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Observer Accuracy and Precision in Aerial and Foot Survey Counts of Pink Salmon in a Southeast Alaska Stream

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Abstract.—Within- and between-observer variability and bias in aerial and foot survey estimates of spawning abundance of pink salmon *Oncorhynchus gorbuscha* were determined for survey counters from Chaik Bay Creek on southern Admiralty Island, Southeast Alaska, in 1992–1994. Multiple counts of pink salmon escapement in predetermined sections of the creek were made. At the same time, a mark–recapture experiment was performed to estimate the actual number of pink salmon and chum salmon *O. keta.* Observer counting abilities were also examined by using computer images that simulated aerially observed fish; four object types aggregated at predetermined numbers were tested. Observers tended to undercount the actual number of salmon present, and accuracy decreased nonlinearly with an increase in actual salmon escapements. On average, observers counted between 25% and 68% of the salmon present. Correction factors determined for each observer can be used to reduce bias in estimates of total abundance and make counts comparable between observers. Comparison of relative biases of observers making aerial surveys in both 1993 and 1994, years of nearly equal pink salmon abundance, suggested that learning occurred during the study.

Observer counts of salmon escapement have been an essential tool in the management of Pacific salmon *Oncorhynchus* spp. Accuracy, or closeness to the true value, of observer counts is increasingly important because more reliable estimates of total escapement are needed for population studies and because biased estimates produce biased estimates of optimum harvest rate and escapement in stock–recruitment analysis (Walters 1981; Walters and Ludwig 1981). Fisheries managers require high levels of confidence or precision in these estimates.

The first recorded aerial observer count of salmon escapement in Alaska was made in the Lake Clark district of Bristol Bay in 1930 (Eicher 1953). In Southeast Alaska, observer counts are made by Alaska Department of Fish and Game (ADFG) personnel responsible for managing fisheries targeting pink salmon *O. gorbuscha.* Currently, aerial counts are the most practical means of estimating escapements because more than 2,000 streams produce pink salmon in Southeast Alaska, an area of about 100,000 km^2.

The current process was initiated in 1977 (K. Hofmeister, ADFG, personal communication) and uses two strata, large streams with peak aerial escapement counts of 10,000 or more fish and small streams with fewer than 10,000 fish. All unsurveyed streams are assumed to be small streams and are assigned an escapement equaling the average peak aerial escapement count for the surveyed small streams. Peak aerial counts for large streams and for surveyed and unsurveyed streams are summed as the total escapement index for individual management districts. A multiplier of 2.5 expands this index to an estimate of the district's total escapement. The multiplier accounts for fish not present in the escapement at the time of the peak count and others not seen or counted. This multiplier, which assumes the pink salmon run is normally distributed (Hofmeister, personal communication), was not rigorously determined.

Biases due to counting have been widely documented (Bevan 1961; Cousins et al. 1982; Symons and Waldichuk 1984; Dangel and Jones 1988; S. Sharr, ADFG, personal communication). Pacific salmon escapements are difficult to esti-

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mate because fish move into and out of streams, spawn, and die over extended periods. Therefore, the population of returning adult fish present in a stream on any given day is almost always less than the total escapement. Moreover, an observer may not see and, therefore, may undercount the actual number present that day. Dangel and Jones (1988) conducted a pink salmon daily tagging project and found that weighted mean escapement estimates for aerial counts were 35% of the actual number present and 56% of foot counts. Studies performed in 1990 and 1991 in Prince William Sound found that foot counts of pink salmon were approximately 50% of the actual number present and that aerial counts were approximately 33–50% of the actual number (Sharr, personal communication). In general, past studies have indicated that observer counting accuracy decreases with increasing escapement size (Sharr, personal communication).

Accuracy of escapement estimates, based on observer counts, vary with stream types, visual perceptiveness of the observer, and visibility of spawning salmon (Bevan 1961; Jones 1995). Salmon visibility is influenced by weather; water clarity; canopy cover; pool-to-riffle ratio; sinuosity of the stream; density of fish; extent of undercut banks; aircraft speed; and fish behavior, size, and color (Bevan 1961; Neilson and Geen 1981; Labelle 1994).

The purpose of this study was to determine the within- and between-observer variability and bias attributable to aerial and foot surveys for estimating pink salmon escapement. A field study in Chaik Bay Creek, combining a mark–recapture experiment with aerial and foot surveys, was conducted from 1992 to 1994 to determine the accuracy and precision of observer counts. To analyze observer counting abilities, we also used computer images of different numbers of objects that simulated aerial observations of fish. Comparisons were made between the field and the laboratory studies. We hoped that a computer simulation of observer-specific counting rate could be identified that approximated the field results and would enable a model for each individual to be constructed. Thus, observer variability and bias could be removed from individual observers without the need for costly, time-consuming field studies. Simulations also have potential use in training new observers. Counts from both studies were synthesized by means of an allometric model that describes observer-specific counting rate as a nonlinear function of population abundance.

Methods

To evaluate accuracy and precision of observer counts, we conducted mark–recapture experiments to estimate the actual population size. Mark–recapture estimates have been shown to be accurate for determining Pacific salmon escapement (Johnston et al. 1986), although some bias due to immigration, emigration, or heterogeneous capture probabilities could occur for pink salmon, as described below.

Chaik Bay Creek, on southern Admiralty Island in Southeast Alaska (Figure 1), is similar to other streams in the area, except that it has an intertidal zone spanning more than 2 km at mean low tide. The limits of the study section, which extended from the upper intertidal zone upstream for a distance of 533 m (Figure 2), were marked each year with white plastic bags placed high in the tops of trees so that bears could not remove them and they would be visible from both the air and ground.

Mark–recapture experiment.—Mark–recapture experiments in the study section were conducted September 1–2, 1992; August 31–September 2, 1993; and August 30–September 1, 1994. On September 1, 1992, we used a 30-m beach seine with 2.54-cm-bar mesh to seine salmon; seining started at the upper end of the study section and proceeded downstream. Because both pink salmon and chum salmon *O. keta* were present in the study section, both species were marked with adipose fin clips, which were easily applied and recognized. Sampling was conducted in both pools and riffles; distance between seine sets was approximately 30 m in riffles and approximately 10 m in pools. We tried to distribute tags equally across the study section. Marked fish were released back into the stream at their capture site. The following morning, we began seining at the lower end of the study section and proceeded upstream.

The actual number of salmon in the study section (N^*) was estimated with Chapman's nearly unbiased estimator (Seber 1982),

$$N^* = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1, \qquad (1)$$

where n_1 is the number marked, n_2 is the number sampled on the day of recapture, and m_2 is the number recaptured. We wanted our estimates to be within 10% ($A = 0.10$) of the true estimate 95% of the time ($\alpha = 0.05$) and determined the necessary mark–recapture sample sizes as recommended by Robson and Regier (1964). For planning purposes, we used a preliminary total es-

