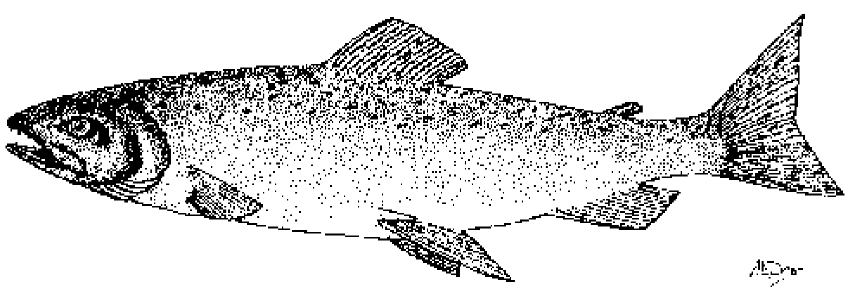
Skagit River Chum Escapement Strategy

Project # SF-2007-I-28

Final Report

January 2009



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I. Introduction

This report details the second year of a two-year study designed to improve the methodology of chum salmon escapement estimates in the Skagit River. This study used a mark-recapture experiment to generate a population estimate of Skagit chum for each year of the study. Those population estimates, along with live counts of spawning chum in potential index reaches, would "recalibrate" the model that biologists use to estimate the spawning escapement of chum throughout the Skagit basin.

Currently, escapements are estimated by comparing live counts in just 4 index areas to the counts recorded in those sections in 1976 and 1977, when mark-recapture studies were conducted (Hendrick 2003). However, these estimates are highly imprecise, because chum distributions in the index sections were very different between these two years, and because changes in river morphology, habitat restoration actions, and improvements in managed flow regimes, which started in 1984, have significantly changed the distribution of chum spawning on the Skagit River, (Connor and Pflug 2004) thereby violating the basic assumption that the indexes still represent the same proportion of system escapement as in the base years.

Any inaccuracy in the escapement estimate has far-reaching implications in the management of Skagit chum. Most of the harvest management tools, such as harvest rate models, test fishery models, and run reconstructions, depend on meaningful escapement estimates to be effective. Efforts to restore chum habitat on the Skagit also depend on escapement estimates to monitor the effectiveness of restoration actions.

In response to these problems, the Skagit River System Cooperative (SRSC), and the Washington Department of Fish and Wildlife (WDFW) proposed a multi-year study to improve the methods used in estimating the escapement of Skagit chum. Funding for the study was approved by the Pacific Salmon Commission Southern Fund, as well as the Non-Flow Coordinating Committee (a group representing the interveners in the Seattle City Light Flow Agreement). Since Skagit chum abundance follows a four-year cycle, 2006 (a "high-high" year) and 2007 (a "low-low" year) presented an opportunity to conduct the study at both endpoints of the abundance cycle.

The specific objectives of this study were to:

1. Tag and sample sufficient Skagit chum to estimate total system spawning escapement to within a C.V. $\leq$ 10%.

2. Establish new chum index sections in the mainstem Skagit from Newhalem to Shovel Spur and from Alma Creek to Marblemount, in three sections of the mainstem Sauk, in the lower Cascade, and in selected Lower Skagit tributaries.

3. Use 2006 and 2007 as base years, and the new index sections, to calculate Skagit chum escapements in future years, and recalculate Skagit chum escapements back to 1984 (which is when the current flow regime went into effect).

In order to achieve these objectives, we planned to estimate chum spawning escapement in the Skagit System by capturing, tagging, and releasing live chum salmon in the lower part of the Skagit River, and recovering them on the spawning grounds and in in-river fisheries. Simultaneously, spawning survey crews would conduct the normal live and dead counts in existing index areas, as well as in potential future index areas. These data would then be used to estimate chum spawning escapement in the study years, and to recalibrate the index areas for past and future escapement estimates.

In 2006, the first year of this study, a major flood occurred at the peak of the chum season. This flood severely disrupted tagging operations, displaced tagged fish, prevented effective surveys, and generally prevented the successful operation of the mark-recapture study (Conrad et al. 2007).

II. Methods

A. Capture and tagging

Tagging operations took place on a gravel bar at river mile 25.8, about two miles upstream from the town of Sedro-Woolley (Figure 1). Chum were captured using a 3.875" mesh beach seine that was 370 feet long and seventeen feet deep, tapered along 100 feet of one end to six feet deep. To set the seine, the shallow end was fastened to a pickup truck stationed at the waterline, and a jet boat was used to deploy the net across the river and downstream to form a "hook." The truck and the boat then towed each end of the net slowly downstream and down the gravel bar. The boat then returned to the shore, where the net was attached to another truck, and both ends were towed up the beach until most of the seine had been pulled out of the water. As the net was hauled up the beach, the crew would adjust the cork and lead lines, and then pull the bunt in by hand. At that point, any chum salmon caught were placed in floating PVC-frame net pens. Other species, such as coho, were counted and released. After each set, the seine was restacked in the boat for the next set.

After being held in the floating net pen, each chum was then removed from the water and placed in a foam-lined V-shaped trough. While one crew member immobilized the fish, another applied a jaw tag and punched a hole in its operculum as a secondary mark. The jaw tags were metal hog-rings fitted with a sequentially numbered, bright yellow plastic sheath. The sex and length of each fish was recorded, as well as a condition code of '+' or '-'. Healthy fish were assigned a '+', while fish with predator scars, fungus, or other impairments were assigned a '-'. Any fish that appeared unlikely to survive was released without tagging. After being tagged, each fish was held in the water for a few seconds to regain equilibrium and released once it could swim away vigorously.

Tagging was planned for a 3 days/ 2 days per week rotation to evenly distribute effort throughout the run. Because the tagging site was within the fishing area of the Upper Skagit tribe, tagging was usually rescheduled when it conflicted with Upper Skagit fishing openings. The Thanksgiving weekend and a period of high river flows in the first week of December also disrupted the planned tagging schedule.

As part of another project investigating the migration timing and patterns of Skagit chum, some chum salmon were implanted with acoustic tags. These acoustic tags emitted uniquely-coded “pings” designed to be received by a network of hydrophones throughout the Skagit basin. Chum that were implanted with an acoustic tag were tagged with a red jaw tag and two holes were punched in their opercula to differentiate them from conventionally tagged chum. The acoustic tag was implanted orally into the gut, after which the fish were placed in vinyl holding bags for up to several hours to recuperate. After this holding period, the bag was checked for a regurgitated tag, and the fish was released. Of the 263 total chum tagged, 125 were implanted with acoustic tags.

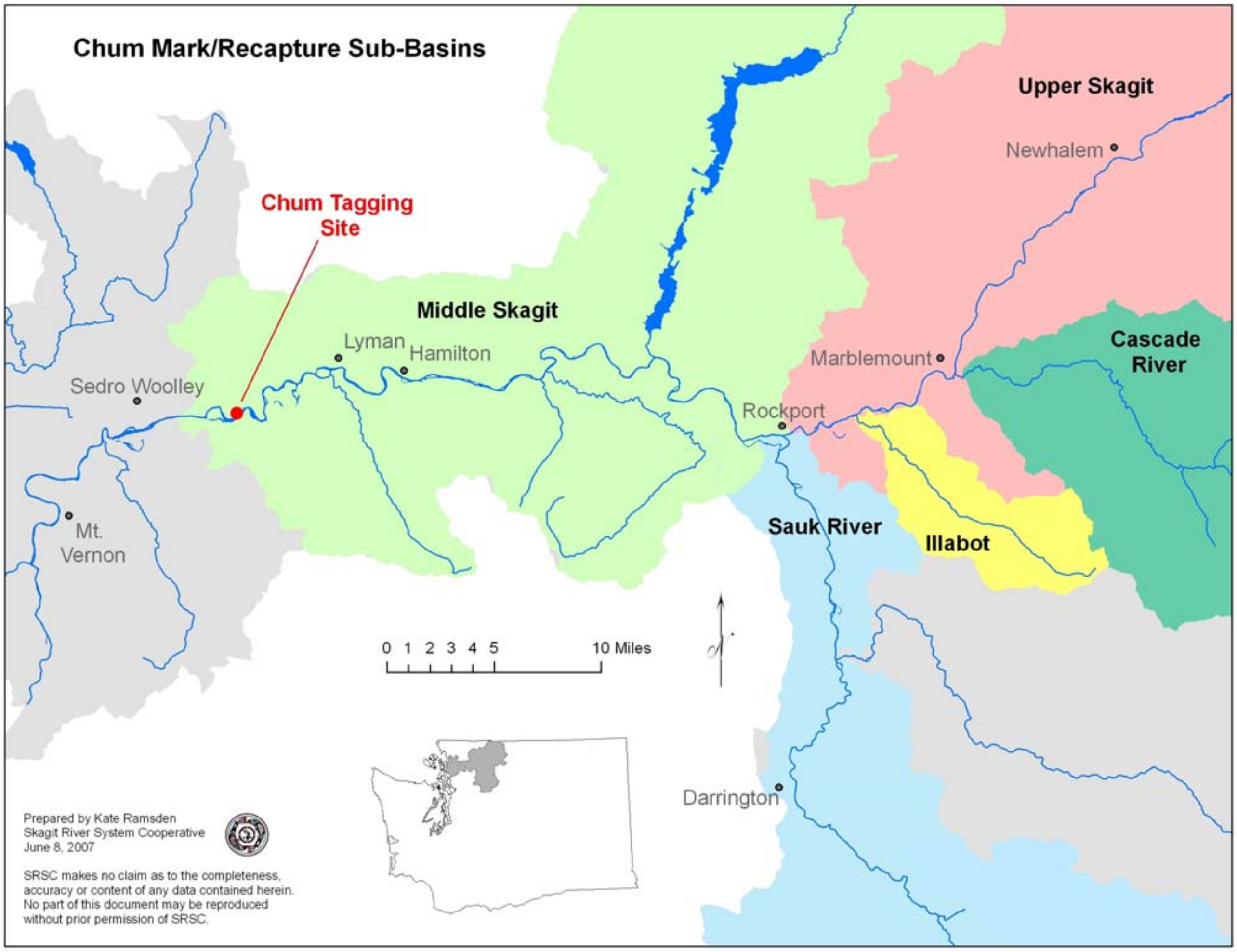


Figure 1. Location map of Skagit River sub-basins.

