Estimating Salmon Escapement using Area-Under-the-Curve, Aerial Observer Efficiency, and Stream-Life Estimates: The Prince William Sound Pink Salmon Example

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Accurate estimates of Pacific salmon spawners are needed to set spawning escapement goals and regulate harvests. Estimating the number of pink salmon *Oncorhynchus gorbuscha* spawning in Prince William Sound, Alaska, is difficult since annual runs have ranged between 2.2 million and 19.6 million and spawning occurs in over one thousand individual freshwater systems. Escapement monitoring is accomplished by surveying a collection of 208 index creeks several times over a period of weeks from fixed wing aircraft. Unadjusted survey counts are used to monitor escapements during the commercial fishing season, while estimates of the total number of spawners are calculated after the season using area-under-the-curve methods. We examined the accuracy of area-under-the-curve estimates by using information obtained on creeks with intertidal weirs: 3 creeks in 1990, 8 creeks in 1991, and 7 creeks in 1992. Aerial observer efficiency and stream-life values, calculated for each study creek each year of the study, used in conjunction with aerial observations, produced pink salmon escapement estimates that were on average within 10% of weir counts for these same creeks. Currently used methods, using only the area-under-the-curve and a constant stream life of 17.5 days, produced escapement estimates that were on average less than 50% of the corresponding weir counts. The use of a correction for aerial observer efficiency provided the greatest improvement in escapement estimates, although, the adjustment for stream life also provided substantial improvement. An investigation of the effect of survey frequency on area-under-the-curve estimates indicated that accuracy deteriorated when the survey interval exceeded 7 days.

INTRODUCTION

The annual wild pink salmon *Oncorhynchus gorbuscha* run to Prince William Sound, Alaska, has ranged between 2.2 million and 19.6 million since 1977 (Morstad et al. 1996). These salmon are harvested within nine commercial fishing districts and spawn in over one thousand freshwater systems within Prince William Sound. To ensure the continued viability of the run, district spawning goals have been set and spawning populations have been monitored by aerial surveyors in a collection of 208 index creeks (Fried 1994). Although unadjusted survey counts are used to monitor spawning escapements during the fishing season, estimates of the total number of spawners within each surveyed creek are calculated after the season using area-under-the-curve calculations (e.g. English, Bocking, and Irvine 1992; Johnson and Barrett 1988; Pirtle 1977).

The accuracy of total escapement estimates based on aerial surveys depends upon the number of observations made and their distribution throughout the run, the accuracy of counts (observer efficiency), and the amount of time salmon entering the survey area were visible to observers (stream life). In this paper, we report results of studies conducted in 1990-1992 on 10 creeks with intertidal weirs. Our results indicate that survey frequency was adequate, that aerial observers tend to undercount, and that stream life, while quite variable, appears to be less than the 17.5 day estimate currently used for Prince William Sound. These findings show that current methods used to estimate pink salmon spawning populations in Prince William Sound provide values that are biased low.

