Coos Watershed Tide Gate Replacement Project-Effectiveness Monitoring
OWEB 204-289
Project Completion Report
Submitted by Coos Watershed Association
December 5, 2006

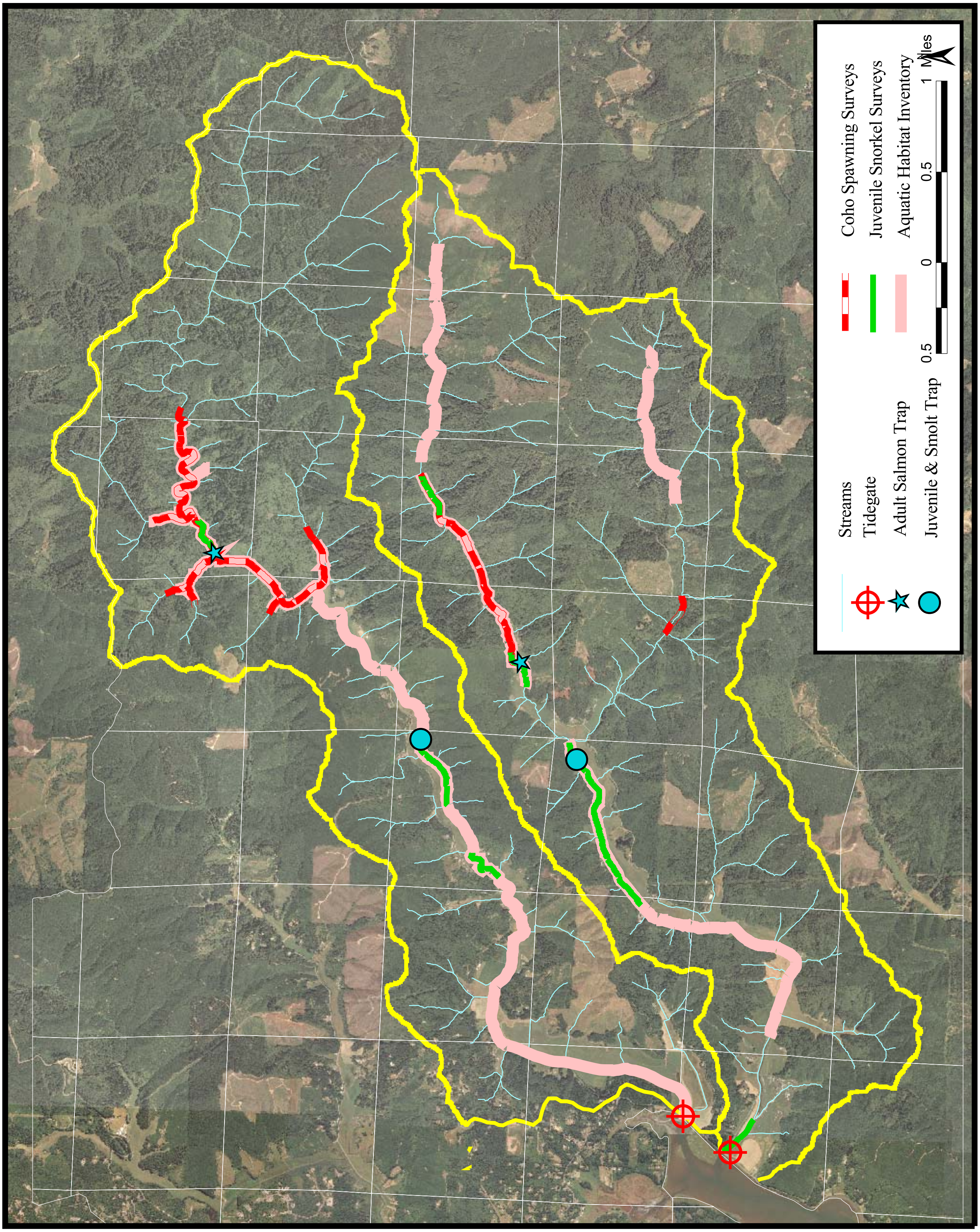
Project Background

This project was generated from the need to know whether the tide gate replacement on Larson had an impact, positive or negative, on the salmon populations, specifically coho salmon due to their prominence in the system. Having tide gates on these streams creates a number of questions: How do the tide gates affect fish passage? Clearly, adult salmon can pass through the tide gates on their spawning migration, but it is not known if there are critical time delays that could have an effect on run timing or artificially increase the risk of predation. Similarly, the smolt migration could be affected by the tide gates. Are smolts able to adjust their osmoregulatory systems when they pass from fresh water (<10 ppt) to very salty water (>30 ppt) without transitional habitat? Do the tide gates prevent a slow acclimatization from fresh to salt water conditions? Again during the smolt migration, the tide gates may present an increased risk of predation by creating a bottleneck and detaining the fish while the gates are closed. Finally, there is evidence that some portion of 0+ juvenile coho in a non-tide gated system in Coos Bay have a summer estuary rearing period (Miller and Sadro, 2005). Is this summer rearing strategy viable in tide gated systems? Are these juveniles able to re-enter the stream system during the winter rearing period?

All of the preceding questions focus on the influence the tide gates have on fish passage during the stages of the coho life-history that would may be affected. There are another set of questions that may be equally important. These question focus on the effect that the tide gate has on the habitat and water quality conditions of the area impacted by the tide gates. The impact of the tide gate is at least as far into the stream system as the water backed up during the closed cycle of the tide gate. As the water is detained in this temporary reservoir, the water velocity is lost and sediment settles out at the head of this reservoir. Such sediment deposition typically occurs near the historic head-of-tide area of the stream. Another impact of the water detention is the additional solar loading which can cause high water temperatures. Such high water temperature can affect fish physiology, dissolved oxygen and bacteria production. Other impacts include changes from salt-tolerant to obligate fresh water vegetation and associated changes to macro-invertebrate communities. How do these changes in habitat and water quality affect the rearing strategies of juvenile coho?

This report will not necessarily answer all of these questions, but will detail the efforts of the Coos Watershed Association (CoosWA) in beginning to understand the function and impacts of the tide gates on two important coho-producing streams. We have focused our study on very similar stream systems with different tide gate configurations and are working to compare and contrast the coho population dynamics, juvenile rearing strategies, tide gate functions, and associated habitat conditions (see Map 1 below). We will first discuss the way these two tide gates function, demonstrating the water exchange through the tide gate and the period that the gates are opened. We will then discuss the information that has been collected on these fish populations. This includes both adult and juvenile sampling. Finally, we will discuss the habitat

Map 1. Tide gate effectiveness monitoring sampling sites



conditions found in these systems that could be influenced by the tide gates and relate habitat condition to habitat selection by coho during the different life-history stages.

The tide gate replacement effectiveness monitoring project was initiated in 2004 to monitor salmonid populations and life-histories in streams with different tide gate configurations. Fish populations in tide gated stream systems have not received much investigation because these systems have been thought of by the biological community as highly altered and generally unproductive places for salmon. However, Larson and Palouse Creeks are examples where this is not the case. Both of these streams have relatively large coho salmon populations given the size of the watersheds and a large diversity of other aquatic species.

In 2001, the tide gate at Larson Creek was replaced. The previous tide gate featured wooden, top-hinged doors. When the tide gate was replaced, the doors were replaced with stainless-steel side-hinged doors. The invert elevation of the tide box was dropped about three feet below the existing box. These changes, intended to improve fish passage at the gates have had a number of effects, some anticipated and some not. The side-hinged gates opened with very little difference in water surface elevation during the ebb tide. Instead of the heavy top-hinged doors forcing high velocity water through a small opening, the new doors open much wider allowing as much or more water to drain at a much lower velocity. By lowering the sill elevation of the tide box, even the lowest tide cycle does not create an outlet drop because of the morphology of the tidal channels below the site. However, the tide gate has been so efficient at opening and draining with the tide cycle that the pool that had existed above the tide gate previous to the replacement has now been drained. Also, during the summer period when the fresh water flow inputs reach levels as low as one to two cubic feet per second (cfs), the tide gate drains low enough at the spring tide that at there is not enough freshwater to cause the gates to open at all during the neap tide, and so the gate only opens once each day.

ANALYSIS OF TIDE GATE OPENING SEQUENCES

The amount of time that a tide gate is open provides the first indicator of its affect on fish passage: gates that are not open provide no passage! Once the patterns of tide gate openings are known, further questions related to passage conditions—such as velocity distributions through the opening and other considerations—can begin to be evaluated. The results reported here are based on water surface elevation (WSE) information collected by submersible pressure transducers over four years at the Larson Tide Gate. Because of equipment problems, the dataset does not cover the entire period, but we were able to extract information on 551 tidal cycles over the period from 2002 – 2006. These cycles provide data over various years during each of the passage periods of interest: spawning migrations during November through February; smolt out-migration during March through May, and potential summer rearing use of the estuary during June through October. The information presented looks only at the opening and closing cycles; no data on the degree of opening or the velocity distributions throughout the opening was obtained.