B. Spawning grounds surveys and sampling

Two kinds of spawning grounds surveys were conducted: live counts and tag recovery surveys. Live count surveys were performed in current and potential new index areas. Surveyors periodically counted live and dead chum visible from foot or a boat. Generally, surveyors performing live counts did not stop to sample carcasses for tags, unless doing so did not interfere with the live counts.

Prior to the spawning season, we developed a list of potential new index reaches to survey during the 2007 season. These index reaches were selected based upon:

- Distribution throughout the watershed
- Logistical possibility of doing future surveys
- Geomorphic stability
- Abundance of spawning chum

Using these criteria, the ideal index reach would be readily accessible by foot or boat; not be subject to frequent changes in habitat due to meandering river channels, etc.; and have numbers of chum spawning that reflect the overall population size. In addition, these reaches would ideally be distributed throughout the watershed so that all components of the run are reflected in index counts. In some cases, these conditions were difficult or impossible to meet. For example, survey conditions in the middle Skagit mainstem are typically hampered by poor visibility in turbid water, so that mainstem middle Skagit index reaches are probably not realistic. Similarly, the morphology of most reaches of the Sauk River change from year to year, making them unsuitable as indexes.

Using these criteria, we developed the following list of potential index reaches:

Sub-basin	Stream	Reach	River mile	Comments
Upper Skagit	Skagit River	Goodell Creek - Shovelspur	92.9-87.3	Current index
		Alma Creek - Marblemount	85.2-78.2	Current index
		Marblemount-Rockport	78.2-67.8	Current Index
		Marblemount Slough		Current index
		Rockport Slough		
Illabot	Illabot Creek	Illabot Slough		Current Index
		Illabot Creek		Current index
		Upper Illabot Slough		
		Upper Illabot Creek		
Sauk	Sauk River	Bryson Rd. – Suiattle R.		
		Dan Creek Slough		Current index
Middle Skagit	Hansen Creek		3.0 – 4.3	
	Jones Creek			
	Alder Creek		0.0 – 0.4	
	Pressentin Cr.			

Tag recovery surveys were conducted in chum spawning grounds throughout the Skagit basin. Unlike the live count surveys, carcass surveys were not confined to index areas. Instead, carcass surveyors directed effort to areas where the maximum numbers of carcasses could be sampled. During these surveys, chum carcasses were checked for the presence of jaw tags and punched opercula. The number of carcasses checked in each location and date was tallied, as well as the tag numbers of any tags found. If the tag numbers were not legible, the tag color and any legible digits were recorded. After being sampled, the tail was cut off of each carcass to prevent it from being resampled on subsequent surveys.

C. Commercial catch sampling

During the study, tribal commercial fisheries targeting salmon were conducted in the Skagit River both upstream and downstream of the tagging site. The Skagit River is divided into statistical catch areas for purposes of managing these fisheries (Figure 2.) The fishing grounds of the Upper Skagit Tribe include the Skagit River upstream of the confluence of the North and South Fork distributaries near Mount Vernon. This includes areas 78D-4, 78D-3, 78D-2 and a portion of 78C. The Swinomish Tribe fishes Skagit Bay (Area 8) and the Skagit River upstream to Mount Vernon (Area 78C). The tagging site is located near the boundary of Areas 78D-2 and 78D-3.

Since the tagging site was within the area of Upper Skagit commercial fisheries, the chum catch in these fisheries was sampled for tags. Most of the catch is delivered to a buying station located on the Upper Skagit reservation. Tribal fisheries personnel checked chum delivered to this buying station for tags. A reward was also offered to tribal fishers reporting tag recoveries to the fisheries office. However, only tags recovered as part of systematic random sampling were considered “in-sample.”

The Swinomish tribe fishes downstream of the tagging site. Rather than sampling chum at the buyer, two Swinomish tribe fishers were enlisted to check chum they caught for tags, and report any tags found. Both fishers were tribal fisheries department employees, and one was part of the chum tagging crew. These two fishers accounted for about 16% of the reported Swinomish chum catch.

Chum caught in weekly test fisheries conducted by the Upper Skagit Tribe and SRSC were also checked for tags. These fisheries take place at Blakes and Spudhouse drifts in catch area 78C, and at the Highway 9 bridge in area 78D-2. The catch from the Jetty and Skagit Bay test fisheries was also checked. All of these fisheries occur downstream of the tagging site. The Upper Skagit tribe also collects chum broodstock from the Skagit River in areas 78D-3 and 78D-4 (upstream of the tagging site), for use in their hatchery. These fish were checked for tags and marks as well.

Some tags were recovered in other fisheries and reported to SRSC or WDFW biologists. The SRSC telephone number was printed on each jaw tag so that anybody encountering a tagged chum could report it. However, these volunteer tag recoveries were not part of any systematic sampling and were considered “out of sample.”

III. Results

A. Population estimate from mark-recapture

The SPAS software and documentation (available at http://www.cs.umanitoba.ca/~popan/) were applied to the 2007 Skagit River chum salmon tagging and recovery data in order to find the most appropriate estimation method. Two assumptions were particularly important in these data when using Peterson type estimation methods on pooled data (i.e. a single tagging stratum and a single recovery stratum):

- all animals in the population have an equal probability of capture during he first (tagging) sample, and
- the recovery sample is a simple random sample of the population.

The first assumption may be violated if the tagging period does not span the entire period when animals are passing the tagging area. Figure 1 suggests some portion of the run may have passed after the last tagging effort.

The second assumption may be violated when multiple recovery strata are sampled and non-random mixing has occurred. This is tested by comparing strata with regard to tagged recovery rate using Fishers exact test. A significant test ($p < 0.05$) indicates significant difference of recovery rates of tagged fish so the strata should not be pooled.

If a stratified estimator is used these assumptions are modified:

-all animals in the i^{th} release stratum have an equal probability of capture during the tagging period, and
-all animals in the j^{th} recovery stratum, whether tagged or not, have an equal probability of being sampled.

Thus stratification allows different recovery rates between strata but the probability of capture should be the same for all animals within a given stratum.

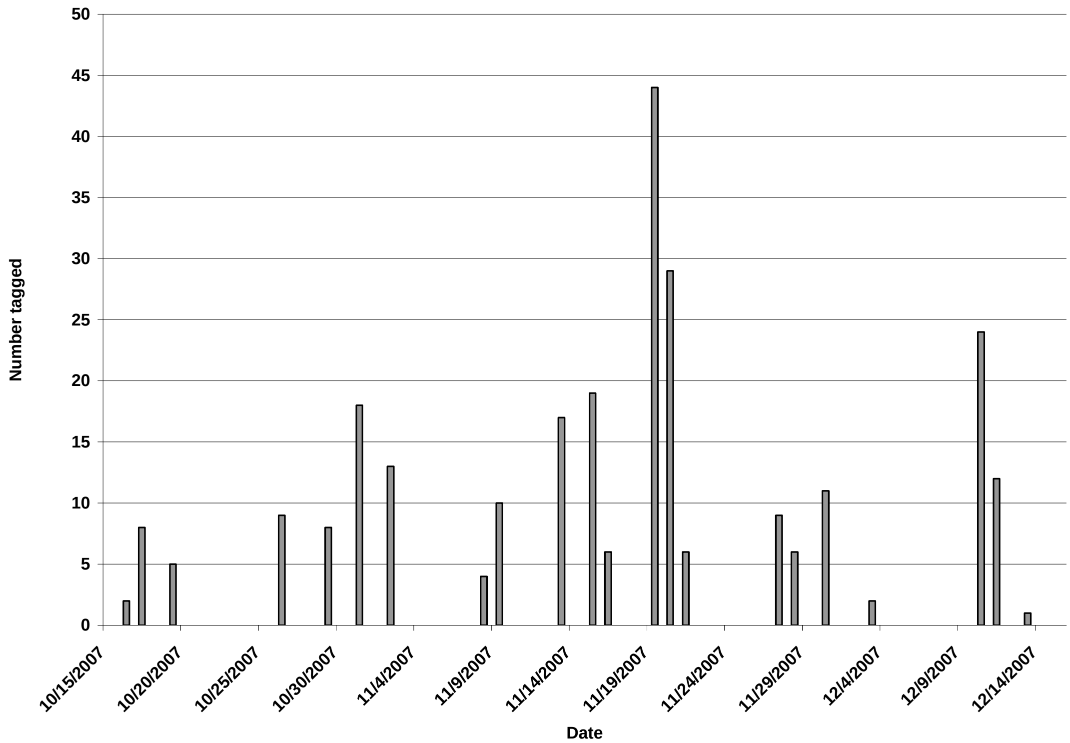


Figure 1. Numbers of chum salmon tagged vs. tagging date in the Skagit River in 2007.