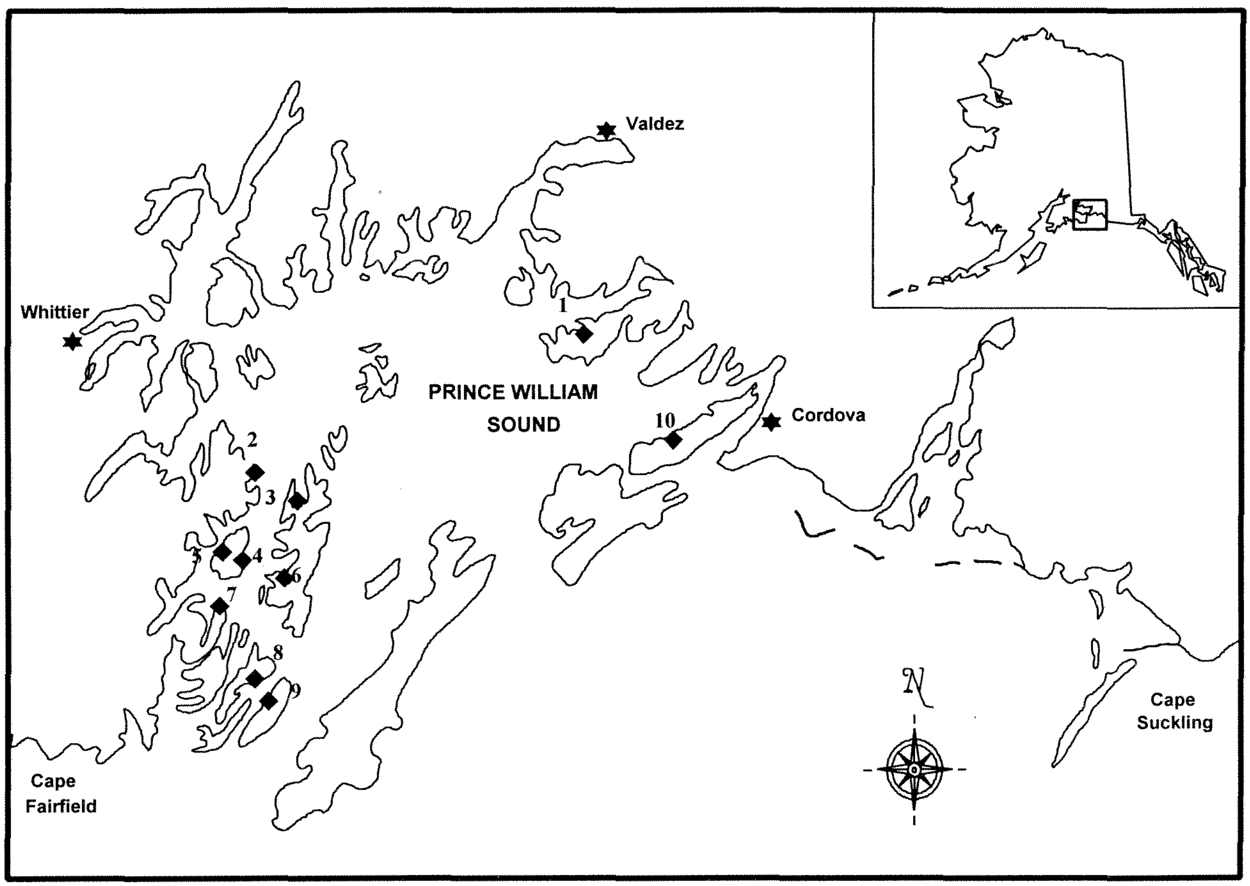
MATERIALS AND METHODS

Weir Operation

Weirs were installed on pink salmon creeks in Prince William Sound during 1990-1992 to enumerate spawning escapement. All weirs were installed in the intertidal zone because approximately 75% of Prince William Sound pink salmon spawn within this area (Helle et al. 1964). This appears to have been the first time that intertidal weirs were used in Alaska. Four weirs were used in 1990, while 10 were used in 1991 and 1992 (Fig. 1). The study creeks included two moderate sized creeks in the eastern Sound (Irish and Hawkins creeks) and eight small to medium creeks in western Prince William Sound (Loomis, Totemoff, Chenega, Point Countess, O'Brien, Hayden, Herring, and Cathead creeks). Salmon were visually counted as they swam upstream through a small opening in the weir made by raising a few pickets. No live boxes were used. Salmon were passed through the weir several times each day in response to tides and salmon movement patterns. Total escapement into each creek was defined as the sum of daily counts of pink salmon passed upstream through the weir.

Daily ground surveys were made above each weir to enumerate pink salmon that had recently died. The tail was removed from each dead salmon, and its carcass was thrown onto the streambank to avoid counting an individual salmon more than once. The combination of total weir live counts and total ground survey dead counts by day allowed the number of live pink salmon in the creek to be estimated on a daily basis. We estimated the number alive $(\hat{L})_j$ for day j of the run by,

Fig. 1 Location of creeks (filled diamonds) used to examine pink salmon aerial escapement estimation methodology, Prince William Sound, Alaska, 1990-1992. Stream identifiers are (1) Irish Creek, (2) Loomis Creek, (3) Herring Creek, (4) Chenega Creek, (5) Totemoff Creek, (6) Cathead Creek, (7) Point Countess Creek, (8) O'Brien Creek, (9) Hayden Creek, (10) Hawkins Creek.



$$\hat{L}_j = \sum_{k=1}^{j} (W_k - D_k) \; , \qquad (1)$$

where W_k was the number of live pink salmon counted through the weir and D_k was the number of newly dead pink salmon on day k. Counts of live pink salmon were also made during ground surveys.

During periods of high creek flows, caused by heavy rains, weir pickets had to be raised to avoid weir destruction, and ground surveys often could not be conducted. In these instances, missing weir ($\hat{W}$) and ground survey dead ($\hat{D}$) counts were estimated by,

$$\hat{W}_j = [(G_j - G_{(j-1)}) \; / \; O] + D_j \; , \text{ and} \qquad (2)$$

$$\hat{D}_j = D_{next} \; / \; m \; , \qquad (3)$$

where G_j was the number of live pink salmon counted during the ground survey on day j; O was the slope of the linear regression, fitted through the origin, of the estimated number alive ($\hat{L}_j$) during ground survey counts for each day of the season prior to the day of the first missing count; D_{next} was the first daily dead count after the period to be interpolated; and m was the number of consecutive days of missed observations.

In designing the project, we assumed that (1) errors made in estimating pink salmon past the weirs due to breaches in the weir or errors in counting were small, and (2) errors made in counting dead salmon above weirs due to removals by predators or errors in counting were also small. If both assumptions were valid, we expected the total weir count of live pink salmon to equal the total ground survey count of dead pink salmon within each creek. If the ratio of weir live to ground survey dead counts was not close to one, we assumed that at least one of these assumptions had been violated and that stream life and aerial observer efficiency estimates based on these data were not accurate.

Aerial surveys were flown at least weekly, weather permitting, from mid-June to mid-September by biologists stationed in Cordova. Four observers were used each year.

Escapement Estimation

Three components are required to estimate salmon escapements using visual counts: (1) counts collected systematically throughout the time salmon are present in the study area; (2) an estimate of observer efficiency; and (3) an estimate of the average time an individual salmon remains in the survey area, commonly called stream life. The area-under-the-curve is a commonly applied method of estimating salmon escapement (E) when periodic visual counts are used (e.g. English, Bocking, and Irvine 1992, Johnson and Barrett 1988),

$$\hat{E} = \frac{\hat{A}}{\hat{S}\hat{B}} \; , \qquad (4)$$

where $\hat{A}$ is an estimate of the area under the escapement curve, $\hat{S}$ is an estimate of stream life, and $\hat{B}$ is an estimate of observer efficiency.

