Estimation of the 1994 Seymour River System Sockeye Salmon *(Oncorhynchus nerka)* Escapement

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1997

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2430

Fisheries and Oceans   Pêches et Océans

Canada

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Cat. No. Fs 97-4/2430E ISSN 0706-6473

Correct citation for this publication:

Schubert, N.D. 1997. Estimation of the 1994 Seymour River system sockeye salmon (*Oncorhynchus nerka*) escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2430: 37 p.

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ABSTRACT

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In 1986, the Department of Fisheries and Oceans (DFO) assumed responsibility from the Interna-tional Pacific Salmon Fisheries Commission (IPSFC) for the estimation of the escapement of Fraser River sockeye salmon (*Oncorhynchus nerka*) stocks. DFO adopted the IPSFC's two-tiered system whereby large escapements (25,000+) were estimated using enumeration fences or mark-recapture studies, and small escapements (less than 25,000) were estimated using visual techniques.

The Seymour River supports a major sockeye salmon stock which exhibits a quadrennial escape-ment cycle, with spawner abundance highest on the 1914-1994 dominant and 1915-1991 subdominant cycles. Escapements on these cycles have exceeded 25,000 almost every year since 1958. Sockeye were captured at two sites in the lower Seymour River; 994 were released with disk tags. The spawning grounds were surveyed through the period of spawning and die-off; 7,301 carcasses were recovered, of which 116 had disk tags. The 1994 escapement was estimated, using the pooled Petersen estimator, at 44,699 adult males, 19,339 adult females and 45 jacks (age 3_2).

The report identified a spatial application bias and a potential temporal application bias; however, because there was no significant difference between the pooled population estimator and the spatially and temporally stratified estimators, it was concluded that the population estimates were not seriously biased. The report concludes with recommended study design changes, including an elevated level and improved allocation of sampling effort, improved resurvey procedures and the assessment of disk tag loss and handling stress.

RÉSUMÉ

Schubert, N.D. 1997. Estimation of the 1994 Seymour River system sockeye salmon (*Oncorhynchus nerka*) escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2430: 37 p.

En 1986, la Commission internationale des pêcheries de saumon du Pacifique chargeait le ministère des Pêches et des Océans (MPO) d'estimer les échappées des stocks de saumon rouge (*Oncorhynchus nerka*) du Fraser. Le MPO a adopté le système d'estimation à deux niveaux de la Commission, selon lequel les grandes échappées (25,000 et plus) ont été évaluées aux barrières de dénombrement ou par des opérations de marquage-recapture, et les petites échappées (moins de 25,000) ont été évaluées par des techniques visuelles.

La rivière Seymour abrite un important stock de saumon qui présente un profil quadriennal d'échappée, dans lequel l'abondance des géniteurs est au plus haut avec le cycle dominant 1914-1994 et le cycle sous-dominant 1915-1991. Les échappées de ces deux cycles dépassent 25,000 individus presque chaque année depuis 1958. Des saumons rouges ont été capturés à deux sites du cours inférieur de la Seymour; 994 ont été libérés après marquage avec des disques. Les frayères ont été surveillées pendant la période de fraye et de mortalité massive; on a récupéré 7,298 carcasses, dont 116 portaient un disque. L'échappée de 1994 a été évaluée, par l'estimateur de Petersen combiné, à 44,699 mâles adultes, 19,339 femelles adultes et 0 saumon précoce (âge 3_2).

Le rapport fait ressortir un biais spatial d'application et un biais temporel potentiel d'application; toutefois, comme il n'y avait pas de différence significative entre l'estimateur combiné de la population et les estimateurs spatialement et temporellement stratifiés, nous concluons que les estimations de la population ne sont pas gravement biaisées. Le rapport conclut en recommandant des modifications à la conception de l'étude, notamment un accroissement et une meilleure allocation de l'effort d'échantillonnage, une amélioration des méthodes de répétition de l'étude et une évaluation de la perte de disques et du stress dû à la manipulation des poissons.

INTRODUCTION

The accurate estimation of spawning escapement has long been recognized as an essential element in the management of Fraser River sockeye salmon (*Oncorhynchus nerka*) (Thompson 1939; Howard 1948). The International Pacific Salmon Fisheries Commission (IPSFC) developed a two-tiered system whereby the estimation method selected for each stock was based on the number of spawners expected to return to the spawning grounds in a given year. For stocks with large expected returns (greater than 25,000), enumeration fences and mark-recapture studies were used because they provided the statistically defensible estimates which were required to determine if system-wide precision objectives were met. For stocks with small expected returns (less than 25,000), a variety of stock-specific visual estimation methods were used (Andrew and Webb MS 1987). The IPSFC system was adopted by the Department of Fisheries and Oceans (DFO) in 1986 and remains largely in place throughout the Fraser River watershed.

The Seymour system supports two sockeye stocks, a large stock in the Seymour River and a small stock in McNomee Creek (Fig. 1). The stocks exhibit a quadrennial escapement cycle, with abundance increasing on three of the cycles since the early 1980's. Escapements in the 1950's and 1960's versus the 1980's and 1990's increased from 41,000 to over 130,000 on the 1914-1994 dominant cycle, from 34,000 to 73,000 on the 1915-1991 subdominant cycle, and from 4,000 to 12,000 on the 1916-1992 off-cycle (Appendix 1). Escapements on the 1913-1993 cycle have remained at about 8,000 fish.

Stream surveys have been conducted in the Seymour River at least since 1902 following the construction of the Granite Creek Hatchery. The Seymour was a source of hatchery brood stock in the early 1900's. Escapement estimates have been reported regularly since 1939. Escapements on the dominant and subdominant cycles have exceeded 25,000 almost every cycle year since 1958. Consequently, mark-recapture studies were used to estimate the escapement on these cycles each year since 1963 (Appendix 1).

The current report provides the first published documentation of the study design, field methods, analytic techniques and results of the Seymour sockeye escapement estimation study. Included are estimates of the 1994 adult age and length, and escapement by sex and age for the populations which spawned in the Seymour River and McNomee Creek. The report concludes with a discussion of the results and recommendations for the design of future studies.

STUDY AREA

The Seymour River originates in the Monashee Mountains of south-central British Columbia and flows south for 66 km, entering Shuswap Lake at the north end of Seymour Arm (Fig. 1). The river and its two main tributaries, McNomee and Ratchford creeks, drain a steep, glaciated watershed of approximately 805 km^2. Near the mouth, the Seymour River has a mean daily discharge of 36 m^{3}s^{-1} (1915-1990), with mean daily maxima (114 m^{3}s^{-1}) and minima (6 m^{3}s^{-1}) occurring in June and January, respectively (Environment Canada 1991).

The Seymour River was divided into five reaches based on homogeneity of physical characteristics and to facilitate the data aggregations required for bias testing (Fig. 2). Reaches 1-3 comprise the upper section of the accessible part of the river. In this section, the river is confined to a single channel which has a maximum width of 40 m and a gradient of 0.6% (Sebastian MS 1983). The substrate is predominantly large gravel and cobble, and the spawning density is light except in discrete areas.

Reach 1 (3.5 km) extends downstream from an impassable falls located 12.3 km upstream to a point immediately above the horseshoe-like bend in the river. The gradient is relatively high, the water depth is 1 m and the substrate is predominantly cobble and boulders. Sockeye spawning is scattered in peripheral areas.

Reach 2 (2.9 km) extends downstream to a short bedrock canyon which is spanned by the road bridge. The channel gradient declines in the upper part of Reach 2, resulting in a short section with heavily utilized spawning gravel. The horseshoe consists of a 0.9 km long section where the the gradient is low and and the depth increases to 5 m. The remainder of the reach is similar to Reach 1, except the channel has a lower gradient and scattered gravel.