1. Tag Release Data

The strata in Table 1 were delineated by 6-7 day gaps between sampling periods. Comparison of recovery rate between the five release groups showed no evidence of recovery rate difference ($p \leq 0.3365$) so all release strata were pooled.

2. Tag Recovery Data

Exploration of recovery data began by looking for recovery rate differences between the two different sample types: fishery (commercial, brood stock sample, and test) and carcass sampling. Fishers exact test found no evidence of a difference ($p = 0.5564$.) The next step was to look for differences between the sample locations (river reaches) within fishery and carcass sampling. Fishers exact test indicated that carcass sampling recovery locations (sub basins) could be pooled ($p \leq 0.4241$; Table 2.)

Date	Number Tagged and Not Recovered	Number Tagged and Recovered	Total Tagged	Percent Recovered
10/16/2007	2	0	2	0.0%
10/17/2007	8	0	8	0.0%
10/19/2007	5	0	5	0.0%
10/26/2007	9	0	9	0.0%
10/29/2007	8	0	8	0.0%
10/31/2007	16	2	18	11.1%
11/2/2007	12	1	13	7.7%
11/8/2007	4	0	4	0.0%
11/9/2007	10	0	10	0.0%
11/13/2007	13	4	17	23.5%
11/15/2007	13	6	19	31.6%
11/16/2007	5	1	6	16.7%
11/19/2007	39	5	44	11.4%
11/20/2007	28	1	29	3.4%
11/21/2007	5	1	6	16.7%
11/27/2007	8	1	9	11.1%
11/28/2007	5	1	6	16.7%
11/30/2007	10	1	11	9.1%
12/3/2007	2	0	2	0.0%
12/10/2007	20	4	24	16.7%
12/11/2007	10	2	12	16.7%
12/13/2007	1	0	1	0.0%
Total	233	30	263	11.4%

Table 1. Recovery rates vs. tagging date of chum salmon tagged in the Skagit River is 2007. Banding delineates tagging periods separated by 6 – 7 day gaps (Figure 1.)

Sub-basin	Start Date	End Date	Number Examined	Number of Tags Recovered	Percentage Tagged
Illabot	11/20/2007	12/24/2007	312	2	0.64%
Middle Skagit	10/29/2007	1/3/2008	69	0	0.00%
Sauk	11/9/2007	12/10/2007	82	0	0.00%
Upper Skagit	11/8/2007	1/4/2008	2,540	5	0.20%
Total			3,003	7	0.23%

Table 2. Carcass survey results from five Skagit River sub-basins in 2007.

Fishery strata was tested at two levels of aggregation: upstream or downstream and specific reaches (Table 3.). Fishers exact tests at both levels show significant evidence of recovery rate difference ($p = 0.0027$ and $p \leq 0.0001$ respectively.)

Because the carcass survey data could be pooled and considered a single sample (with a recovery rate intermediate between the recovery rates of the fishery reaches), it was added to the fishery location strata (Table 4.) The resulting set of strata were ordered by recovery rate and tested for pooling based on recovery rate similarity. Fishers exact tests of all possible groupings showed that the two strata with the highest recovery rates could be pooled and the 5 lowest could be pooled (Table 4).

3. Population Estimate

Strata with few or no tag recoveries (such as the last four strata in Table 4) can result in implausible (negative) estimates. Pooling can remedy this problem and increase precision of estimates. However pooling of dissimilar strata can bias estimates.

In the pooled data set used for estimation (Table 4) the number of release strata (1) was less that the number of recover strata (2). When this occurs the assumption of similar movement of tagged and untagged fish from tagging to the recovery strata remains but losses between tagging and recovery may occur because the estimation applies to the number of chum passing the tagging site. Using this pooling, the population estimate is 86,445, with a standard error of 14,300. The 95% confidence interval is from 58,417 to 114,472.

As previously stated recovery rate differences between recovery strata may cause bias (positive or negative) in the pooled Peterson estimate. For comparison interest the pooled Peterson estimate was 84,151 with a 95% confidence interval of 57,733 to 110,569.

Because the estimate refers to the number of chum passing the tagging site, and some fisheries occurred between the tagging site and the spawning grounds, the number of chum salmon caught in those fisheries must be subtracted from the total estimate to estimate the spawning escapement. Tagged chum were recovered in both catch areas 78D-2 (below the tag site) and 78D-3 (above the tag site), so we subtracted the catch in all of 78D (3,694 chum) from the population estimate to arrive at a spawning escapement of **82,751**.

Type	Reach	Upstream or downstream	Start Date	End Date	Number Examined	Number Recovered	Percentage Tagged
Commercial	78C	Down	10/23/2007	11/27/2007	3,487	2	0.05%
	78D-2	Down	11/6/2007	12/28/2007	1,433	10	0.70%
	78D-3	Up	11/6/2007	12/28/2007	1,951	10	0.51%
	78D-4	Up	11/6/2007	11/27/2007	0	0	0.00%
Commercial Total					6,871	22	0.32%
Broodstock Total	78D-3	Up	11/27/2007	12/14/2007	110	3	2.73%
Test Fishery	78C-Blakes	Down	10/26/2007	11/12/2007	316	0	0.00%
	78C-Spudhouse	Down	10/17/2007	11/1/2007	71	0	0.00%
	78D-2	Down	10/26/2007	10/30/2007	33	0	0.00%
	8-Jetty	Down	10/30/2007	11/8/2007	114	0	0.00%
Test Fishery Total					534	0	0.00%
Total Upstream					2,061	13	0.63%
Total Downstream					5,454	12	0.22%
Grand Total					7,515	*25	0.33%

*Includes 2 recoveries where tag was lost before recorded.

Table 3. Commercial fishery, brood stock sampling, and test fishery results from reaches in the Skagit River in 2007.

Strata	Location	Fish Examined	Tags Recovered	Recovery Rate	Groups	P-value for within group pooling	P-value for pooling of all areas	Pooled Tags Examined	Pooled Tags Recovered	Pooled Recovery Rate
78D-2	down	1,466	10	0.68%	1	≤ 1.0000	≤ 0.0001	3,527	24	0.68%
78D-3	up	2,061	14	0.63%						
carcass		3,003	7	0.23%	2	0.1663		6,991	8	0.11%
78C	down	3,487	1	0.03%						
8-Jetty	down	114	0	0.00%						
78C-Spudhouse	down	71	0	0.00%						
78C-Blakes	down	316	0	0.00%						

*Includes 2 recoveries where tag was lost before recorded.

Table 4. Fishery (commercial fishery, brood stock sampling, and test fishery) and carcass survey results from reaches in the Skagit River in 2007. P-values are from Fishers exact tests for similarity of recovery rate between groups. P-values indicate that strata pooling into group 1 and group 2 was permissible but full pooling was not.

B. Spawning ground surveys

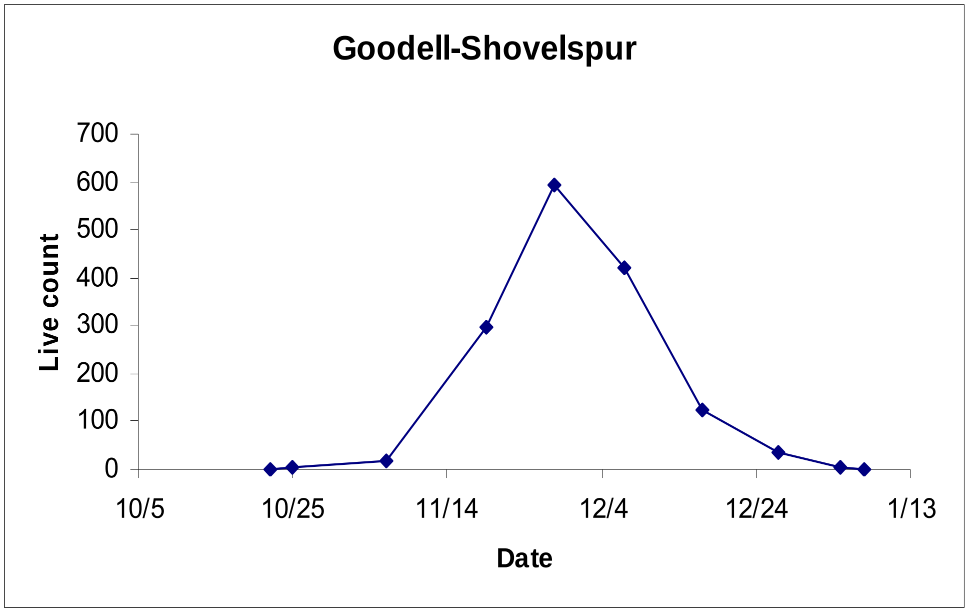
Spawning grounds surveys were conducted throughout the Skagit basin. Surveyors counted live and dead chum beginning in late October, and continued until spawning had concluded in early January. Visibility conditions throughout the season were better than average, with only one relatively brief period of turbid water in early December.

The live counts in the selected index reaches are shown in figures 2-16. In general, counts were substantially below average, indicating a relatively small escapement. Using the method based on the 1976-77 study, the escapement was estimated at 21,476.

Figures 2-6. Spawning ground survey live counts in the Upper Skagit sub-basin.

