the fish handling process, we plumbed a 100 L tote using a portable generator and a 1/4 hp water pump to provide a livebox with a continuous supply of fresh flowing water.

After the trap was emptied, fish were anaesthetized approximately 10 at a time in buffered ($NaHCO_3$) MS-222 solution (~ 60 mg/l). For each specimen, we noted species, presence or absence of fin clips, other marks (described below), fork length (FL) to the nearest mm, and weight (WT) to the nearest 0.1 of a gram. Further, salmonids were classified as parr, pre-smolt, or smolt (Rawding et al. 1999). The criteria for parr included well-developed parr marks and heavy spotting across the dorsal surface. Pre-smolts were those fish that had faint parr marks, less prominent dorsal spotting, silvery appearance, and no dark caudal fin margin (or tips, in the case of coho). Smolts consisted of those salmonids with deciduous scales, silver appearance, and a dark band on the outer margin of the caudal fin. Since smoltification is a process that salmon, steelhead, and cutthroat undergo along their downstream migration, and these salmonids are more than 120 km from the ocean, we felt it was more accurate to combine smolts and presmolts for the outmigration analysis.

For each salmonid species, we also created an archive of DNA samples by removing fin clips from the upper or lower lobe of the caudal fin of a representative subsample of all the salmonids caught throughout the season. Fin clips were stored in 1.5 ml vials containing 100% ethanol. In general, for wild steelhead, coho, and fall Chinook, we systematically sampled by taking fin clips from all fish captured on the same day once per week throughout the trapping season until we obtained a target sample size of 100. We reasoned that systematic sampling should provide a sample representative of the run. For cutthroat, after it became apparent that systematically sampling in that fashion would not generate 100 specimens, we began sampling nearly every fish of that species until an adequate sample size was obtained. We also obtained a supplemental series of samples of fall Chinook that were migrating later than is considered normal for that species (N=21 on July 14 in trapping interval 16). For wild steelhead and cutthroat, scale samples were also obtained from the same fish that were DNA sampled.

When large numbers of fish were migrating, especially after the hatchery steelhead release, the trap was emptied several times throughout the day and night but fish were otherwise processed as described.

In all cases, fish were sampled as quickly as possible and were allowed to recover fully before being either released back into the river downstream of the trap in rapidly flowing water or placed into a perforated livebox near the trapping location. Fish in the recovery livebox were marked (described below) and transported upstream to serve as a marked group to permit estimates of trap efficiency. The release occurred at the next available access point approximately two Rkm above the trap site. Since the release location was greater than 1.6 km above the trap and the river reach between the release location and the trap is turbulent and comprised of diverse habitat types (alternating riffles, pools, and boulder gardens), we reasoned that adequate mixing of marked fish with unmarked fish of each species occurred.

Fish Marking

Before we began the trapping operation, we performed an experiment (Appendix 1) to test mark retention and mark visibility of three marking methods: Microject^{R} injection of colored dye into the anal fin and Elastomer^{R} injection into either the base of the pectoral fin(s) or the adipose eyelid(s). Because of high tag retention and ease of use, we used colored elastomer injections for steelhead, cutthroat, and coho for most of the trapping operation. A small number of fish were marked using the Microject method in the first two weeks of the trapping operation until we could assemble the equipment and materials for using the Elastomer method.

We used a different color/location combination for each marking interval. The intervals ran from Thursday through Wednesday each week (Table 1) except that the first marking interval was from March 26 through April 6.

Table 1. Marking and recapture intervals and marks used in the Coweeman watershed in 2005 for steelhead, coho, and cutthroat. Microject marking was only used in weeks 1 and 2.

Mark Used	Trapping interval	Marking Interval		Recapture Interval	
		Begin	End	Begin	End
Red anal	1	3/26/05	4/6/05	3/27/05	4/7/05
Green anal	2	4/7/05	4/13/05	4/8/05	4/14/05
Red right eye	3	4/14/05	4/20/05	4/15/05	4/21/05
Red left eye	4	4/21/05	4/27/05	4/22/05	4/28/05
Blue right eye	5	4/28/05	5/4/05	4/29/05	5/5/05
Blue left eye	6	5/5/05	5/11/05	5/6/05	5/12/05
Green right eye	7	5/12/05	5/18/05	5/13/05	5/19/05
Green left eye	8	5/19/05	5/25/05	5/20/05	5/26/05
Yellow right eye	9	5/26/05	6/1/05	5/27/05	6/2/05
Yellow left eye	10	6/2/05	6/8/05	6/3/05	6/9/05
Red right eye	11	6/9/05	6/15/05	6/10/05	6/16/05
Red left eye	12	6/16/05	6/22/05	6/17/05	6/23/05
Blue right eye	13	6/23/05	6/29/05	6/24/05	6/30/05
Green right eye	14	6/30/05	7/6/05	7/1/05	7/7/05
--	15	7/7/05	7/13/05	7/8/05	7/14/05
--	16	7/14/05	7/20/05	7/15/05	7/21/05
--	17	7/21/05	7/27/05	7/22/05	7/28/05
--	18	7/28/05	8/3/05	7/29/05	8/4/05

Sub yearling fall Chinook were too small to use either Microject or elastomer injections so for that species we used a single batch mark. When large numbers of fall Chinook began to appear in the trap, a subsample (approximately 40/d) was stained with bismark brown dye following protocols established by the WDFW Natural Production Monitoring Unit (Pete Topping, WDFW, pers. comm.). The limitation of this mark is that we must assume that recaptures in a recapture interval came from the corresponding marking intervals: some of the recaptures may have been released as marked fish two or more marking intervals earlier. We checked for this phenomenon by applying a second mark (a small caudal clip) to some of the bismark brown marked fish. By noting the recapture of caudal-clipped fish with and without the primary mark, we calculated both the mark loss rate and the likelihood that bismark brown marked fish migrated within their trapping interval.

On January 11 and 12, 2005, the acclimation pond steelhead received fin clips in addition to the normal adipose clip to permit identification upon their later capture in the smolt trap. Steelhead acclimated in the Rauth and Turner Creek Ponds received left and right ventral fin clips, respectively. On 2 March 2005 the acclimation pond fish were transferred from the Elochoman facility to the ponds. The ponds are covered with bird netting to limit predation of rearing fish.

On April 15, 2005 the steelhead were released. Adipose-clipped direct plant steelhead were trucked in an aerated WDFW fish transport truck to the bridge crossing at Rkm 21 and released directly into the mainstem Coweeman. On the same day, the acclimation pond fish were released by removing the standpipes and draining the ponds. Prerelease samples noting size of the fish at release were obtained from all release groups. Fork length (mm), weight (gm) and fin clips were noted from representative samples of all release groups just prior to release.

Juvenile Production Estimates

The number of juvenile outmigrants was estimated by using a trap efficiency method of releasing marked fish upstream of the trap (Dempson and Stansbury 1991, Thedinga et al. 1994). Captured juvenile salmonids were marked as described above. Since the marking schedule was Thursday through Wednesday, marks were recovered Friday through Thursday. Thus, the “marking intervals” ran from Thursday through Wednesday while the “recapture intervals” ran from Friday through Thursday.

Murphy et al. (1996) listed the standard assumptions of the Petersen method that apply in trap efficiency experiments: (1) the population is closed; (2) all fish have the same probability of capture in the first sample; (3) the second sample is either a simple random sample, or if the second sample is systematic, marked and unmarked fish mix randomly; (4) marking does not affect catchability; (5) fish do not lose their marks; and (6) all recaptured marks are recognized. During the smolt trapping season, we took steps to reduce the possibility that these assumptions were violated. Assumption 1 is that of closure, which assumes that no fish leave or enter between sampling occasions. Since smolts are actively emigrating this assumption cannot be met. However, the Petersen estimate is still consistent if the loss rate of tagged and untagged smolts is the same (Arnason et al. 1996). Therefore, the closure assumption is considered be met in this study.