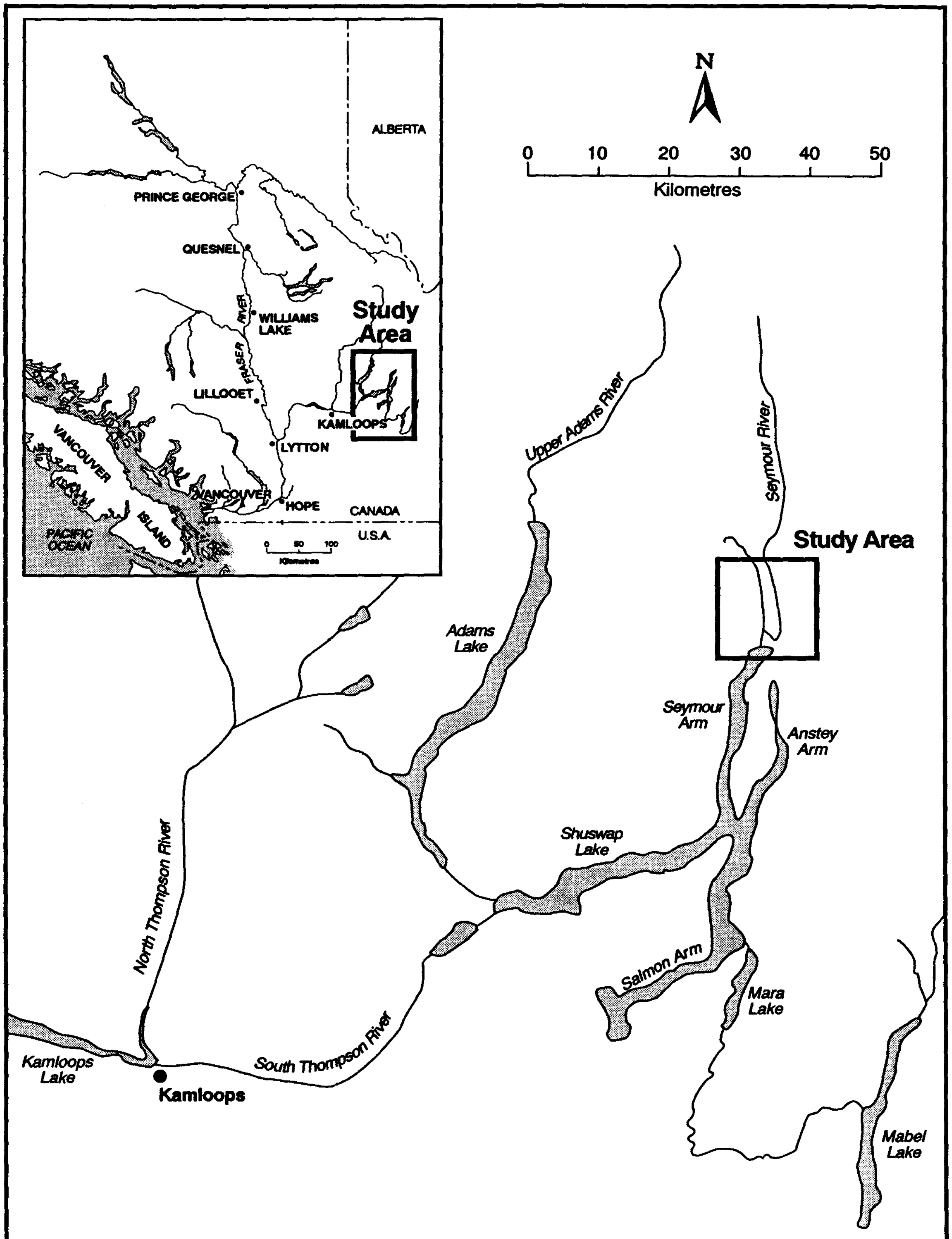
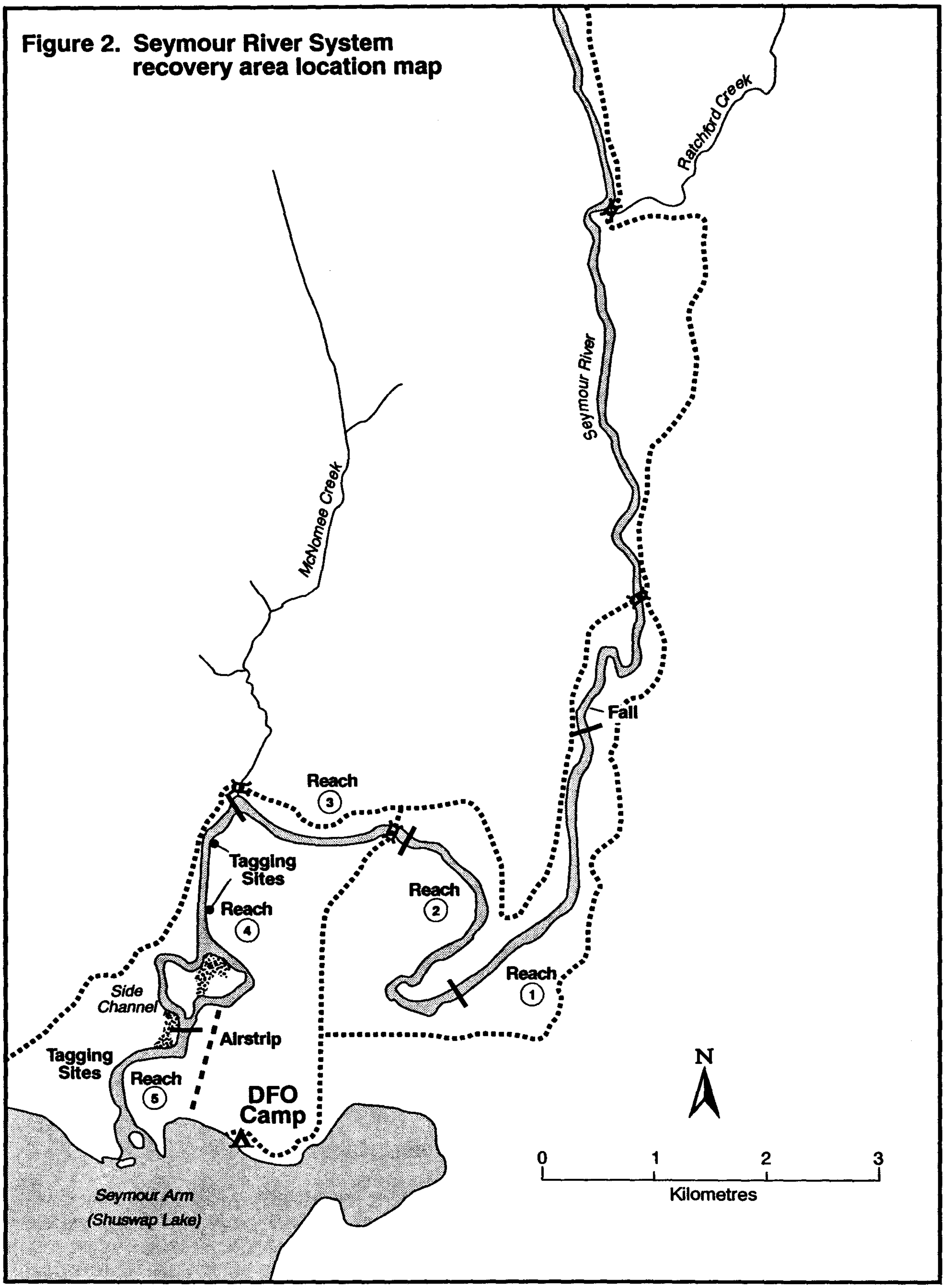


Figure 1. Seymour River System study area location map

Figure 2. Seymour River System recovery area location map



Reach 3 (1.6 km) extends from the bridge to McNomee Creek. The channel gradient is higher than in Reach 2, resulting in a predominantly cobble substrate and lower spawning density.

In reaches 4-5, the gradient is lower (0.3%) and the river changes from a single channel to one which is wide and unconfined. The substrate is predominantly gravel, and spawning density is high. Reach 4 (2.8 km) extends from McNomee Creek downstream to a point near the end of the airfield. The river flows in a single 25 m wide channel for 1.3 km, then forms two main branches (the west branch is Reach 4a) and a number of side channels which reform into a single channel 1.5 km above the mouth. Debris jams contribute to frequent channel shifts by scouring pools and creating new side channels. Tag application occurred at several sites in the upper half of Reach 4.

Reach 5 (1.5 km) extends downstream to Shuswap Lake and includes the lakeshore immediately adjacent to the river mouth. The river is characterized by a wide flood plain with extensive side channels. The lower tagging site was located immediately upstream from the lake.

McNomee Creek (Fig. 2) is the only Seymour River tributary which supports sockeye spawners (Appendix 1c). The creek, originating at Celista Mountain and draining the northwest part of the basin, flows south for 19 km and enters the Seymour River 4.3 km from the mouth. Although accessible to anadromous salmonids for 10 km, sockeye spawning is restricted to the lower 2.3 km where the creek is characterized by a 0.7% gradient, riffles and pools, and extensive instream debris.

FIELD METHODS

VISUAL SURVEYS

Visual counts were recorded in McNomee Creek during all carcass recovery surveys, and every 2-3 days in the Seymour River until the peak of spawning was observed.

TAG APPLICATION

The study objective was to apply tags to 1% of the sockeye as they migrated past the tagging sites located in the lower Seymour River (Fig. 2). Because an independent estimate of abundance was unavailable, proportional tag application was to be achieved by standardizing effort at three or four sets per day. Tagging began after sockeye had arrived in the river but before abundance was high and continued until the run was virtually complete. Migrating sockeye were captured using a 64 m x 7.5 m x 5 cm-mesh beach seine net which was set from an inflatable boat in a downstream arc and withdrawn from the river to enclose a small area of water along the river bank. Captured fish were held in the net until removal for tagging.

Sockeye which were damaged or showed advanced stages of maturation were released untagged. For previously tagged fish, the tag number was recorded and the tag was checked; if loose, the fish was retagged with the same disk. The remainder were removed from the net and marked with Petersen disk tags in a wooden tray (12 cm x 20 cm x 100 cm) constructed with a flexible plastic bottom and a metre stick recessed in one side; the tray was set in a stand elevated above the water surface. The tags consisted of two red 15 mm diameter laminated cellulose acetate disks threaded through centrally punched holes onto a 77 mm long nickel pin. The pin was inserted with pliers through the musculature and pterygiophore bones approximately 12 mm below the anterior portion of the dorsal fin insertion. The disk tags, arranged with one on each side of the fish, were secured by twisting the pin into a double knot. One disk per pair was numbered with a unique code; no secondary marks were applied. Date of capture, disk tag number, nose-fork (NF) length ($\pm$0.5 cm), sex (fish with a NF length less than 50 cm were recorded as jacks) and marks (troll, gill net, lamprey or *Flexibacter columnaris* scars) were recorded for each fish released with a disk tag. Condition at release was recorded as 1 (swam away vigorously), 2 (swam away sluggishly) or 3 (required ventilation).

SPAWNING GROUND SURVEYS

Main Survey

All known spawning areas in the Seymour River system were surveyed during the die-off period. The shores were surveyed on foot by two-person crews using an inflatable boat to leapfrog down the river; up to two crews were required at the peak of die-off. The surveys began two days after the start of tagging; each survey required two to three days.

All carcasses which were retrievable by wading into the river to waist depth were enumerated (except predator kills, which where excluded from the survey) and thrown on the bank above the high water mark. Carcass recoveries were recorded by date, reach, sex, mark status, carcass condition (fresh, tainted or rotten) and female spawning success (0%, 50% or 100% spawned). If a disk tag was present, it was retrieved and the tag number was recorded before the carcass was processed.

Resurvey

Previously processed carcasses were resampled through the recovery period to estimate the number of tagged carcasses which had not been correctly identified. The resurvey, conducted by an experienced technician, recorded carcasses by date, reach, sex and mark status.

BIOLOGICAL SAMPLING

Biological samples were obtained following a protocol provided by the Pacific Salmon Commission. Twenty-five females, killed during the peak of arrival at the Seymour River tagging site, were sampled for postorbital-hypural plate (POH) length ($\pm$0.5 cm), otoliths and scales (one from each preferred region, as defined by Clutter and Whitesel (1956)), and the egg skeins and loose eggs were removed and preserved in a 10% formaldehyde solution.

Adult carcasses were sampled as above for POH length, otoliths and scales. One hundred and twenty adults of each sex were sampled. All recovered jacks were sampled for standard length and scales.