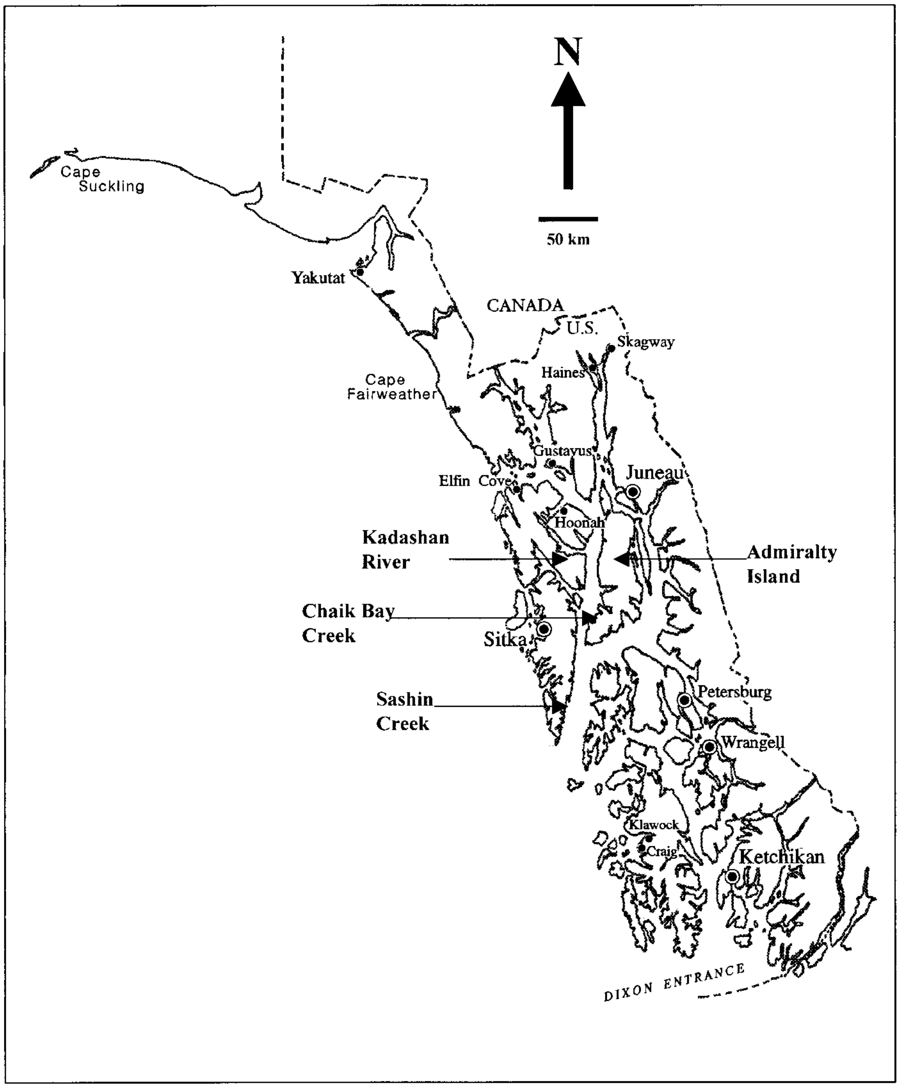

FIGURE 1.—Map of Southeast Alaska showing the location of Chaik Bay Creek, Kadashan River, and Sashin Creek.

capement estimate of 50,000 pink and chum salmon, based on historical records, to determine the number to be marked (n_1), which then was to equal the sample size at the time of recapture (n_2). This sample size was about 4,100, according to the formulae in Seber (1982).

The general assumptions that must hold for N^* to be a suitable estimate of N are listed in Seber (1982). Because sampling was not strictly random, random mixing of marked and unmarked fish was assumed. The population of salmon was not strictly closed, and presumably immigration to and emigration from the study section occurred. Immigration into the study section, although decreasing the tag ratio, does not affect the abundance estimate. However, emigration from the study section would result in a loss of tags, which does affect the abundance estimate. Emigration was believed to be more than negligible, and to account for this, n_1 was modified as

$$n_1^* = n_1(1 - y), \qquad (2)$$

where y = emigration expressed as a proportion. Data from nearby Sashin Creek and Kadashan River (Figure 2) suggest that from 0% to 7% of a run moves past a given point on a given day (Jones 1995). We used a y-value of 0.07 for pink salmon

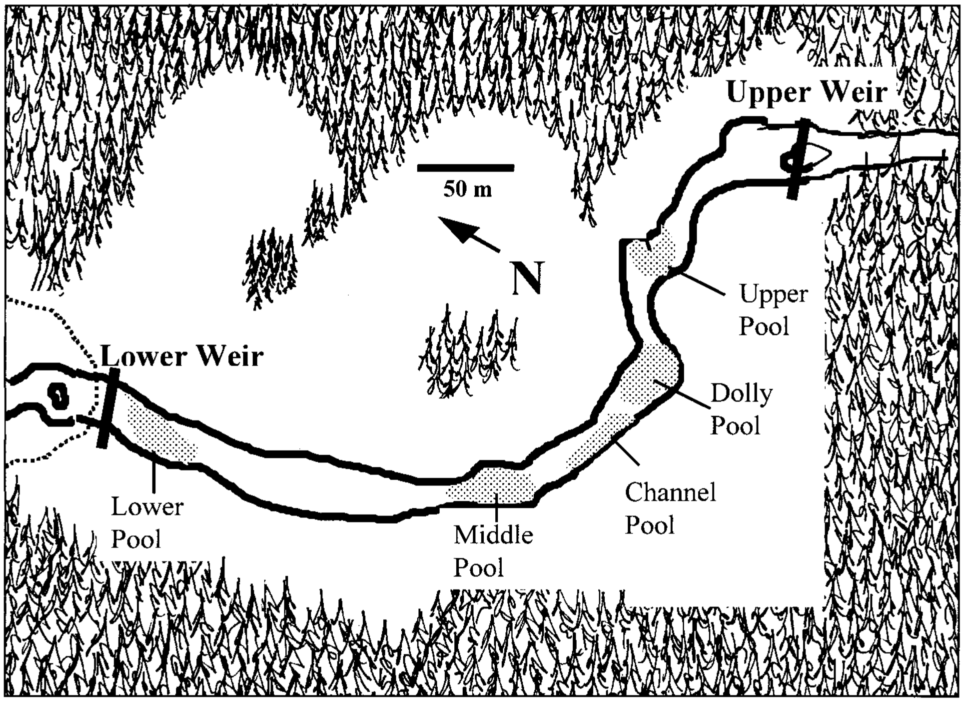

FIGURE 2.—A detailed drawing of the 533-m study section at Chaik Bay Creek.

to provide the most conservative correction factor. For chum salmon, we used a y-value of 0.0 because most were on their spawning grounds and not moving farther upstream.

In 1992, we found that pools and riffles had different concentrations of fish, and as a result, proportions of tagged fish differed. Thus, the assumption that salmon mixed randomly between marking and recovery was probably not satisfied. Therefore, in 1993 and 1994, different marks for fish tagged in pool and riffle strata were used. Adipose fin clips were used in pool strata and left ventral fin clips were used in riffle strata. This modification allowed us to use different probabilities of capture between strata but still required that probabilities of capture among individuals within a stratum be equal. For this design, we used the Darroch estimate (Seber 1982) for abundance estimates and associated variance estimates for both pink and chum salmon. To satisfy the underlying assumption that movement between strata is the same throughout the study area, we attempted to spread out the sampling spatially.

In 1993 and 1994, the ground crew installed a weir at the lower and upper ends of the study section so that the population would be closed. Because damage to weirs and excessive water discharge can allow fish to pass upstream (Labele 1994), both weirs were checked on the second day to ensure that they were operating correctly. With the exception of some very small pink salmon and Dolly Varden *Salvelinus malma*, the stream was adequately blocked off to prevent movement of salmon into or out of the study section.