We tested for bias caused by violations of the principal assumptions. We reasoned that the most likely violations of assumptions 2 and 3 would be because of a relationship between trap avoidance and size of the smolts, especially with steelhead, where large steelhead might avoid the trap more readily (Pete Topping/WDFW, pers comm.). We addressed this issue by testing for differences in recovery rates by length. Although Seber (1982) recommends a comparison of recaptured fish with those not seen again, this is not possible with the batch mark we used for smolt trapping. For batch marked fish, we followed the recommendation of Thedinga et al. (1994) and compared recaptured fish with all marked fish. Assumptions 4, 5, and 6 were tested by holding marked fish to assess tag loss, tag readability, and handling mortality (Appendix 1). Also, we intentionally marked only those fish that were not obviously injured or descaled during trapping or handling. Further, we held all marked fish in live boxes for approximately 8 h before transporting them to our upstream release site. This protocol allowed us to release marked fish at or near dark, presumably decreasing the likelihood of predation on the marked fish. Importantly, we were also able to examine all the fish before releasing them. Marked fish that were dead, moribund, or simply swimming erratically were removed from each release group. Species, length, and weight of the fish that were removed from the release groups were noted so that those data could be extracted from the database. Taken together, by marking only healthy fish and waiting for delayed negative effects of handling and marking, we increased the likelihood that we were releasing groups of marked fish that were more representative of the populations we were assessing.

Statistics

Population and trap efficiency estimates were calculated using the Darroch Analysis with Rank Reduction (DARR) method employing software DARR (v. 2.0) and documentation provided by Bjorkstedt (2005). For the DARR analyses, trap efficiency estimates were compared over time to determine which weeks could be pooled thus increasing precision of production estimates over those time intervals. To accomplish this, we used the G-test (Sokal and Rohlf 1981) to compare the proportion of marked fish recaptured among weeks and used the outcomes to determine which weeks for which species could be pooled to generate the final, most precise population estimates. We report the calculated G statistic for the compared proportions, the degrees of freedom (df) for the test and the probability (*P*) of test's significance.

We also used the G-test to compare the relative abundance of hatchery steelhead from each of the three release groups in the catch and infer differences in migration timing among the release groups.

Variance in size between maiden (captured for the first time) and recaptured fish was examined using the Kolmorogrov-Smirnov (KS test) and the Mann-Whitney Rank Sum Test. Variance in size over time was examined using the Kruskal-Wallis One Way Analysis of Variance. The non-parametric ANOVA proved to be very sensitive to small sample size, i.e. when a single specimen was captured within a trapping week. Therefore, when that occurred we arbitrarily pooled that specimen with the previous week's collection. We followed the Kruskal-Wallis One Way Analysis of Variance with Dunn's Multiple Comparison Procedure to provide statistical confidence in increasing or decreasing trends in size.

Differences in size among hatchery steelhead before release and after capture in the smolt trap were examined using ANOVA and Tukey's Multiple Comparison Procedure.

We examined the relationship between stream flow and trap efficiency in an attempt to estimate trap efficiency during those times when we could not release marked fish upstream of the trap. A flow gauge on the Coweeman approximately 100 m upstream of the trap location was operated continuously between January 1, 1977 and September 30, 1982. A flow gauge on the nearby East Fork Lewis watershed (at Heisson Falls) was operated over the same time interval. Linear regression of historical Heisson flows on historical Coweeman flows was performed. Current Heisson flows are available from the USGS (at http://waterdata.usgs.gov/wa/nwis/uv?14222500) and, in combination with the regression model, were used to estimate Coweeman flows during the trapping operation.

The statistical package used was SigmaStat^R version 3.0.1. A significance level for estimated probabilities (*P*) of 0.05 was adopted throughout.

Results and Discussion

Production Estimates by Species/Release Group

Wild steelhead

We captured 2,765 maiden wild smolt and presmolt steelhead (WST) and marked for recapture 1,873. We recaptured 258 marked specimens throughout the course of the migration between March 26 and July 8, 2005, the dates that the first and last wild steelhead migrants were noted in the trap, respectively. Trap efficiency estimates ranged from 8% to 22% but did not vary significantly among capture intervals (G-test: $G = 6.975$, $df = 9$, $P = 0.64$). Thus, after pooling recaptures across trapping intervals, the production estimate for emigrating wild winter-run steelhead from the Coweeman watershed in 2005 (number (N) ± standard deviation (SD) is 20,073 ± 1,153 (Table 2 and Figure 2).

Table 2. Production estimates for salmonids emigrating from the Coweeman in 2005 in the period after March 25, when the trap was installed. For most species, that probably represents most or all of the production. For fall Chinook, the majority of the emigrants likely left before the trap was installed (see text). Production estimates ("Emigration") are derived from analysis of pooled strata (weekly intervals), except as noted.

Species	Captured	Marked	Recaptured	Emigration	SD
Wild steelhead	2765	1873	258	20073	1153
Wild steelhead[1]	2765	1873	264	19691	1118
Wild cutthroat	236	178	14	3001	768
Wild cutthroat[2]	236	178	14	3264	977
Wild cutthroat[3]	236	178	29[3]	1503[3]	282[3]
Fall Chinook	10081	1276	218	52126	3258
Wild coho	1648	1046	99	17412	1660
Hatchery coho	138	--	--	~1,300[4]	--
Hatchery steelhead (total)	1967	1046	129	15666	1285
Direct Plant	1065	519	57	9174	1139
Rauth Pond	491	253	41	2994	425
Turner Creek Pond	411	274	31	3580	602

[1] Wild steelhead estimate after inflating number of recaptured marked fish by 2.5% (the tag loss rate for the species).

[2] Wild cutthroat estimate derived from unpooled strata. See text.

[3] Wild cutthroat estimate derived from wild steelhead trap efficiency. See text.

[4] Based on seasonal trap efficiency of wild coho.

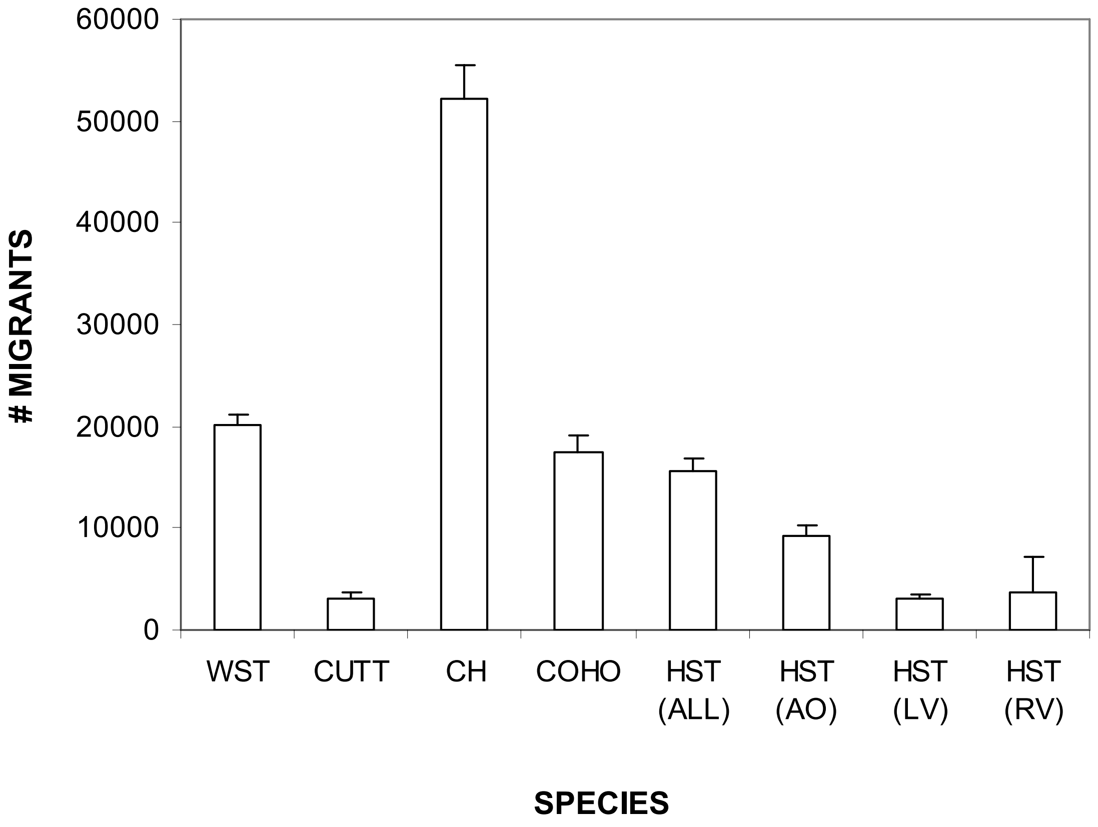


Figure 2. Estimated wild steelhead (WST), wild cutthroat trout (CUTT), wild fall Chinook (CH), and hatchery steelhead (HST) emigrants (± SD) from Coweeman watershed in 2005. AO, LV, and RV refer to HST released directly and from the Rauth and Turner Creek ponds, respectively. Hatchery coho emigrants are not included but see text and Table 2.