ANALYTIC PROCEDURES

TESTS FOR SAMPLING SELECTIVITY

A bias profile was developed by evaluating five potential biases, temporal, spatial, fish size, fish sex and handling stress. Statistical tests were performed to assess whether the conditions of equal probability of capture, complete mixing, and simple random recovery sampling were violated (Seber 1982; p 434-9). Biases were treated in three ways. First, sex-related biases are common in mark-recapture studies and were addressed by stratifying the data by sex. Second, stress-related biases were treated by removing the high stress group from the application sample. Third, the severity of temporal or spatial biases was evaluated by comparing the simple or pooled Petersen estimates with those calculated using Darroch's (1961) and Schaefer's (Ricker 1975) stratified models. A stratified model was used if the confidence limits did not overlap.

Period

Temporal bias was assessed using chi-square tests of application and recovery data stratified by equal periods, approximately equal effort (numbers of sets or passes through the sampling area), and approximately equal numbers of sockeye tagged or recovered. Application sample bias (unequal probability of capture) was assessed by stratifying the recovery sample as above and comparing the mark incidence among recovery strata, where mark incidence was the proportion of the fish marked with a disk tag. Recovery sample bias (nonrandom sampling in the recovery sample) was assessed by stratifying the application sample as above and comparing the proportions recovered among application strata.

Location

Spatial bias was similarly assessed using chi-square tests. Application sample bias was assessed by stratifying the recovery data into geographically discrete groups which allowed sufficient sample sizes in each stratum; mark incidences in each stratum were compared. Recovery bias was examined by stratifying the application sample by reach and comparing proportions recovered.

Fish Size

Size related bias was assessed using the Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981). Application bias was not assessed because the untagged carcasses were not sampled for length. Recovery bias was examined by partitioning the application sample into recovered and nonrecovered components and comparing the NF length-frequency distributions of each.

Fish Sex

Sex related bias was assessed using a chi-square test. Application bias was examined by comparing the sex ratio of the marked and unmarked spawning ground recoveries. Recovery bias was examined by partitioning the application sample into recovered and non-recovered components and comparing the sex composition in each.

Stress

Potential bias resulting from handling and tagging stress was assessed in two ways. First, three tests were performed to determine whether specific tags should be excluded from the application sample: a) fish with less than five days between tag application and recovery were assumed to be stressed and were removed from the samples. Five days was an arbitrary selection but was generally associated with poor spawning success; b) the sample was partitioned into fish which required ventilation at release and those which did not. If a chi-square test showed a significant difference in the proportions recovered, the high stress group was removed from the samples; and c) an identical procedure was used to evaluate fish which were recaptured in subsequent beach seine sets.

Second, two chi-square tests were performed as general indicators of stress: a) percent spawning success was compared between marked and unmarked spawning ground recoveries; and b) disk tag incidence and the percent spawning success of tagged females was compared between those sockeye recovered above and below the tagging site. These tests were not used to exclude specific data from the study. Rather, they provided an indicator of whether study design changes would be required in future studies to address a systemic problem with stress.

STUDY AREA POPULATION ESTIMATE

The Seymour River system study area consisted of the Seymour River and McNomee Creek. The escapement to the study area was estimated from the mark-recapture data, with the McNomee Creek population estimated from the visual data. The Seymour River escapement was derived by subtraction.

Data Corrections

Sex Identification Error: The tag application data were corrected for sex identification error. Error occurred because the development of sexually dimorphic traits was often not advanced and internal examinations could not be made. The correction of the recovery data was unnecessary because development was complete and dead fish could be examined more carefully. Sex identification error was corrected as described by Staley (1990):

1) Estimated true number of adult males released with disk tags:

$$M_m = \frac{M^*_m - (M_t R_{m,f})/R_f}{1 - (R_{m,f}/R_f) - (R_{f,m}/R_m)}$$

where:

- M^*_m = the field estimate of the number of adult males released with disk tags;
- M_t = the total number of sockeye adults released with disk tags;
- $R_{m,f}$ = the number of adult females recovered with disk tags which were released as males;
- $R_{f,m}$ = the number of adult males recovered with disk tags which were released as females;
- R_f = the number of adult females recovered with disk tags;
- R_m = the number of adult males recovered with disk tags.

2) Estimated true number of adult females released with disk tags:

$$M_f = M_t - M_m$$

Tag Recognition Error: Resurvey data were used to correct the disk tag recovery totals for tags missed in the initial survey. The following was calculated by sex:

3) Estimated true number of tags recovered, corrected for disk tags missed on the initial survey:

$$R_{cor} = R_{is} + ((R_{rs}/C_{rs}) \cdot C_{is})$$

where:

R_{is} = the number of disk tags recovered on the initial survey;
R_{rs} = the number of disk tags recovered on the resurvey;
C_{rs} = the number of carcasses examined on the resurvey;
C_{is} = the number of carcasses examined on the initial survey.

Population Estimator

The escapement estimates were calculated from the mark-recapture data using: a) the simple or pooled Petersen estimator (Seber 1982; p 60); and b) the Darroch (Seber 1982; p 431-445) and Schaefer (Seber 1982; p 439) estimators for stratified populations. Total escapement (adults and jacks) was calculated as follows:

4) Estimated Seymour River system sockeye escapement:

$$N_t = N_m + N_f + N_j$$

where:

N_m = the adult male escapement estimate;
N_f = the adult female escapement estimate;
N_j = the jack (male and female) escapement estimate.

Pooled Petersen Estimator: The pooled Petersen estimator was used to estimate the Seymour River system escapement unless biases were identified which required the stratification of the data set.

5) Pooled Petersen estimate of the escapement of male adults:

$$N_m = \frac{(M_m + 1)(C_m + 1)}{(R_m + 1)}$$

where:

M_m = the number of adult males released with disk tags;
C_m = the number of adult male carcasses examined for disk tags;
R_m = the number of adult males recovered with disk tags.

The female and jack escapements were calculated analagous to the above.

6) Variance of the pooled Petersen population estimate was calculated by sex as follows:

$$V_t = V_m + V_f + V_j$$

= variance of the total escapement estimate (males, females and jacks);

$$V_m = \frac{(N_m^2)(C_m - R_m)}{(C_m + 1)(R_m + 2)}$$

= variance of the adult male escapement estimate;
V_f = variance of female escapement estimate, analogous to above;
V_j = variance of jack escapement estimate, analogous to above.

Ninety-five percent confidence limits were calculated for the male, female, jack and total population estimates as follows:

$$N \pm 1.96\sqrt{V}$$

Stratified Estimators: When spatial or temporal biases were identified, stratified estimates were calculated using Schaefer's and Darroch's estimators. The pooled Petersen was the preferred estimator because precision is generally higher; however, if the confidence intervals of the pooled and the stratified estimates did not overlap, the bias was judged to be severe and the stratified estimator was considered more appropriate. Variance estimation procedures have not been developed for the Schaefer estimator. The variance of the stratified Darroch estimator was calculated using the procedures described by Seber (1982; page 433).

Alternate Jack Population Estimator

If fewer than five disk tags were recovered, the jack population (where jacks were defined as fish with a NF length of less than 50 cm regardless of sex) was estimated as the product of the number recovered, an expansion factor developed from previous IPSFC studies, and the inverse of the 1994 recovery rate of adult males:

7) Estimate of the escapement of jacks when fewer than five disk tagged jacks were recovered:

$$N_j = \frac{C_j \cdot 1.26}{R_m / M_m}$$

where:

C_j = the number of jacks recovered on the spawning grounds.

STOCK-SPECIFIC POPULATION ESTIMATES

The McNomee Creek escapement was estimated from the visual counts and carcass recoveries. Escapement was the product of the peak live count plus the cumulative carcass recovery to the date of the peak live count, and an expansion factor (Andrew and Webb MS 1987). The Seymour River escapement was the difference between the study area and McNomee Creek estimates.

8) Stock-specific escapement estimated from visual data:

$$N_t = (PL + CD) \cdot I$$

where:

PL = the maximum daily count of live spawners in the stream;
CD = the cumulative recovery of adult male, female and jack carcasses during stream surveys conducted prior to and including the date of the PL count;
I = an expansion factor of 1.8, developed by the IPSFC to adjust for observer efficiency (Andrew and Webb MS 1987).

If the stream-specific carcass sample was large (10% or more of the escapement estimate), then the sex-specific adult escapement was estimated from the sex ratio of the total adult carcass recovery (rather than the cumulative recovery to the date of the *PL*); the jack escapement was estimated from the jack recovery as in Equation 7. For streams with few carcass recoveries (less than 10% of the escapement), the sex and jack compositions from the mark-recapture study were used; jacks were excluded if none had been recovered in the stream.

FECUNDITY ESTIMATION

Mean fecundities were calculated by age as follows:

8) Estimated mean fecundity of age class *a*:

$$\bar{F}_a = \frac{\sum (f_{ai}/w_{ai}) W_{ai}}{n_a}$$

where:

f_{ai} = the number of eggs in a weighed subsample (w_i) of fecundity sample *i* of age *a* females;
w_{ai} = the weight, in grams, of a subsample of fecundity sample *i* of age *a* females;
W_{ai} = the weight, in grams, of fecundity sample *i* of age *a* females;
n_a = the number of age *a* females sampled for fecundity.

RESULTS

VISUAL SURVEYS

The Seymour River was surveyed using an inflatable boat six times from August 22 to September 6 (Appendix 2). A peak live count of 25,339 was recorded on September 1. At the peak, 55% of the spawners were in the lower river and 45% were in the upper river; the most important reaches were 4 (32%) and 2 (28%). The live surveys were terminated after peak abundance had been observed.

McNomee Creek was surveyed on foot five times between August 31 and September 20 (Appendix 5b). A peak live count of 3,558 was recorded on September 7.

TAG APPLICATION

Disk tags were applied to 985 sockeye adults and 11 jacks from August 18 to September 10, 1994 (Appendix 3). These data were first adjusted for sex identification error. The sex of 1.9% (1) of the recovered males and 0.0% of the re-

Table 1. Disk tags applied, carcasses examined and marks recovered, by sex, for Seymour River system sockeye salmon, 1994.

			Marks recovered					
Sex	Disk tags applied [a]	Carcasses examined	Disk tag and secondary mark [b]	Secondary mark only [b]	Disk tag only	Resurvey adjustment	Total	Percent recovered
Male	624	3,861	0	0	53	0	53	8.5%
Female	359 [c]	3,437 [c]	0	0	61 [c]	2	63	17.5%
Jack	11	0	0	0	0	0	0	0.0%
Total	994	7,298	0	0	114	2	116	11.7%

[a] Corrected for sex identification errors.

[b] Secondary marks were not applied in 1994.