Observer counts.—All observers were employed by ADFG, with the exception of one 1993 observer. Many observers participated during all 3 years. Multiple survey counts of salmon were made by aerial observers in 1992, 1993, and 1994 and by foot observers in 1993 and 1994. Data independence was achieved by having each observer make counts without knowing what they and other observers had counted previously, a technique described by Bevan (1961). The mechanical counters used were preset, and the numbers were concealed with opaque tape. After each observer completed counting, the tape was removed by a designated researcher, and the total was recorded. Later, the same researcher subtracted the preset value from the total recorded to get the actual count for the observer.

Other than having to use mechanical counters, aerial observers were told to count in a fashion similar to their routine aerial escapement surveys and to count each time as though they had no prior knowledge of previous count totals. Supercub airplanes, commonly employed for aerial counting, were used. The air speed was kept at about 95 km/h at an altitude of approximately 100 m, which is normal practice in escapement counts (Bevan 1961; W. Petaja, ADFG, personal communication). Aerial counters cannot distinguish between pink and chum salmon. After aerial counts were completed, some of the same observers conducted foot counts in the study section. Foot observers performed counts upstream and then downstream, using preset tally-whackers to make separate counts for pink and chum salmon.

Analysis of variance (ANOVA) was used to determine within- and between-observer variability (Snedecor and Cochran 1980). A fixed-effects model was used with observers as the effects. The model is

$$X_{ij} = \mu + A_i + \epsilon_{ij} \tag{3}$$
$$[i = 1, \ldots, a;\ j = 1, \ldots, n_i;\ \epsilon_{ij} \sim N(0, \sigma^2)];$$

X_{ij} = the jth count by observer i,
a = the number of observers,
n_i = the number of counts made by observer i,
μ = the expected mean count over all observers and counts,
A_i = the expected mean difference between observer i's count and the mean count μ (between-observer error), and
ϵ_{ij} = the error term for each count (within-observer error).

The null hypothesis, H_o, that $A_i = 0$ for all i (i.e., the between-observer error is zero) was tested with the F-test procedure (Kleinbaum et al. 1988).

Relative bias, a measure of relative accuracy of the mean count of an observer, was calculated as

$$RB_i = \frac{(\bar{X}_i - N^*)}{N^*} = \frac{\bar{X}_i}{N^*} - 1, \tag{4}$$

with estimated variance from the delta method (Seber 1982),

$$\hat{\sigma}^2_{RB_i} = \left(\frac{\bar{X}_i}{N^*}\right)^2 \left(\frac{\hat{\sigma}^2_{\bar{X}_i}}{\bar{X}_i^2} + \frac{\hat{\sigma}^2_{N^*}}{N^{*2}}\right), \tag{5}$$

where $\bar{X}_i$ is the mean of observer i's counts and N^* is the estimated actual number present as determined from the mark–recapture experiment. Because $\bar{X}_i$ and N^* were obtained independently, we assumed their covariance was equal to 0. A correction factor for each observer i was provided by

$$CF_i = \frac{N^*}{\bar{X}_i}, \tag{6}$$

and the estimated variance was

$$\hat{\sigma}^2_{CF_i} = \left(\frac{N^*}{\bar{X}_i}\right)^2 \left(\frac{\hat{\sigma}^2_{\bar{X}_i}}{\bar{X}_i^2} + \frac{\hat{\sigma}^2_{N^*}}{N^{*2}}\right). \tag{7}$$

In addition, measures of precision were calculated as the between-observer coefficient of variation,

$$\mathrm{CV}_{B-O} = \frac{\left(\sum \dfrac{(\bar{X}_i - \bar{X})^2}{(a - 1)}\right)^{1/2}}{\bar{X}}, \tag{8}$$

and for observer i, as the within-observer coefficient of variation,

$$\mathrm{CV}_{W-O,i} = \frac{\left(\sum \dfrac{(\bar{X}_{ij} - \bar{X}_i)^2}{(n_i - 1)}\right)^{1/2}}{\bar{X}_i}. \tag{9}$$

To synthesize the results for individual observers, the allometric model with a multiplicative error structure,

$$X_i = \alpha N_i^{\beta} e^{\epsilon_i}, \tag{10}$$

was used, where ϵ_i is a random error term with a mean of 0 and constant variance, σ^2; X_i is the observer count; and N_i is the actual number of salmon. Estimation was performed by taking logarithms and using linear regression. We assumed a lognormal distribution to model the variation as a function of population abundance.

Correlation analysis (Snedecor and Cochran 1980) was used to examine the consistency in the aerial counts among observers between each pair of years and in aerial and foot counts among observers between 1993 and 1994. Because abundance in the study section was approximately equal in 1993 and 1994, we tested whether learning occurred. The mean relative bias for the 11 observers who made aerial counts in 1994 was plotted against their mean relative bias in 1993, and a regression line through the origin was fitted. If no learning occurred, then the slope b should equal 1; we tested this using standard regression techniques. The analysis was also performed for the 10 observers who made foot counts in both 1993 and 1994.

Computer simulation study.—Additional investigation of observer counting ability was undertaken with a computer program, Counting Wild-

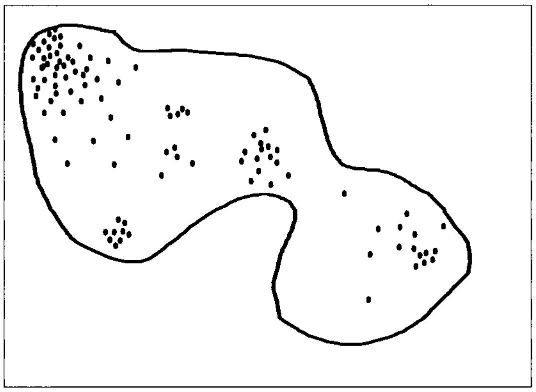

FIGURE 3.—An example of the computer simulation for the ''ducks on a pond'' object type; the true number of objects in this example was set at 100.

life,[2] that simulated field counting situations (Figure 3). The computer simulation consisted of four object types: fish in a stream, ducks on a pond, random dots, and an overflight of birds. These object types were chosen with the idea that at least one object type could be identified that produced results similar to those seen in the field.

For each pass, or program run, every object type had 10 separate screens, except the random dots, which had 20 screens. The actual number of objects on each screen ranged from 42 to 4,992, depending on object type. The screens were placed in random order, and the time for viewing each screen was set at 5 s for all object types, except for an overflight of birds, which was set at 9 s because, unlike the others, the objects moved from the bottom of the screen to the top. Breaks could be taken at any time during a pass, and results from each pass were automatically stored by name and date in a specified file. The program was identical for all observers, and it usually took less than 30 min to complete one pass.

Twenty observers participated in this study; 19 made two passes, and 1 made a single pass. The second pass was at least 2 d after the first. This stipulation was made to reduce possible learning that might occur from one pass to another. Results were not released to the participants until each management biologist and assistant, the observers of primary concern, had participated. Analysis of covariance (ANCOVA; Kleinbaum et al. 1988) tested whether results were consistent among object types and then whether the field and laboratory results were comparable. As in the field studies, ANOVA was used to test for within- and between-observer variability in observer counts. Relative bias, correction factors, and their estimated variances were also calculated. Comparison of field and laboratory results for each observer was done with graphical and regression techniques.

Results

Mark–Recapture Experiment

The goal of a sample size of 4,100 was achieved in 1992 for both the number of pink and chum salmon marked and the number sampled for marks (Table 1). In 1992, pink salmon composed 86% of the total on the tagging day and 95% of the total and 81% of the recaptures on the recovery day. These sample sizes were obtained from 23 seine sets on the tagging day and 12 seine sets on the recovery day.