The peak of the steelhead emigration occurred at the end of April (Figure 3). Size of the migrants varied significantly over the course of the migration period tending to decrease over time (Kruskal-Wallis, $P < 0.001$: Figure 4).

Wild cutthroat trout

We captured 236 maiden wild smolt and presmolt cutthroat (CUTT) and marked for recapture 178. We recaptured 14 marked specimens throughout the course of the migration between April 1 and June 24, 2005, the dates that the first and last wild cutthroat migrants were noted in the trap, respectively. Trap efficiency estimates ranged from 4% to 14% but did not vary significantly among capture intervals (G-test: $G = 1.16$, $df = 5$, $P = 0.95$). Thus, after pooling recaptures across trapping intervals, the production estimate for emigrating wild winter-run steelhead from the Coweeman watershed in 2005 (N ± SD) is 3,001 ± 768 (Table 1 and Figure 2).

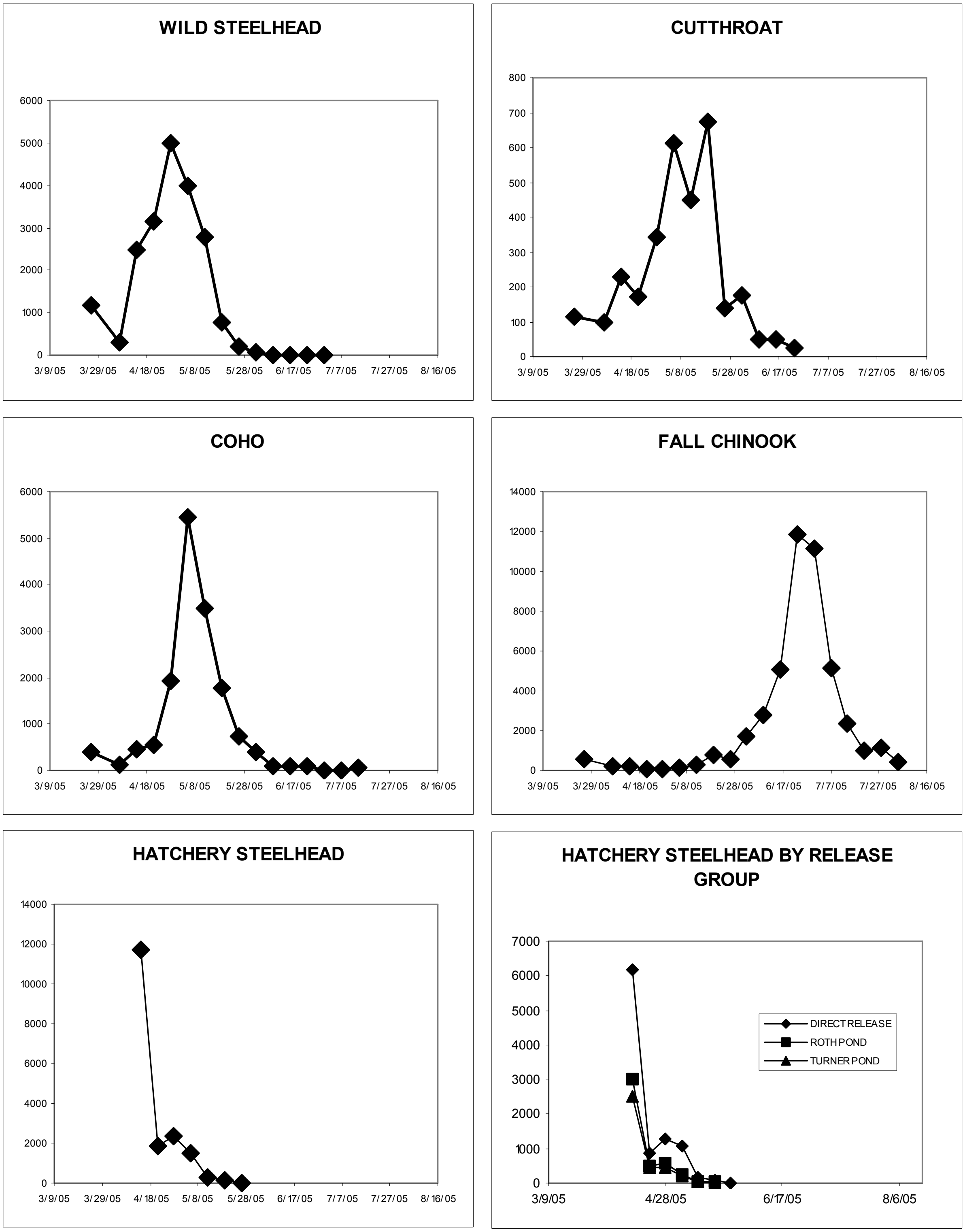


Figure 3. Weekly emigration of salmonid species from the Coweeman watershed in 2005. The Y-axis is the estimated number of emigrants derived from trap catch of each species divided by the probability of capture of that species in that week, as calculated by the DARR software (see text).