[c] Excludes 2 females which were recovered within 5 days of release.

covered females was recorded incorrectly at the time of tagging. When adjusted for this error, an estimated 624 (63.3%) males and 361 (36.7%) females were released with disk tags. The data were then tested to determine if specific tags should be excluded from the analyses. First, fish with less than five days between tag application and recovery were removed from the application sample. This resulted in the removal of two females, one released on September 2 and recovered on September 3, the other released on September 9 and recovered on September 12. Second, the sample was partitioned into fish which required ventilation at release and those which did not. Seven adults (0.7%) and one jack (9.1%) required ventilation; however, the proportion of these groups which was recovered (14.3% and 0.0%) was not significantly different ($P > 0.05$; chi-square) from the nonventilated fish (11.6% and 0.0%). Consequently, they were not removed from the application sample. Third, an identical procedure was used to evaluate fish which were recaptured in subsequent beach seine sets. Because the tags were applied in the lower part of the spawning grounds, the incidence of recaptures was relatively high: 47 adults were recaptured once and 3 were recaptured twice. The proportion of the recaptured males and females which was later recovered as carcasses (5.7% and 33.3%) was not significantly different ($P > 0.05$; chi-square) from the nonrecaptured fish (8.7% and 16.3%). When the recaptures were further divided into fish recaptured once and those recaptured twice, again the difference was not significant (Table 2). Consequently, recaptured fish were not removed from the application sample. When adjusted for females stressed by recapture, the final disk tag application sample totalled 624 males, 359 females and 11 jacks (Table 1).

The mean NF length for males, females and jacks was 63.4 cm, 58.7 cm and 34.8 cm, respectively; none were sampled for age. The incidence of net, lamprey and hook marks was 5%, 22% and 1% in males, 15%, 14% and 1% in females, and 0%, 9% and 0% in jacks, respectively (Appendix 4).

SPAWNING GROUND SURVEYS

Main Survey

In 1994, 7,298 sockeye adults and 0 jacks were recovered in the study area from August 20 to September 20 (Table 1; Appendix 5). Of the adults, 53% were male and 47% were female, and 1.4% and 1.8% had a disk tag. Female spawning success averaged 99.5% (Table 2).

Each river reach was surveyed an average of eight times from August 20 to September 20 (Appendix 5a). Survey frequency varied between reaches and was highest in the lower river. The Seymour River accounted for 75% (5,458) of the study area carcasses; 1.7% of the males and 2.1% of the females had disk tags. The most important recovery areas were reaches 4 (27% of the total recovery), 5 (22%) and 2 (14%). The average time between release and recovery for disk tagged males and females was

Table 2. Number of disk tags applied and recovered on the spawning grounds for fish which were recaptured 0, 1 and 2 times in subsequent beach seine sets in the Seymour River, 1994.

Recapture status	Disk tags applied [a]			Disk tags recovered			Percent recovered		
	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Not recaptured	589	344	11	51	56	0	8.7%	16.3%	0.0%
Recaptures									
1 recapture	33	14	0	2	5	0	6.1%	35.7%	-
2 recaptures	2	1	0	0	0	0	0.0%	0.0%	-
Total	35	15	0	2	5	0	5.7%	33.3%	-
Chi-Square Test Results									
Not recaptured versus 1 recapture:							0.04	2.35	-
Not recaptured versus 2+ recapture:							0.68	0.84	-
Not recaptured versus all recapture:							0.09	1.88	-
Critical Chi-Square (df = 1; α = 0.05):							3.84	3.84	-

[a] Corrected for sex identification errors.

Table 3. Average elapsed time between tag application and recovery and female spawning success (all recoveries), by recovery section, period and sex, in the Seymour River system, 1994.

Location	Section	Period [a]	Time out between tag application and carcass recovery (days)					Female spawning success	
			Male	(n)	Female	(n)	Jack	%	(n)
Seymour River	Lower River	Early	12.8	(25)	12.6	(16)	-	96.1%	(203)
		Late	11.9	(23)	10.5	(31)	-	99.8%	(1,825)
		Total	12.0	(48)	11.2	(47)	-	99.4%	(2,028)
	Upper River	Early	13.0	(1)	15.3	(3)	-	90.9%	(11)
		Late	11.0	(1)	13.8	(4)	-	99.1%	(493)
		Total	12.0	(2)	14.4	(7)	-	98.9%	(504)
McNomee Creek	-	Early	13.5	(2)	17.0	(1)	-	100.0%	(302)
		Late	14.0	(1)	10.2	(6)	-	100.0%	(603)
		Total	13.7	(3)	11.1	(7)	-	100.0%	(905)
Total	-	Early	13.0	(28)	13.3	(20)	-	98.3%	(516)
		Late	11.1	(25)	10.8	(41)	-	99.7%	(2,921)
		Total	12.1	(53)	11.6	(61)	-	99.5%	(3,437)

[a] Time out to recovery: early = 18-Aug to 28-Aug releases; late = 29-Aug to 10-Sep releases. Female spawning success: early = 20-Aug to 07-Sep recoveries; late = 08-Sep to 20-Sep recoveries.

Table 4. Percent at age and mean POH length at age in Seymour River sockeye sampled on the spawning grounds, 1994

Recovery location	Sex	Percent at age					POH length (cm) at age				
		3_2	4_2	4_3	5_2	5_3	3_2	4_2	4_3	5_2	5_3
Lower	Male	-	100.0%	-	-	-	-	49.3	-	-	-
Shuswap	Female	-	100.0%	-	-	-	-	47.4	-	-	-
River	Jack [a]	-	-	-	-	-	-	-	-	-	-

[a] No jacks were sampled in 1994,

12 days and 14 days, respectively, and was longer among those tagged earlier in the study (Table 2). Two of the tagged fish were out for less than five days. Female spawning success averaged 99.0%, with lower success among the early spawners (Table 2).

McNomee Creek was surveyed five times from August 31 to September 20 (Appendix 5b). The creek accounted for 25% (1,843) of the study area carcasses; 0.3% of the males and 0.8% of the females had disk tags. The average time between release and recovery for disk tagged males and females was 14 days and 11 days, respectively (Table 2). None of the tagged fish were out for less than five days. Female spawning success averaged 100% (Table 2).

Resurvey

Each reach was resurveyed an average of twice from September 9 to September 19; 2,408 males and 1,641 females were reexamined, and 1 disk tag was recovered from a female (Appendix 6). An estimated 0 and 2 (1.7%) disk tagged males and females processed during the main survey were not correctly identified as tagged fish (Table 1). When corrected for this error, a total of 53 male and 63 female disk tags were recovered, a disk tag incidence of 1.4% and 1.8%, respectively.

BIOLOGICAL SAMPLING

Fecundity samples from 25 females were obtained at the tagging site; all were age 4_2 (Appendix 7). They had an average POH length of 48.7 cm (range 44.5 cm to 53.0 cm) and an average fecundity of 3,515 (range 1,537 to 4,429).

The adult carcass sample consisted entirely of age 4_2 fish (Table 4; Appendix 8). Males and females averaged 49.3 and 47.4 POH length, respectively. No jacks were sampled in 1994.

SAMPLING SELECTIVITY

Period

Temporal bias in the application sample was examined by comparing disk tag incidences in four recovery periods which were stratified in three ways: by equal periods; equal recovery effort; and equal numbers recovered (Table 5). Tag incidence in adults ranged from 0.0% to 2.6%, with a higher incidence early in the study. These differences were significant ($P < 0.05$; chi-square), however, only among males in one of the stratifications. Such a bias would be important because McNomee Creek spawners migrated through the lower river later than other spawners (Table 6).

Recovery bias was examined by comparing the proportions recovered from four application periods which were stratified in two ways: by equal periods and equal numbers applied (Table 7). The proportion of the adults recovered ranged from 0.0% to 21.5%; however, the difference was not significant ($P > 0.05$; chi-square) in either stratification.

Location

Spatial bias in the application sample was examined by comparing the mark incidence in three recovery sections (Table 8). Mark incidence among adults ranged from 0.24% to 2.28%, with a lower incidence among upper river and McNomee Creek spawners. These differences were significant ($P < 0.025$; chi-square) in both sexes.

Recovery bias was examined by stratifying the application sample into two reaches and comparing proportions recovered in each (Table 9). Proportions among adults ranged from 6.6% to 18.0%; however, the difference was not significant ($P > 0.05$) in either sex. Despite the lack of a significant difference, upper river female spawners may have been more vulnerable at the Reach 4 tagging site (Table 10).

Fish Size

Application bias could not be assessed because the length of untagged carcasses was not measured. Recovery bias was examined by partitioning the application sample into recovered and nonrecovered components and comparing the NF frequency distributions. There was no difference in either sex ($P > 0.05$; Kolmogorov-Smirnov two-sample test), although the difference approached significance in males. When the data were stratified in 3-cm NF groups, the proportion of the males recovered tended to be lower among larger fish (Table 11).

Table 5a. Incidence of disk tags in sockeye salmon recovered on the Seymour River system spawning grounds, by recovery period and sex, 1994. Data are stratified by equal recovery periods.

Recovery period	Number of surveys [b]	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
20-Aug to 04-Sep [a]	4	4	2	0	282	82	0	1.4%	2.4%	-
05-Sep to 10-Sep	2	27	24	0	1,770	1,025	2	1.5%	2.3%	0.0%
11-Sep to 15-Sep	3	17	22	0	1,326	1,366	1	1.3%	1.6%	0.0%
16-Sep to 20-Sep	2	5	13	0	483	964	0	1.0%	1.3%	-
Chi-Square Test Result:								0.80	3.31	-
Critical Chi-Square (df = 3; $\alpha = 0.05$):								7.81	7.81	-

[a] Regular surveys did not begin until 31-Aug.

[b] Based on recovery effort in reaches 4-5 and McNomee Creek.

Table 5b. Incidence of disk tags in sockeye salmon recovered on the Seymour River system spawning grounds, by recovery period and sex, 1994. Data are stratified by approximately equal recovery cycles.

Recovery period	Number of surveys [a]	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
20-Aug to 31-Aug	3	1	0	0	57	3	0	1.8%	0.0%	-
01-Sep to 08-Sep	2	21	22	0	1,557	833	2	1.3%	2.6%	0.0%
09-Sep to 14-Sep	3	25	23	0	1,580	1,384	1	1.6%	1.7%	0.0%
15-Sep to 20-Sep	3	6	16	0	667	1,217	0	0.9%	1.3%	-
Chi-Square Test Result:								1.68	5.22	-
Critical Chi-Square (df = 3; $\alpha = 0.05$):								7.81	7.81	-

[a] Based on recovery effort in reaches 4-5 and McNomee Creek.