The Petersen estimate for pink salmon, includ-

[2] Counting Wildlife, Version 2.0. Wildlife Counts, 2215 Meadow Lane, Juneau, Alaska 99801, USA.

TABLE 1.—The numbers of pink and chum salmon marked, sampled, and recaptured, in each year of the Chaik Bay Creek mark–recapture studies. In 1992, marking and recapture were not segregated by pool and riffle strata.

Year and species	Stream section	Number of salmon		Recaptured in		
		Marked	Sampled	Pool	Riffle	Total
1992						
Pink		3,637	3,958			246
Chum		593	291			57
1993						
Pink	Pool	1,843	1,686	255	178	433
	Riffle	527	1,368	87	162	249
Chum	Pool	127	71	8	37	45
	Riffle	172	239	12	71	83
1994						
Pink	Pool	1,798	1,502	196	151	347
	Riffle	1,335	1,942	82	408	490
Chum	Pool	36	43	7	5	12
	Riffle	25	35	2	3	5

TABLE 2.—Mean aerial counts by different observers of live pink and chum salmon in the study section of Chaik Bay Creek compared with the mark–recapture (M–R) estimates for 1992, 1993, and 1994. Also shown are estimates of relative bias (RB) and observer-specific correction factors (CF) with associated standard errors (in parentheses); N = number of counts.

OIN[a]	Mean	N	RB (SE), %	CF (SE)
1992: M–R estimate = 57,219				
8	1,833	3	−97 (0)	
17	25,000	2	−56 (3)	31.21 (3.14)
19	12,500	2	−78 (2)	2.29 (0.18)
21	11,000	2	−81 (3)	4.58 (0.37)
23	10,000	2	−83 (5)	5.20 (0.73)
24	8,667	3	−85 (4)	5.72 (1.65)
28	18,500	2	−68 (2)	6.60 (1.63)
40	15,000	2	−74 (8)	3.09 (0.21)
41	25,000	1	−56 (0)	3.81 (1.10)
42	15,000	1	−74 (0)	2.29
43	12,000	1	−79 (0)	3.81
All	14,045		−75 (12)	4.77
1993: M–R estimate = 13,227				
7	1,933	3	−85 (2)	6.84 (0.74)
17	11,333	3	−14 (9)	1.17 (0.12)
19	3,500	3	−74 (3)	3.78 (0.46)
20	2,067	3	−84 (2)	6.40 (0.77)
21	5,667	3	−57 (8)	2.33 (0.43)
23	10,000	3	−24 (14)	1.32 (0.24)
24	7,167	3	−46 (5)	1.85 (0.19)
25	2,767	3	−79 (4)	4.78 (0.88)
28	3,800	4	−71 (7)	3.48 (0.81)
40	3,133	3	−76 (3)	4.22 (0.52)
41	9,667	3	−27 (8)	1.37 (0.14)
42	14,000	1	6 (0)	0.94
44	4,000	1	−70 (0)	3.31
45	13,500	1	2 (0)	0.98
46	2,460	1	−81 (0)	5.38
All	6,333		−52 (32)	
1994: M–R estimate = 15,366				
7	21,750	4	42 (42)	0.71 (0.21)
13	6,075	4	−60 (3)	2.53 (0.21)
17	10,000	4	−35 (3)	1.54 (0.07)
19	9,500	4	−38 (9)	1.62 (0.23)
20	5,250	4	−66 (4)	2.93 (0.31)
21	18,500	4	20 (31)	0.83 (0.21)
23	9,000	4	−41 (21)	1.71 (0.60)
24	12,750	4	−17 (7)	1.21 (0.10)
25	17,500	4	14 (10)	0.88 (0.08)
28	7,000	4	−54 (6)	2.20 (0.27)
40	2,950	4	−81 (6)	5.21 (1.53)
41	9,000	1	−41 (0)	1.71
54	6,000	4	−61 (6)	2.56 (0.37)
All	10,406		−32 (37)	

[a] Observer identification number.

ing a 7% loss of tags due to emigration, was 54,229. The estimate for chum salmon, assuming no emigration, was 2,990. Thus, the tag-recovery estimate for both species was 57,219 (SE = 3,227). The 95% confidence interval is approximately ±2 SEs.

TABLE 3.—Between-observer variability and statistical results for aerial and foot counts of pink and chum salmon in the study section of Chaik Bay Creek, 1992–1994.

Year and method	N[a]	$CV_{B\text{-}O}$[b] (%)	Statistics[c]
1992			
Aerial	8	90	$F_{7,\,8} = 19.6$, $P \leq 0.001$
1993			
Aerial	11	92	$F_{10,\,22} = 34.2$, $P \leq 0.001$
Foot	7	95	$F_{6,\,14} = 52.1$, $P \leq 0.001$
1994			
Aerial	12	83	$F_{11,\,36} = 21.2$, $P \leq 0.001$
Foot	11	83	$F_{10,\,11} = 11.0$, $P < 0.001$

[a] N = number of observations.
[b] Between-observer coefficient of variation calculated with equation (8).
[c] Subscripts on F are degrees of freedom.

On the tagging day in 1993, pink salmon composed 89% of the total fish sampled (Table 1). All pink and chum salmon caught in pools were additionally marked with an adipose fin clip. Of the total salmon marked, 78% of the pink salmon and 42% of the chum salmon were caught in pools. On the recovery day in 1993, pink salmon composed 91% of the total and 84% of the recaptures. Adipose fin clips were present on 64% of the pink salmon and 35% of the chum salmon recaptures.

In 1994, pink salmon composed 98% of both the total and recaptures. Adipose fin clips were placed on 57% of the pink salmon marked and 7% of the chum salmon marked. Adipose fin clips were present on 42% of the pink salmon and 71% of the chum salmon recaptures. The Darroch estimates for combined pink and chum salmon in the study section were 13,277 (SE = 1,298) in 1993 and 15,366 (SE = 662) in 1994.

Observer Counts

The observer counts and summary statistics from the various analyses performed are contained in Appendix A of Jones (1995). In 1992, 8 of the 11 observers made two or three aerial counts in the study section (Table 2). Their between-observer variability was significantly different from zero, and most of the variation in the total counts occurred among the observers (Table 3). Correction factors for those eight observers ranged from 2.29 (SE = 0.16) to 31.21 (SE = 2.31). Relative bias was generally high and the observers underestimated the actual number on average by 75% (SE = 12%).

In 1993, 15 observers made aerial counts (Table 2) and 12 made foot counts (Table 4). Correction factors for the aerial observers conducting multi-

TABLE 4.—Mean foot counts by different observers of live pink and chum salmon in the study section of Chaik Bay Creek compared with the mark–recapture (M–R) estimates for 1993 and 1994. Also shown are estimates of relative bias (RB) and observer-specific correction factors (CF) with associated standard errors (in parentheses); N = number of counts.