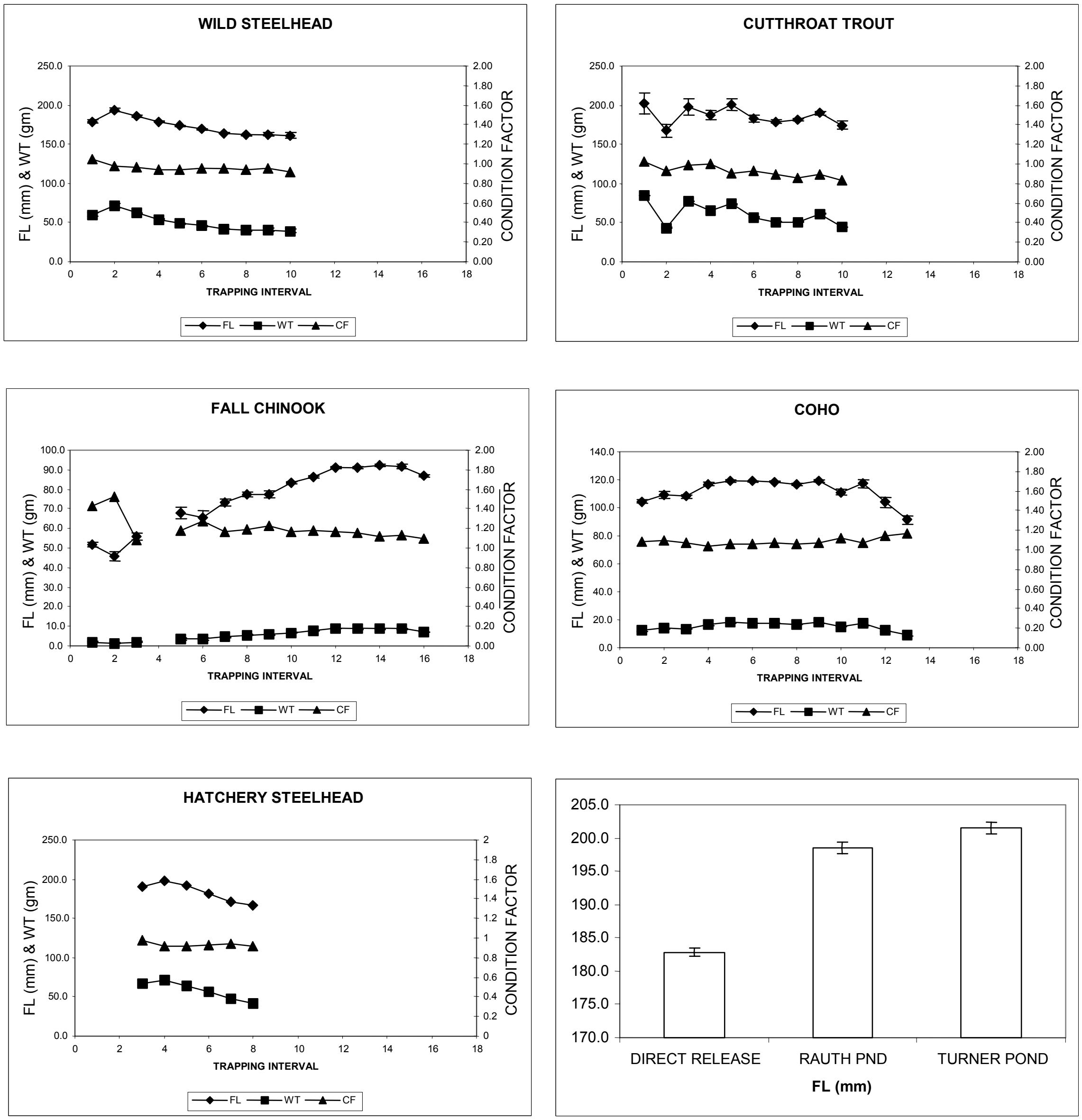


Figure 4. FL, WT, and Condition Factor (CF) ± Standard Error (SE). Only sampling intervals with N>5 are included. At lower right, FL ± SE for different release groups of hatchery steelhead are provided.

Because the number of cutthroat recaptures was low, the test for homogeneity across trapping intervals undoubtedly has low statistical power. Therefore, we also estimated production without pooling the trap data across weekly intervals. Cutthroat production with unpooled sampling strata (± SD) was 3,264 (± 977), an increase of 8.8% from the estimate derived from pooled strata.

Further, and also because the number of cutthroat recaptures was low, there were trapping intervals with no recaptures within that interval. Bjorkstedt (2005; and references therein) noted that at least one “immediate” recapture within each trapping interval must occur or the Darroch estimator can fail. To test for this, we pooled pairs of contiguous trapping intervals (interval 1 &

2, 3 & 4…) and repeated the estimate. Cutthroat production with 2-week pools (± SD) was 3,054 (± 821), a increase of 1.8% from the estimate derived from pooled strata.

It is important to recognize that the number of cutthroat captures and recaptures is so low that the production estimates are very imprecise. A final option for generating a production estimate is to use the wild steelhead trap efficiency estimates as a proxy for expanding the trap capture of cutthroat. Volkhart et al. (2004) estimated trap efficiency for the two species in Abernathy Creek, WA, and found them to be similar. As a modeling exercise, we repeated the DARR analysis with the cutthroat data except we applied the trap efficiencies for wild steelhead to the numbers of cutthroat marked at the trap. Assuming then that the marked cutthroat should have been recaptured at the same rate as wild steelhead, the emigration estimate decreases substantially to 1,503 (± 282).

Peak cutthroat migration occurred in mid May (Figure 3). The size of the migrants remained constant throughout the migration (Figure 4).

Wild fall Chinook

We captured 10,081 maiden subyearling fall Chinook (FCH) and marked for recapture 1,276. We recaptured 218 marked specimens throughout the course of the migration between March 26 and August 8, 2005, the dates that the first and last wild Chinook migrants were noted in the trap, respectively. Importantly, very large numbers of subyearlings likely emigrated soon after emergence (in January, February, and March, before we began trapping; Pat Hanratty/WDFW pers. comm.) and some Chinook were still being captured each day of trap operation at the end of the season.

The production estimate provided herein is thus an estimate of abundance of emigrants in late spring and early summer and, at that, is biased low since migrants were still leaving when the trap was pulled. Trap efficiency estimates ranged from 8% to 23% with highly significant differences among capture intervals (G-test: G = 19.3, df = 7, *P* <0.01). Thus, it was necessary to partition the production estimate among trap intervals. We reasoned the trap efficiencies for Chinook subyearlings likely varied inversely with flow. Because a smaller proportion of the stream passed through the trap at high flow, a lower trap efficiency was achieved at high flow (early season; Figure 5). Further, at low flow later in the season a higher proportion of the stream passed through the trap (but the trap was still operating at 7 RPM or greater, a speed more than adequate to entrain subyearling Chinook). We iteratively tested contiguous subsets of the weekly trap efficiency estimates to see if some could be pooled to increase precision of the overall production estimate. Of the eight intervals for which we have efficiency estimates, weeks one through four are statistically homogeneous (G-test: G = 2.53, df = 3, *P* = 0.47) as are weeks 5 through 8 (G-test: G = 2.98, df = 3, *P* = 0.39). Independent emigration estimates for those two pooled intervals were summed and the production estimate for fall Chinook emigrants leaving the Coweeman watershed in spring and early summer 2005 (N ± SD) is 52,126 ± 3,258 (Table 2 and Figure 2).

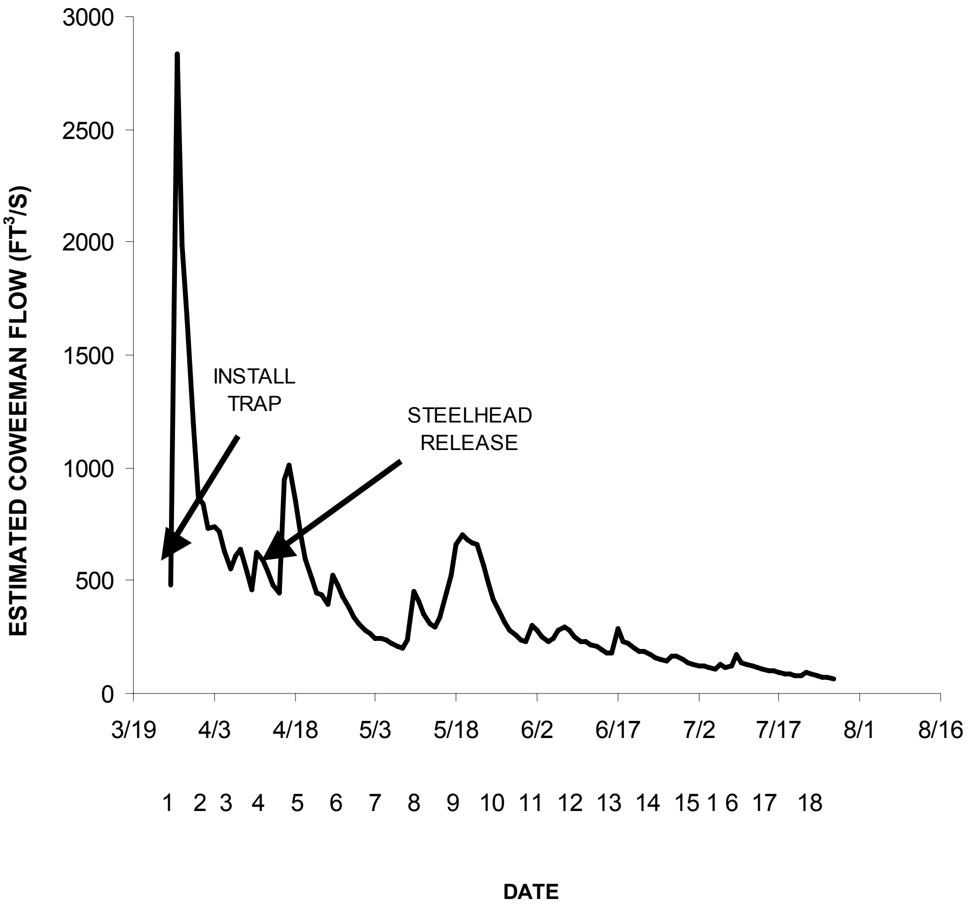


Figure 5. Estimated daily mean flows in the Coweeman. X-axis is date and trapping interval.

As noted, trap efficiency estimates were only obtained for trapping intervals 8 through 15 (19 May through 13 July). Thereafter, we could not tag or transport fish because of high water temperatures: mortality of fry during marking increased. We did attempt to relate estimated trap efficiency to estimated flow and derive an adjusted trap efficiency for trapping intervals 16 through 19 when flows decreased and efficiency could have increased. However, the relationship was not statistically significant (Linear Regression, $P = 0.059$: Figure 6). Therefore, after 13 July, we assumed that the trap efficiency remained constant. Still, the statistical power of the test was low (Power = 0.473) and inspection of Figure 6 does suggest a negative relationship between flow and trap efficiency. We reason that, for future work, increased precision in estimates of flow or trap efficiency or both might permit a better estimate of late-migrating fall Chinook. If the trap efficiency estimates used for the DARR analyses were biased high, actual estimates of fall Chinook production are further biased low.