Area-under-the-curve (A) was estimated using a trapezoidal approximation procedure similar to that described in English, Bocking, and Irvine (1992),

$$\hat{A} = \sum_{i=2}^{n} \frac{(t_i - t_{i-1})(c_i + c_{i-1})}{2} \; , \qquad (5)$$

where t_i was the date and c_i was the number of salmon observed for the i^{th} survey. Attempts were made to initiate surveys prior to the presence of pink salmon in the creek. When pink salmon were present for the first survey, the parameter A prior to the first survey was estimated as,

$$\hat{A}_{first} = \frac{c_1 \hat{S}}{2} \; . \qquad (6)$$

We also made an effort to continue surveys until all pink salmon had died. When this was not possible, we estimated A after the final survey as,

$$\hat{A}_{last} = \frac{c_1 \hat{S}}{2} \; . \qquad (7)$$

Stream life (S), the residence time or survey life of pink salmon within each creek, was estimated as the mean number of days which elapsed between creek entry and post-spawning death,

$$\hat{S} = \frac{\sum_{j=1}^{n} \hat{L}_j}{\sum_{j=1}^{n} W_j} \; . \qquad (8)$$

Calibration regression was used to estimate observer efficiency (Neter, Wasserman, and Kutner 1990). We assumed that (1) the relationship between the estimated number of live pink salmon in a creek (independent variable) and survey counts (dependent variable) was linear, and (2) aerial observers would not see salmon in a creek when none were present (i.e. the fitted line passed through the origin). Observer efficiency (*B*) was estimated by the slope of the linear fit, constrained to pass through the origin, of survey counts regressed against daily estimates ($\hat{L}_j$).

Evaluation of Survey Frequency

An evaluation of the effect of survey frequency on area-under-the-curve estimates was undertaken using a simple systematic simulation and our estimates of the number of live salmon above the weirs ($\hat{L}_j$; equation 1). The simulation assumed (1) the number of live salmon above the weir was known and (2) the first survey occurred during the first week salmon were in the creek. The simulation was initiated by selecting a survey frequency (*F*) and a day during the first week salmon were present in the creek (j_1, where j_1 was in the range of 1 to 7). The second day (j_2) was selected by

$$j_2 = j_1 + F , \tag{9}$$

and all remaining days were selected at intervals of *F*. The number of live salmon above the weir ($\hat{L}_j$) for each selected j was then used to estimate area-under-the-curve using equations 5, 6, and 7. Seven simulations were performed for each $F \geq 0$, one simulation for each day of the first week that salmon were present in the stream. The number of simulations for $F<7$ was equal to *F*. Average area-under-the-curve for a survey frequency (*F*) was estimated as the mean of the simulated estimates.

Comparison of Historic Escapement Estimates to Revised Estimates

Total spawning escapement estimates from currently applied methods for each study creek were compared to estimates using the new information obtained from our study. Currently, area-under-the-curve is estimated using the trapezoidal approximation method described previously, and total escapement estimates are made using a stream life of 17.5 days and no observer efficiency adjustment. We used the same method to estimate area-under-the-curve, but used our estimates of creek-specific stream life and observer efficiency to estimate escapements. Escapement estimates were expressed as a percent of the corresponding weir count to determine the incremental effect of each modification.

RESULTS

Weir Operation

While 24 creek-year data sets were obtained from 10 different creeks over the three years of the study, we chose to use only 18 data sets from 9 different creeks (Table 1). Three data sets were not used because the total number of dead pink salmon far

Table 1. Aerial observer, stream life, and observer efficiency data collected for spawning pink salmon in study creeks with weirs and daily ground surveys, Prince William Sound, Alaska, 1990-1992.

Stream Name	Total Weir Count	W/D Ratio [a]	Number of Surveys	Days Between Surveys: Average	Min	Max	A^b	Stream Life	Observer Efficiency b^c
1990									
Irish Creek	44,900	0.97	18	4.7	2	7	474,010	18.1	0.499
Herring Creek	4,927	0.97	12	6.0	3	9	43,896	11.4	0.888
Cathead Creek	7,971	1.01	12	5.1	2	9	58,305	9.8	0.825
1991									
Irish Creek	95,034	1.00	17	5.1	1	16	397,733	16.0	0.177
Loomis Creek	20,315	1.08	10	5.3	3	8	51,741	6.8	0.322
Chenega Creek	49,769	0.96	5	8.0	5	10	140,680	10.2	0.234
Pt. Countess Creek	15,028	1.06	10	5.3	3	8	61,192	9.7	0.456
Hayden Creek	18,372	1.12	10	5.3	2	8	73,947	11.7	0.485
Herring Creek	13,022	0.95	10	5.3	2	8	72,337	11.8	0.371
Cathead Creek	9,629	1.10	10	5.3	2	8	23,007	11.0	0.246
Hawkins Creek	40,433	0.95	9	8.8	4	14	236,768	15.6	0.406
1992									
Irish Creek	8,208	0.94	14	5.2	2	9	117,169	21.5	0.554
Loomis Creek	3,845	1.21	10	7.4	1	15	5,939	9.6	0.177
Totemoff Creek	8,428	1.09	9	7.4	6	9	61,675	14.7	0.535
Chenega Creek	10,658	1.21	6	7.6	5	11	38,722	14.2	0.245
Hayden Creek	2,708	1.08	9	7.1	6	8	8,337	9.0	0.359
Herring Creek	911	1.24	9	7.4	1	11	5,625	13.7	0.388
Cathead Creek	3,937	1.22	9	7.4	1	11	27,450	11.9	0.685

[a] W/D ratio is the ratio of total weir count to total dead count.
[b] Area-under-the-curve estimate.
[c] Slope of the regression of aerial counts on estimated number of salmon above the weir.

exceeded the total number of live pink salmon counted through weirs (Totemoff Creek, 1990; Totemoff and O'Brien Creeks, 1992). Three other data sets were excluded because large amounts of weir and ground survey data were missing due to several high creek flow events (O'Brien, Point Countess, and Hawkins Creeks, 1992).