Methods Using Pressure Transducers

Tide gate operations are evaluated using a system of three pressure transducers that measure water surface elevations. One transducer was placed on the Haynes Inlet side of the Larson tide gate to provide measurements of tide cycles. A second transducer was placed on a bridge bent inside of the Larson tide gate to measure water surface elevations in the reservoir pool behind the tide gate. A third transducer is located on the bridge abutment behind the Palouse tide gate to use for comparative purposes.

Figure A shows a representation of the Larson transducers with data on their elevations above sea level (NGVD). Elevations were determined from the "As-built" ODOT plans for the Larson Slough Bridge, taken at the northeastern corner of the wingwall and face of the tide gate structure. Metric elevations from the blueprints were converted to the English measurements used in this study. A laser level was used to determine the top point of the PVC pipes that hold the pressure transducer data loggers, and a measuring tape was used to determine the length from the top of the data logger to the bottom of the pressure transducer. These measurements were then used to determine the relative transducer heights, as well as the invert elevation of the tide gates.

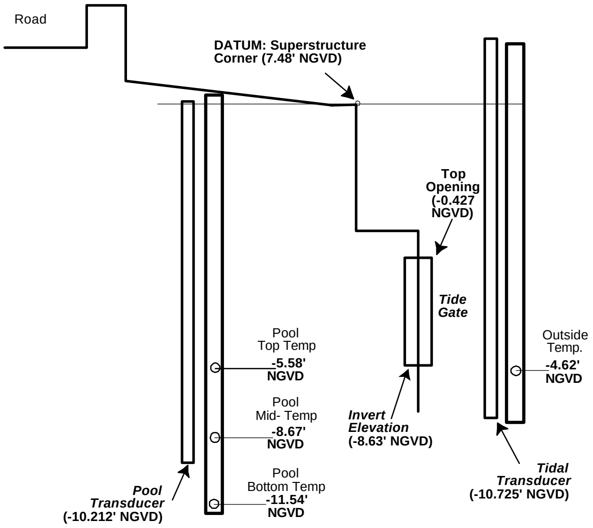


Figure A. Schematic of the water surface elevation transducers and temperature sensors at the Larson Tide Gate, October, 2006.

Global Water Pressure Transducers (Model WL15-003) supply three types of data: the time of a water elevation reading, the water surface elevation, and the temperature of the probe. The raw data is output in ASCII "comma separated values" (.csv) format that can be easily imported into a Microsoft Excel spreadsheet. Time readings are provided as numeric days consistent with the Windows date numbering scheme (Day 1 = January 1, 1900). Hours, minutes, and seconds are represented as fractional equivalents for the day (e.g., each hour is 1/24th of a day [0.04167], while each minute is 1/1440th of a day [24 * 60, or 0.000694]). Times can be added or subtracted using this system. Water surface elevations can be stored in either English or Metric units. Storage of temperature data is optional, and was not done during most periods for this study because it reduced the amount of WSE data that could be stored.

The general format for the spreadsheet was of two columns: date and WSE. No additional processing is needed if the desired task is to simply classify tide gate opening and closing sequences. There is a three-part routine for this task.

First, whether the water level is rising, stable, or falling needs to be determined. This can be done using the following Excel formula:

$$= \mathrm{IF}(\mathrm{WSE}_{t-1} \geq \mathrm{WSE}_t, \text{"FALLING"}, \mathrm{IF}(\mathrm{WSE}_{t-1} = \mathrm{WSE}_t, \text{"FLAT"}, \text{"RISING"}))$$

where: WSE_{t-1} = the water surface elevation at the previous reading; and
WSE_t = the water surface elevation at the current time;

The WSE condition is calculated for each row (other than the first row) in the dataset by copying and pasting the formula in an empty column of the spreadsheet. Status of the water surface elevation can be calculated for both the inside and outside pressure transducers and these compared side-by-side by consolidating the two datasets being careful to match the measurement times and intervals. There is no need to adjust WSE to their true elevations to determine opening cycles.

The duration of the open cycle is determined by evaluating the sequence of WSE conditions. Figure B shows tidal elevation readings outside the tide gate, as well as backwater pool elevations on the inside of the tide gate; pool elevation readings are represented as circles in Figure B to indicate the interval between water surface elevation measurements. Tidal elevations and pool elevations will rise and fall together, albeit at different rates. The basic heuristic is to examine both the tidal and pool conditions: while the tidal condition can be "Falling" for a significant time before the two WSE are roughly equivalent, once the pool condition changes to "Falling" the tide gates have opened. The gates will remain open until the tidal condition changes to "Rising", at which point the pool condition will typically be either "Flat" or "Rising" (see Figure B). Depending upon the interval between measurements, and wind and wave action, there may be fluctuations or oscillations in the WSE, (i.e., rising, flat, or falling conditions outside the regular cycles). These are generally of a transitory nature of a single measurement, and do not represent inflections in the overall cycles. There will be a very clear sequence of "Falling" WSE's for the inside of the tide gate. These will then transcend to "Flat" and/or "Rising", while at the same time the tidal WSE will be "Rising".

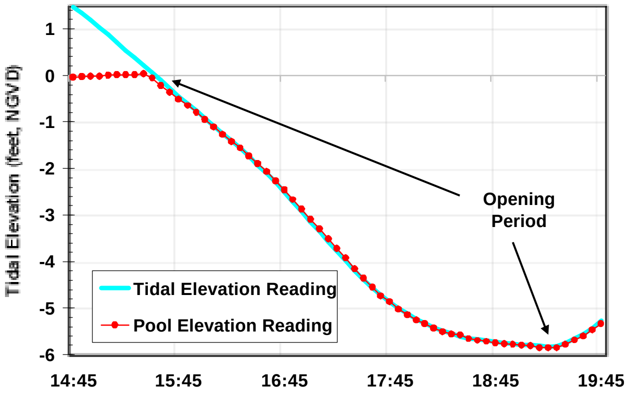


Figure B. Opening cycle illustrated using water surface elevation transducer data.

The "brute force" method to determine the period, or time, that the tide gate is open is done by identifying the latest period when the WSE indicates that the tide gate was open. Start by inserting a blank column to the right of the WSE Condition column (called "Time Open"). Then, in the cell in the Time Open column just to the right of the last open period, insert the following Excel formula:

$$= (T_{End} - T_{Begin}) * 1440$$

where: T_{End} = the last time the gate is considered open;
T_{Begin} = the first time the gate is considered open; and
1440 = the number of minutes in a day (i.e. to convert the fractional day to minutes).

Once this process is completed for an entire dataset, insert a new Worksheet (called "Open & Close Cycles") into the file. Select all the records from the original dataset (including the column headings), then Paste Special into the new Worksheet using the Values and Number Formats option. This provides a data set with just the values rather than any formulas so as to avoid problems with cell references. Once the pasting is done, sort the entire data set using the Time Open column as the sort criterion. Either copy only those rows where there is a non-blank (or non-zero) Time Open value into a new Worksheet, or just highlight those rows with blank Time Open entries (they will appear at the bottom of the Worksheet after the previous operation) and delete them. You will be left with a much smaller file containing only those rows that contain entries for Time Open.

Sort this Worksheet again, using the Date+Time field as the sort criterion. At this point you will have the sequential record showing the ending time and previously open period for each tide gate opening sequence in the dataset. In order to utilize all the data on openings, if there is a record of the last open time from a previous dataset it should be pasted into the first row of this Worksheet. Next, insert a new column to the right of the Time Open column (called “Time Closed’). To determine the time that the tide gate was closed prior to an Open cycle, use the following Excel formula in the second row of the Worksheet:

$$= ((T_t - T_{t-1}) - (T_{Open} * 0.000694)) * 1440$$

where: T_t = the last time the gate is considered open;
T_{t-1} = the first time the gate is considered open;
$694^{10^{-6}}$ = the fractional equivalent of a minute; and
1440 = the number of minutes in a day (i.e. to convert the fractional day to minutes).

The Time Open and Time Closed minute values can be divided by 60 to display the values as hours.

Data Analysis and Results

We conducted a meta-data analysis of the water surface elevations to obtain information on the duration of tide gate openings as a first step towards understanding the effects of tide gates on anadromous fish. Table A shows the period for which tidal cycle records were analyzed. Water surface elevations inside and outside the Larson Slough tide gate were measured intermittently over the period from 2002 through 2006. Measurements were not continuous due to equipment malfunctions that either resulted in data losses or precluded deployment. All told, we were able to obtain opening and closing times for 551 tide cycles over this period, with measurement intervals ranging from 15 minutes to 1 minute.

Table A. Periods of water surface elevation measurement to determine tide gate opening cycles.

Pressure Transducer Deployment Period	Opening Cycles
8/3/2002 to 10/17/2002	79
8/29/2003 to 3/15/2004	255
4/29/2004 to 9/2/2004	142
8/5/2006 to 10/18/2006	75
Total	551

The primary concern related to fish passage at tide gates is the percentage of time that the gate is open and the percentage of time during openings where flows are suitable for passage. Our pressure transducer data provide good information to answer the former question, but not the latter. Figure C and Table B provide the results of an analysis of the 551 opening cycles, to determine monthly average percentages of times that the tide gates were likely open. It is clear from this analysis that the period during which salmon are migrating upstream to spawn (considered to be mid-November through late February) corresponds to the period when the gate are open most: approximately 24% of the time. Conversely, during the late summer and early fall, the tide gates are open the least amount, approximately only 5% of the time (see Table B). Opening periods during smolt out-migration during March through May show declining available passage as winter rains decline in the spring.