Fall Chinook subyearling emigration was protracted and late, beginning in early June and peaking late that month (Figure 3). The timing of the emigration was unexpected because in other Lower Columbia tributaries (Pat Hanratty/WDFW, pers. comm.: Abernathy, Germany and Mill Creeks; Dan Rawding/WDFW, pers. comm.: Cedar Creek) and in the author's (CS) experience in Puget Sound watersheds, significant emigration of subyearling smolts begins in March and ends early in June. Size of the emigrants increased significantly over time among the migrants (Kruskal-Wallis, $P < 0.001$: Figure 4).

As detailed above, our production estimate is limited to those fish emigrating after March 25, a fraction of the total juvenile production. We attempted to use recent production estimates and patterns of migration from other nearby watersheds to determine what total production of Coweeman Chinook might have been had our trapping season begun earlier. In Cedar Creek, a tributary to the Lewis watershed, approximately 90% of the fall Chinook emigrants left that stream before March 25. Assuming a similar pattern for the Coweeman, given emigrants after March 25 of ~52,000, total production might have been ~500,000. We recognize that the value of this extrapolated estimate is limited by its imprecision and the number of untested assumptions required to make the extrapolation.

Wild Coho

We captured 1,648 maiden wild smolt and presmolt coho and marked for recapture 1,046. We recaptured 99 marked specimens throughout the course of the migration between March 26 and July 15, 2005, the dates that the first and last wild coho migrants were noted in the trap, respectively. Trap efficiency estimates ranged from 3% to 25% but did not vary significantly among capture intervals (G-test: $G = 13.7$, $df = 11$, $P = 0.25$). After pooling recaptures across trapping intervals, the production estimate for emigrating wild coho from the Coweeman watershed in 2005 (N±SD) is 17,412 ± 1,660 (Table 2 and Figure 2).

However, in the first three trap intervals, trap efficiency ranged from 3% to 7% at a time when wild steelhead trap efficiency ranged from 10% to 17%. Trap efficiency for coho should equal or exceed that of wild steelhead (Dan Rawding/WDFW, pers. comm.) We suspect that while we were learning how to mark and handle the relatively fragile coho salmon migrants, excessive post-release mortality might have occurred. Thus, it may be appropriate to pool the coho captured over those three intervals with those captured in interval four. The alternate production estimate using that logic (N±SD) is 17,389 ± 1,769.

Peak coho emigration occurred in early May (Figure 3). Size of the migrants varied significantly over the course of the migration period tending to increase initially (Kruskal-Wallis, $P < 0.001$; Figure 4).

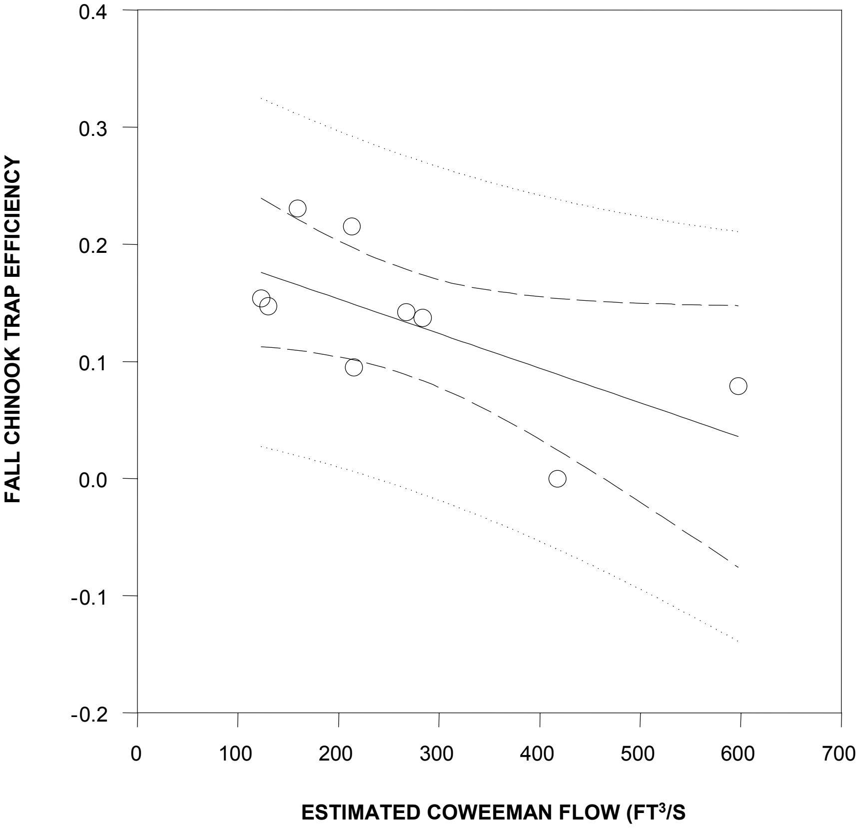


Figure 6. Relationship between estimated trap efficiency for fall Chinook and estimated flow for trap intervals 8 through 15. Relationship is not statistically significant. See text.

Hatchery steelhead

An estimated 20,200 hatchery steelhead (HST) were recorded as delivered from the Elochoman Hatchery -- 10,000 for direct release and 5,100 each for two acclimation ponds (but see discussion, below). We captured 1,967 maiden hatchery smolt and presmolt steelhead and marked for recapture 1,046. We recaptured 129 marked specimens throughout the course of the migration between April 15 and May 26, 2005, the dates that the first and last hatchery steelhead migrants were noted in the trap, respectively. Trap efficiency estimates ranged from 7% to 14% but did not vary significantly among capture intervals (G-test: $G = 0.95$, $df = 3$, $P = 0.81$). Thus, after pooling recaptures across trapping intervals, the production estimate for emigrating hatchery winter-run steelhead from the Coweeman watershed in 2005 (N±SD) is 15,666 ± 1,285. (Table 2 and Figure 2).

Hatchery steelhead from the three release groups began migrating in large numbers immediately after release. Overall, the size of the hatchery steelhead emigrants decreased significantly over time (Kruskal-Wallis, $P < 0.001$: Figure 3), paralleling the pattern noted for wild steelhead.

Direct plant steelhead were significantly smaller at the time of planting (Figure 3, lower right panel and Figure 7).

Some problems with the steelhead release became apparent after the project began. In pre-release samples for fork length and weight from the two acclimation ponds, hatchery coho salmon (HCO) were noted. In the Turner Creek Pond, three of the 103 fish sampled were hatchery coho: two were adipose clipped and one was both adipose and right ventral fin clipped. In the Rauth Pond, out of 105 fish sampled, five were hatchery coho: one was adipose clipped and four were both adipose and left ventral clipped. In addition, we captured 138 hatchery coho in the smolt trap. The sample sizes from the acclimation pond were inadequate to accurately estimate the actual abundance of coho released and we do not know if a similar proportion of hatchery coho were included with the 10,000 fish planted directly. Still, if we use the trap efficiency for wild coho as a proxy for trap efficiency of the hatchery coho, approximately 1,300 hatchery coho were inadvertently planted in the Coweeman, a watershed not intended by WDFW to receive any hatchery coho plants.

Given that the total plant for steelhead was actually ~18,900 fish (20.2K HST – 1.3K HCO), a high proportion of the plant (83%) actually migrated. A higher proportion of the acclimated fish appeared to migrate than the direct plant fish, an outcome matched by the observation that direct plant fish were smaller than either acclimation pond group. (ANOVA, $P \leq 0.001$; Figure 7). The mean size of the migrants captured in the trap was greater than the mean size of the fish from each group at release (ANOVA and Tukey's Multiple Comparison Procedure, $P < 0.001$: Figure 7).

Other species

Other species, in some cases in great abundance, were encountered during the trapping operation (Figure 8). Of particular note because of their effect on the trapping operation were the northern pikeminnow, peamouth, and largescale sucker.