For the 18 creek-year data sets used in our study, escapements ranged from 95,034 (Irish Creek, 1991) to 911 (Herring Creek, 1992) pink salmon (Table 1). The ratio of weir live to ground survey dead counts ranged from 0.94 (Irish Creek, 1992) to 1.24 (Herring Creek, 1992). Odd-year escapements in 1991 were greater than even-year escapements in 1990 and 1992 for all creeks retained in the data set for two (Loomis, Chenega, and Hayden Creeks) or three (Irish, Herring, and Cathead Creeks) years. For example, the Irish Creek 1991 escapement of 95,034 pink salmon was more than two times greater than the 1990 escapement of 44,900 pink salmon, and more than 11 times greater than the 1992 escapement of 8,208 pink salmon.

Escapement Estimation

Aerial survey frequency declined from an average of 5 days between surveys in 1990, to 6 days in 1991, and to 7 days in 1992 (Table 1). Area-under-the-curve estimates, unadjusted for either observer efficiency or stream life, did not always show trends similar to those of weir counts for all study streams. For example, total weir counts for Irish Creek in 1990 and 1991, and Cathead Creek in 1990, 1991, and 1992 increased while area-under-the-curve estimates decreased.

Our simulation results on the effect of survey frequency on area-under-the-curve estimates indicated that accuracy and precision decreased as surveys became less frequent (Table 2; Fig. 2). It appears that a survey frequency of 5-7 days would provide the best allocation of survey effort for Prince William Sound pink salmon.

Stream-life estimates for the 18 creek-year combinations ranged from 6.8 days (Loomis Creek, 1991) to 21.5 days (Irish Creek, 1992; Table 1 and Fig. 3). The median stream-life value for all 18 data sets was 11.6 and the mean was 12.6 days. While pink salmon stream life was shorter in 1991 than 1992 for five (Irish, Herring, Cathead, Loomis, Chenega, and Herring Creeks) of the six creeks retained in the data set both these years, only one (Irish Creek) of the three creeks retained in the data set all three years had a shorter stream life in 1991 than in either 1990 or 1992.

Table 2. Average error in area-under-the-curve estimates for simulated systematic pink salmon escapement surveys.

	Average Error[a] in Area-Under-The-Curve Estimates[b]												
	Number of Days Between Surveys												
Stream Name	2	3	4	5	6	7	8	9	10	11	12	13	14
1990													
Irish Creek	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01	-0.02	-0.02	-0.01	-0.06	**0.10**	0.01
Herring Creek	0.00	-0.02	-0.01	-0.01	0.06	0.00	0.06	**0.14**	**0.19**	**0.38**	**-0.13**	**0.29**	**0.74**
Cathead Creek	0.00	-0.01	-0.02	-0.04	-0.04	-0.07	-0.07	-0.08	-0.01	**-0.14**	**-0.18**	0.06	**0.13**
1991													
Irish Creek	0.00	0.00	0.00	0.00	-0.01	-0.01	0.02	0.02	0.00	0.03	-0.03	-0.01	0.06
Loomis Creek	-0.04	-0.05	-0.04	0.02	-0.05	0.04	**0.17**	**0.25**	**-0.30**	0.07	**0.38**	**-0.51**	**-0.40**
Chenga Creek	0.00	-0.01	-0.01	-0.02	**0.11**	0.09	**0.24**	**0.39**	**0.26**	0.09	**0.32**	**0.31**	**-0.25**
Pt. Countess Creek	-0.02	-0.02	-0.01	-0.02	0.01	0.03	**0.24**	**0.38**	**0.26**	**0.10**	**0.31**	**-0.25**	**-0.11**
Hayden Creek	0.00	-0.01	-0.01	-0.02	-0.02	-0.08	-0.09	**-0.12**	-0.06	**-0.11**	**-0.12**	0.04	0.01
Herring Creek	0.00	0.00	-0.02	-0.02	-0.02	-0.02	-0.02	**0.17**	0.03	-0.02	**0.19**	**0.29**	**0.26**
Cathead Creek	-0.03	-0.05	-0.04	-0.07	-0.09	-0.09	-0.08	**0.14**	-0.06	0.09	0.08	0.04	**-0.34**
Hawkins Creek	0.00	0.00	-0.01	-0.01	0.00	0.00	0.00	0.03	-0.01	**0.14**	0.04	0.05	**0.16**
1992													
Irish Creek	0.00	0.00	0.00	0.00	-0.01	-0.01	0.04	0.08	-0.05	0.07	**0.37**	**0.23**	0.09
Loomis Creek	-0.01	-0.03	-0.07	-0.06	**-0.14**	-0.07	-0.01	**-0.10**	**0.14**	0.05	**-0.40**	**-0.22**	-0.02
Totemoff Creek	-0.01	0.00	-0.02	-0.04	-0.04	-0.03	-0.03	-0.06	**-0.10**	-0.04	**-0.12**	-0.06	**-0.19**
Chenega Creek	-0.02	-0.03	-0.06	-0.09	**-0.12**	**-0.11**	**-0.12**	**-0.14**	0.04	-0.05	-0.04	0.07	0.03
Hayden Creek	-0.02	-0.03	-0.05	-0.07	-0.05	0.02	0.06	-0.08	**0.11**	**-0.34**	-0.07	**0.15**	**-0.43**
Herring Creek	0.00	-0.01	-0.06	-0.09	-0.06	-0.01	0.02	-0.09	0.04	**-0.10**	-0.02	0.00	**-0.42**
Cathead Creek	0.04	0.04	0.07	0.09	0.05	0.08	0.04	-0.05	**-0.16**	**-0.11**	**-0.19**	**-0.11**	-0.08

[a] Average Error is defined as $(\bar{A}-A)/A$ where A is the true area and $\bar{A}$ is the average area from simulations.