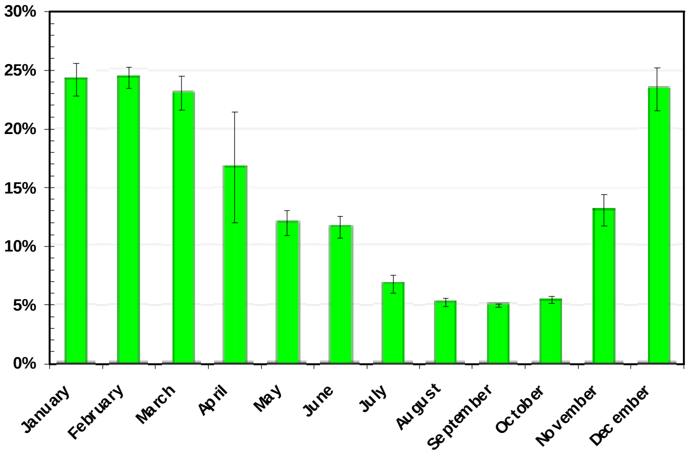
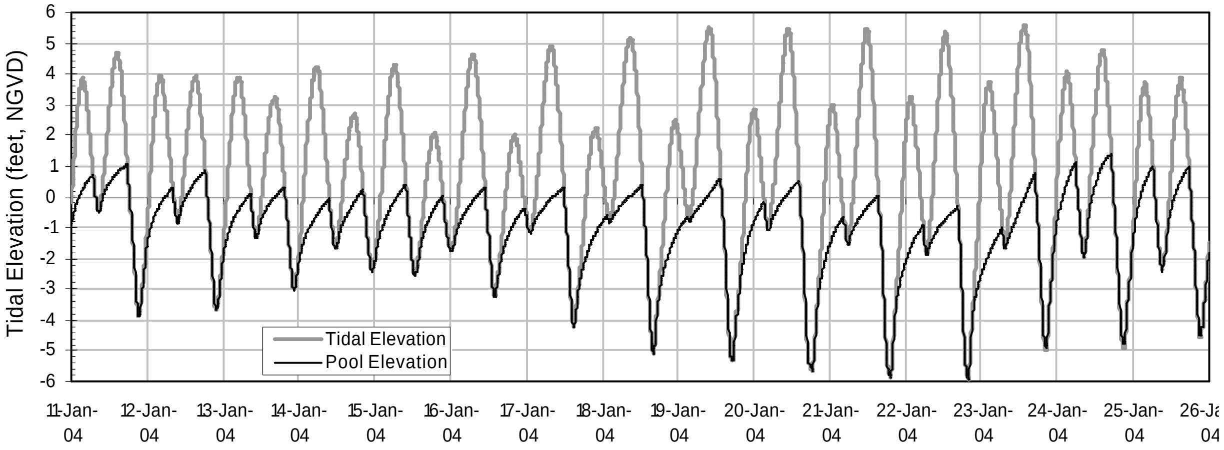


Figure C. Percent opening periods at the Larson Tide Gate by month (with standard error bars).

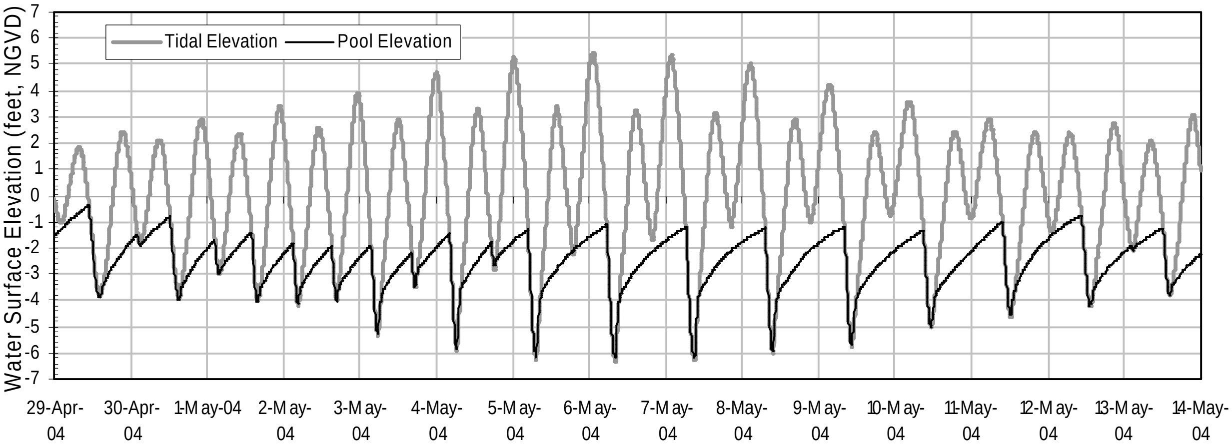
TableB. Summary data for the Larson Tide Gate opening cycle analyses.

		January	February	March	April	May	June	July	August	September	October	November	December
Percent Time Open	Samples (n=)	42	55	28	3	43	35	30	82	99	68	38	26
	Average	24%	24%	23%	17%	12%	12%	7%	5%	5%	5%	13%	23%
	Stanard Deviation	0.089	0.067	0.077	0.082	0.069	0.053	0.040	0.031	0.015	0.024	0.082	0.093
	Standard Error	0.014	0.009	0.015	0.047	0.010	0.009	0.007	0.003	0.002	0.003	0.013	0.018
Open Time (Hours)	Samples (n=)	42	55	28	3	43	35	30	83	100	68	38	26
	Average	2.98	3.09	2.92	2.39	1.83	2.10	1.51	1.20	1.04	1.14	2.19	3.12
	Standard Deviation	1.13	0.95	1.04	1.39	0.66	0.66	0.59	0.40	0.30	0.39	0.97	1.15
	Standard Error	0.17	0.13	0.20	0.80	0.10	0.11	0.11	0.04	0.03	0.05	0.16	0.22
Closed Time (Hours)	Samples (n=)	42	55	28	3	43	35	30	83	100	68	38	26
	Average	9.32	9.56	9.82	11.58	15.50	17.45	23.36	25.45	20.79	21.72	17.11	10.71
	Standard Deviation	1.40	1.85	2.54	2.25	6.23	5.96	5.47	11.59	5.27	6.39	6.51	3.99
	Standard Error	0.22	0.25	0.48	1.30	0.95	1.01	1.00	1.27	0.53	0.78	1.06	0.78

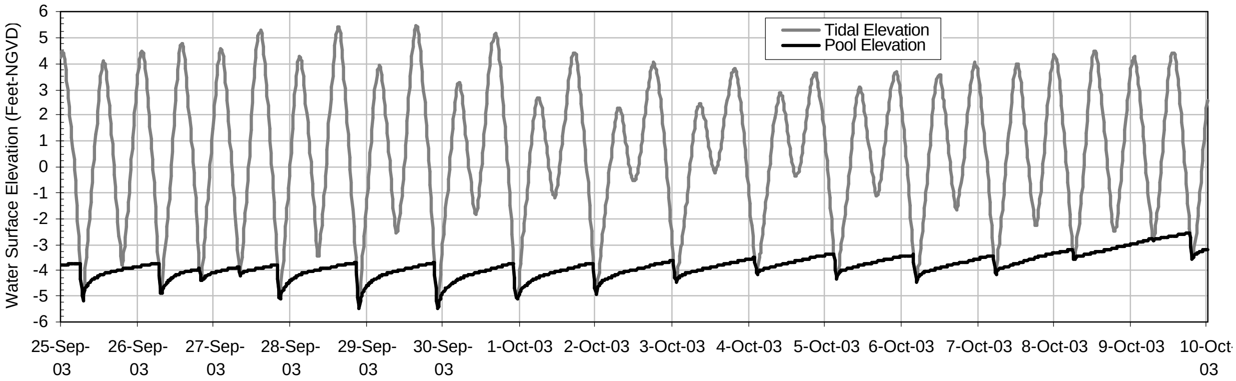
The amount of time that a tide gate is open—as a percent of time—provides one measure of the effects of tide gates on fish passage. However, the amount of time during which the gates are open varies temporally by month based on hydrological patterns, as well as by where you are within the 14-day spring tide – neap tide cycle. Figure C shows the effects of the first temporal factor based on the relative amounts of freshwater inflow into the reservoir pool behind the Larson tide gate. As is apparent in Figure C, the relationship between open and closed cycles differs between those times of the year when there are significant flows from Larson Creek into the reservoir pool behind the tide gate.



a). Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the spawning season.



b.) Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the smolt out-migration season.



c.) Representative sequence of Larson tide gate openings for a 14-day tidal cycle during the early fall juvenile rearing season.

Figure D. Effects of seasonality and spring tide:neap tide semi-diurnal cycle on the dynamics of the Larson tide gate opening sequences.