The northern pikeminnow (NPM) is a voracious piscivore. On some occasions, in excess of 20 adult NPMs were captured in a single night. When NPMs were present in the livebox with juvenile salmonids, especially the abundant fall Chinook juveniles, large numbers of the juvenile salmonids were ingested. Since the count of marked and unmarked salmonids is the foundation of our population estimates, on several occasions we performed gastric lavage on the NPMs and attempted to count marked and unmarked prey. While it was possible in most cases to obtain an accurate count of the number of prey consumed, because of the condition of the (always fragmented and usually partially digested) prey items, routine identification to species and, especially, confident resolution of mark status was difficult. An important assumption, therefore, is that the marked and unmarked salmonids were ingested at a rate proportional to their abundance in the trap, i.e. the numbers of live marked and unmarked fall Chinook juveniles remaining in the trap after an evening of predation is still an unbiased estimate of the marked and unmarked fish migrating past the trap site. We tested this on four occasions between June 9 and

12, 2005 by performing gastric lavage on 52 NPM and carefully inspecting every salmonid or part thereof that had been ingested and noting species and mark status. Five marked and 82 unmarked fall Chinook were recovered from the stomachs of the 52 adult NPM. Over the same time, 11 live recaptures and 149 live unmarked fall Chinook were noted. A comparison of proportions of live and ingested marked and unmarked fall Chinook was not significant statistically (G = 0.116, df = 1, *P* = 0.73). We conclude that given that the sample sizes of live fish, both marked and unmarked, remained large, the predation by NPMs had a negligible effect on our population estimates of fall Chinook.

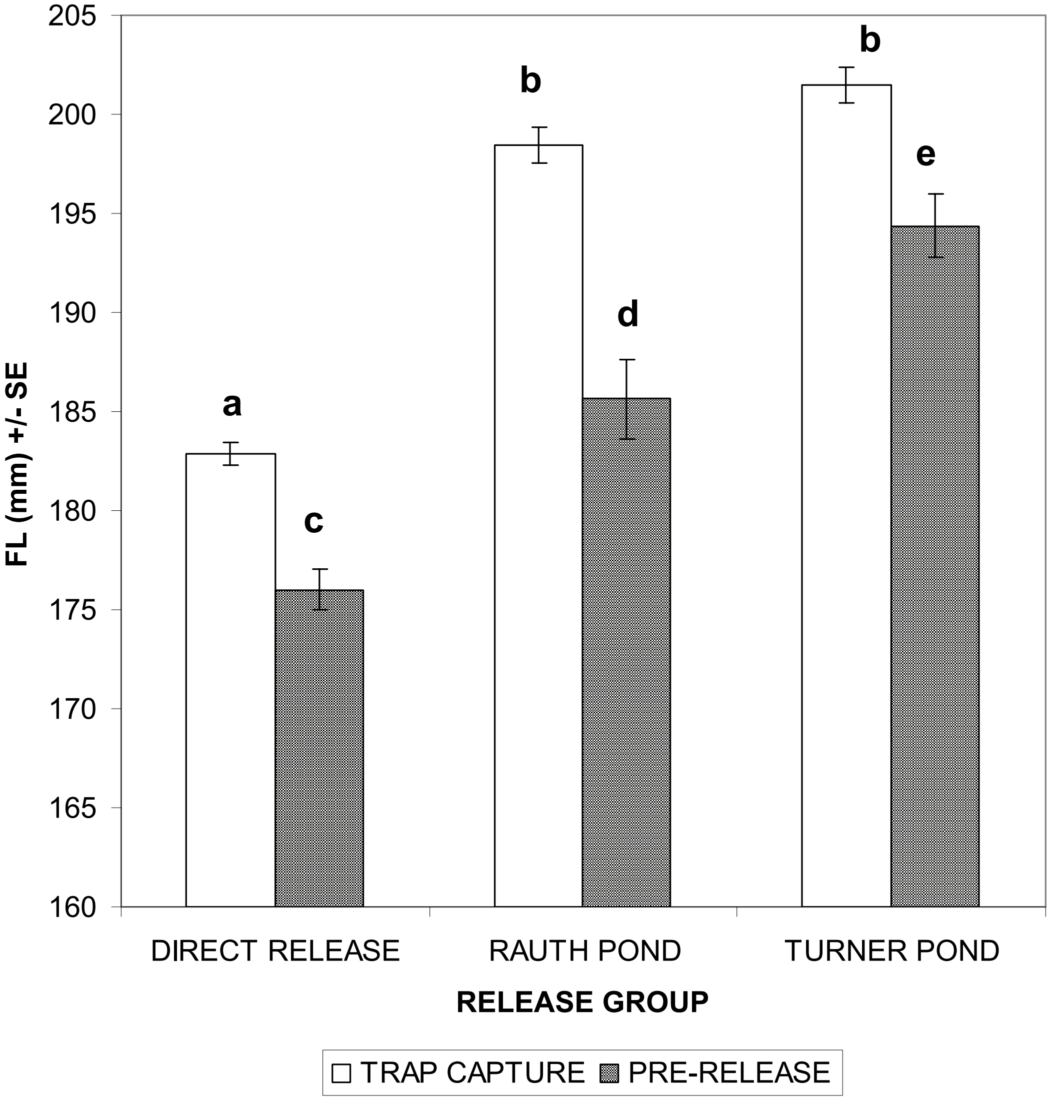
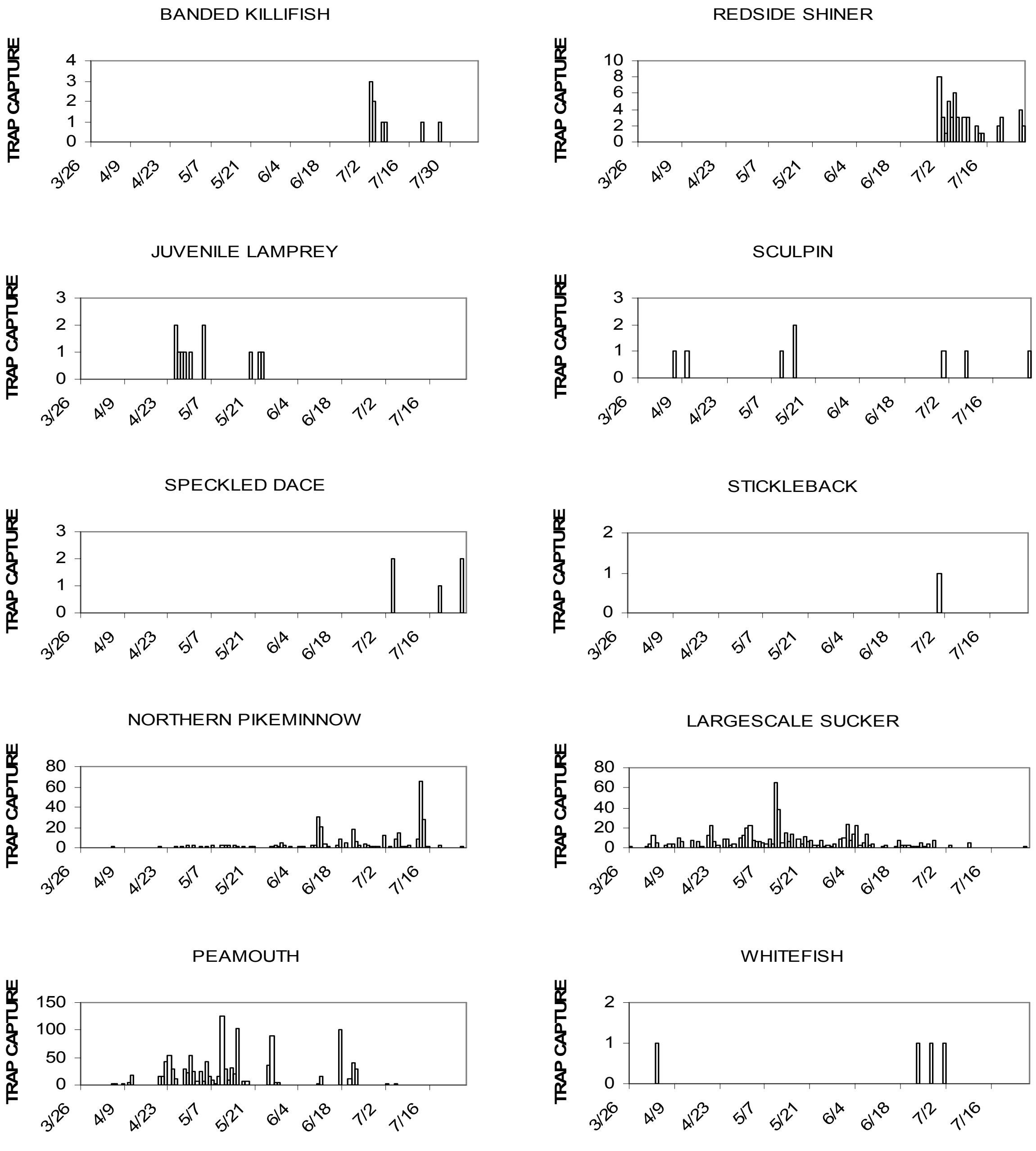


Figure 7. Fork length (±SE) immediately before release (pre-release) and as fish captured in the smolt trap (trap capture). Letters in common indicate no statistically significant difference between bars.