Table 5c. Incidence of disk tags in sockeye salmon recovered on the Seymour River system spawning grounds, by recovery period and sex, 1994. Data are stratified by approximately equal numbers of total recoveries.

Recovery period	Number of surveys [a]	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
20-Aug to 07-Sep	4	7	11	0	1,004	517	2	0.7%	2.1%	0.0%
08-Sep to 11-Sep	2	25	18	0	1,305	825	1	1.9%	2.2%	0.0%
12-Sep to 14-Sep	1	15	16	0	885	878	0	1.7%	1.8%	-
15-Sep to 20-Sep	3	6	16	0	667	1,217	0	0.9%	1.3%	-
Chi-Square Test Result:								8.01	2.64	-
Critical Chi-Square (df = 3; $\alpha = 0.05$):								7.81	7.81	-

[a] Based on recovery effort in reaches 4-5 and McNomee Creek.

Table 6. Distribution of recovered disk tagged sockeye adults on the Seymour River system spawning grounds, by sex and tag application date, 1994.

Sex	Application date	Recovery location of disk tagged carcasses [a]					
		Lower River		Upper River		McNomee Creek	
		No.	%	No.	%	No.	%
Male	18-Aug to 29-Aug	27	90%	1	3%	2	7%
	30-Aug to 04-Sep	18	95%	1	5%	0	0%
	05-Sep to 10-Sep	3	75%	0	0%	1	25%
Female	18-Aug to 29-Aug	21	84%	3	12%	1	4%
	30-Aug to 04-Sep	20	74%	3	11%	4	15%
	05-Sep to 10-Sep	6	67%	1	11%	2	22%

[a] Section definitions: Lower River - reaches 4, 4a and 5; Upper River - reached 1-3.

Table 7a. Proportion of the disk tag application sample recovered on the Seymour River system spawning grounds, by application period and sex, 1994. Data are stratified by equal application periods.

Application period	Number of sets	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
18-Aug to 23-Aug	17	6	1	1	0	0	0	0.0%	0.0%	0.0%
24-Aug to 29-Aug	b	314	132	4	30	25	0	9.6%	18.9%	0.0%
30-Aug to 04-Sep	b	243	153	5	19	27	0	7.8%	17.6%	0.0%
05-Sep to 10-Sep	b	61	73	1	4	9	0	6.6%	12.3%	0.0%
Chi-Square Test Result:								1.45	1.73	-
Critical Chi-Square (df = 3; $\alpha = 0.05$):								7.81	7.81	-

[a] Corrected for sex identification error.

[b] Not available.

Table 7b. Proportion of the disk tag application sample recovered on the Seymour River system spawning grounds, by application period and sex, 1994. Data are stratified by approximately equal numbers of tags applied.

Application period	Number of sets	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
18-Aug to 26-Aug	b	163	54	3	22	8	0	13.5%	14.8%	0.0%
24-Aug to 29-Aug	b	157	79	2	8	17	0	5.1%	21.5%	0.0%
30-Aug to 01-Sep	b	168	100	4	12	18	0	7.1%	18.0%	0.0%
02-Sep to 10-Sep	b	136	126	2	11	18	0	8.1%	14.3%	0.0%
Chi Square Test Result:								8.01	2.06	-
Critical Chi-Square (df = 3; $\alpha = 0.05$):								7.81	7.81	-

[a] Corrected for sex identification error.

[b] Not available.

Table 8. Proportion of the Seymour River system sockeye salmon spawning ground recovery sample marked with disk tags, by recovery location and sex, 1994. [a]

Recovery river	Recovery Section	Carcasses recovered with disk tags			Total carcasses examined			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Seymour River	Lower	48	47	0	2,108	2,027	0	2.28%	2.32%	-
	Upper	2	7	0	818	505	0	0.24%	1.39%	-
McNomee Creek	All	3	7	0	935	905	3	0.32%	0.77%	0.00%
Chi-Square Test Result:								28.07	9.09	-
Critical Chi-Square (df = 2; α = 0.025):								7.38	7.38	-

[a] Section definitions: Lower - reaches 4, 4a and 5; Upper - reaches 1-3.

Table 9. Proportion of the disk tag application sample recovered on the Seymour River system spawning grounds, by application reach and sex, 1994.

Application location	Number of days [b]	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Reach 4	10	426	209	6	40	34	0	9.4%	16.3%	0.0%
Reach 5	17	198	150	5	13	27	0	6.6%	18.0%	0.0%
Chi-Square Test Result:								1.05	0.08	-
Critical Chi-Square (df = 1; α = 0.05):								3.84	3.84	-

[a] Corrected for sex identification errors.

[b] Number of sets was not recorded.

Table 10. Distribution of recovered disk tagged sockeye adults on the Seymour River system spawning grounds, by sex and tag application reach, 1994.

Sex	Application reach	Recovery location of disk tagged carcasses [a]					
		Lower River		Upper River		McNomee Creek	
		No.	%	No.	%	No.	%
Male	Reach 4	36	90%	2	5%	2	5%
	Reach 5	12	92%	0	0%	1	8%
Female	Reach 4	27	79%	3	9%	4	12%
	Reach 5	20	74%	4	15%	3	11%

[a] Section definitions: Lower River - reaches 4, 4a and 5; Upper River - reached 1-3.

Table 11. Proportion of the disk tag application sample recovered on the Seymour River system spawning grounds, by sex and 3 cm increments of nose-fork length, 1994.

Nose-fork length (cm)	Disk tags applied [a]			Carcasses recovered with disk tags [b]			Percent recovered		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
31-33.9	2	2	4	0	0	0	-	-	-
34-37.9	5	1	6	0	0	0	-	-	-
43-45.9	1	0	1	0	0	0	-	-	-
49-51.9	2	0	2	0	0	0	0.0%	-	0.0%
52-54.9	0	20	20	0	5	5	-	25.0%	25.0%
55-57.9	7	103	110	1	15	16	14.3%	14.6%	14.5%
58-60.9	59	173	232	5	33	38	8.5%	19.1%	16.4%
61-63.9	262	60	322	30	7	37	11.5%	11.7%	11.5%
64-66.9	262	0	262	16	0	16	6.1%	-	6.1%
67-69.9	30	0	30	1	0	1	3.3%	-	3.3%
70-72.9	1	0	1	0	0	0	0.0%	-	0.0%
73-75.9	1	0	1	0	0	0	0.0%	-	0.0%
Kolmogorov-Smirnov 2-sample test Dmax (continuous data; see text):							0.176	0.077	-
Kolmogorov-Smirnov 2-sample test Dcritical ($\alpha = 0.05$):							0.195	0.192	-

[a] Corrected for sex identification error. Excludes 3 females for which size at release was not recorded. Includes jacks and jills.
[b] Excludes 1 female for which size at release was not recorded.

Table 12. Sex composition of Seymour River system sockeye adults in the disk tag application and spawning ground recovery samples, 1994.

Sex	Application sample, by recovery status [a]				Recovery sample, by mark status			
	Sample size	Recovered	Not recovered	Total	Sample size	Marked	Unmarked	Total
Male	624	45.7%	65.9%	63.5%	3,861	45.7%	53.0%	52.9%
Female	359	54.3%	34.1%	36.5%	3,437	54.3%	47.0%	47.1%
	Chi-Square Test Result:			17.09	Chi-Square Test Result:			2.18
	Critical Chi-Square ($\alpha = 0.005$):			7.88	Critical Chi-Square ($\alpha = 0.05$):			3.84

[a] Corrected for sex identification error.

Fish Sex

There was no difference (P > 0.05; chi-square) in the sex ratio of the marked and unmarked spawning ground recoveries (Table 12). The application sample, therefore, was relatively unbiased with respect to sex.

The sex ratios of the recovered and nonrecovered components of the application sample were significantly different (P<0.005; chi-square), with a higher proportion females in the recoveries (Table 12). A similar difference was noted in the proportion of males (8.5%) and females (17.5%) released with disk tags and recovered on the spawning grounds (Table 1). The recovery sample, therefore, was biased toward females.

Stress

Potential bias resulting from handling and tagging stress was assessed in two ways. First, three tests were performed to determine whether specific tags should be excluded from the application sample. The results of these tests were reported on Page 9; two disk tagged females which were recovered within five days of release were removed from the samples. Second, two tests were performed as general indicators of stress: a) spawning success was compared between tagged (98.1%) and untagged (99.3%) females. The test data (0%, 50% and 100% spawned groups) were collapsed into two groups (0%%-50% and 100%) because of the low number of expected recoveries in the 50% group. No significant difference ($P < 0.05$; chi-square) was noted; and b) the recovery sample was partitioned into those recovered above and below the tagging site and the disk tag incidence and female spawning success were compared in each. Tag incidence below (2.9%) and above (1.2%) the tagging site were significantly different ($P < 0.05$; chi-square) in both sexes (Appendix 5); spawning success (99.6% versus 99.3%) was almost identical in each. The high disk tag incidence in the lower river may have reflected stress; however, the similar spawning success in each area suggests that the difference may also have resulted from sampling selectivity.

SPAWNER POPULATION ESTIMATES

The 1994 Seymour River system sockeye adult escapements are presented in Table 13 and are discussed below. The jack escapement could not be calculated because, although 11 jacks were tagged, no jack carcasses were recovered in 1994 (Table 1).

Petersen Estimator

The pooled Petersen estimate was calculated from the data presented in Table 1. Escapement was estimated for the adults only; jack (NF length of less than 50 cm) recoveries were insufficient for a mark-recapture estimate.

The 1994 study area sockeye adult escapement was estimated at 64,038 with 95% confidence limits of $\pm$ 21,621 (19.7%) (Table 13). The escapement of males and females was 44,699 $\pm$ 11,731 (26.2%) and 19,339 $\pm$ 4,658 (24.1%), respectively. The age-specific estimates were calculated from the pooled sample data. All of the adults were age 4_2 (Appendix 8).