Figure D shows tidal cycles at the Larson tide gate for three different seasons over a neap tide:spring tide sequence. Figure Da provides a representative example for tidal cycles during the salmon spawning season (generally from late November through February). The 14 day cycle includes the "spring" tides that begin around January 15th and extend through about January 24th, showing the highest high and lowest low tides, while the "neap" tide cycle (from 1/11 – 1/15, and 1/25 – 1/26) show tides of relatively equal magnitude. During the winter spawning period, the Larson tide gates open at least for a short time during both the diurnal tide cycles. At the maximum extent of the spring tides, these openings can be of relatively short duration (see January 18th and 19th on Figure Da). While the opening period is relatively short of the higher of the low tides, the opening period for the lower of the low tides is significant: at some times this period will correspond to as much as four to five hours (the highest measured opening was for 5.2 hours), or approximately 30+% of the tidal cycle. During the neap tide sequence in the winter spawning period openings are of shorter duration, but more equal in length between the higher and lower of the low tides (see January 15th and 16th). For example, the second opening cycle for January 14th was 2.9 hours (at 23:10), for January 15th it was 2.8 hours (at 12:35), and the two openings on January 16th were 2.6 hours and 3.1 hours.

As flows decrease in the spring, the Larson tide gate opening sequences begin to reflect substantial differences between diurnal tidal cycles during the period when coho smolts are out-migrating to the estuary and the ocean. This period lasts generally from March to May in Larson Creek. As shown in Figure Db, a typical opening sequence for the latter part of this period shows that the gate opening sequence is more influenced by the neap tide:spring tide pattern than during the winter. During this time of year, the tide gates typically open only once daily during spring tides, with the reservoir pool behind the Larson Tide Gate filling at an insufficient rate to raise its elevation enough to match the higher of the low tides and thus provide the head difference needed to open the gates. As during the winter, tide gate openings during the neap tide cycle occur twice daily, however the length of time the gates are open goes from slightly less than 25% in March down to about 12% in May.

The third significant period where tide gate openings may affect fish passage and usage of the Haynes Inlet estuary and Larson Creek freshwater is during the summer rearing period. Miller and Sadro (2003) found that in a certain life history of coho salmon age 0+ juveniles migrated down to the upper estuary from March through October prior to moving back upstream to rear in the winter. If this life history is/was present in Larson Slough, then coho juveniles would need to be able to move upstream during the late fall. As Figure Dc shows, movement would be significantly constrained by the effects of the Larson tide gate. During this period of extremely low flows the Larson tide gate opens only once a day throughout most of the spring tide: neap tide cycle due to low reservoir inflows, the high drainage capacity of the side-hinged gates, and the low invert elevation. Opening periods run between one and two hours, with only about one hour opening on average during September and usually only one opening per day.

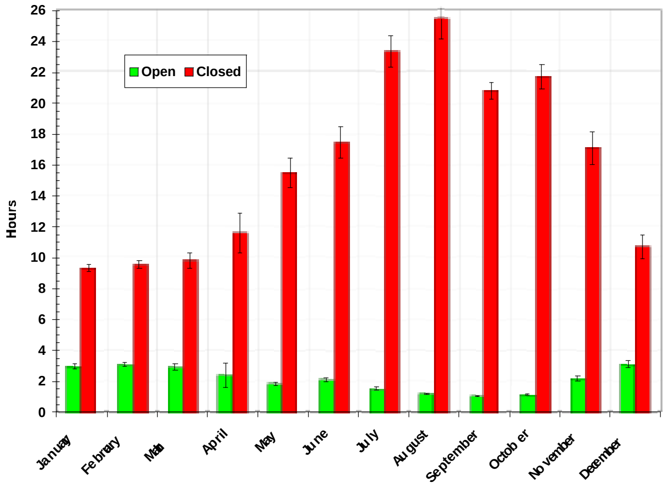


Figure E. Monthly average opening and closing cycles at the Larson Tide Gate, 2002 – 2006.

The overall pattern of Larson tide gate opening and closing cycles is characterized by the greatest extent of fish passage occurring during the salmon spawning period from November through March. Figure E shows this on an average tide cycle basis. Recognizing that there are usually two opening cycles daily, each opening is approximately three hours in length separated by about nine hours when the gate is closed and fish passage is blocked. The pattern for the remainder of the year is one of shorter openings and longer periods when the gates are closed (see Figure E). Beyond the effects of tide cycles discussed above, the primary causal factor for the seasonal change in tide gate opening periods is related to freshwater inflow into the reservoir pool behind the Larson tide gate. This inflow refills the reservoir pool after it has drained during the previous opening cycle. The tide gate will not open during the next low tide if this inflow is insufficient to raise the pool elevation at least to the level of the low tide. And the length of opening is reflected by how much higher the pool elevation is compared to the ultimate level at the next low tide.

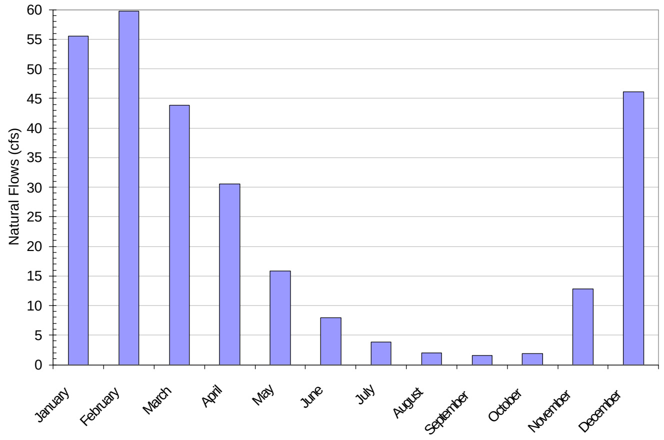


Figure F. Natural freshwater inflows in Larson Creek at the Larson Tide Gate

Natural flows into the reservoir pool at the Larson tide gate result from rainfall in the approximately 5,000 acre watershed that drains into Larson and Sullivan Creeks. Based on models developed by the Oregon Department of Water Resources, estimated Larson Creek monthly flows at the tide gate are shown in cubic feet per second in Figure F. Winter flows, from December through March, typically are above 45 cfs, with flows highest in February averaging about 60 cfs. Conversely, natural flows during the late summer and early fall (July through October), are usually less than 5 cfs. These “natural” flow estimates do not include water withdrawn for irrigation upstream in Larson Creek, which will at times deplete streamflows significantly.

The pattern seen in Figure F is almost exactly the opposite of the number of hours that the tide gates are closed as shown in Figure E immediately above it. Similarly, there appears to be a close relationship between natural streamflows and the number of hours that the tide gates are open (see Figures F and E above). The nature of these relationships were defined using a linear regression between the percentage of time that the gates were open (Figure C) compared to the natural flows in Larson Creek (Figure F). Figure G shows the results of this regression.

As can be seen in Figure G, there is a strong correspondence between flows in Larson Creek and the average monthly percent of a tide cycle that the gates are open. For these two variables, the amount of natural flow explains approximately 95% of the average opening time (i.e., $r^2 = 0.951$). A slightly more sophisticated non-linear regression equation raises the r-squared to 0.986 by fitting a curve to the data points in Figure G. In either case, the influence of stream flow on the tide gates' opening sequence is significant because it defines the amount of, and the recovery of, the reservoir pool that provides the hydraulic head difference needed to open the tide gates during ebbing tide cycles.

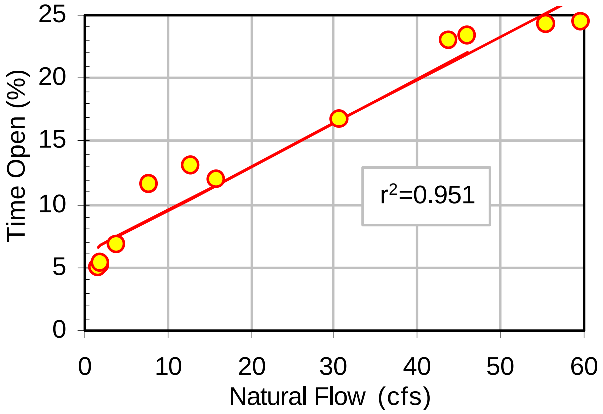


Figure G. Correlation between natural stream flows in Larson Creek and the monthly average time that the Larson Tide Gate is open.

Given the design of the Larson tide gates, where no provision for back flows was provided, the theoretical maximum opening period would be—in the best of situations—only about 50%. Monitoring at the Larson tide gate indicates that during the spawning period the gates are typically open on average slightly less than a quarter of the time, and that these openings occur in about 3 hour increments twice daily. As streamflows decrease in the spring and early summer—the time when coho salmon smolts out-migrate—the percentage of time that the tide gates are open and the number of openings per day decrease. During the March through May smolt out-migration period, average monthly opening cycles decrease from about 23% of the time to only about 12%, (i.e., from just under 3 hours per opening to under two hours per opening). At the same time, the cycle of tide gate openings changes from twice daily during the entire spring tide: neap tide cycle to twice daily during the neap tides but only once daily during spring tides. Summer provides almost a complete barrier for fish passage at the Larson tide gates. Opening periods are on the order of one to two hours per tide cycle, with generally only one opening per day. If juvenile salmon desired to use the upper estuary in Haynes Inlet, their passage downstream to the estuary, and back upstream during the late fall, would almost entirely be precluded.