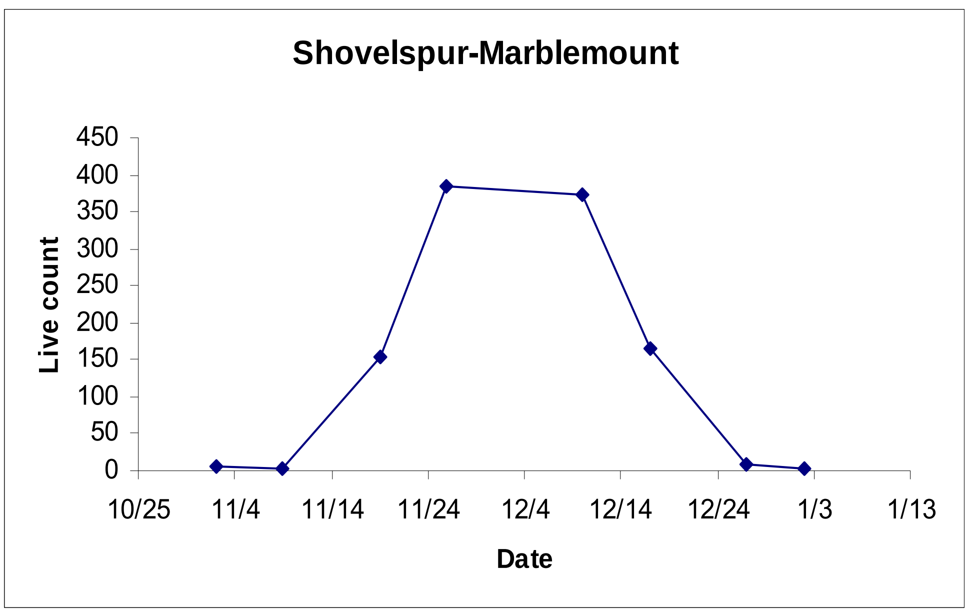
Skagit River Goodell-Shovelspur

Date	Live count
10/22/07	0
10/25/07	3
11/6/07	16
11/19/07	295
11/28/07	592
12/7/07	422
12/17/07	123
12/27/07	37
1/4/08	6
1/7/08	0



Skagit River Shovelspur-Marblemount

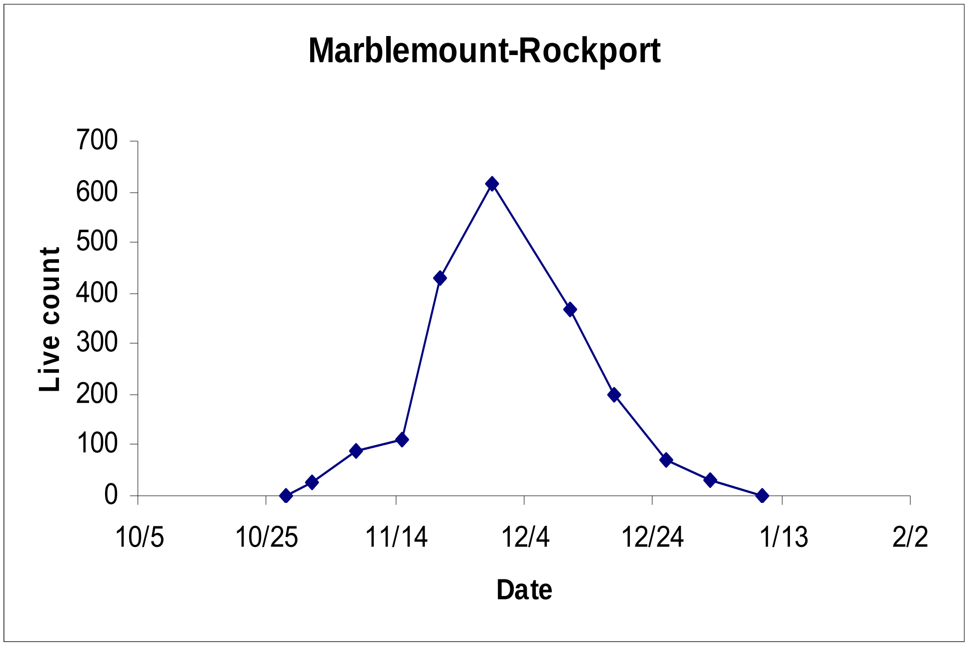
Date	Live count
10/30/07	0
11/2/07	5
11/9/07	4
11/19/07	155
11/26/07	385
12/10/07	373
12/17/07	166
12/27/07	8
1/2/08	4
1/5/08	0



Figures 2-6 continued. Spawning ground survey live counts in the Upper Skagit sub-basin.

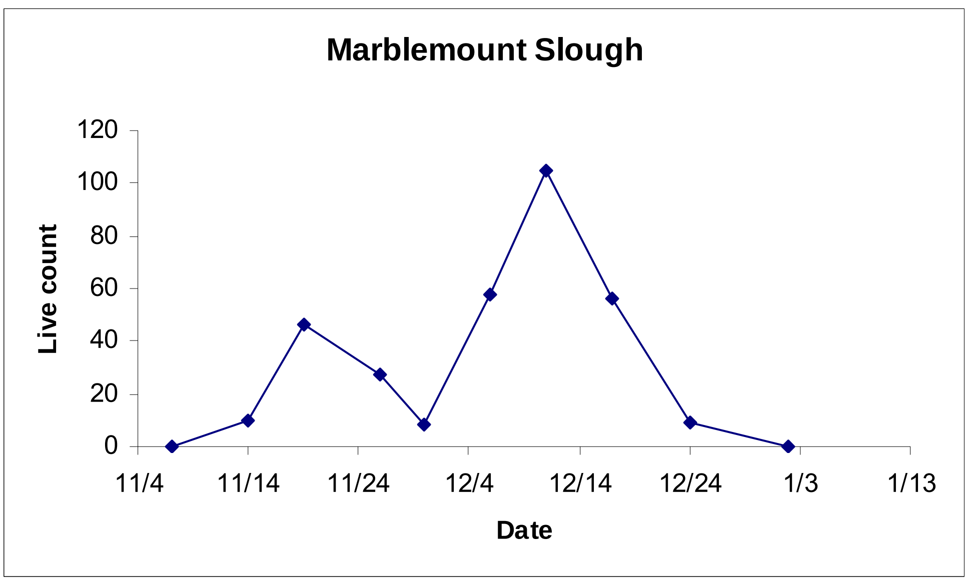
Skagit River Marblemount-Rockport

Date	Live count
10/28/07	0
11/1/07	26
11/8/07	89
11/15/07	110
11/21/07	430
11/29/07	616
12/11/07	367
12/18/07	198
12/26/07	71
1/2/08	33
1/10/08	0



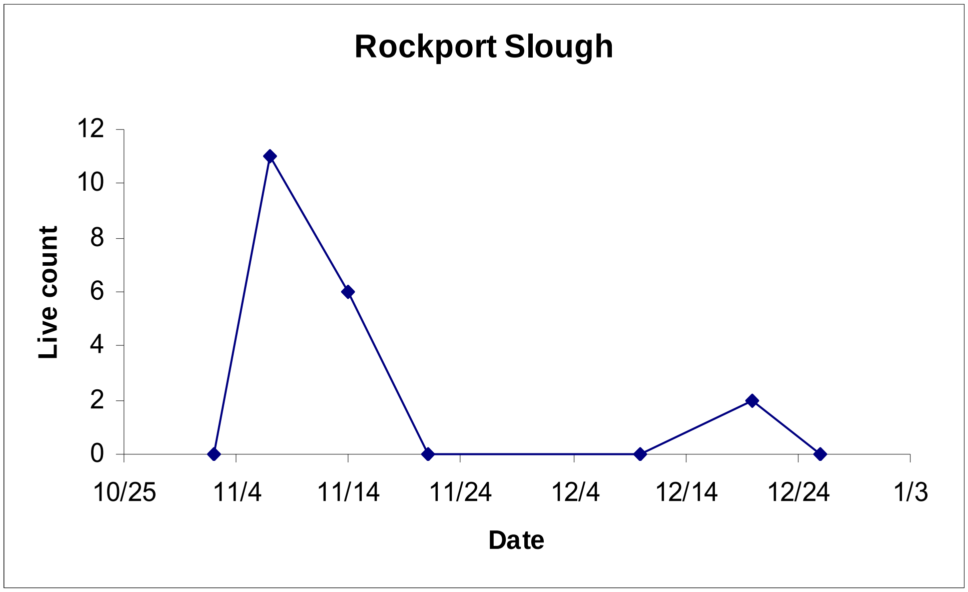
Marblemount Slough

Date	Live count
11/7/07	0
11/14/07	10
11/19/07	46
11/26/07	27
11/30/07	8
12/6/07	58
12/11/07	105
12/17/07	56
12/24/07	9
1/2/08	0



Figures 2-6 continued. Spawning ground survey live counts in the Upper Skagit sub-basin.

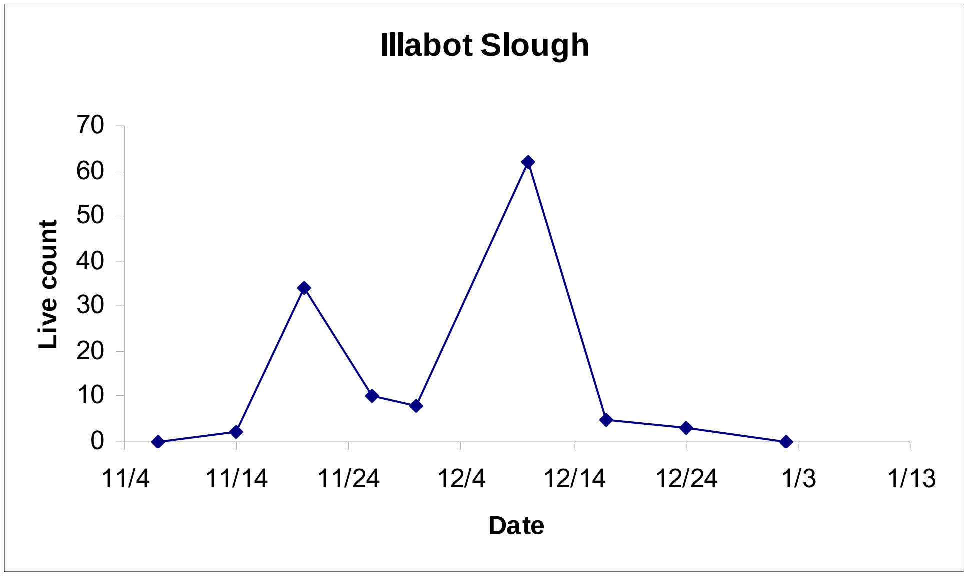
Rockport Slough	
Date	Live count
11/2/07	0
11/7/07	11
11/14/07	6
11/21/07	0
12/10/07	0
12/20/07	2
12/26/07	0



Figures 7-10. Spawning ground survey live counts in the Illabot sub-basin.