[b] Underestimate is indicated by a negative sign; all errors greater than or equal to 0.10 are underlined and bold.

Fig. 2 Number of salmon present by day and the results of a systematic simulation of area-under-the-curve estimates for Irish Creek (A and B) and Herring Creek (C and D) in 1990, Prince William Sound, Alaska. Large solid dots indicate the mean of the simulations while the short lines indicate individual simulations.

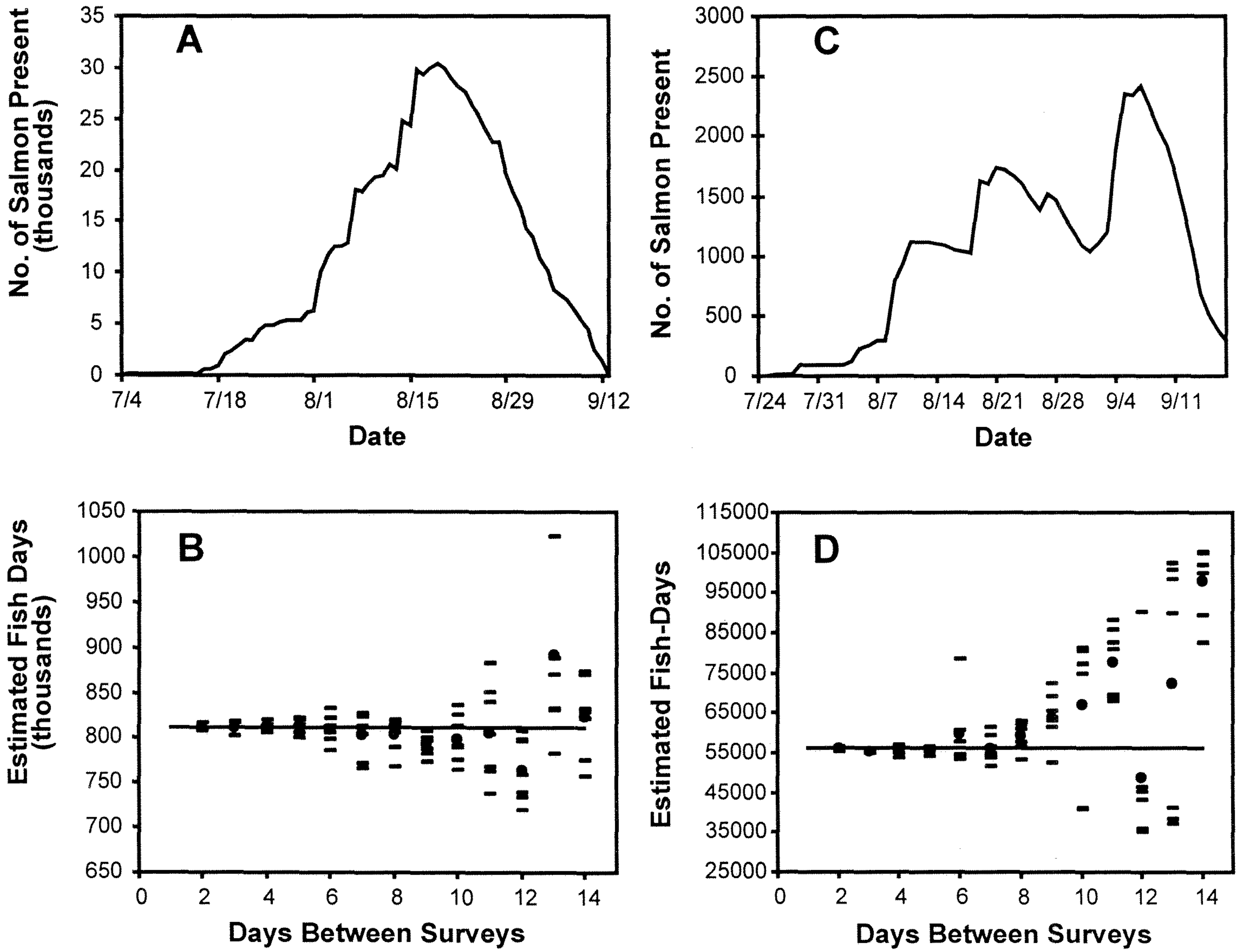
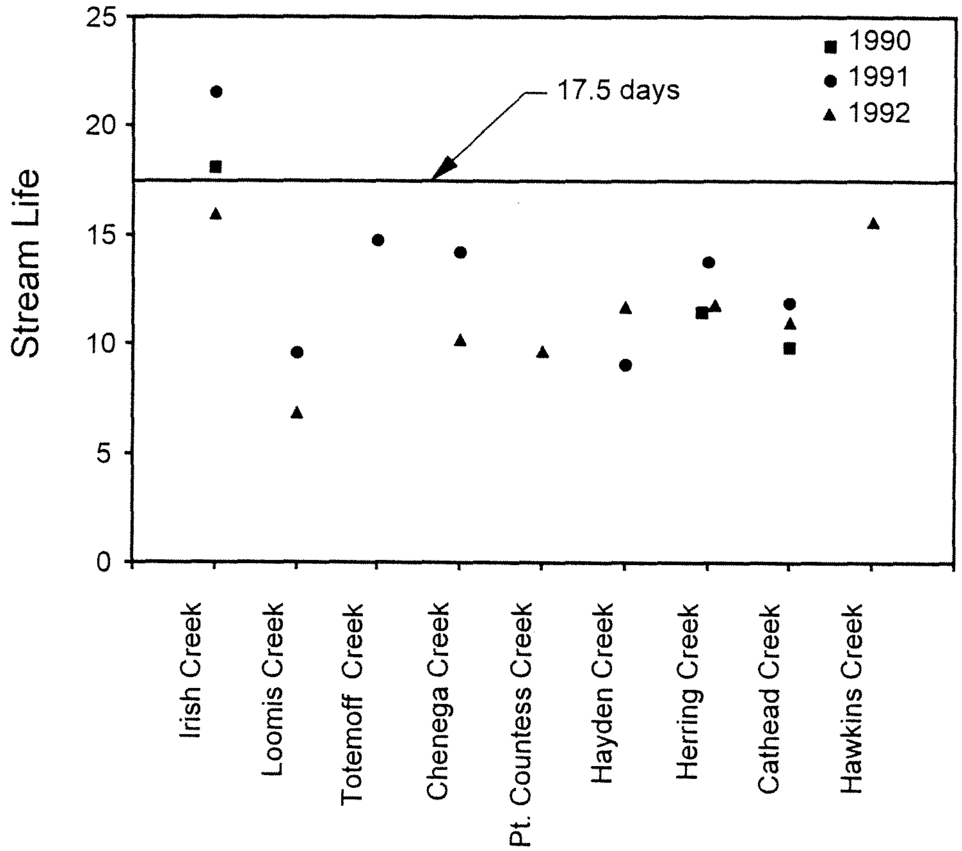