OIN[a]	Mean	N	RB (SE), %	CF
1993: M–R estimate = 13,227				
5	6,880	1	−48 (0)	1.92
19	5,046	2	−62 (4)	2.62 (0.27)
24	6,573	2	−50 (5)	2.01 (0.21)
31	13,500	1	2 (0)	0.98
40	4,177	2	−68 (4)	3.17 (0.35)
47	5,000	2	−62 (4)	2.65 (0.27)
48	5,623	2	−57 (6)	2.35 (0.34)
49	2,400	2	−82 (2)	5.51 (0.57)
50	5,125	2	−61 (5)	2.58 (0.33)
51	8,880	1	−33 (0)	1.49
52	11,780	1	−11 (0)	1.12
53	4,750	1	−64 (0)	2.78
All	6,644		−50 (24)	
1994: M–R estimate = 15,366				
5	9,145	2	−40 (3)	1.68 (0.09)
19	7,489	2	−51 (3)	2.05 (0.12)
23	12,350	2	−20 (18)	1.24 (0.28)
24	7,165	2	−53 (3)	2.14 (0.15)
31	3,887	2	−75 (2)	3.95 (0.23)
40	6,105	2	−60 (4)	2.52 (0.24)
47	5,789	2	−62 (7)	2.65 (0.48)
49	6,815	2	−56 (4)	2.25 (0.21)
50	6,945	2	−55 (2)	2.21 (0.10)
51	10,680	1	−30 (0)	1.44
52	9,393	2	−39 (5)	1.64 (0.12)
54	6,533	2	−57 (2)	2.35 (0.11)
All	7,691		−50 (15)	

[a] Observer identification number.

ple counts ranged from 1.17 (SE = 0.12) to 6.84 (SE = 0.74). Aerial observers underestimated the actual number on average by 52% (SE = 32%). Foot counts in the study section were made by 12 observers making one count downstream; 7 of these observers made an additional count upstream (Table 4). Correction factors for the foot observers with multiple counts ranged from 2.01 (SE = 0.21) to 5.51 (SE = 0.57). For the foot observers, the mean relative bias was −50% (SE = 24%).

In 1994, 13 observers made aerial counts (Table 2), and 12 made foot counts (Table 4). Correction factors for the aerial observers with multiple counts ranged from 0.71 (SE = 0.21) to 5.21 (SE = 1.53). Aerial observers underestimated the actual number on average by 32% (SE = 37%). Foot counts in the study section consisted of 12 observers making one count downstream, and 11 of these observers made an additional count upstream (Table 4). Correction factors for the foot observers making multiple counts ranged from 1.24 (SE = 0.28) to 3.95 (SE = 0.23). For the foot observers, the mean relative bias was −50% (SE = 15%).

TABLE 5.—Within-observer ($CV_{W\text{-}O}$) and between-observer ($CV_{B\text{-}O}$) coefficients of variation (calculated with equations 9 and 8, respectively) for aerial and foot counts of pink and chum salmon in the study section of Chaik Bay Creek, 1992–1994.

Year	Method	$CV_{W\text{-}O,}$ range (%)	$CV_{B\text{-}O}$ (%)
1992	Aerial	4–28	49
1993	Aerial	4–42	92
	Foot	4–15	49
1994	Aerial	0–35	55
	Foot	2–22	30

In 1993 and 1994, between-observer variability for observers with multiple counts was significantly different from zero; therefore, most of the variability in total counts was among observers (Table 3). Within-observer coefficient of variation was lower than between-observer CV (Table 5), and the relative bias was generally high (Tables 2, 5).

The mean aerial and foot counts for each observer within a given year compared with the population estimates for that year are shown in Figure 4, in which the heavy line depicts no bias and the light line depicts the allometric fit from equation (10). Although there is substantial variability, the allometric relationship provides a convenient summary of the trend in observer bias. The parameter estimates for the field counts combined are 4.43 (SE = 0.59) for $\log_e\alpha$ and 0.46 (SE = 0.14) for $\log_e\beta$. The $\log_e\beta$ estimate is statistically different from 1 (t = 3.92; df = 61; $P \leq 0.001$), confirming that observer bias is a nonlinear function of population abundance. Correlation analysis for the eight observers who made aerial counts in all 3 years of study was performed pairwise between years. The correlation coefficient was highest for 1992–1993 (r = 0.39, P = 0.33), followed by 1993–1994 (r = 0.21, P = 0.61), and 1992–1994 (r = −0.32, P = 0.44), but in no case was it statistically significant. For the six observers who participated in both aerial and foot counts in 1993 and 1994, the correlation between aerial and foot counts was highly significant (r = 0.80, P = 0.03). Figure 5 compares the mean relative bias obtained for the 11 observers who made aerial counts in the study section in 1993 and 1994. A regression line through the origin (b = 0.36, SE = 0.20) is included in the figure. The mean relative bias varied among observers, suggesting that observers count

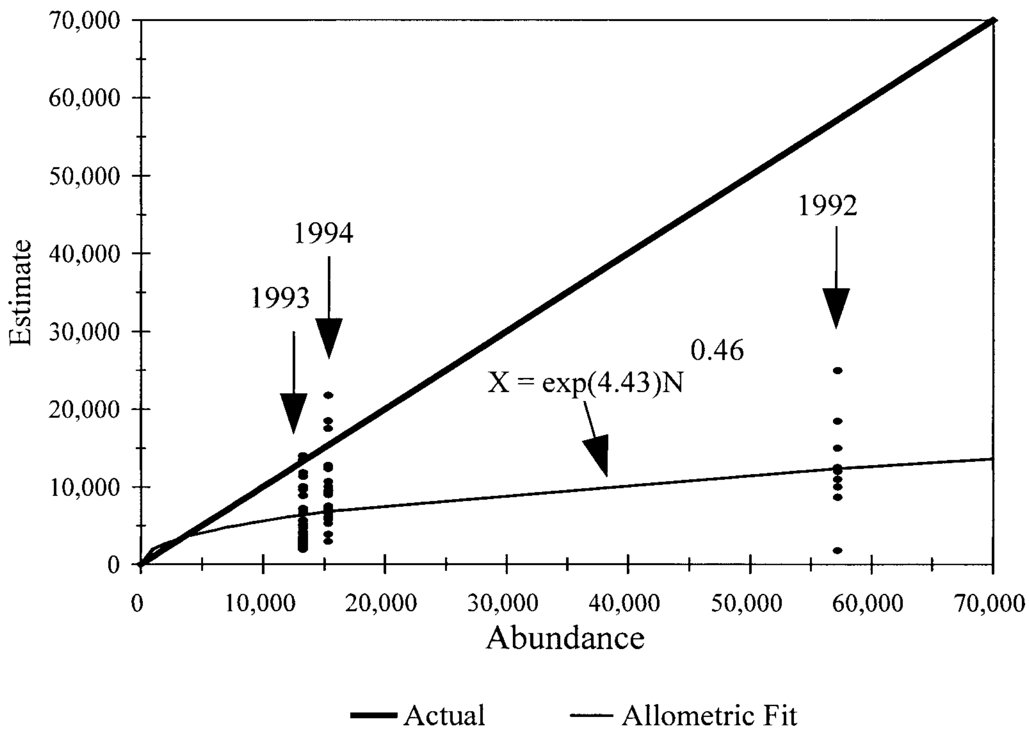

FIGURE 4.—Mean aerial and foot counts of pink and chum salmon in Chaik Bay Creek for each observer within a given year compared with population estimates in 1992, 1993, and 1994. Also shown is the line $X = N$, where the estimate would coincide with the population estimate, and an allometric fit of the counts to the population estimates.