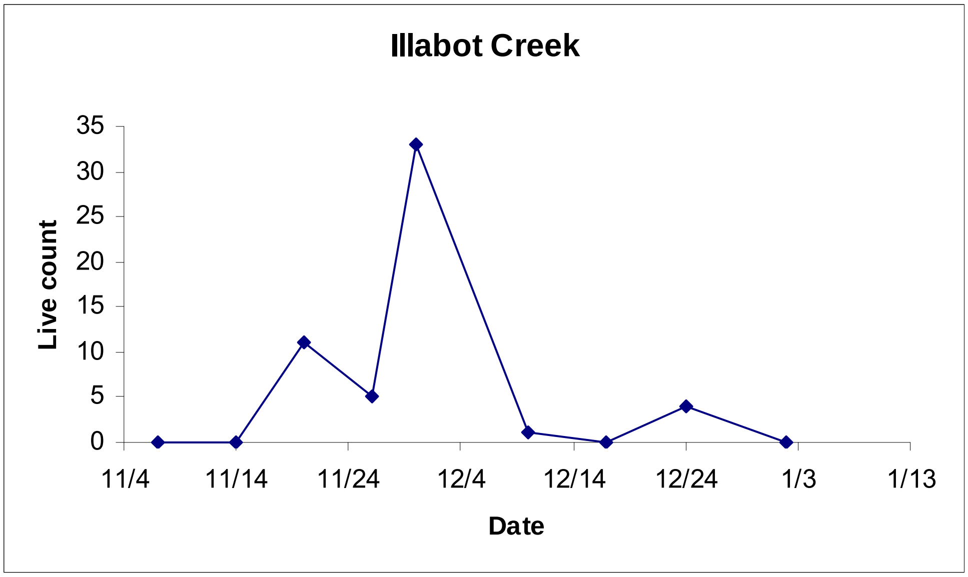
Illabot Slough

Date	Live count
11/7/07	0
11/14/07	2
11/20/07	34
11/26/07	10
11/30/07	8
12/10/07	62
12/17/07	5
12/24/07	3
1/2/08	0



Illabot Creek

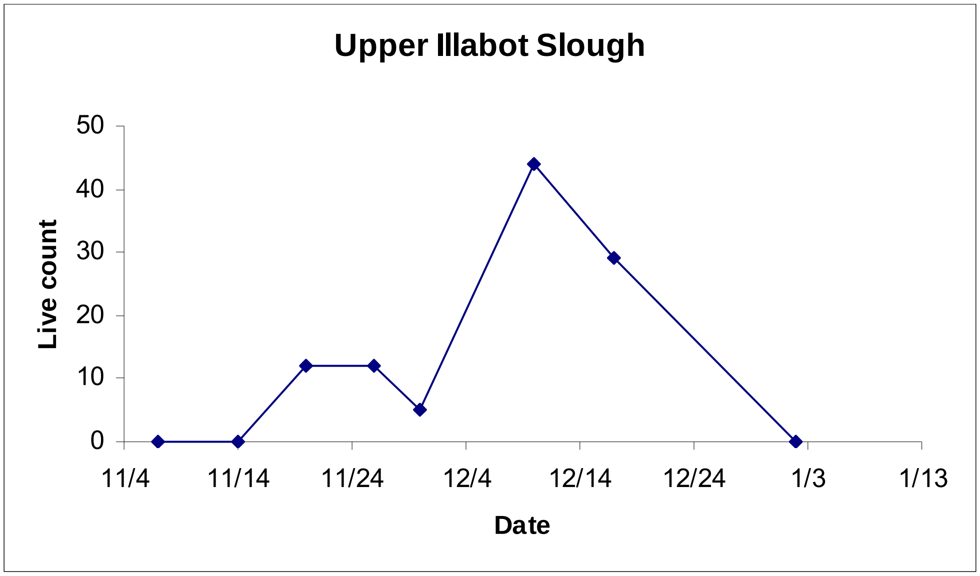
Date	Live count
11/7/07	0
11/14/07	0
11/20/07	11
11/26/07	5
11/30/07	33
12/10/07	1
12/17/07	0
12/24/07	4
1/2/08	0



Figures X-X continued. Spawning ground survey live counts in the Illabot sub-basin.

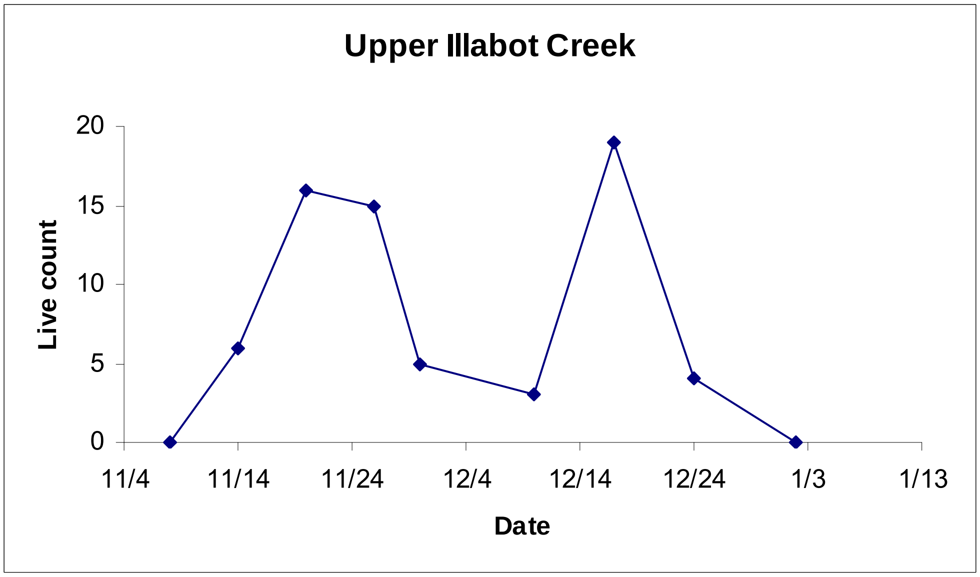
Upper Illabot Slough

Date	Live count
11/7/07	0
11/14/07	0
11/20/07	12
11/26/07	12
11/30/07	5
12/10/07	44
12/17/07	29
1/2/08	0



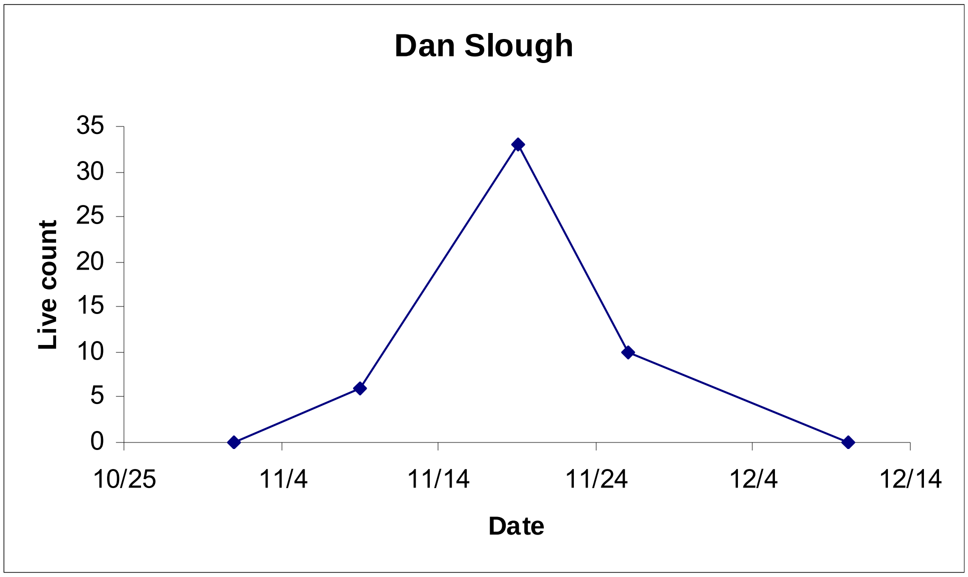
Upper Illabot Creek

Date	Live count
11/8/07	0
11/14/07	6
11/20/07	16
11/26/07	15
11/30/07	5
12/10/07	3
12/17/07	19
12/24/07	4
1/2/08	0