The operation of the Larson tide gate could be improved by a couple of fairly simple and inexpensive equipment and operational measures. First, opening times could be increased during the late spring, summer, and fall by simply locking one of the two gates closed. This would require installation of a latch mechanism, and active management in the spring to lock the gate and in the fall to unlock the gates. Additional passage—as well as mixing of brackish and freshwater—could be accomplished by adding a "mitigator"-type device that would hold the gates open for a period of time during flooding tides. This could be operated by a float mechanism, but would probably need to be seasonally adjusted as well. These two improvements are compatible with each other, and would provide the most effective means to improve fish passage at the Larson tide gates.

COHO POPULATION MONITORING

Coho populations have been monitored on Larson and Palouse Creeks for many years. ‘Peak Counts’ of spawning coho have been conducted on a standard reach of Larson since 1950 and on Palouse Creek since 1958. Peak counts are not the ideal method for estimating the population because there is no guarantee that the count was made during the true peak of the spawning season and because the peak number of spawners is not necessarily proportional to entire spawning population. However, the data does allow a general insight into the historic fish runs on the stream and some general trends in the population. Based on this data, it appears that the spawning populations on each of these streams since 2002 are as high or higher than they have been since the 1950s (see figure below).

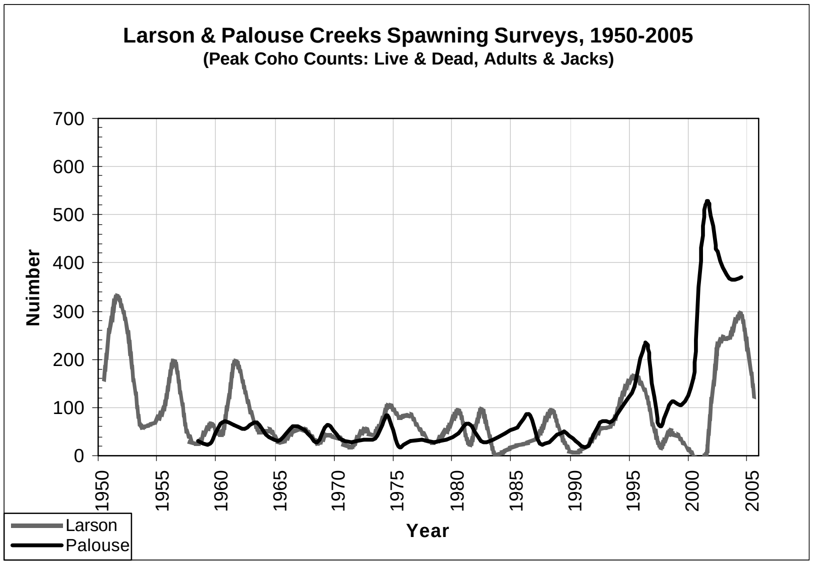


Figure H. Larson and Palouse historical coho spawning survey peak counts.

Beginning in 2002, with the need to more closely quantify the fish population, CoosWA began basin-wide, full-season spawning surveys in order to quantify the spawning population and determine the geographical distribution of spawning habitat. In order to do so, the standard ODFW spawning surveys were conducted in each of these streams, and supplemental spawning surveys were conducted on small, headwater tributaries on Palouse Creek in an attempt to conduct full-season spawning surveys on all significant spawning habitat on these streams. These surveys allowed a much more comprehensive assessment of the spawning coho population than had previously been available. By conducting spawning surveys on previously unsurveyed streams in the basin, in some cases seasonal tributaries, it became clear that a large number of fish were not enumerated by only counting fish in the mainstem of these creeks (see Figures J and I).

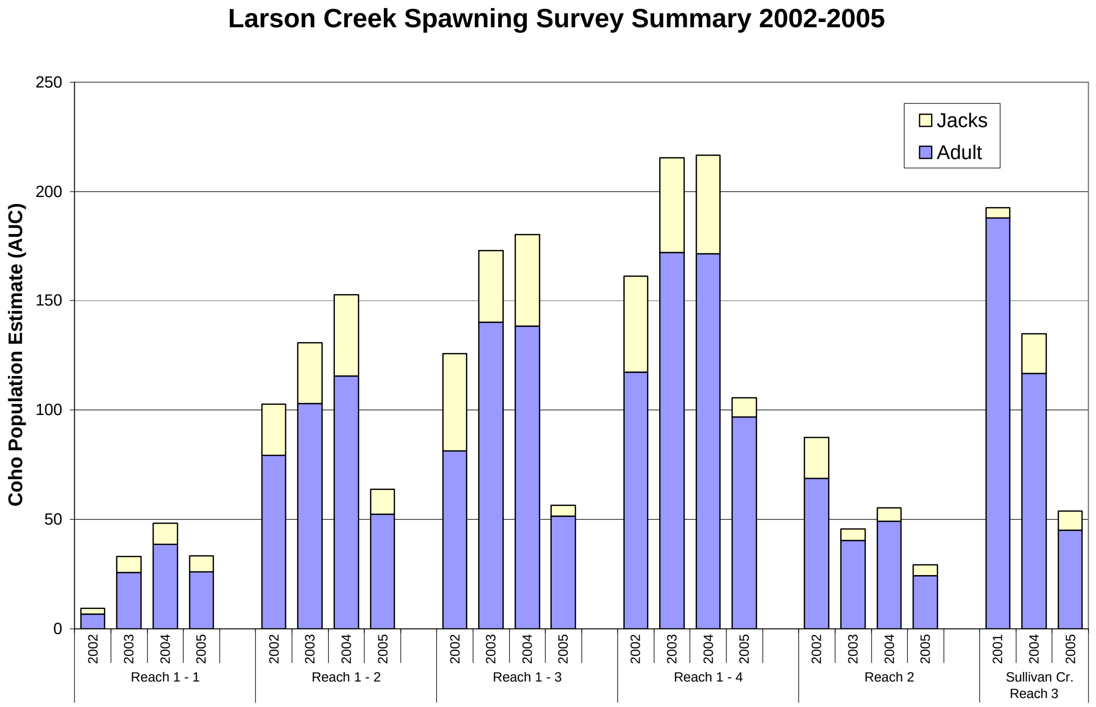


Figure I. Larson Creek coho spawning survey population estimates 2002-2005

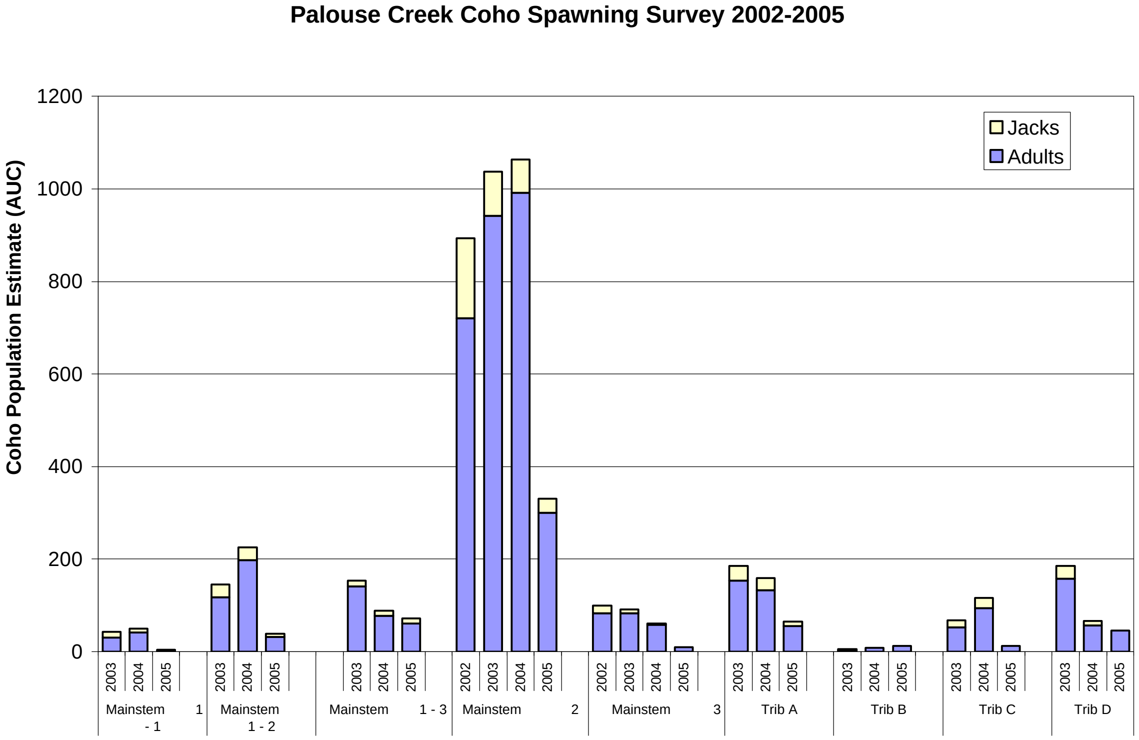


Figure J. Palouse Creek coho spawning survey population estimates 2002-2005

COHO LIFE-CYCLE MONITORING

Adult Coho Traps

Spawning surveys alone, however, are insufficient to understand the population dynamics of the coho in these streams at the resolution and statistical standard necessary to evaluate the function of the tide gates. In 2004, we proposed establishing long-term coho life-cycle monitoring sites on both of the streams in order to understand the population size, population density in the available habitat, and the marine and freshwater survival. The life-cycle monitoring includes adult fish trapping coupled with spawning surveys for a mark-recapture estimate of the spawning population and rotary screw traps to catch fry and out-migrating smolts in the spring. Changes in the population numbers can be compared between Larson and Palouse Creeks, among the streams of the Coos Basin, and among the coho population along the Oregon Coast.