Fig. 3 Estimated stream life for selected study creeks in Prince William Sound, Alaska, 1990-1992.



Stream-life values were generally much shorter than the 17.5 day value currently used to estimate total pink salmon escapement into Prince William Sound spawning creeks (Table 1 and Fig. 3). Only Irish and Hawkins Creek pink salmon had stream-life values similar to (16.0 days, Irish Creek, 1991; 15.6 days, Hawkins Creek, 1991) or greater than (18.1 days, Irish Creek, 1990; 21.5 days, Irish Creek, 1992) the 17.5 day stream-life value. Pink salmon in all other study creeks had stream-life values that ranged from 1.9 (Hawkins Creek, 1991) to 10.7 (Loomis Creek, 1991) days shorter than the currently used 17.5 day value.

Individual creeks were surveyed five to 18 times during the course of each season (Table 1). Aerial observer efficiency estimates ranged from 0.177 (Irish Creek, 1991; Loomis Creek, 1992) to 0.888 (Herring Creek, 1990). This meant that aerial observers generally were able to count from 17.7% to 88.8% of the live pink salmon present. The median observer efficiency value for all 18 data sets was 0.406, while the mean value was 0.436. There appeared to be a trend in aerial observer efficiency between odd- and even-year escapements. Values were lower in 1991 than in 1992 for three (Irish, Chenega, and Cathead Creeks) of the six creeks retained in the data set both these years, and values were lower in 1991 than in both 1990 and 1992 for the three creeks (Irish, Herring, and Cathead Creeks) retained all three years. Overall, aerial observers tended to under-count the actual number of pink salmon available, and this trend appeared to be accentuated in odd-years as well as when the number of pink salmon available to observers increased (Fig. 4).

Comparison of Historic Escapement Estimates to Revised Estimates

Total escapement estimates based on currently applied methods accounted for, on average, 51%, 22%, and 35% of the total weir counts in 1990, 1991, and 1992, respectively (Table 3; Fig. 5). These estimates improved when the appropriate stream-life value was used in place of the currently used 17.5 day value. On average, total escapement estimates based on appropriate stream-life values accounted for 70%, 34%, and 42% of the total weir counts in 1990, 1991, and 1992, respectively. A greater improvement in estimates was obtained when observer efficiency was taken into account, even when a 17.5 day stream-life value was used for all study creeks. On average, total escapement estimates which had been adjusted for observer efficiency accounted for 76%, 71%, and 80% of the total weir counts in 1990, 1991, and

Fig. 4 Observer efficiency relationships used for Irish Creek, Prince William Sound, Alaska for 1990 (A), and 1992 (B). Solid line is the regression fit while the dashed line represents the 1:1 line.