Stratified Estimators

Because both temporal and spatial biases were identified, stratified estimates were calculated using the Schaefer and Darroch estimators (Table 13). The number of strata examined was limited by the small number of disk tags recovered. Spatially, the data were stratified into one and two application and two recovery locations. Temporally, the data were stratified into two application periods, each with an approximately equal number of tags applied, and two recovery periods, each with an approximately equal number of carcasses recovered. The spatially stratified Darroch estimator was highly unstable with this data set (Table 13) and was excluded from further consideration. The remaining stratified estimates were very similar to the pooled Petersen estimates, ranging from +1.0% to +2.0% in males and +1.3% to +9.1% in females. The results of the temporal stratification suggest that the identified biases did not seriously bias the population estimate. We are concerned, however, that the pronounced heterogeneity in the spatial distribution of disk tags potentially could introduce a bias in the population estimate. On the basis of the similarity of the pooled and stratified estimators and the consistency between the pooled estimate and the visual data, however, the pooled Petersen was accepted as the most appropriate population estimator.

Stock-Specific Estimates

The McNomee Creek escapement was estimated from the peak live and cumulative dead data using Equation 8 (Table 12). Because the carcasses recoveries in McNomee Creek exceeded 10% of the escapement estimate, they were used to estimate the sex-specific adult escapement.

DISCUSSION

MARK-RECAPTURE ASSUMPTIONS

The Petersen mark-recapture technique is based on the principle that, by tagging a random sample of fish, permitting them to redistribute through the population, and by obtaining a second random sample of tagged and untagged individuals, the number of fish in the population can be estimated with known precision. Even a very precise estimate, however, can be inaccurate. The accuracy of an escapement estimate depends on how well the assumptions underlying the technique have been addressed. These as-

Table 13. Escapement estimates and 95% confidence limits, by age and sex, for Seymour River system sockeye adults and jacks, 1994. The symbol * indicated the final study area escapement estimates.

Stratification type	Estimator	Sex	Escapement at age [a] 3_2	4_2	4_3	5_2	5_3	Total	95% confidence limits on total escapement Lower	Upper
Pooled	Petersen	Male	0	44,699	0	0	0	44,699 *	32,969	56,430
		Female	0	19,339	0	0	0	19,339 *	14,681	23,996
		Total	0	64,038	0	0	0	64,038 *	51,417	76,659
		Jack	-	-	-	-	-	0 *	-	-
Spatial	Schaefer	Male [b]	-	-	-	-	-	45,140	-	-
		Male [c]	-	-	-	-	-	45,458	-	-
		Female [b]	-	-	-	-	-	20,524	-	-
		Female [c]	-	-	-	-	-	19,585	-	-
	Darroch	Male [b]	-	-	-	-	-	-230,210	-2,356,300	1,895,880
		Male [c]	-	-	-	-	-	67,127	54,863	79,391
		Female [b]	-	-	-	-	-	11,646	-35,218	58,510
		Female [c]	-	-	-	-	-	32,196	27,075	37,317
Temporal	Schaefer	Male [d]	-	-	-	-	-	45,484	-	-
		Female [d]	-	-	-	-	-	19,650	-	-
	Darroch	Male [d]	-	-	-	-	-	45,583	33,540	57,626
		Female [d]	-	-	-	-	-	21,102	16,174	26,030

[a] Does not include 25 females which were killed for fecundity samples.

[b] Used a 2x2 matrix: Reaches 4 and 5 application; lower Seymour and upper Seymour/McNomee recovery.

[c] Used a 1x2 matrix: lower Seymour application; lower Seymour and upper Seymour/McNomee recovery.

[d] Used a 2x2 matrix: 18-Aug to 29-Aug and 30-Aug to 10-Sep application; 20-Aug to 11-Sep and 12-Sep to 20-Sep recovery.

Table 14. Estimated escapement of adult males, females and jacks to Seymour River and McNomee Creek, 1994.

Stock	Peak live	Cumulative dead	Adult escapement Males	Females	Total	Jacks
Seymour River	n/a	n/a	39,222	16,970	56,192	0
McNomee Creek	3,558	801	5,477	2,369	7,846	0
Total [a]	-	-	44,699	19,339	64,038	0

[a] Does not include 25 females which were killed for fecundity samples.

sumptions have been described in various forms by Ricker (1975), Otis *et al.* (1978), Eames *et al.* (1981) and Seber (1982) and are restated below in the context of the current study.

Population Closure

A closed population is one where the number of animals does not change during the study. In spawning salmon populations, this implies that there is neither recruitment nor immigration, and that death and emigration affect tagged and untagged fish equally. Functionally, closure also implies that all components of the population will be vulnerable to either capture or recapture. The Seymour study addressed the closure assumption through study design elements which ensured that the study encompassed virtually the entire period of immigration, spawning and die-off in all of the terminal spawning areas. These efforts attempted to ensure that all fish would be vulnerable to the application or recovery surveys, although the survey effort was not consistent across all spatial and temporal strata. We concluded, therefore, that the closure assumption was adequately addressed in the current study.

Identification of Tag Status

The failure to correctly identify the tag status of a carcass is a common one in mark-recapture studies. It generally results from surveyor inexperience, fatigue, or from assigning a higher priority to the speed of carcass processing than to the thoroughness of carcass examination. The latter applies primarily to tagging studies on the major stocks where the number of carcasses processed each day can be large (greater than 2,500 carcasses per person); that was not the case in the current study. If uncorrected, this type of error results in an underestimate of the proportion of tags in the population and an overestimate of escapement. In the current study, the proportion of the tags missed by the initial survey was evaluated by resurveying about one-half of the carcasses in previously surveyed areas; the proportion of the tags missed was 1.7% or 2 tags. This proportion was small relative to other 1994 studies (Schubert 1997); however, two procedural changes are recommended with the objective of reducing the missed tag rate to 0% in future studies: staff training should reemphasize the importance of carefully examining each carcass; and the crew chief, through more frequent resurveys, should provide immediate feedback and retraining to staff who miss tags.

The resurvey was successful in that a large proportion of the available carcasses were processed. I have four recommendations, however, which would improve the design of the resurvey sample and its analytic treatment. First, the resurveys were unsystematic. Resurvey effort in McNomee Creek and most of the upper Seymour River was only half that in the lower river, and the resurvey did not begin until 20 days after the start of the initial survey. Unsystematic resurveys could introduce error in the population estimate if the missed tag rate was not uniform, e.g. if the proportion of tags missed was related to the daily number of fish processed, to surveyor fatigue, or to the physical characteristics of the survey area. While stratification is an option, it was not considered in the current study because sample size was inadequate in several spatial and temporal cells. This issue should be addressed in future studies by a more frequent and representative resurvey. Second, tagged fish could be injected into the population between the initial survey and the resurvey of an area in two ways: a) rising and falling river levels between the two surveys could inject new tags into the resurvey population; and b) animals could inject new tags by dragging ashore carcasses which later could not be identified as predator kills. Such actions would result in an overestimate of the proportion of tags in the population and an underestimate of the escapement. This type of error was possible in the current study because flows were unstable and, in McNomee Creek predator activity was intense. This issue is potentially a serious one which should be addressed in the design of future studies. Such error could be controlled by reducing the elapsed time between the two surveys; it could be eliminated by applying an unambiguous mark (e.g. abdominal incision or chopping the fish in two) to processed carcasses. Third, as with the sex identification error correction, there is no variance estimator for the resurvey sampling stage. Consequently, the precision of the population estimate was overstated. This should be addressed in the analytic design of future studies. Fourth, if estimator variance is to be minimized, simulation studies are required to determine the optimal allocation of effort between the initial and resurvey sampling stages.

Tag Loss

The undetected loss of tags between tag application and recovery would result in an underestimate of the proportion of the population with tags and an overestimate of escapement. Tag loss can result from poor tag application technique, tangling of the tag in the net after release, or the fighting which is common among males during spawning. It can be easily evaluated (although with an incremental labour cost) by applying a secondary tag, or a mark such as an opercular punch or fin clip, in addition to the primary tag. Tag loss in the current study could not be assessed because secondary marks were not applied. A 1989 tag loss study, however, reported an average 3.5% (range 0% to 9.7%) loss of the primary tag in seven Fraser river sockeye stocks (DFO, unpublished). Studies of Fraser River chinook (Schubert *et al.* 1994a) and coho (Schubert *et al.* 1994b) also reported levels of tag loss which varied annually within about the same range. If tag loss in the current study was similar to that reported in the 1989 studies, the 1994 escapement would have been overestimated by approximately 2,200 sockeye (range 0 to 6,100). Clearly, tag loss could introduce a substantial bias in the population estimate and its assessment should be an integral part of all future mark-recapture studies. We note, however, that a positive bias of the same relative magnitude would also have occurred in past years because tag loss was not evaluated by any previous mark-recapture study.

Tagging Effects

Tagging can influence subsequent catchability if, for example, a tagged fish becomes more vulnerable to a fishery, to technicians or to predators. This type of tagging effect had little impact on the current study because: there were no fisheries upstream from the tagging site; the capture net was the only net used in the river, and the recapture data were examined for evidence of stress; the technicians were trained to recover carcasses independent of their tag status; and, although there was no indication that predators differentially removed tagged fish, predator recoveries were excluded from the sample.

The capture, holding and tagging of fish can subject sockeye to physiological stress (Ricker 1975). Two potentially serious tagging effects are: a) behavioral changes which violate the assumption of constant and equal probability of capture and recapture; and b) acute or short-term mortality, which violates the closure assumption and causes an underestimate of the proportion of tags in the population and an overestimate of escapement. The impact of low level or subacute stress may be trivial, or it may be manifested in subtle behavioral changes which influence subsequent catchability but which do not affect the ability of the fish to spawn successfully. If the stress is particularly severe, some individuals may die within a few days of release, and others may drift downstream and die outside the study area. The potential impact on the current study of a spectrum of subacute to severe acute stresses is discussed below.