The adult trap on Larson Creek consists of one inch vertical aluminum tubes (pickets) arrayed in a chevron pattern pointing upstream (see Figure below). The pickets guide the fish into the V-fyke joined to a holding pen. The Palouse Creek trap is built on bedrock. Instead of having individual pickets, the trap has panels that hinge on a frame bolted to the stream bottom. Panels are held up by bridled guy-wires that can be released during high flows.

Photo A. Larson adult trap

Photo B. Palouse adult trap

Each trap is visited at least daily, and multiple times a day during storms or periods of peak fish movement to clear accumulated debris and mark and measure fish. Pickets are removed during high flows to protect damage to the traps or the stream in the trap area. Adult salmon caught in the traps are typed by species and age (jack or adult), measured (fork length), and marked with plastic floy tags inserted in the tissue posterior to the dorsal fin on each side of the fish (2 tags increase the chance of recovery). The traps are placed as near as possible to the bottom of the salmon spawning habitat in each of the systems; however, in the Palouse trap, there is a small portion of the population that will spawn in tributaries below the trap. All potential spawning habitat, above and below the trap, have full-season spawning surveys. Each carcass recovered during the spawning surveys is examined to determine whether a tag is present. This data is then used to determine trap efficiency and calculate population sizes using modified Peterson mark and recapture procedures.

The ‘flashy’ nature of these streams has made operation and maintenance of the adult traps difficult. The traps have had problems due to bank erosion, bed-load mobility, and heavy debris loads. During the winter adult trapping season of 2005/2006 both traps were damaged by heavy flows and stormy conditions. Because of these difficulties in trap operation, data from the Larson trap in the 2004/2005 spawning season is the only data set that has enough mark-recapture data to analyze. Other adult spawning population estimates at this point will rely solely on basin-wide spawning survey Area-Under-the-Curve (AUC) calculations.

Photo C. Larson Creek adult trap after flood flows

Because of the past difficulties, the trap designs have been modified for the 2006 winter. The Palouse trap was relocated to a bedrock location. Previously, it was installed in a similar fashion as the Larson trap, but failed to catch fish because of the problems with erosion. The Larson trap has been improved with willow wall bioengineering along both banks to prevent the bank erosion, and rock has been placed in a weir configuration below the bed surface to help minimize down-cutting at the fish weir. It is hoped that these improvement will result in increased efficiency of the fish trapping this year.

Adult fish trap estimates are calculated with a modified Peterson mark-recapture calculation based on the ODFW life cycle monitoring methodology (Jepson et al. 2006):

$$N = \frac{(M(1-p^2)+1)(C+1)}{(R+1)}$$

Where:

N = the spawning population estimate
M = the number of fish marked with Floy tags
C = the total number of carcasses recovered
R = the number of fish carcasses recovered that have Floy tags
P = the probability that a fish lost both tags derived from

$$p = n_1/(2n_2 + n_1)$$

Where:

n_1 = the number of fish with one tag
n_2 = the number of fish with two tags

The confidence limits were calculated by deriving the binomial distribution of the variance (V) of the population estimate (N):

$$V(N) = \frac{M^2 C(C-R)}{R^3}\text{; and}$$

$$CL \pm 1.96\sqrt{V(N)}$$

and the 95% confidence range was calculated again using the F distribution as described in ODFW 2006.

Based on this method the Larson Creek population in 2004 was estimated as follows:

Table C. Larson Creek adult coho mark-recapture population estimate

Stream	Year	Population Est	± (95% CL binomial)	Range (95% CL F distribution)
Larson Creek	2004	1043	738	593-1951

Population estimates based on spawning survey data were derived from an Area-Under-the-Curve calculation found in Jacobs and Nickelson (1998).

Table D. Larson and Palouse spawning survey population estimates

Spawning coho populations estimates		
Year	**Larson**	**Palouse**
2002	612	
2003	724	1915
2004	787	1837
2005	341	587

Juvenile Coho Traps

Photo D&E. Donated rotary screw trap

Juvenile coho sampling involved obtaining, refurbishing, and operating the two rotary screw traps on Larson and Palouse Creeks. Traps were obtained from ODFW in Roseburg and the USFS-Pacific Northwest Research Station. Both traps required significant repairs and motorization prior to being installed. The traps utilize an Archimedes screw that is wrapped with a cone-shaped screen. The trap sits on pontoons and relies primarily on the stream flow to turn the trap. Because of the low gradient at the trapping sites on Larson and Palouse creeks, a photo activated motor is used to ensure the trap is revolving at a minimum of 3 revolutions per minute to maximize trapping efficiency. Downstream migrating fish that enter the cone are forced into a live trap. Fish are removed from the trap daily and a portion are marked and released upstream of the trap to calibrate the operating efficiency of the trap. The rotary screw traps were operated on Larson Creek from March to July 2005 and February to June 2006, and on Palouse Creek from April to July 2005 and February to June 2006. Because the Palouse trap was not operational through a large portion of the smolt migration in 2005, those results will not be included in the life-cycle calculations.

Photo F. Larson smolt trap deployed

Population estimates for the rotary screw traps are calculated by deriving trap efficiency each week that the traps are operated and adjusting the number of fish caught in the traps by the estimated weekly efficiency. Trap efficiency must be recalculated regularly because of the changing flow conditions, debris interference with trap operation, and other variables. Each week, the first 25 individuals of each target species/ life stage are anesthetized, measured (fork length) and marked with a small nick on the caudal fin. The sampled fish are released in various locations 100-200 meters upstream of the trap once they have fully recovered from the anesthesia. As the marked fish pass by the trap a second time, the recaptured individuals can be used to calculate the trap efficiency. All other individuals are enumerated and released below the fish trap. Populations estimates were calculated as described in the methodology of Jepson et al. (2006). Other aquatic species caught in the trap are counted and released. See Appendix A for a summary.

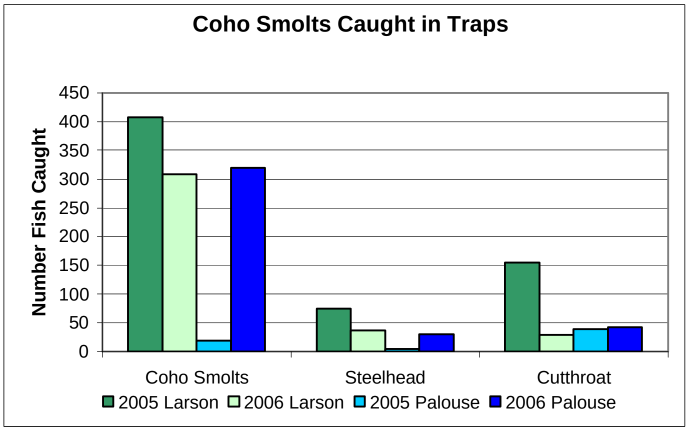


Figure K. Number of coho smolts caught in Larson and Palouse traps in 2005 and 2006

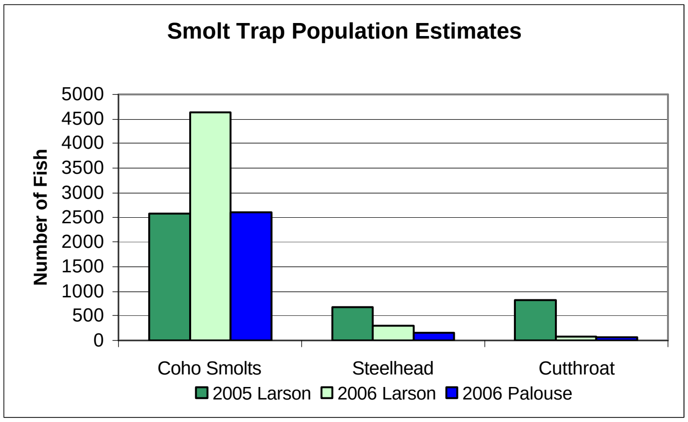


Figure L. Estimate of salmonid migrants from Larson and Palouse Creeks in 2005 and 2006

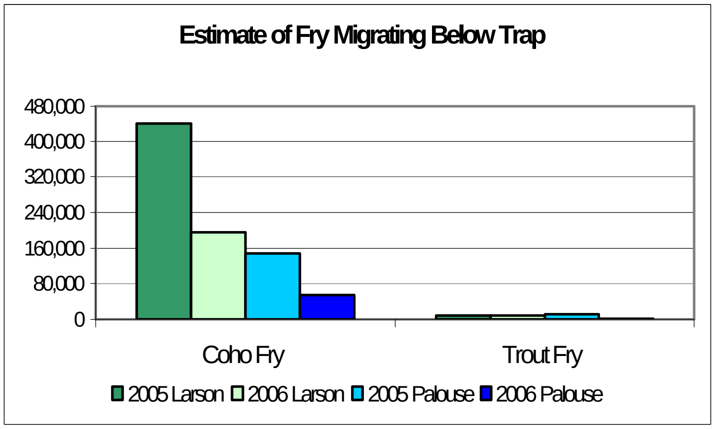


Figure M. Estimate of coho and trout fry that migrate downstream of the trap.