BANDED KILLIFISH

REDSIDE SHINER

JUVENILE LAMPREY

SCULPIN

SPECKLED DACE

STICKLEBACK

NORTHERN PIKEMINNOW

LARGESCALE SUCKER

PEAMOUTH

WHITEFISH

Figure 8. Trap capture of non-salmonid fishes in the Coweeman in 2005.

The capture of peamouth and largescale suckers also presented a significant problem to the trapping operation. On one occasion (May 10, 2005) large numbers of both species were captured (126 and 65, respectively) and, in, combination with the other species in the trap (N=354), the mass grossly exceeded the holding capacity of the trap's livebox: the salmonid mortalities included 98 wild steelhead, 62 wild coho, 13 wild cutthroat, and 33 hatchery steelhead.

Assumption Testing

The assumptions of the Petersen method that apply in trap efficiency experiments are (1) the population is closed, (2) all fish have the same probability of capture in the first sample, (3) the second sample is either a simple random sample, or if the second sample is systematic, marked and unmarked fish mix randomly, (4) marking does not affect catchability, (5) fish do not lose their marks, and (6) recaptured marks are seen.

We believe assumption 1 is met based on the argument presented in the Methods section. Assumptions 2 and 3 address equal catchability. To test these assumptions, Mann-Whitney Rank Sum tests and Kolmogorov-Smirnov (KS) tests were performed to compare the size distributions of maiden–capture juveniles that received a mark and were planted upstream to recaptured fish from those releases. The test results were not significant for wild steelhead, hatchery steelhead, sea-run cutthroat, and steelhead smolts ($P> 0.05$: Table 3). We conclude that our trapping was not selective by size for those species and that no adjustments for size bias are necessary for our production estimates. For wild coho, size of maiden and recaptured fish did vary significantly with recaptures significantly larger than maiden captures (medians differed by 2 mm: Mann-Whitney Rank Sum Test, $P = 0.006$; KS Test, $P = 0.05$). That outcome is driven by the size of maiden and recaptured fish in the first 3 trapping intervals when we believe post-release mortality was excessive (discussed in Production section, above). Excluding size of maiden and recaptured fish in those first three intervals and repeating the test for size variance on the fish captured in the remaining intervals shows that for the bulk of the trapping season and, especially when large numbers of coho were captured, size of maiden and recaptured coho did not differ (Mann-Whitney Rank Sum Test, $P = 0.068$; KS Test, $P = 0.25$).

Table 3. Test results for comparison between size of fish marked and released upstream and size of those fish that are eventually recaptured. Numbers of marked and recaptured fish are numbers of fish for which we recorded fork length. Maiden refers to fish on their initial capture. *P* is probability value of test result.

Species	# Marked	# Recap.	Mean FL Maiden (mm)	Mean FL Recap. (mm)	Mann-Whitney *P*-Value	K-S *P* -Value
Wild Steelhead	1876	258	172	172	0.756	0.91
Fall Chinook	1279	218	90	91	0.161	0.13
Coho (Int. 1-16[1])	1054	94	117	119	0.006	0.05
Coho (Int. 4-16[1])	921	93	113	114	0.068	0.25
Cutthroat Trout	178	14	183	180	0.571	0.57
Hatchery Steelhead[2]						0.42
Direct	519	57	184	181	0.899	--
Rauth	253	41	199	200	0.468	--
Turner	274	31	202	207	0.609	--

[1] Interval 1 through 16 includes all coho marked and released and all marked coho recaptured. Intervals 4-16 excludes those coho marked and released and recaptured in the first 3 trapping intervals when post-release mortality was high. See text.

[2] Direct = fish trucked and released at Rkm 21. Rauth and Turner refer to acclimation ponds entering the Coweeman at Rkm 21 and 15, respectively.

Assumption 4 addresses tag induced mortality. Tag induced mortality was low in the experiments conducted at Kalama Falls Hatchery (Appendix 1) and the release of unhealthy marked fish was controlled by our holding of marked fish for 8 h before release and release of only marked fish that appeared to be behaving normally at the time of release.

Assumption 5 addresses tag loss. The tag loss rate of the primary mark (using Microject and Elastomer marking) was extremely low in the experiments conducted at Kalama Falls Hatchery (Appendix 1). The tag loss rate estimated from double-marking of some of the Coweeman fish was slightly higher, depending on species. For fall Chinook, no recaptured fall Chinook had a caudal clip but no stain and we conclude that tag loss for this species was negligible. For coho, one specimen was recovered with a caudal clip but no primary mark. The lost mark had to have been a Microject mark in the anal fin because that was the only primary mark in use when we recaptured the specimen. Since none of the elastomer marked fish appeared to have lost their mark and since we did not use the recapture data for Microject marked coho (see wild coho production section) we conclude that, for coho, tag loss had a negligible effect on our production estimates. For cutthroat and hatchery steelhead, none of the double marked fish appeared to have lost their mark and we conclude that for those species mark loss was negligible. For wild steelhead, we recaptured two specimens that had lost their mark, one a Microject marked fish, the other an elastomer marked fish. Overall, tag retention of the elastomer mark was estimated at greater than 97% and retention of the bismark brown mark was estimated at 100%. We assume that across all species tag loss had a negligible effect on the precision or accuracy of our production estimates.

As an *a posteriori* test of that assumption we repeated the DARR analysis for wild steelhead (the only species with measurable tag loss during use of the elastomer marking protocol) after inflating the counts of recaptured fish by 2.5% (the tag loss estimate). The production estimate decreased from (N ± SD) 20,073 ± 1,153 to 19,691 ± 1,118, a change of less than 1%.

Assumption 6 addresses tag recognition. We did not specifically assess if field staff properly identified marked or tagged fish at the trapping location. However, these experienced staff knew the importance of carefully sampling fish and the need to identify all tagged fish. Based on this and the experience with the tag retention work showing that, in our judgment, the elastomer marks are easy to see (Appendix 1), the likelihood that field staff missed tags in this study is believed to be low.

Coweeman Flow Modeling

Regression of historical flows on the Lewis River, Washington on historical flows in the Coweeman between January 1 1977 and December 31 1981 generated a regression equation of *Coweeman Flow = 0.5441 * Heisson Flow + 9.5284* with regression coefficient (R^2) = 0.9082 (Figure 9). We conclude that because of the high regression coefficient and the location of the historical stream gauge on the Coweeman just upstream of the trapping operation, we can use current Heisson flows to estimate Coweeman flows at the trap (e.g. Figure 5).