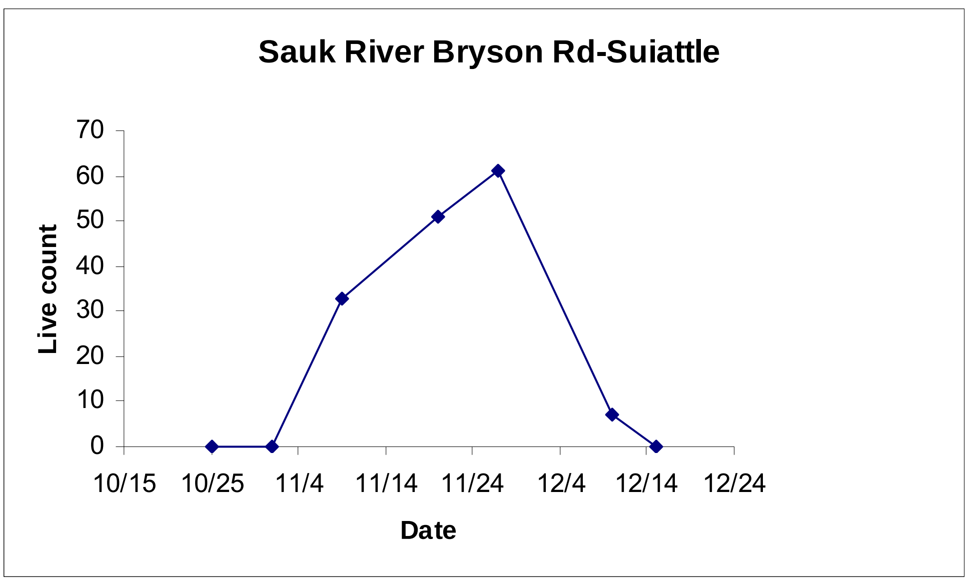


Figures 11-12. Spawning ground survey live counts in the Sauk sub-basin.

Date	Dan Slough and Sauk Slough Live count
11/1/07	0
11/9/07	6
11/19/07	33
11/26/07	10
12/10/07	0



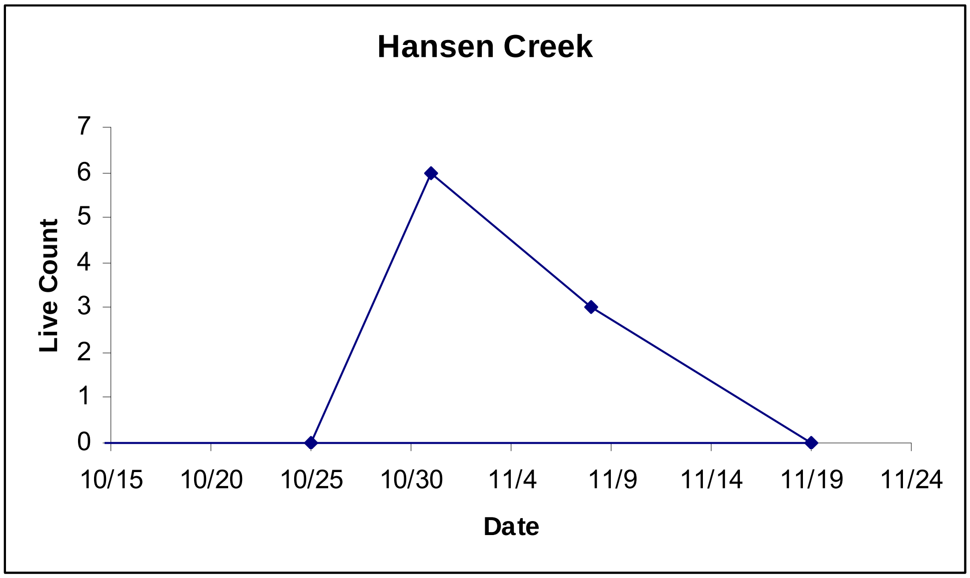
Date	Sauk River Bryson Rd. -Suiattle Live count
10/25/07	0
11/1/07	0
11/9/07	33
11/20/07	51
11/27/07	61
12/10/07	7
12/15/07	0



Figures 13-16. Spawning ground survey live counts in the Middle Skagit sub-basin.

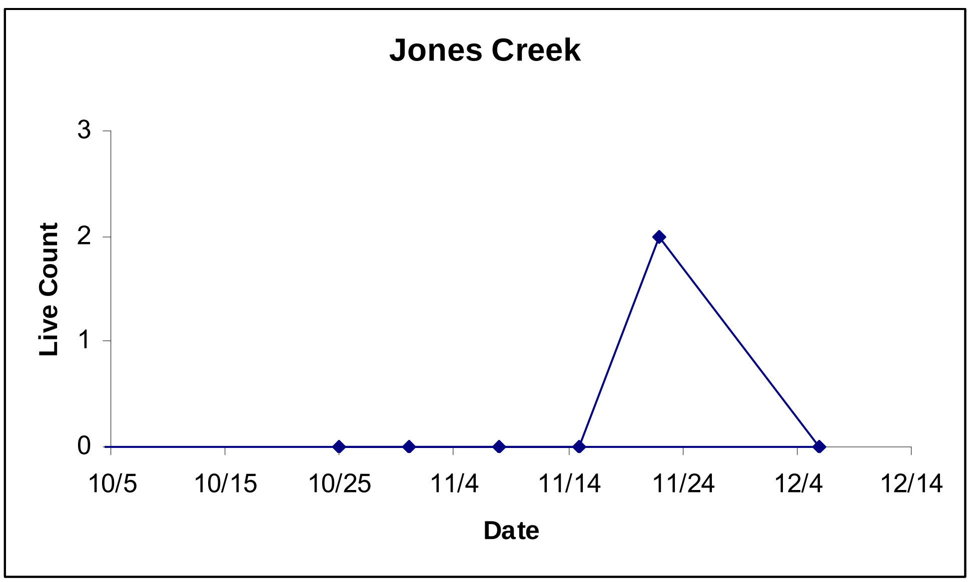
Hansen Creek
R.M. 3.0-4.3

Date	Live count
10/18/07	0
10/25/07	6
10/31/07	3
11/8/07	0
11/19/07	0



Jones Creek

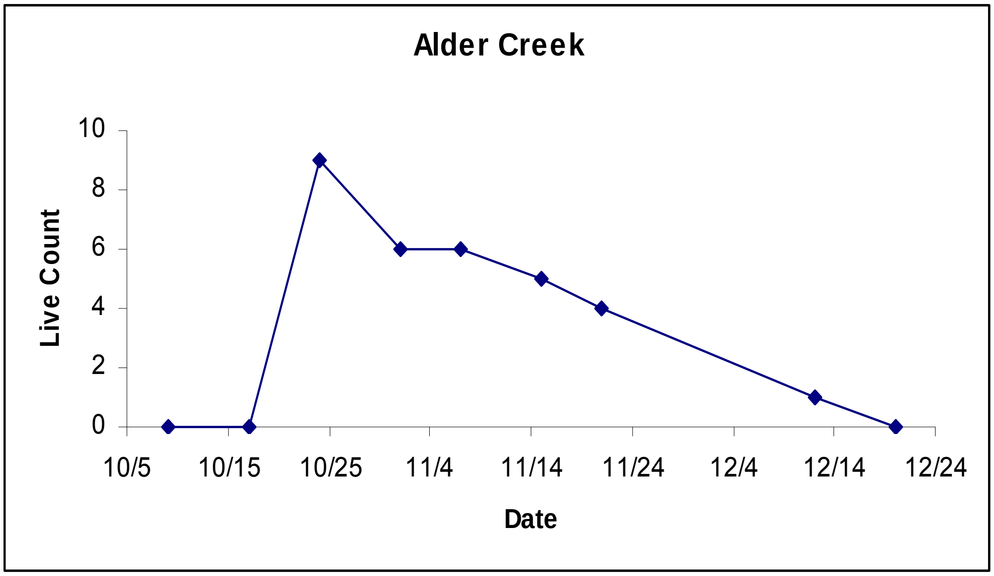
Date	Live count
10/16/07	0
10/25/07	0
10/31/07	0
11/8/07	0
11/15/07	2
11/22/07	0
12/6/07	0



Figures 13-16 continued. Spawning ground survey live counts in the Middle Skagit sub-basin.

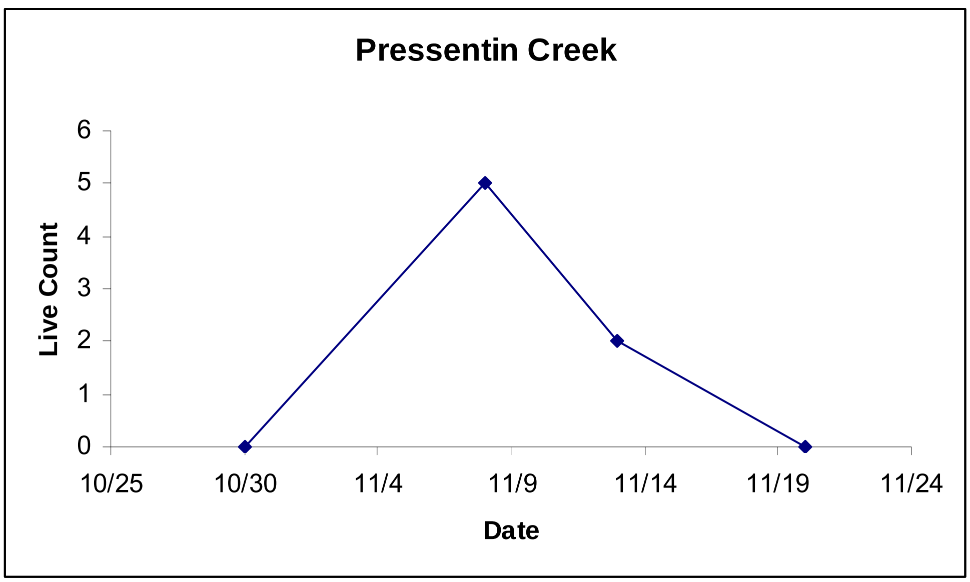
Alder Creek
R.M. 0.0-0.4

Date	Live count
10/9/07	0
10/17/07	32
10/24/07	60
11/1/07	36
11/7/07	44
11/15/07	27
11/21/07	53
12/12/07	4
12/20/07	0



Pressentin Creek

Date	Live count
10/30/07	0
11/8/07	5
11/13/07	2
11/20/07	0



IV. Discussion

The intent of this study was to recalibrate the method used to estimate the escapement of chum salmon to the Skagit River. The current method is based on a similar mark-recapture study conducted in 1976-1977, which developed a set of index reaches for future surveys. In subsequent years, counts in these index reaches were compared to the base years to generate an escapement estimate. In the 30 years since the original study, the distribution of chum salmon spawning has changed, violating the assumption that the base year is representative of the current distribution. This study was designed to remedy this situation, and develop new base years that reflect the present distribution of chum salmon spawning in the Skagit River. Because chum salmon returns in the Skagit River are cyclical, it was planned for 2006 and 2007, which were expected to be high and low years, respectively.