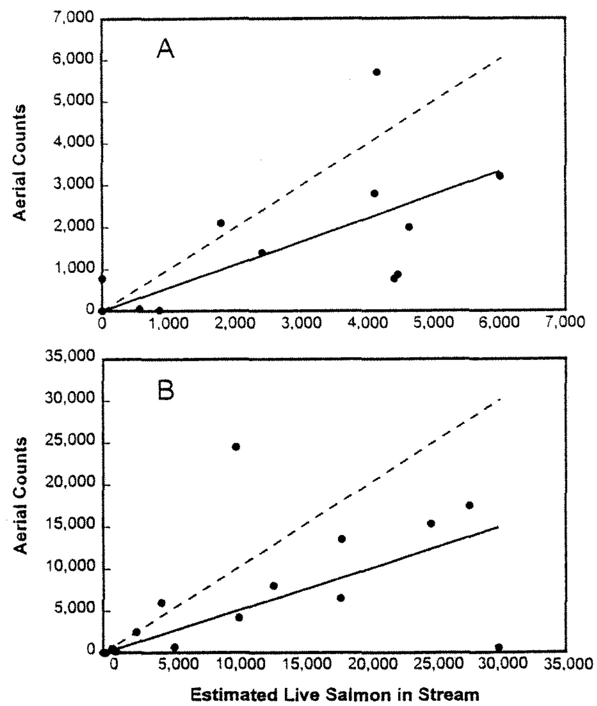
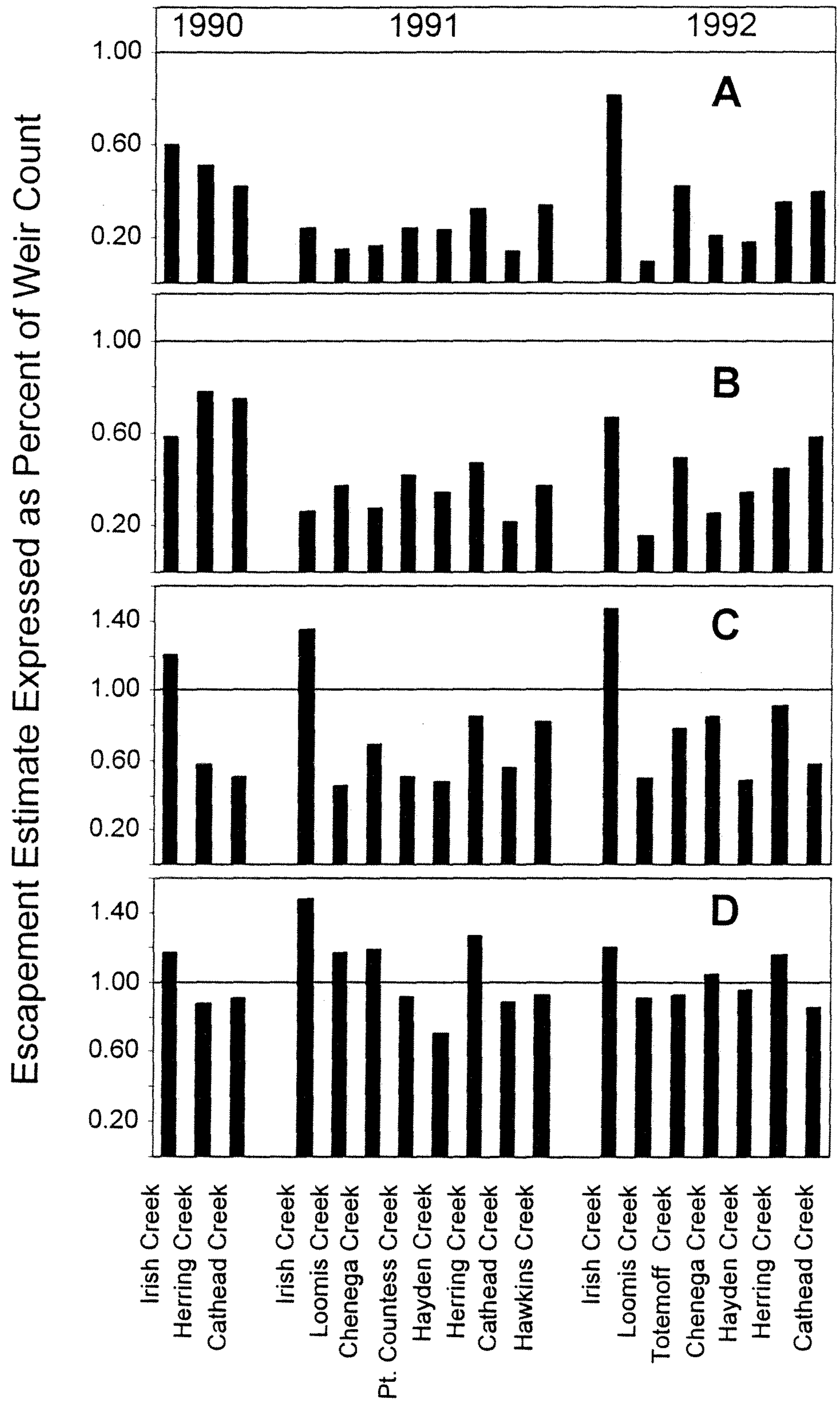


Table 3. Escapement estimates obtained using current and adjusted methods for spawning pink salmon in study creeks with weirs and daily ground surveys, Prince William Sound, Alaska, 1990-1992.

Stream	Total Weir Count	Estimates from Aerial Surveys: Current Method [a] Estimate	Current Method [a] % [c]	Adjusted [b] Estimate	Adjusted [b] % [c]
1990					
Irish Creek	44,900	27,086	60	52,482	117
Herring Creek	4,927	2,508	51	4,336	88
Cathead Creek	7,971	3,332	42	7,212	90
Average			**51**		**98**
1991					
Irish Creek	95,034	22,728	24	140,442	148
Loomis Creek	20,315	2,957	15	23,630	116
Chenega Creek	49,769	8,039	16	58,941	118
Pt. Countess Creek	15,028	3,497	23	13,834	92
Hayden Creek	18,372	4,226	23	13,031	71
Herring Creek	13,022	4,134	32	16,524	127
Cathead Creek	9,629	1,315	14	8,502	88
Hawkins Creek	40,433	13,530	33	37,383	92
Average			**22**		**107**
1992					
Irish Creek	8,208	6,695	82	9,837	120
Loomis Creek	3,845	339	9	3,495	91
Totemoff Creek	8,428	3,524	42	7,842	93
Chenega Creek	10,658	2,213	21	11,130	104
Hayden Creek	2,708	476	18	2,580	95
Herring Creek	911	321	35	1,058	116
Cathead Creek	3,937	1,569	40	3,367	86
Average			**35**		**101**

[a] Constant 17.5 day stream life and no observer efficiency adjustment.
[b] Creek-specific stream life and observer adjustment.
[c] Percent of total weir count.