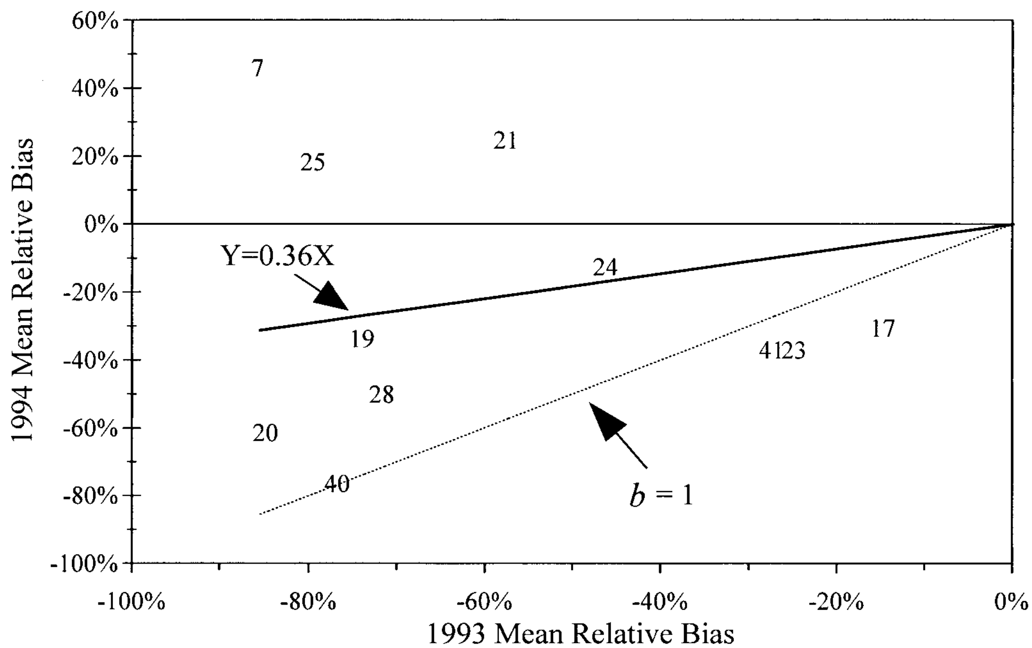

FIGURE 5.—Mean relative bias for the 11 observers making aerial counts in the study section in 1993 and 1994.

TABLE 6.—Number of objects, between-observer variability ($CV_{B\text{-}O}$), and relative bias (RB) for each computer object type by minimum (min), maximum (max), and mean across trials. The minimum and maximum across categories do not necessarily correspond to the same observer trials. The parameters $\log_e \alpha$ and $\log_e \beta$ are estimated for each observer across trials; the minimum, maximum, and mean are reported for each object type. Means for field counts of pink and chum salmon are given for comparison.

Statistic	Number of objects	$CV_{B\text{-}O}$ (%)	RB (%)	Parameter $\log_e \alpha$	Parameter $\log_e \beta$
Computer object: fish					
Min	42	0	−76	−0.72	0.58
Max	1,200	79	368	2.76	1.16
Mean	621	41	−9	0.62	0.86
Computer object: ducks					
Min	69	21	−88	−1.10	0.38
Max	2,000	84	40	2.63	1.05
Mean	1,035	55	−50	0.90	0.74
Computer object: dots					
Min	136	0	−86	−2.54	0.37
Max	2,500	74	121	3.08	1.27
Mean	1,318	47	−31	1.34	0.72
Computer object: birds					
Min	816	2	−84	−2.40	0.09
Max	4,992	70	116	6.44	1.25
Mean	2,898	39	−43	1.38	0.74
Computer object: all					
Mean	1,450	46	−35	1.05	0.76
Field count: salmon					
Mean	28,621	89	−51	4.43	0.46

quite differently. The b-estimate is statistically different from 1 ($t = 3.25$, df = 9; $P = 0.004$), suggesting that learning may have occurred in aerial counts between 1993 and 1994. However, this was not the case for foot counts between 1993 and 1994. The regression line slope ($b = 0.87$, SE = 0.11) was not significantly different from 1 ($t = 1.13$; df = 8; $P = 0.14$), suggesting that learning did not occur.

Computer Simulation Study

Data and summary statistics for each observer and pass, fixed-effects ANOVA results for each object and number, and estimates for each observer and pass from equation (10) are contained in Appendix B of Jones (1995). Results are summarized across observer trials of two passes (Table 6). The minimum, maximum, and mean values for the summary statistics in Table 6 do not necessarily correspond to the same observer trial. Numbers ranged from 42 (for fish) to 4,992 (for birds; Table 6). Nineteen observers made two passes each. Between-observer variability was high for all object types (Table 6) and was significantly different from zero in 60% of fish counts, 80% of duck counts, 70% of dot counts, and 65% of bird counts. On average, relative bias was negative in all cases, and observers usually underestimated the actual number of objects (Table 6).

The minimum and maximum estimates of $\log_e\alpha$ and $\log_e\beta$ across observers covered a large range (Table 6). The mean estimates of $\log_e\alpha$ increased with the mean number of objects for the four object types. The mean estimates of $\log_e\beta$ did not have a trend and ranged between 0.72 and 0.86.

Estimates of parameters $\log_e\alpha$ and $\log_e\beta$ from the individual object types with all counts combined and the field counts from equation (10) are shown in Table 7. The estimate of $\log_e\alpha$ increased and the estimate of $\log_e\beta$ decreased from fish to

TABLE 7.—Parameter estimates of $\log_e \alpha$ and $\log_e \beta$ for individual object types from the computer simulation and the field study.

Object type	$\log_e \alpha$ Estimate	$\log_e \alpha$ SE	$\log_e \beta$ Estimate	$\log_e \beta$ SE
Fish	0.65	0.22	0.86	0.34
Ducks	0.96	0.24	0.74	0.04
Dots	1.27	0.22	0.73	0.03
Birds	1.45	0.49	0.73	0.06
Field	4.43	0.59	0.46	0.14