In 2006, a large flood at the peak of the spawning migration disrupted nearly every aspect of the study. Despite the flood, we were able to tag and sample a sizable number of chum, but counts in index reaches were impossible due to post-flood turbidity. For unknown reasons, very few tagged fish were recovered. While a population estimate was generated (2.4 million), it was unrealistically high and essentially meaningless because of the violation of the statistical assumptions of a Peterson estimate. The results of the 2006 season are detailed in that season's final report (Conrad et al. 2007).

In 2007, river conditions were substantially more cooperative. There was only one relatively brief period of high water during the field season, and it did not substantially affect tagging or surveying activities. Unfortunately, there were still relatively few tagged fish recovered, despite intensive sampling. Because of the low tag recovery rate, the resulting escapement estimate (82,000) again seems unrealistically high. This estimate was nearly four times the estimate using the "old" model.

In order to determine possible reasons for low tag recovery rates, we examined the statistical assumptions involved, and considered whether they had been met. The fundamental assumptions are:

1. Population is closed (no births or deaths or movements out or in)
2. All animals have same probability of being caught in the first sample (random tagging)
3. Marking does not affect catchability of an animal
4. Second sample is a random sample
5. No loss of tags between samples
6. All tags are reported in the second sample

We believe that these conditions were fulfilled. Tagging effort was spread evenly throughout the run to ensure that tags were applied randomly (assumption 2). Sampling of carcasses and commercial catch was intensive and distributed throughout the watershed (assumption 4). The jaw tags used were extremely securely attached, to the extent that samplers found them difficult to remove, so extensive tag loss is unlikely (assumption 5). An operculum punch was also used as a secondary mark, and no chum were found with only a punched operculum, indicating tag loss. The tags were also brightly colored and easy to see, so failing to recognize a tagged fish during sampling is also unlikely (assumption 6). Unlike Peterson disk tags, jaw tags do not make a fish more likely to be tangled in a gillnet (assumption 3).

Because a substantial portion (48%) of the chum we tagged were also implanted with acoustic tags, we were able to track many of them throughout their spawning migration (Dave Pflug, Seattle City Light, unpublished data). The post-tagging detection rate (91.2%) of these fish suggests that tagging mortality was not significant, and that most tagged chum continued on their spawning migration. This partially satisfies the first assumption.

An unexpected finding of the tracking study was that 61% of the acoustic tagged chum quickly swam downstream and left the river after spawning. Obviously, fish that left the river would no longer be available to samplers, which would reduce the potential number of tagged fish to be found. It also would appear to violate the first assumption of a closed population. However, since the population estimate uses the proportion of tagged fish in the sample, the downstream movement of some fish should not bias the population estimate *as long as tagged and untagged fish leave in the same proportion*. The overall effect would be to simply reduce the number of carcasses available for spawning grounds sampling. We have no way of determining whether the acoustic tags somehow created the downstream movement behavior, but it seems unlikely. Whatever the mechanism, the loss of tagged fish from the system may have affected the accuracy of the population estimate somewhat, but probably not enough to explain the apparent large overestimate.

Because of the apparent failure of the mark-recapture portion of the study, we examined the data from the tracking study to see if it could:

1) confirm our suspicion that the mark-recapture study resulted in a large overestimate of the population size and/or

2) be used to develop an alternate escapement estimate strategy.

From the tracking study, we knew that about 60% of the tagged chum spawned in the upper Skagit basin, between Rockport and the uppermost extent of spawning near Newhalem. This reach is both intensively spawned and intensively surveyed. A spawning escapement of 82,000, as suggested by the mark-recapture study, would mean that about 50,000 chum spawned in this reach. However, at the peak of spawning, only 1500 to 2000 live fish were counted throughout this area. The survey conditions were better than average and almost all of the habitat is surveyed, so our counts should have captured the majority of chum present on the spawning grounds. Assuming that surveyors were able to count even a modest percentage of the fish present, the number of chum spawning between Rockport and Newhalem was clearly much less than 50,000.

This supports the conclusion that the true basin-wide spawning escapement was much less than 80,000.

While the tracking study did not offer a better way to directly estimate population size, we were able to determine the relative distribution of chum spawning throughout the basin. Based on run timing and geographical distribution, it appears that at least three populations of chum are present in the Skagit (Dave Pflug, Seattle City Light, unpublished data). The earliest timed and smallest population spawns in the Sauk River. In 2007, this population was about 5% of the total. A second population spawns in the mainstem Skagit and tributaries below Finney Creek, and is timed slightly later than the Sauk population. This population was 35% of the total. The third and largest (60% of the total) population spawns in the upper Skagit River, and is the latest timed run.

We have developed a method that uses the observed distribution between these three populations to generate a more meaningful population estimate for the 2007 base year. As mentioned above, the Rockport-Newhalem reach is the most intensively spawned portion of the river, and almost all of the available habitat was surveyed under good conditions in 2007. Using the live counts in this reach, and the observed residence times from the tracking study, we were to generate an estimate of the total number of chum that spawned in this reach in 2007. From that, we estimated the size of the other two populations based on the distribution seen in the tag study. This gave us a basin-wide population estimate so that we can use 2007 as a base year for future escapement estimates. Unfortunately, because the new method uses index sections that were not historically surveyed, we will not be able to "redo" past escapement estimates.

While a single base year with a somewhat uncertain population estimate is hardly the ideal basis for future escapement estimates, it may still be an improvement over the current model. The 1976-1977 base years had their own set of problems. For example, each base year provides a very different estimate when used separately, so the two years are averaged to generate the estimate. It also depends almost entirely on index reaches within the upper Skagit sub-basin, which fails to reflect possible year-to-year changes between the different populations. The proposed new method includes indexes in the Sauk and middle Skagit, and calculates separate estimates for each of these populations. It also would reflect the current hydropower flow regime, which has been shown to substantially affect the distribution of spawning chum (Connor and Pflug 2004).

The new escapement estimate method is described in detail in Appendix 1. It will be considered by the co-managers of Skagit chum for possible use in future escapement estimates.

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Conrad, R., Musslewhite, J. and Barkdull, B. 2007. Skagit River chum escapement strategy. (Technical report). Final report for Southern Fund project SF-2006-I-14. Skagit River System Cooperative and Washington Dept. of Fish and Wildlife. La Conner, WA.

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Appendix I.

Skagit River Chum Escapement Estimation
Based on 2007 Acoustic Tracking Study

January 2009

I. **Background**

In 2006 and 2007, a mark-recapture study of chum salmon was conducted in the Skagit river basin. This study was designed to recalibrate the method used to estimate the spawning escapement of chum in the Skagit. Unfortunately, this study did not achieve its objectives. In 2006, a large flood disrupted tagging and surveying operations (Conrad et al 2007). In 2007, field operations were conducted successfully, but the mark-recapture experiment generated an unrealistically high population estimate (Musslewhite et al 2009). For these reasons, the tag study was not used to improve the method of Skagit chum escapement.

While the primary purpose of the study was to refine the escapement estimate methodology, an adjunct project may have proven more valuable. During both study years, a subset of tagged fish were also implanted with acoustic tags. Fish with these tags were detected by an array of receivers stationed throughout the basin. The resulting data was then used to determine the movement and timing of chum salmon as they completed their spawning migration. This project is discussed in detail in Pflug (and Connor?) 2008.

II. Summary of methodology

A. Sub-basin proportional escapement

The first step was to determine the proportion of the run that spawned in each of three sub-basins. These sub-basins were:

1. The Upper Skagit, upstream of Rockport
2. Sauk River
3. Middle Skagit, downstream of Rockport

Using detections from acoustic receivers, we could determine the proportion of the acoustic tagged chum that spawned in each of these areas. However, the acoustic tags were not applied randomly throughout the run, so using the raw percentage of detections would produce a biased result. The study plan called for a set number of acoustic tags to be deployed each week, and the remainder of chum caught to be tagged with a jaw tag only. Thus, when catches were low, a higher percentage of chum received acoustic tags.

Without adjustment, this would have the effect of making chum early and late in the run (when catches were low) over-represented by acoustic tags compared to chum in the peak of the run (when catches were higher). We corrected for this by expanding the number of acoustic tag "recoveries," or detections in each sub-basin, based on the total weekly number tagged:

Expansion factor = 1 / (# acoustic tags deployed / total # tags deployed)

These expansions were calculated for each week of tagging (table 1). In some weeks, all chum caught were implanted with acoustic tags.