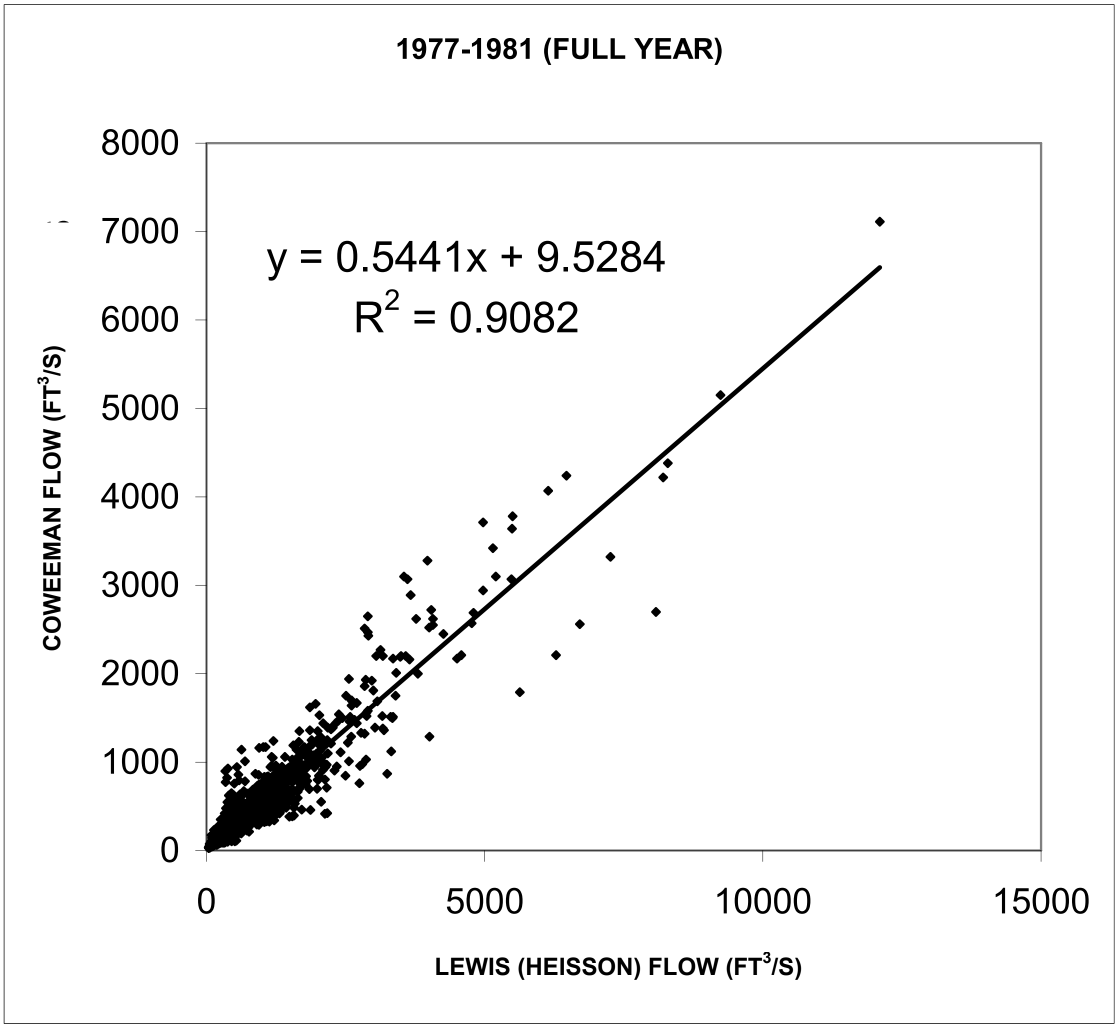


Figure 9. Regression of historical Coweeman flows on contemporaneous East Fork Lewis River flows at Heisson Falls between 1977 and 1981.

Conclusions

The trap location on the Coweeman is suitable for estimating production of spring-migrating salmonids. The potential for operating the trap earlier to obtain a comprehensive estimate of fall Chinook production is unknown. Accuracy and precision of all estimates, but especially for cutthroat, will benefit if trap efficiency or the numbers of marked fish placed upstream can be increased. Trap efficiency might be improved by placement of temporary weir panels upstream and on either side of the trap. Removing fish from the trap more often might increase the number of fish that can be marked and placed upstream by reducing descaling and other injuries to the fish.

One of the more interesting observations from this year's trapping operation was the unusual migration timing of the fall Chinook migrants. Other nearby trapping operations in systems producing fall Chinook (Abernathy, Germany, Mill, and Cedar Creeks) did not and have not in the past shown substantial numbers of emigrants past June. Interestingly, a previous genetic survey of Fall Chinook in the lower Columbia showed that the Coweeman stock was genetically distinct from all other fall and spring Chinook in the area (Anne Marshall/WDFW pers. comm., Myers et al. 2006).

An unintended release of hatchery-origin coho occurred in the watershed and every effort should be made to curtail that in the future, based on management intentions for the watershed.

A high proportion of the hatchery steelhead planted in the Coweeman appears to migrate efficiently from the watershed. Some effort should be made to estimate the adult returns from those plants. Further, the differences in successful emigration by acclimated vs. direct plant fish suggests that at a minimum the quality of the fish planted directly in the river be increased. The differences between successful migrants from the two acclimation sites may simply be a reflection of the different distances each release group must migrate. Alternatively, rearing protocols used for the fish in the Rauth Pond acclimation site might be reviewed to determine if those fish can be reared to a slightly larger size before release.

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Appendix 1

Kalama Elastomer Tag Retention Test

GOAL: To ensure that the elastomer tagging protocols do not conflict with our ability to accurately and precisely estimate the trap efficiency of the Coweeman rotary screw trapping operation.

> Objective 1: Determine the tag retention of elastomer marks in four different locations (left eyelid, right eyelid, left pectoral, & right pectoral) on smolt-sized steelhead (FL > 150 mm).
>
> > Task 1 (Mark Steelhead): On March 1, place four different marks on two replicate groups of juvenile steelhead at Kalama Falls Hatchery using the standard manual injection protocols (anaesthetize, record length, inject marks, wipe off excess). Place steelhead into covered net pens.
> >
> > Task 2 (Check for Marks): On March 3, 10, and 24, remove steelhead from net pen and record marks. Qualitatively score marks as "Good" (bright mark, immediately obvious), "Poor" (faint or fragmentary), or "Lost" (no sign of the mark). For fish missing marks, note location/color of missing marks. Note number of mortalities, if any.
>
> Objective 2: Determine the tag retention of the typical use of Microject marking (one color injected into the anal fin) on smolt-sized steelhead (FL > 150 mm).
>
> > Task 1 (Mark Steelhead): On March 1, use the Microject device to mark the same juvenile steelhead used for Objective 1, above using the standard protocol (anaesthetize, record length, inject marks, rinse fish, inspect mark). Place steelhead into covered net pens.
> >
> > Task 2 (Check for Marks): On March 3, 10, and 24, remove steelhead from net pen and record marks. Qualitatively score the marks as with the elastomer test. Note number of mortalities, if any.

Results

On March 1, 2005, two groups of steelhead (N = 80 and 68) were marked with the elastomer and Microject methods (Table A1). All of the elastomer marks in the adipose eyelids and all of the Microject marks in the anal fin were retained for 21 d. Several of the elastomer marks in the pectoral fins were missing after only 2 d but that outcome was probably in part the result of poor initial condition of one or both pectoral fins. Mortality rate was low despite the amount of handling required to apply the different marks to each fish. A single mortality was noted on day 3, none on day 10, and five on day 24.

Table A1. Mark retention results for Elastomer marks in steelhead adipose eyelids and for Microject marks in the anal fin.

			Elastomer Eye Marks			**Elastomer Pectoral Marks**			**Micro-ject Marks**	
Rep	Day	# Fish	Good	Poor	Lost	Good	Poor	Lost	Good Anal Marks	Mortalities
1	3	80	160	0	0	152	4	4	80	1
1	10	79	156	2	0	147	9	2	79	0
1	24	79	156	2	0	148	8	2	79	2
2	3	68	134	2	0	127	5	4	68	0
2	10	68	135	1	0	128	5	3	68	0
2	24	68	134	2	0	126	5	5	68	3

Qualitatively, we noted that scoring the presence or absence of the pectoral fin marks was variable from day to day. In both replicates, the number of marks recorded as lost decreased on day 10. We believe that some of the marks recorded as "lost" on day 3 must actually have been present but difficult to see.

This work directly addresses the testing of Petersen Estimator assumptions 4, 5, and 6 related to tag induced mortality, tag retention, and tag visibility and recognition, respectively. The reliability of the pectoral fin mark was not good. However, noting that for the elastomer eye marks that mortality was uniformly low, none of the marks were lost over 24 days, and that even the "poor" eye marks were easy to see, the method is as reliable a tool for marking steelhead of this size as is the Microject technique.