Based on the data that we have collected so far we are able to begin to formulate preliminary life-cycle population statistics for Larson Creek.

Table E. Larson Creek Coho Life-Cycle Monitoring Data

Brood Year	Spawners (adult and jack)	Female coho	Fem mean FL	Egg est.	Fry migrant est	Smolt est.	FW Survival	Mar. Survival
2003	612	176.5						
2004	724	240	690	631,991		2,576	0.41%	
2005	787	256	695	684,306	631,557	4,630	0.68%	
2006	351	125	690	329,162	194,852			

The first attempt at calculating freshwater survival in the Larson Creek population indicates a notably low freshwater survival. This survival is based on an egg to smolt survival rate. However, because we have 0+ age fry migrating past the trap in a high abundance, there seems to be a fairly high likelihood that a portion of these ‘early migrant’ fry are surviving. There are a number of possible life-history strategies that could explain this early migration. The fry that move past the trap could be rearing in the lower portion of the stream and migrating to the ocean as 0+ smolts, they could be rearing in the lower portions of the stream and the slough behind the tide gate and not moving back upstream as far as the trap, or they could be moving into the upper estuary and rearing until their smolt migration. If the two years that we are analyzing are typical, then the data indicate a freshwater survival rate less than 1% and a marine survival rate between 17% and 30%. If the fry that migrate past the trap in spring are not included in the smolt estimate, meaning they do not migrate back upstream and the same survival rate is assumed upstream and downstream of the trap, it would nearly double the number of smolts leaving the system. In order to answer this critical question of estuary or slough rearing habitats, it will be necessary to sample the lower portion of the system during both summer and winter to determine rearing densities and to understand the importance of this lowland habitat.

Coho Life-Histories and Habitat Selection

Understanding the life-history adaptations to tide-gated streams is also critical to understanding how the tide gates affect fish rearing and habitat utilization in these streams. The seasonal distribution of rearing juveniles within the system (summer rearing and winter rearing) is especially important in identifying the ways in which the tide gates are impacting the coho population. Are juvenile coho rearing in the pool above the tide gate? Is there an estuary-rearing portion of the population? In order to understand the habitat selection, we have monitored various aspects of the habitat through both Larson and Palouse Creeks. In order to understand the ways that the streams are utilized, we quantified the physical habitat through aquatic habitat inventories. We then used that habitat data to populate a Limiting Factors Analysis in order to understand the potential coho production levels of these systems (Reeves et al. 1989, Nickelson 1992).

To analyze the habitats that were limiting in these systems, potential coho summer populations were estimated using both stream habitat surveys and expected fish carrying capacity for those habitats according to Reeves et al. (1989). Area of spawning and various seasonal habitats needed to support the estimated potential summer population was calculated based on area/survival factors derived by Reeves et al. (1989) from the coho salmon literature. Usable areas were derived from summer aquatic habitat and spawning surveys. Numbers of smolts were estimated by multiplying the usable areas by the smolt factors. The smolt factor is the potential number of smolts that could be produced from a given life history stage if no limiting factors occurred at a life history stage further along in the life cycle. This factor is the mean density of fish expected at a given life history stage multiplied by the density-independent mortality rate of the succeeding life history stages. The smolt factor aids in determining which habitat represents the most important bottleneck. This can also be corroborated by comparing the "usable area" with the "area needed"; if the former is smaller than the latter then the amount of habitat available for that life history stage is in short supply.

Table F. Results of Limiting Factors Analysis (based on Reeves et al. 1989 for coho salmon in Palouse Creek.

Palouse Creek Habitat	**Potential summer Population**	**Area/ Survival factor**	**Area needed (m^2)**	**Current Usable area (m^2)**	**smolt factor**	**smolts produced**
Spawning	50,486	0.006	303	1,141	95.5	108,966
Spring Rearing	50,486	0.3	1,5146	7,676	1.7	13,049
Summer Rearing	50,486	0.6	30,292	7,676	0.9	6,908
Winter Rearing	50,486	0.4	20,194	7,849	1.2	9,419

Table G. Results of Limiting Factors Analysis (based on Reeves et al. 1989 for coho salmon in Larson Creek.

Larson Creek Habitat	**Potential summer Population**	**Area/ Survival factor**	**Area needed (m^2)**	**Current Usable area (m^2)**	**smolt factor**	**smolts produced**
Spawning	43,539	0.006	261	2,337	95.5	223,184
Spring Rearing	43,539	0.3	13,062	1,2509	1.7	21,266
Summer Rearing	43,539	0.6	26123	12,509	0.9	11,258
Winter Rearing	43539	0.4	17,416	1,670	1.2	2,004

The Limiting Factors Analysis on Palouse Creek indicated that summer rearing habitat was limiting coho production in the stream. When based solely on physical habitat, winter rearing was the limiting habitat, however, when summer stream temperatures were considered, a significant amount of potential summer habitat in the lower, tide gate influenced reach of the stream were excluded from the calculation based on the high summer temperatures. Larson Creek had no summer habitat excluded due to temperatures, but the analysis indicated that winter habitat was highly limited. The analysis was conducted based primarily on summer habitat surveys, and so winter habitat is more difficult to estimate from this data. Basin-wide winter surveys are still needed to substantiate or correct this analysis.

Water temperature monitoring in both Larson and Palouse creeks has indicated that the high summer temperatures in these streams may be an important element limiting the populations and the extent of usable habitat during the warmest summer months. Each of these streams had an array of five to seven HOBO Pro-V1 temperature loggers deployed from the forested headwaters to the tide gate reservoirs in 2003 and 2004. Based on these data collection efforts, temperature mapping was completed based on a 7-day maximum average water temperature analysis. Figure N and O below show the results of the temperature mapping on Larson and Palouse Creeks. The 7-day maximum average is the mean daily high temperature recorded on the hottest 7 consecutive days of the season. The 7-day average means that fish are required to regularly sustain these temperatures to occupy the habitat, and does assume that the fish are not abandoning and re-occupying the reach each day. The maps also show the riparian shade condition. The darker buffers surrounding the stream layer indicate a greater potential to provide shade through improved riparian conditions.

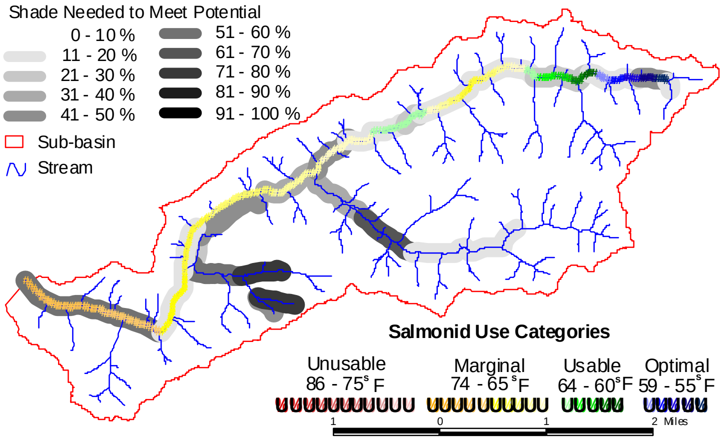


Figure N – Larson Creek 7-day maximum average temperature and riparian shade map

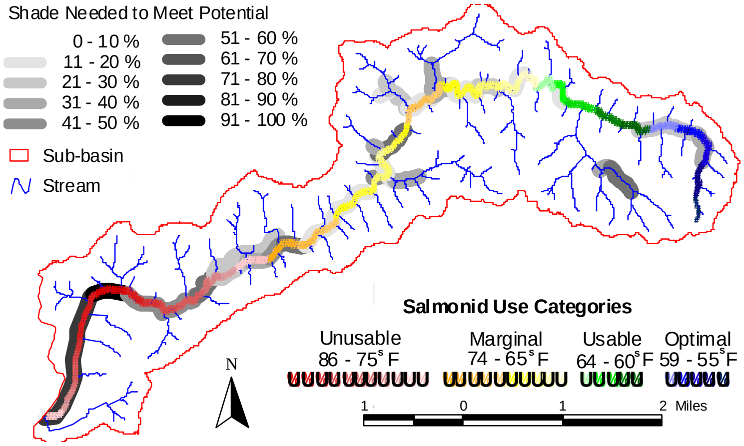


Figure O – Palouse Creek 7-day maximum average temperature and riparian shade map

Although high temperatures could have deleterious effects on the coho populations in each of these streams, Palouse Creek has notably higher temperatures in a greater portion of the stream. Temperatures are highest in the long slough or tide gate reservoir of the stream. A closer analysis of the temperatures in this area indicates that the temperature analysis is not based on a data anomaly. Figure P below shows the daily maximum and the daily minimum temperatures recorded in the reservoir pool during the summer of 2004. The water temperature in this reach exceeds 70ºF in early July and stay above that temperature throughout the diurnal cycle until near the end of August.