Fig. 5 Escapement estimates expressed as a percent of the weir count for the currently used method (A: 17.5 day stream life, no correction for observer efficiency), adjusted for stream life only (B: stream-specific stream life used, no correction for observer), adjusted for observer efficiency only (C: stream-specific observer correction with 17.5 day stream life), and adjusted for stream life and observer efficiency combined (D: stream-specific stream life and observer efficiency corrections). The solid line at 1.00 in each plot indicates the weir count.



1992,respectively. When both appropriate stream-life and observer efficiency values were used, total escapement estimates accounted for, on average, 98%, 107% and 101% of the total weir counts in 1990, 1991, and 1992, respectively (Fig. 5). This provided total escapement estimates that were within 20% of the total weir count in 15 of the 18 cases examined (Table 3).

DISCUSSION

This study shows that aerial surveys can be used to estimate pink salmon escapement if survey frequency is maintained at 5-7 day intervals throughout the run and reasonable estimates of stream life and observer efficiency are available. One could argue that an unbiased evaluation of the methodology was not performed because total weir counts were used to estimate stream life and observer efficiency as well as measure total escapement. However, we obtained strong evidence that escapement estimates based on appropriate stream-life and observer efficiency values were more accurate than those based on the currently used 17.5 day stream-life value and no adjustment for observer efficiency. This is best evidenced by Irish and Cathead Creeks in 1990 and 1991 where estimates based on the currently used method declined while corresponding total weir counts increased. The most dramatic example can be seen at Irish Creek in 1991, when the total weir count was more than double the estimate based on the currently used method. Although escapement estimates to Irish and Cathead Creeks using appropriate stream-life and observer efficiency values were not always very accurate (48% over-estimate for Irish Creek in 1991), they at least trended in the correct direction and were closer to the total weir count than estimates based on currently used methods.

Some of the error presently associated with estimating pink salmon escapements in Prince William Sound from aerial survey data is due to use of a stream life of 17.5 days for all creeks. This value was based on Helle et al. (1964) study of the pink salmon run to the middle portion of Olsen Creek in eastern Prince William Sound. Results of studies by McCurdy (1984) suggested that stream life varies among Prince William Sound pink salmon spawning systems and that the 17.5 day estimate used to calculate total escapement may be too large, especially for smaller streams. Our studies confirm McCurdy's (1984) findings. Most stream-life values for pink salmon in our study creeks were shorter than 17.5 days. However, pink salmon spawning in Irish Creek, a large system more similar to Olsen Creek, had annual stream-life values similar to 17.5 days.

Another, and possibly greater, source of error in estimating pink salmon spawning escapements is due to aerial observer efficiency. Our study indicates that aerial observers tend to under-count pink salmon in Prince William Sound spawning systems. Great differences can exist among different observers, and we assume that each observer's efficiency changes in response to both viewing conditions and learning.

Great fluctuations in water level and velocity due to heavy rain, effects of which were magnified by steep gradients and loose gravel substrate, all contributed to problems in maintaining weirs in the various creeks used in this study. Not only did these high water flow events make it necessary to remove weir pickets and miss counts, but they also caused gaps at the bottom of weirs which sometimes went unnoticed and allowed salmon to pass uncounted. We caution that weirs will provide accurate counts of spawning salmon only if efforts are made to carefully maintain their integrity. The use of properly designed ground surveys to count dead salmon can provide a valuable independent check on weir counts.

Finally, our results suggest that use of appropriate stream-life and aerial observer efficiency values will provide more accurate aerial estimates of salmon spawning populations. We caution, however, that treating stream life and aerial observer efficiency as constants will continue to introduce unknown errors into annual spawning population numbers. We recommend that weirs be maintained on a subset of the 208 index creeks both to calibrate aerial observers and to track changes in stream life more closely. Such projects need not be done every year, but particular care should be taken when changes in aerial observers occur.

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REFERENCES

English, K.K, R.C. Bocking, and J.R. Irvine. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences 49:1982-1989.

Exxon Valdez Oil Spill Trustees (EVOST). 1989. Detailed operational plans for studies in the State/Federal natural resource damage assessment plan for the Exxon Valdez oil spill, volume 2, fisheries studies 1-17. Exxon Valdez Oil Spill Trustees, Juneau, Alaska.

Fried, S.M. 1994. Pacific salmon spawning escapement goals for the Prince William Sound, Cook Inlet, and Bristol Bay areas of Alaska. Alaska Department of Fish and Game, Division of Commercial Fisheries, Management and Development. Special Publication No. 8. Juneau, Alaska.

Helle, J.H., R.S. Williamson, J.E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries. Special Scientific Report-Fisheries No. 483. Washington D.C.

Johnson, B.A., B.M. Barrett. 1988. Estimation of salmon escapement based on stream survey data. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Informational Report No. 4K88-35. Kodiak, Alaska.

McCurdy, M.L. 1984. Eshamy District Pink Salmon Stream Life Study, 1984. Alaska Department of Fish and Game, Division of Commercial Fisheries. Prince William Sound Data Report No. 84-18. Cordova, Alaska.

Morstad, S., D. Sharp, J. Wilcock, and J. Johnson. 1996. Prince William Sound management area 1995 annual finfish management report. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report No. 2A96-25. Anchorage, Alaska

Neter, J., W. Wasserman, and M.H. Kutner. 1990. Applied linear statistical models - third edition. Irwin. Homewood, Illinois.

Pirtle, R.B. 1977. Historical pink and chum salmon estimated spawning escapements from Prince William Sound, Alaska, creeks, 1960-1975. Alaska Department of Fish and Game, Division of Commercial Fisheries, Technical Data Report No. 35. Juneau, Ak.