There are a number of stress-related tagging effects which are of potential concern in the current study. First, stress could impair the ability of an affected fish to swim in stronger currents. In a subacute case, the ability of a stressed fish to hold position in faster currents could be impaired, forcing it to spawn in slower flowing water along the river periphery. This would increase the probability that the fish would wash ashore and could result in a higher recovery rate among the stressed group, a violation of the equal probability of recapture assumption. In a more severe case, the ability of the fish to move beyond the tagging site could be impaired, resulting in a higher probability of recovery downstream. In an extreme case, such fish could be flushed from the study area, a violation of the closure assumption. Second, stress may impair the ability of a fish to spawn successfully, resulting in a measurable reduction in spawning success. Lower spawning success among disk tagged fish could indicate a subacute stress, while lower success below the tagging site could indicate a more severe, acute stress. By itself, differential spawning success does not violate the basic mark-recapture assumptions; however, it does demonstrate behavioural differences which could violate the assumptions in a way which would be undetectable using current study techniques. Such differential spawning success should be treated as an indicator that the study stock may be highly susceptible to stress; low stress study techniques should be considered. Third, the time span between release and death could be shorter among stressed fish. Shorter time spans among tagged fish in general could indicate a subacute stress which would violate the assumption of random mixing. The detection of such a stress, however, requires an independent estimate of the time between release and death for untagged fish; such an assessment was unavailable in the current study. In contrast, acute stresses should be detectable because behaviour was assessed immediately after release.

In the current study, we attempted to minimize handling stress by ensuring that the capture and tagging processes were as stress-free as possible. This was done by selecting a tagging site proximal to the main spawning areas, where fast water would not stress the fish being held for tagging, and by minimizing the holding and handling time. These conditions were intended to minimize stress induced mortality while at the same time permit the complete mixing of tagged and untagged fish. Our tests (described earlier) detected a higher disk tag incidence in the lower river which may have reflected handling stress. Because tagging occurred at several sites in two reaches, however, this test was relatively gross and was more likely to have reflected sampling selectivity rather than stress. We detected no difference in spawning success between fish recovered upstream and downstream from the tagging site. Two fish which were recovered less than five days after release probably suffered stress-induced mortality; however, this was a rare event and was addressed by removing the fish from the application sample. We concluded, therefore, that the was little evidence in support of a role for acute stress in the results of the current study.

In summary, none of our tests demonstrated a serious concern with stress-induced tagging effects in the 1994 Seymour study. We were unable to discount the possibility that subacute and acute stresses did not bias the population estimate, however, and we recommend two design changes to permit such an assessment in the future: a) to evaluate the Seymour stock's susceptibility to stress and the potential impact of subacute stress on the study results, high and low stress tag application techniques should be developed; and b) to permit a more thorough assessment of acute tagging effects, surveys of the river below the tagging site should begin immediately after the start of tagging.

Sampling Selectivity

The assumption of equal probability of capture and simple random sampling is violated in virtually all mark-recapture studies and is generally considered to be an unattainable ideal (Otis *et al.* 1978). This condition can be relaxed to some extent, however, without introducing bias in the population estimate. Junge (1963) showed that selectivity can exist in both samples without introducing a bias in the population estimate if the sources of selectivity are independent, and if the selectivity in the recovery sample is independent of tag status. When nonrepresentative sampling occurs, it can be at least partially addressed by using a stratified population estimator.

The design of the current study attempted to address this assumption by making both tag application and recovery as representative as possible. Daily tagging effort was standardized and the fish were captured using a gear (beach seine net) known to minimize selectivity. Standardized effort can still fail to provide a representative sample of migrating sockeye, however, due to variability in: river conditions; the proportion of the fish which migrate at night; daily set times; and the technique used during each set. The spawning ground surveys were planned to cycle on a fixed number of days regardless of carcass abundance. Again, standardized effort can be compromised by variable river conditions or staff levels. Areas where the study design could not be fully implemented are discussed below.

We could not definitively test sample representativeness because the true population parameters were not known. Instead, we constructed a bias profile by examining the samples for five potential biases, temporal, spatial, fish size, fish sex and stress, as indicators of weaknesses in the study design (Table 13). Three biases were detected in the application and recovery samples: a) a potential temporal application bias which resulted in a lower tag incidence among early and late spawning males; b) a spatial application bias which resulted in a low disk tag incidence in McNomee Creek and the upper Seymour River; and c) and a recovery bias toward females in general. The latter bias was easily treated by stratifying the data by sex and calculating independent population estimates. The

Table 15. Bias profile for the 1994 Seymour River system sockeye escapement estimation study. [a]

Sample	Bias type	Test of	Between	Test result
Application	Temporal	Tag incidence:	Equal recovery periods	No bias
			Equal recovery effort	No bias
			Equal numbers of recoveries	Middle period bias in males
	Spatial	Tag incidence:	Three recovery areas	Lower river bias in both sexes
	Fish sex	Sex ratio:	Marked/unmarked recoveries	No bias
	Stress	Recovery rate:	Ventilated/nonventilated releases	No bias
		Recovery of a tag within 5-days of rel:	-	Removed 2 disk tags
		Recovery rate:	Live recaptured/not recaptured	No bias
		Spawning success:	Tagged/untagged recoveries	No bias
		Spawning success:	Above and below tagging site	No bias
		Tag indicence:	Above and below tagging site	Higher below site
Recovery	Statistical	Minimum recovery of 5 tags:	-	No bias
	Temporal	Recovery rate:	Equal application periods	No bias
			Equal numbers applied	Early bias in males
	Spatial	Recovery rate	Two application sites	No bias
	Fish size	Size-frequency distrib:	Recovered/nonrecovered tags	No bias
	Fish sex	Sex ratio:	Recovered/nonrecovered tags	Bias to females

[a] A "no bias" test result indicates that bias was not detected; undetected bias may be present.

other biases are potentially more serious and are discussed below in greater detail.

The temporal application bias reflected an low tag incidence among early and late male spawners. The low incidence in early spawners may have reflected the crew's difficulty in locating an adequate tagging site. The Reach 5 site, used in the first seven days of the study, was not effective; it was not until the Reach 4 site was used that substantial numbers of fish were tagged. The fact that the bias was specific to males supports this explanation. Because males generally arrive on the spawning grounds earlier than females (Killick 1955), the sex ratio would have been skewed toward males in the first week of the study. We cannot explain, however, the low apparent tag incidence among late spawning males. Effort was relatively consistent once adequate tagging sites were identified. Because this bias was detected in only one of the stratifications, it may have been an artifact of stratification rather than a true bias.

The spatial application bias, resulting from a tag incidence in McNomee Creek and upper Seymour River which was one-quarter of that in the lower river, was the most pronounced bias identified in this study. This likely reflected a differential vulnerability to capture among lower river spawners which resulted from the need to apply tags in the lower spawning area. Future studies should increase the tag incidence in the affected areas by establishing tagging sites in the upper river, and in the lower river near McNomee Creek.

The study data were spatially and temporally stratified to address the above assumption violations. Because the variations among the stratified and pooled estimates were very small and the stratified estimates were within the 95% confidence intervals of the pooled Petersen estimates, it was concluded that the assumption violations were not severe and were unlikely to have introduced significant bias into the population estimates.

RECOMMENDATIONS

1. The resurvey of carcass recovery areas is an important component of a mark-recapture study because, for a number of reasons, errors can be made in the identification of disk tags during the initial survey. The following changes are recommended to improve the resurvey component of this study:

- Staff training must emphasize the importance of thoroughly examining each carcass for a disk tag;
- Crew chiefs should resurvey the recovery areas more frequently, and provide immediate feedback to crew members who miss disk tags;
- The resurvey should be made spatially and temporally more representative;
- The frequency of resurveys should be increased to avoid inter-survey periods of high water which could inject new carcasses into the resurvey area;
- Predator activity should be documented to determine the need to apply an unambiguous mark (e.g. abdominal incision or cutting the carcass in two) to all processed carcasses;
- The variance of the resurvey sampling stage should be incorporated into the variance of the population estimator;
- Simulation studies are required to determine the optimum allocation of effort between the initial and resurvey sampling stages.

2. Secondary tags or marks should be applied to sockeye released with disk tags to permit the assessment of disk tag loss. In 1995, all disk tagged fish should receive a sex-specific opercular punch as a secondary mark. Implicit in this recommendation is the need for improved staff training and feedback discussed under Recommendation No. 1; improved training and clear standards for what constitutes a releasable tag would also reduce actual tag loss.

3. The subacute and acute stresses which may result from the capture, handling and tagging of sockeye adults were identified as a potential concern in 1994. Three study design changes are recommended to assess the role of stress in the Seymour study and to remove the potentially confounding influence of stress effects from the evaluation of sampling selectivity:

- To evaluate the Seymour stock's susceptibility to stress and the potential impact of subacute stress on the study results, high and low stress tag application techniques should be developed;
- To permit a more thorough assessment of acute tagging effects, surveys of the river below the tagging site should begin immediately after the start of tagging;
- Consistent techniques should be developed to estimate spawning success in disk tagged versus untagged females.

4. Three study design changes are recommended to address the sampling selectivity issues identified in the 1994 study:

- Effective tagging sites must be selected before the arrival of sockeye, and live capture should begin as soon as sockeye are observed in the river. Application effort (sets per day) must be recorded as a standard record keeping procedure;
- To permit a more proportional application of disk tags to the McNomee Creek and upper Seymour River spawners, additional tagging sites should be established in the lower river near McNomee Creek and in the upper river;
- McNomee Creek and the lower and upper sections of the Seymour River should be surveyed with equal frequency.

5. Analytic methods should be developed to permit incorporating the variance of the sex identification error correction into the variance of the population estimator.

ACKNOWLEDGEMENTS

Field activities were conducted by T. Ewanyshyn, M. Moss, T. Rathbone, C. Sine and J. Wideman under the supervision of Gary Zwack and Bill Wyett. The maps were drafted by XY3 Graphics. Joe Tadey provided a preliminary analysis of the study data. The final draft of this report was improved by review comments provided by Richard Bailey and Mike Lapointe.

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Appendices

Appendix 1a. Sockeye jack and adult escapement by sex, percent spawning success and the number of females which spawned effectively in the Seymour River system, 1938-1994.