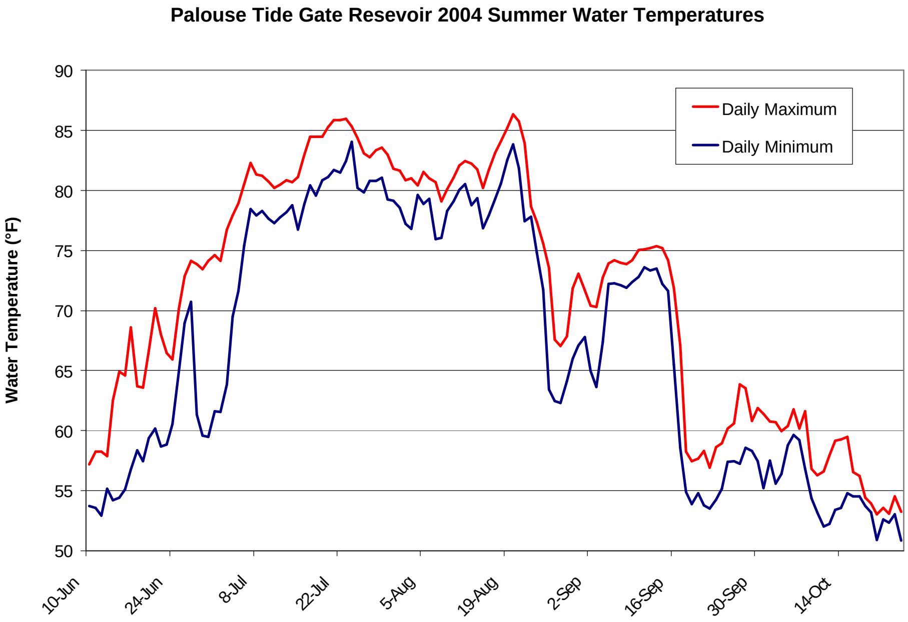


Figure P. Palouse tide gate reservoir 2004 summer water temperatures.

Water temperatures are high in much of the Palouse Creek system, but they reach lethal levels in the tide gate reservoir pools. A close look at the temperature map for Palouse (Figure P) indicates that temperatures are slightly cooler near the tide gate than upstream. So then, how does the tide gate affect the stream temperatures? It is likely that the temperatures are mitigated near the tide gate from water that leaks in from the bay. There is also some temperature stratification in the deepest part of the tide gate pool, just upstream from the gate. However, when the tide gate is closed, it is slowing water for over a mile upstream. This water, which is already warm when it enters the reservoir, is detained in the shallower areas of the reservoir that have little in riparian shade.

Although the likelihood of juvenile coho utilizing this pool seemed unlikely, we sought to confirm such an absence and detect when, and if the habitat was reoccupied to determine if such behavior corresponded to our modeling and analysis. In order to gauge the utilization, the fish were sampled using two methods. Snorkel surveys were conducted in both Larson and Palouse Creeks during August and September 2005. These surveys were conducted to determine the summer habitat use patterns and to calibrate the Limiting Factors Analysis model. Reaches of 500 meters in four geomorphic regions of each creek were snorkeled to evaluate coho rearing densities. The sample reaches included 1) the pool or reservoir immediately above the tide gates, 2) the low gradient stream in the broad, agricultural valleys, 3) slightly higher gradient narrow valleys with some small pastures and rural residential areas, and 4) the forested reaches. All pool and glide habitats within the 500 meter reaches were snorkeled consistent with the ODFW snorkel survey protocol.

Table H. Average Coho Densities by Reach

Snorkel Surveys '05	Palouse	Larson
Reach	coho/m^3	coho/m^3
Forest	0.89	1.35
Upper Valley	1.01	0.9
Lower Valley	1.21	0.75
Tide gate Pool	0	0

The results of the snorkel surveys, shown in Table H, indicated a relatively high summer rearing density in these streams and confirm that the tide gate reservoirs are not being occupied by summer rearing juvenile coho. Interestingly, Larson and Palouse exhibited opposite density trends relative to distance from the mouth of the stream and relative to water temperatures. In Palouse Creek, coho density increased going downstream where the stream has higher water temperatures. In contrast, the densities are highest in the forest reaches where there are somewhat lower water temperatures than downstream. The difference in trends in these two streams may reflect a difference in productivity. The fish could sustain, or even benefit from, higher metabolic rates if enough forage was available. Huff et al. (2005) detected juvenile coho in the south coast of region of Oregon rearing in temperatures as high as 74.6ºF. This survey does only provide a 'snap-shot' of the rearing distribution and the survey should be repeated before strong conclusions are drawn.

Additional juvenile coho sampling was conducted by deploying minnow traps in the tide gate reservoir of Palouse Creek to determine when and if the pool was reoccupied. Three traps were placed, baited with punctured cans of cat food, in a 250 meter stream reach near the upper end of the reservoir. Traps were deployed from October 14th to November 11th of 2005. Each trap was sampled for 13 days during that period, and the traps were checked approximately 24 hours after they were set. No juvenile coho were caught during the first 7 sample periods from Sept 30 to Oct 31. Coho were caught in one or more traps 5 of the 6 sample periods between Nov 2 and Nov 11. The minnow trapping seemed to confirm that the Palouse reservoir pool does not provide summer rearing habitat for juvenile coho because of the high temperatures, but as soon as the temperatures decrease in the winter, that habitat is reoccupied.

Additional sampling of seasonal juvenile coho rearing habits in the tide gated systems will help to determine the role that the tide gate reservoir plays in winter rearing habitat. The CoosWA has proposed to repeat the summer snorkel counts in these streams and conduct winter surveys to determine winter rearing patterns in these streams. Most of the temperature monitoring in these streams has been focused on the summer temperatures; however, by investigating the winter stream temperatures and the behavioral effects of coho during periods of low metabolism and low stream productivity may be equally important to understanding the role that the tide gates play in the life cycle of coho in the streams.

Conclusions

Tide gates are a prominent feature in the Coos estuary and affect a significant portion of the salmon populations supported in the Coos system and elsewhere on the coast of Oregon. Little research has been conducted on tide gate function considering ecosystem dynamics or migratory fish patterns. Clearly tide gates are more than a temporary obstruction to fish passage. Because of the extensive agricultural, residential, and urban development associated with tide gates, eliminating them from the stream systems seems unlikely in the near future. Given this reality, natural resource managers are faced with the challenge of encouraging sustainable ecological systems within the constraints of an absent or muted tidal cycle.

The Coos WA has been studying Larson and Palouse Creeks because of their productivity and potential for sustainable fish populations. In an attempt to improve fish passage at Larson Creek, low water velocities may have been obtained but in exchange of longer periods that the gates were open, leaky gates that allowed salinity exchange, and a deep winter rearing pool behind the gate. However, through continued monitoring of the project and through increasing our understanding of the fish use patterns of the stream, we have the potential to make simple modifications to correct many of the problems that we have detected.

The tide gates create a fish passage obstruction through much of the tidal cycle. Modifications of the gate can likely increase the time available for fish passage. However, during the summer period, when the passage is time is smallest, these tide gate reservoir serves as a thermal barrier to passage as well. Unless the thermal impacts of the tide gates are addressed, summer fish passage improvements may not have the intended benefits.

Continuing to investigate the seasonal habitat selection in these lowland tide gated systems and using that information to calibrate the Limiting Factors Analysis will play a large role in informing and prioritizing the restoration efforts in these and similar watersheds. Specifically continuing annual summer sampling for the distribution should help indicate habitat selection preferences of rearing coho relative to water temperature regimes. Ideally, rehabilitation efforts would be aimed at increasing the area of usable habitat by cooling water temperatures without reducing the productivity that allows for high densities of rearing juveniles in relatively warm water. Investigation of winter rearing distribution in these systems is also a priority. The tide gate reservoir may be providing slow-water habitat that is serving as surrogate or replacement habitat for lost wetlands and winter beaver ponds. The value of the habitat in its current condition should be fully appreciated before substantial changes are proposed.

The life-cycle monitoring is in the early stages, but in the long term, it will be valuable to have status and trend population data on tide gated streams for comparison with the other life-cycle streams on the coast of Oregon. Comparisons of the population data and the life history strategies between these two streams and Winchester Creek of South Slough may prove to be the best way to understand the ways in which tide gates affect the rearing patterns of coho in the estuary.

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Appendix A – Aquatic species caught in the rotary screw trap which were not the target of the investigation.

Figure 1. Lamprey

Year	Stream	Pacific lamprey adult	Brook lamprey adult	Lamprey ammocoete
2005	Palouse	1	111	1
2006	Palouse		11	58
2005	Larson		23	153
2006	Larson	4	43	279

Figure 2. Non-target fishes

Year	Stream	Cottids	Stickleback	Chum fry
2005	Palouse	58	101	21
2006	Palouse	48	109	
2005	Larson	82	49	
2006	Larson	28	141	

Figure 3. Amphibians

Year	Stream	Pacific giant salamander	Tailed frog tadpole	Rough-skinned newt	Northwestern salamander	Red-legged Frog	Pacific tree frog
2005	Palouse						
2006	Palouse	6	2	7	1		1
2005	Larson	39					
2006	Larson	7	3	1		2	