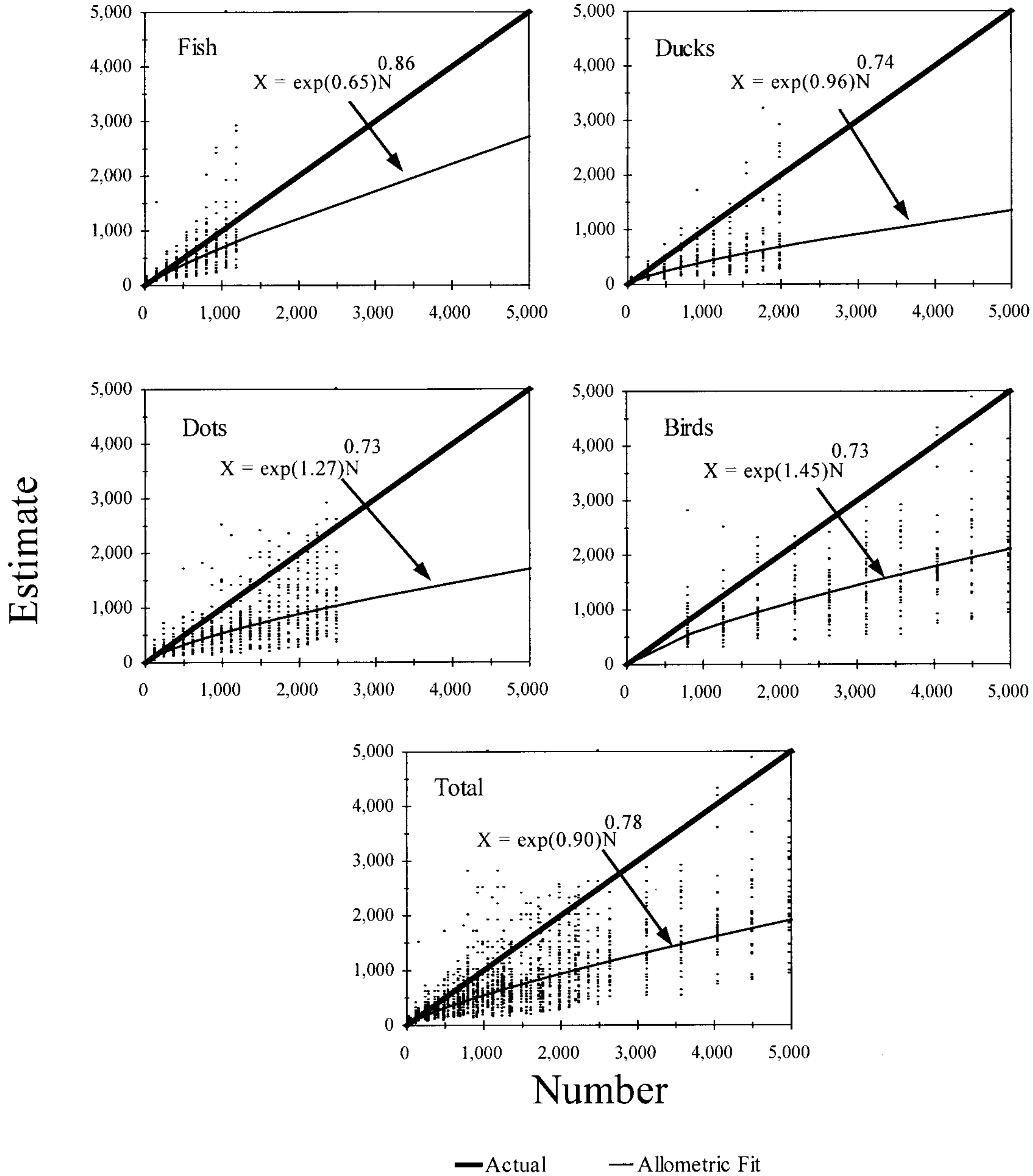

FIGURE 6.—Computer simulation counts for all observers, passes, and object types.

ducks, dots, birds and to the field. For all counts from the laboratory and field, ANCOVA showed that the differences in $\log_e \beta$ were significant (F = 3.9; df = 4, 1,053; P = 0.004). The differences in $\log_e \beta$ were less significant (F = 2.9, df = 4, 633; P = 0.02) when laboratory counts exceeding 1,000 were compared with field counts. This suggests observer-specific counting rate is a function of the number of objects being viewed. When only laboratory object types were compared, differences in $\log_e \beta$ were still significant (F = 3.0; df = 3, 922; P = 0.03). When the object fish was removed and only ducks, dots, and birds were compared, the differences in $\log_e \beta$ were not significant (F = 0.0; df = 2, 794; P = 1.00), which suggests that the fish object differs from the other objects. The observer counts of each object type in comparison to the actual number are shown in

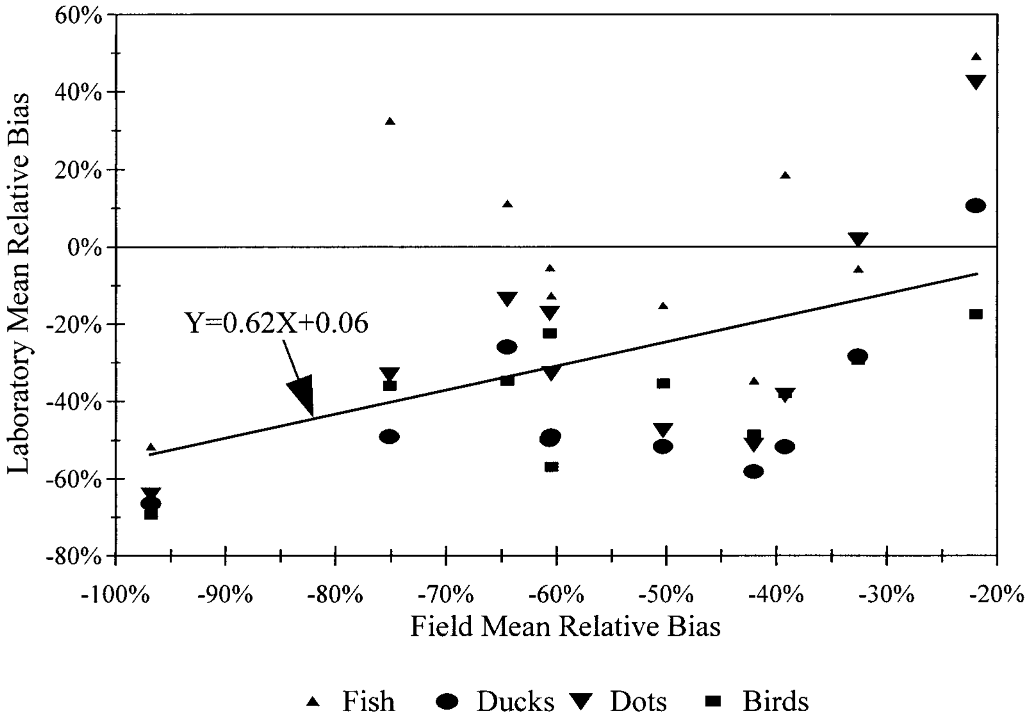

FIGURE 7.—Mean relative bias from the field for each observer compared with the value obtained from the laboratory for each object type.

Figure 6. The allometric relationship provides a clear picture of the observer tendency to undercount the actual number of objects on the screen. All $\log_e\beta$ parameters, except for fish, were significantly different from 1 (t-test, $P \leq 0.05$), confirming the nonlinear relationship with abundance. The fish type could only accommodate a maximum of 1,200 objects, which was much fewer than the other object types. Thus, it is possible that nonlinear effects may have occurred if more fish objects could have been displayed on the screen.

A comparison of the mean relative bias obtained for each observer from the laboratory for each object type and from the field is shown in Figure 7. A regression line slope (b = 0.62, SE = 0.21) is included in the figure, and it appears that observer-specific counting rate, while variable, is consistent between studies and between object types in the laboratory study. Mean relative bias was quite different among observers, as shown by the wide range of values along each axis of the figure. This suggests that observers count quite differently. However, the significant positive slope of the regression line (t = 1.82; df = 36; P = 0.04) suggests that individual observers counted in a similar fashion for both studies.

Discussion

Based on the results, we concluded that (1) observers tend to underestimate the actual number of salmon in a stream, (2) underestimation increases nonlinearly with an increase in the number of salmon, and (3) individual observers generally count consistently (because within-observer variability was low but between-observer variability was high). Further studies identifying observer-specific counting rates are necessary before unbiased, precise estimates of salmon escapement can be provided by aerial and foot surveys.

We tried to keep extraneous factors constant by having field counts performed at about the same time and in a similar fashion. However, differences in the accuracy and precision of observer counts occurred, and these differences may not be due to the varying numbers of salmon alone. For example, school density might have been an important factor. Eicher (1953), in work performed in Bristol Bay, Alaska, suggested that the accuracy of observer counts may be inversely proportional to the density of salmon. Normally, and especially during the heat of the day, salmon can be seen packed into tight schools. In one study of visual surveys, coho salmon *O. kisutch* were much easier to count after they were disturbed, and individual salmon could be counted with the lowering of school density (Irvine et al. 1992). In essence, increasing the density of salmon has much the same effect as increasing the canopy cover, number of undercut banks, glare, or water turbidity. However, we could not analyze the effect of density in our field study because we had no continuous measure of stream area.