Management Week	Week begin	week end	Number tagged and Tag Type: Acoustic	Jaw tag only	Total	Expansion factor
42	10/14/2007	10/20/2007	13	2	15	1.2
43	10/21/2007	10/27/2007	7	2	9	1.3
44	10/28/2007	11/3/2007	18	21	39	2.2
45	11/4/2007	11/10/2007	14		14	1.0
46	11/11/2007	11/17/2007	18	24	42	2.3
47	11/18/2007	11/24/2007	18	61	79	4.4
48	11/25/2007	12/1/2007	26		26	1.0
49	12/2/2007	12/8/2007	2		2	1.0
50	12/9/2007	12/15/2007	9	28	37	4.1
Grand Total			125	138	263	

Table 1. Number of chum salmon tagged with acoustic and jaw tags and associated expansion factors.

We then multiplied each individual tag "recovery" by its associated expansion factor, giving us an adjusted distribution to each of the sub-basins (table 2).

Sub-basin	Percentage of spawning
Upper Skagit	56.9%
Middle Skagit	37.9%
Sauk	5.1%

Table 2. Adjusted distribution of chum salmon spawning in the Skagit River basin in 2007, based on detection of acoustic tags

B. **Estimating population size from live counts**

While the acoustic tag data allowed us to measure the proportion of chum spawning in each sub-basin, we still need to know the total number in the population. We estimated the number of chum that spawned in the upper Skagit sub-basin from live counts conducted throughout the spawning season. We used counts in the upper Skagit because it contains the majority of chum spawning (as shown by acoustic tagging); almost all the spawning habitat is surveyed; and visibility conditions are better than elsewhere in the basin. The visibility conditions in 2007 were generally excellent, especially for chum spawning season, when the river is typically high and turbid.

Typically, live counts from spawning grounds surveys are used as relative indicator of abundance, and not as an absolute count or census. During the 2007 surveys, field crews recorded the "Percent seen," which was their best estimate of what fraction of the total number of fish present they had counted. This measure largely reflected the visibility at the time of the survey. We used the recorded "Percent seen" to adjust the raw live counts, and generate an estimate of the total number of fish present in each surveyed reach for each date, so that:

Adjusted count = Original count / Percent seen

The effect of this adjustment can be seen in figure 1, which illustrates live counts for the Marblemount to Shovelspur reach of the upper Skagit.

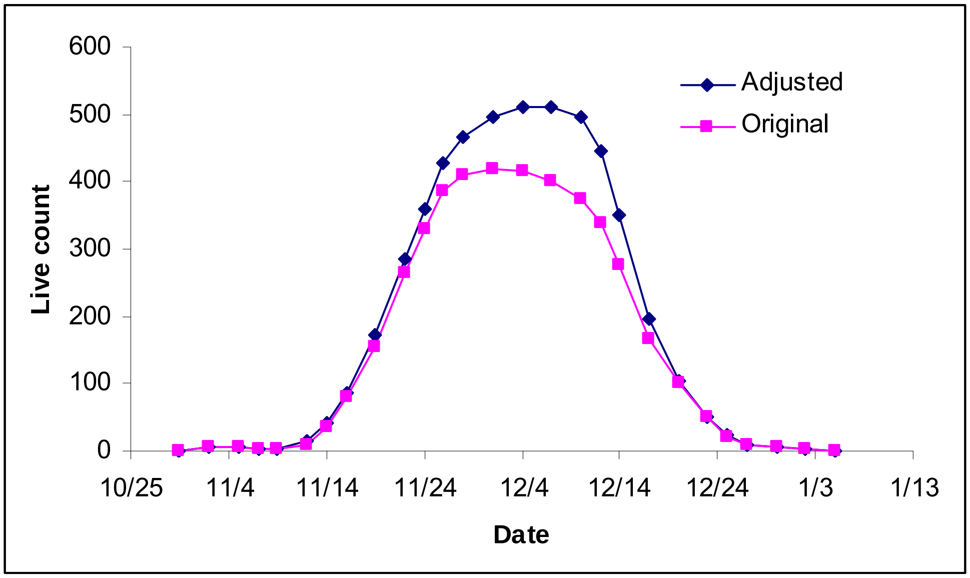

Figure 1. Live counts of spawning chum salmon between Marblemount and the Shovelspur with ("adjusted") and without ("original") use of an adjustment for visibility conditions.

From these adjusted live counts, we generated area-under-the-curve (AUC) estimates of fish-days for each surveyed reach between Rockport and Newhalem. These included a number of constructed channels and off-channel habitats, such as Park Slough, Illabot spawning channels, etc (table 3).

Reach	Reach type	Fish days
Shovelspur-Newhalem	Mainstem	16,969
Marblemount-Shovelspur	Mainstem	13,035
Rockport-Marblemount	Mainstem	19,170
Marblemount Slough	Off-channel	2,126
Illabot Slough	Off-channel	936
Upper Illabot Slough	Off-channel	810
Illabot Creek	Off-channel	382
Upper Illabot Creek	Off-channel	509
Newhalem Ponds	Off-channel	939
Countyline Ponds	Off-channel	1,165
Taylor	Constructed channel	35
Park Slough (new)	Constructed channel	770
Park Slough (old)	Constructed channel	207
Powerline	Constructed channel	669
Illabot (original)	Constructed channel	0
Illabot (extension)	Constructed channel	263
Total		57,985

Table 3. Area-under-the-curve measurements of chum salmon fish-days, from live counts in the Skagit River above Rockport in 2007.

With the acoustic data, we had determined that each chum spent an average of 5.3 days in its spawning area (Dave Pflug, pers. comm.). This was based on fish that followed a behavior pattern of migrating rapidly upstream, stopping between two receivers (presumably to spawn) for several days, and then moving downstream past a receiver. Thus, fish that spawned and died without moving downstream past a receiver could not be used to determine the average time in the spawning area. We also discarded at least one outlier where the acoustically tagged chum had apparently died and came to rest within range of a receiver. Surprisingly, many (61%) of the fish that were tracked to their spawning location left the river shortly after their spawning period.

We then divided the total number of fish days above Rockport (57,985) by the average time each fish spent in its spawning reach (5.3) to arrive at a total of **10,941** fish that spawned above Rockport. As discussed before, this represented 56.9% of the basin-wide total number of spawners. Using those proportions, we then calculated the number in the Sauk and Middle Skagit sub-basins. This gives us a basin wide escapement estimate of **19,211** for the 2007 base year (table 4).

Sub-basin	Percentage of spawning	Number of spawners
Upper Skagit	56.9%	10,941
Middle Skagit	37.9%	7,286
Sauk	5.1%	984
Total		19,211

Table 4. Distribution of chum salmon spawning in the Skagit River basin in 2007, based on acoustic tag detections and spawning grounds live counts.

III. Escapement estimate model

In order to use this base year to estimate the escapement in future years, we would compare the number of fish-days from live counts in that year to those seen in the 2007 base year. This comparison is made separately for each of the three sub-basins. Based on run timing and historic observations, we believe that the populations in these sub-basins fluctuate independently. By making three separate estimates, we would account for the potential that each of these areas does not comprise the same percentage of the total escapement each year.

Index areas in each of the sub-basins were selected for use in the model. These areas were chosen based on the distribution of chum spawning and logistical considerations. Because additional areas were surveyed, they could possibly be used as contingency indexes. For example, if visibility in mainstem reaches was poor, off-channel and constructed channels (which often have better visibility) could be used as index reaches in place of those that could not be surveyed.

For each sub-basin, a population estimate is made using the ratio of that year's fish-days to the number of fish days in the base year for the same indexes:

Sub-basin escapement= 2007 sub-basin escapement * (Current year fish-days/2007 fish-days)

The basin-wide escapement is then the sum of the escapements to the Upper Skagit, Sauk, and Middle Skagit sub-basins. Table 5 lists the preferred indexes and their fish days in 2007, as well as a hypothetical future year for demonstration.

Upper Skagit Chum Population
Includes Area From the Dalles To Newhalem, and Sauk to Government Bridge

Index	2007 Fish Days	"example" 2010 Fish Days
Rockport-Marblemount	19170	17000
Marblemount-Copper Creek	13035	9999
Shovelspur-Goodell Creek	16969	14000
Marblemount Slough	2126	2000
Illabot Creek (RM 0.0-0.7)	382	400
Illabot Slough (RM 0.0-0.3)	936	1000
Illabot Slough (RM 0.3-0.9)	810	800
Total	53429	45199
% of Basin-wide escapement	56.9%	23.0%
Total Escapement For Reach	10941	9256
Lower Skagit River Early Chum Population		
Includes mainstem and tribs from the Dalles downstream		
Pressentin Creek (RM 0.0-0.4)	69	500
Mill Creek (RM 0.0 -0.3)	0	100
Hansen Creek (RM 3.0 -4.3)	67	240
Jones (RM 0.0-1.3)	20	60
Alder RM (0.0 - 1.6)	323	800
Total	478	1700
% of Basin-wide escapement	37.9%	64.4%
Total Escapement For Reach	7286	25922
Sauk River Early Chum Population		
Includes all fish above Government bridge		
Suiattle River-Bryson Road	2416	10000
Dan’s Slough	509	5000
Total	2926	15000
% of Basin-wide escapement	5.1%	12.5%
Total Escapement For Reach	984	5046
Total Escapement	**19211**	**40224**

Table 5. Fish-days and resulting escapement estimate from 2007 base year and hypothetical future year (“2010”).