Prior knowledge of the stream can improve accuracy. In one study, experienced observers obtained an average escapement enumeration accuracy of 56%, compared with 31% for observers unfamiliar with the stream (ADFG 1964). However, the importance of prior knowledge of our study stream did not appear to improve accuracy. For example, two observers in our study had flown numerous surveys on Chaik Bay Creek in years past. However, they were no more accurate than the other observers, and one of the two had the highest relative bias in this study.

Average observer counts were about one-fourth the true number present in 1992, one-half in 1993, and less than one-half by foot survey and nearly two-thirds by aerial survey in 1994. Part of this difference is explained by the actual escapement sizes, which were estimated to be 57,219 in 1992 (the year with more than negligible emigration), 13,227 in 1993, and 15,366 in 1994.

The sudden increase in observer accuracy in the 1994 aerial counts could be attributed to learning. In interviews with observers, some thought that they altered their counting technique as a consequence of viewing results from the prior 2 years of the study. Nevertheless, the field results indicated no apparent difference in the CV and relative bias between passes. This suggests that data independence was achieved within a year and supports Bevan's (1961) technique of covering the window of the mechanical counter with opaque tape.

Results from the computer simulation study support those from the field. Between-observer variability differed significantly from zero in every field study observation and differed in nearly three-fourths of the laboratory observations. For each field and laboratory observation, mean bias was negative, confirming the general trend that observers underestimate the actual number. However, analyses of covariance indicated that results from the laboratory were quite different from those in the field. Results from the laboratory failed to closely reproduce results in the field. However, developing new simulations might produce one that mimics results from the field.

Results suggest that the intercept $\log_e\alpha$ is a parameter directly related to the size and acuity characteristics of the objects being counted. As the size of objects differed, the intercepts differed among object types in both the laboratory and field (Table 7). The largest simulated object was fish, followed by ducks, dots, and birds. The decrease in object size related directly to an increase in the intercept. The intercept for the field study was even larger than the intercepts from the simulation, which makes sense given the greater density of fish in the field. The slope $\log_e\beta$ is the effect of the number of objects on the counting rate. Because the slopes differed among laboratory and field object types, care should be taken in using the laboratory results. The differences in $\log_e\beta$ may be a function of other differences, such as the color or pattern of each object.

In general, results from both of our studies indicate that as the actual number increases, the relative bias in observer counts increases (Figures 3, 5). Other studies (Rogers 1984; Shardlow et al. 1987; Dangel and Jones 1988; Clark 1992; Daum et al. 1992; Evenson 1992; Skaugstad 1992) have shown similar relationships in observer counts of five species of Pacific salmon. Counts from these studies and our study are compared with the actual numbers of salmon in Figure 8. The $\log_e\beta$ parameter estimate of 0.83 (SE = 0.04) is statistically different from one ($t = 4.22$; df = 166; $P \leq 0.001$), implying that observer bias is a nonlinear function of population abundance. Interestingly, when these counts are compared with the laboratory fish counts, differences in $\log_e\beta$ are not significant ($F = 0.2$; df = 1, 364; $P = 0.65$). Further study with a larger range of computer objects should reveal whether the $\log_e\beta$ parameter is the same for field and computer simulations.

If the relationship between observer bias and abundance can be determined, the fact that observers do not count the same may be inconsequential, provided each individual observer is consistent and their estimates increase as the actual numbers increase. Observer-specific correction factors can correct for individual counting peculiarities but not for other factors, such as differences in airplanes, individual counting methods, weather conditions, or behavior of salmon.

Walters and Ludwig (1981) concluded that spawner–recruit data are of little value unless the amount of measurement error in parameter estimates is also determined. Our study attempted to

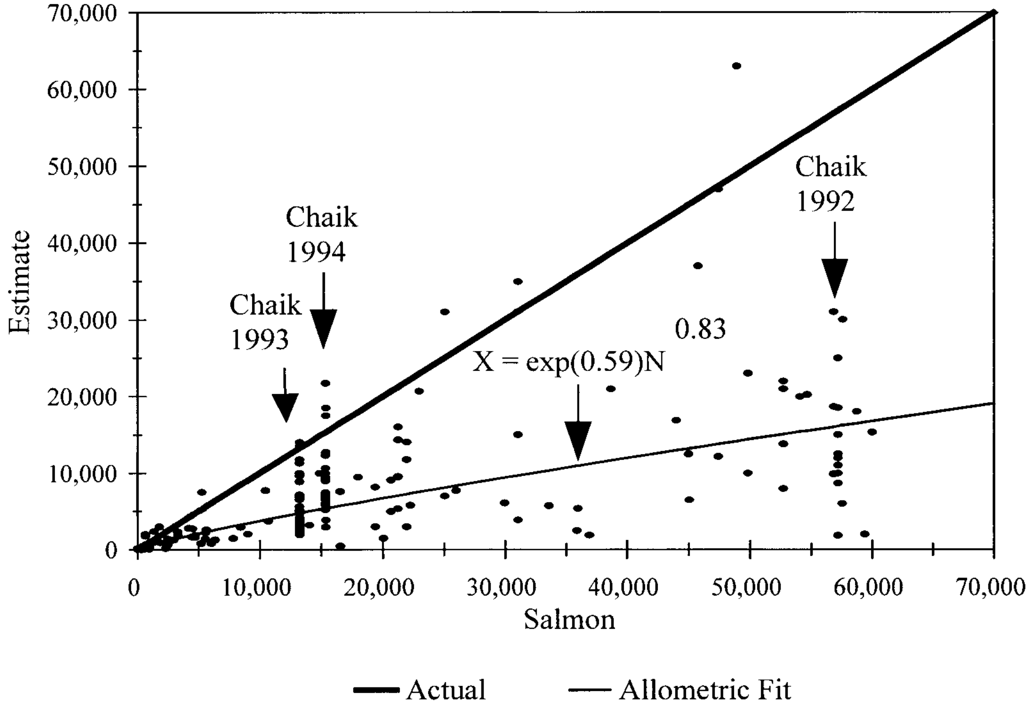

FIGURE 8.—Observer counts from various sources compared with the actual number of salmon in the stream. Also shown is the line $X = N$, where the estimate would coincide with the population estimate and an allometric fit of the counts to the population estimates.

analyze the observer component of measurement error with the hope of developing an index of pink salmon escapement that would quantitatively account for within- and between-observer variability and bias in pink salmon escapement estimation. Such a standardized index would be the basis for estimating total escapements and returns by stock. Spawner–recruit models would then be used to refine escapement goals, leading to increased confidence in the forecasts of returns and the analysis of trends.

The need for reliable, unbiased estimates or indices of escapements is key to the effective management of salmon stocks and fisheries. The ADFG stock assessment and management programs for salmon focus on two main topics: (1) escapement levels that sustain or maximize future production potential, given spawning and rearing limitations and (2) the management of fisheries to achieve escapements that fall within desired ranges, given annual variations in stock abundance, migration patterns, and fleet distribution and effort. Escapement goal ranges are often established based on a combination of methods, including spawner–recruit analysis (Ricker 1954), habitat capacity, and past abundance levels. Annual estimates or indices of escapement are therefore a critical element in these assessments of escapement goals and are the baseline by which the consequences of management actions are judged.

This study has gathered the information necessary to calibrate aerial and foot survey counts between observers in a predefined study area; a minimal number of data points necessary for such calibrations was obtained. Further studies on a variety of streams and observer conditions are still needed. Observer correction should be part of a dynamic management system that constantly changes and improves with the addition of further studies. To improve confidence in observer estimates, correction factors should be developed and continually evaluated and refined.

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