Year	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1938	0	0	0	0	-	0
1939	250	0	125	125	95.0%	119
1940	0	0	0	0	-	0
1941	0	0	0	0	-	0
1942	2,412	0	1,034	1,378	95.0%	1,309
1943	67	0	35	32	95.0%	30
1944	200	0	100	100	95.0%	95
1945	0	0	0	0	-	0
1946	3,778	0	1,814	1,964	95.0%	1,866
1947	19,795	0	11,160	8,635	100.0%	8,635
1948	4,099	210	2,609	1,280	100.0%	1,280
1949	10,772	0	7,273	3,499	99.3%	3,476
1950	12,471	1,422	5,999	5,050	93.0%	4,697
1951	24,344	24	12,026	12,294	93.6%	11,504
1952	6,428	465	2,921	3,042	91.4%	2,780
1953	5,947	255	2,599	3,093	94.0%	2,907
1954	24,876	102	11,595	13,179	97.5%	12,463
1955	9,011 [a]	40	3,677	5,294	97.8%	5,178
1956	2,562	72	1,367	1,123	97.1%	1,102
1957	14,295 [a]	3,425	3,279	7,591	97.7%	7,106
1958	78,578	207	33,684	44,687	99.1%	44,285
1959	52,325 [a]	15	26,511	25,799	99.9%	25,473
1960	3,047	146	1,039	1,862	100.0%	1,862
1961	5,822	2,200	1,492	2,130	91.9%	1,957
1962	58,104 [a]	268	24,583	33,253	86.2%	27,411
1963	71,690 [b]	36	33,287	38,367	69.7%	26,742
1964	2,784 [b]	39	1,408	1,337	98.8%	1,321
1965	6,954 [b]	865	3,341	2,748	92.8%	2,550
1966	28,754 [b]	56	14,349	14,349	90.2%	12,943
1967	13,361 [b]	0	5,600	7,761	93.6%	7,264
1968	3,957	119	1,696	2,142	96.4%	2,064
1969	7,327 [b]	151	3,576	3,600	91.0%	3,276
1970	11,991 [b]	20	6,704	5,267	68.4%	3,603
1971	19,028 [b]	0	8,641	10,387	91.1%	9,463
1972	2,889	87	1,358	1,444	98.2%	1,418
1973	2,856 [b]	152	1,539	1,165	98.7%	1,150
1974	45,189 [a,b]	601	18,459	26,129	99.0%	25,096
1975	37,024 [a,b]	196	19,865	16,963	99.3%	15,756
1976	8,489	183	3,387	4,919	99.6%	4,898
1977	5,911	202	2,696	3,013	95.7%	2,883
1978	62,929 [b]	121	31,955	30,853	99.7%	30,757
1979	49,321 [b]	15	23,834	25,472	97.6%	24,866
1980	8,390	81	3,531	4,778	96.6%	4,616
1981	11,529	170	5,934	5,425	98.7%	5,354
1982	63,306 [b]	35	35,785	27,486	99.0%	27,219
1983	29,838 [b]	7	15,667	14,164	98.9%	14,014
1984	17,172	0	8,024	9,148	100.0%	9,148
1985	6,435	815	2,936	2,684	100.0%	2,684

Appendix 1a. Sockeye jack and adult escapement by sex, percent spawning success and the number of females which spawned effectively in the Seymour River system, 1938-1994, continued.

Year	Escapement				Percent spawning success	Effective females
	Total	Jacks	Males	Females		
1986	128,497 [a,b]	2,331	68,439	57,727	98.9%	57,017
1987	84,409 [b]	94	40,843	43,472	94.5%	41,080
1988	17,014 [a,b]	233	8,641	8,140	98.2%	7,973
1989	5,692	185	2,643	2,864	100.0%	2,864
1990	272,157 [b]	116	162,746	109,295	99.1%	108,234
1991	128,253 [b]	0	66,793	61,460	99.0%	60,797
1992	5,765	23	2,156	3,586	100.0%	3,586
1993	10,206	87	5,169	4,950	100.0%	4,950
1994	64,038 [b]	0	44,699	19,339	99.0%	19,152

[a] Includes fish taken for brood stock or other samples.

[b] Estimated by a mark-recapture study.

Appendix 1b. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females which had spawned effectively in the Seymour River, 1938-1994.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1938	-	-	0	0	0	0	-	0
1939	-	-	250	0	125	125	95.0%	119
1940	-	-	0	0	0	0	-	0
1941	-	-	0	0	0	0	-	0
1942	10-Sep	19-Sep to 22-Sep	2,412	0	1,034	1,378	95.0%	1,309
1943	25-Aug	04-Sep to 10-Sep	67	0	35	32	95.0%	30
1944	-	-	200	0	100	100	95.0%	95
1945	-	-	0	0	0	0	-	0
1946	24-Aug	04-Sep to 10-Sep	3,778	0	1,814	1,964	95.0%	1,866
1947	12-Aug	04-Sep to 10-Sep	19,795	0	11,160	8,635	100.0%	8,635
1948	20-Aug	04-Sep to 10-Sep	4,099	210	2,609	1,280	100.0%	1,280
1949	11-Aug	20-Aug	10,772	0	7,273	3,499	99.3%	3,476
1950	10-Aug	24-Aug to 05-Sep	12,471	1,422	5,999	5,050	93.0%	4,697
1951	10-Aug	22-Aug to 25-Aug	24,344	24	12,026	12,294	93.6%	11,504
1952	11-Aug	19-Aug to 21-Aug	6,428	465	2,921	3,042	91.4%	2,780
1953	10-Aug	25-Aug to 26-Aug	5,947	255	2,599	3,093	94.0%	2,907
1954	a	a	24,876	102	11,595	13,179	97.5%	12,463
1955	16-Aug	26-Aug to 30-Aug	9,011 [c]	40	3,677	5,294	97.8%	5,178
1956	11-Aug	25-Aug to 27-Aug	2,562	72	1,367	1,123	97.1%	1,102
1957	15-Aug	b	14,295 [c]	3,425	3,279	7,591	97.7%	7,106
1958	9-Aug	07-Sep to 10-Sep	78,578	207	33,684	44,687	99.1%	44,285
1959	15-Aug	29-Aug to 03-Sep	52,325 [c]	15	26,511	25,799	99.9%	25,473
1960	10-Aug	25-Aug to 02-Sep	3,047	146	1,039	1,862	100.0%	1,862
1961	22-Aug	31-Aug to 02-Sep	5,822	2,200	1,492	2,130	91.9%	1,957
1962	10-Aug	02-Sep to 04-Sep	58,104 [c]	268	24,583	33,253	86.2%	27,411
1963	7-Aug	25-Aug to 29-Aug	71,690 [d]	36	33,287	38,367	69.7%	26,742
1964	15-Aug	04-Sep to 06-Sep	2,784 [d]	39	1,408	1,337	98.8%	1,321
1965	18-Aug	27-Aug to 28-Aug	6,954 [d]	865	3,341	2,748	92.8%	2,550
1966	16-Aug	26-Aug to 31-Aug	28,754 [d]	56	14,349	14,349	90.2%	12,943
1967	12-Aug	01-Sep to 04-Sep	13,361 [d]	0	5,600	7,761	93.6%	7,264
1968	12-Aug	25-Aug to 28-Aug	3,957	119	1,696	2,142	96.4%	2,064
1969	10-Aug	20-Aug to 28-Aug	7,327 [d]	151	3,576	3,600	91.0%	3,276
1970	17-Aug	06-Sep to 10-Sep	11,991 [d]	20	6,704	5,267	68.4%	3,603
1971	14-Aug	03-Sep to 05-Sep	19,028 [d]	0	8,641	10,387	91.1%	9,463
1972	12-Aug	02-Sep to 04-Sep	2,889	87	1,358	1,444	98.2%	1,418
1973	15-Aug	26-Aug to 30-Aug	2,856 [d]	152	1,539	1,165	98.7%	1,150
1974	15-Aug	28-Aug to 02-Sep	45,189 [c,d]	601	18,459	26,129	99.0%	25,096
1975	-	28-Aug to 01-Sep	37,024 [c,d]	196	19,865	16,963	99.3%	15,756
1976	18-Aug	03-Sep to 05-Sep	8,489	183	3,387	4,919	99.6%	4,898
1977	15-Aug	28-Aug to 03-Sep	5,911	202	2,696	3,013	95.7%	2,883
1978	13-Aug	01-Sep to 05-Sep	62,929 [d]	121	31,955	30,853	99.7%	30,757
1979	-	28-Aug to 05-Sep	49,321 [d]	15	23,834	25,472	97.6%	24,866
1980	-	30-Aug to 02-Sep	8,390	81	3,531	4,778	96.6%	4,616
1981	-	28-Aug to 02-Sep	11,529	170	5,934	5,425	98.7%	5,354
1982	-	09-Sep to 13-Sep	63,306 [d]	35	35,785	27,486	99.0%	27,219
1983	-	30-Aug to 06-Sep	29,838 [d]	7	15,667	14,164	98.9%	14,014
1984	-	29-Aug to 03-Sep	17,172	0	8,024	9,148	100.0%	9,148
1985	-	02-Sep to 05-Sep	6,435	815	2,936	2,684	100.0%	2,684

Continued

Appendix 1b. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females which had spawned effectively in the Seymour River, 1938-1994, continued.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1986	-	05-Sep to 09-Sep	128,497 [c,d]	2,331	68,439	57,727	98.9%	57,017
1987	-	05-Sep to 09-Sep	84,409 [d]	94	40,843	43,472	94.5%	41,080
1988	-	30-Aug to 03-Sep	17,014 [c,d]	233	8,641	8,140	98.2%	7,973
1989	-	31-Aug to 05-Sep	5,692	185	2,643	2,864	100.0%	2,864
1990	-	29-Aug to 05-Sep	272,157 [d]	116	162,746	109,295	99.1%	108,234
1991	-	31-Aug to 08-Sep	128,253 [d]	0	66,793	61,460	99.0%	60,797
1992	-	28-Aug to 04-Sep	5,765	23	2,156	3,586	100.0%	3,586
1993	-	31-Aug to 07-Sep	10,201	87	5,166	4,948	100.0%	4,948
1994	Mid Aug	30-Aug to 03-Sep	56,192 [d]	0	39,222	16,970	98.9%	16,783

[a] Two arrival peaks, on 12-Aug and 22-Aug, and two spawning peaks, 24-Aug to 25-Aug and 01-Sep to 04-Sep.
[b] Two spawning peaks, 25-Aug to 28-Aug and 30-Aug to 03-Sep.
[c] Includes fish taken for brood stock or other samples.
[d] Estimated by a mark-recapture study.

Appendix 1c. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the number of females which had spawned effectively in McNomee Creek, 1986-1994.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1986	-	-	a	a	a	a	-	a
1987	-	-	a	a	a	a	-	a
1988	-	-	a	a	a	a	-	a
1989	-	-	a	a	a	a	-	a
1990	-	-	a	a	a	a	-	a
1991	-	-	a	a	a	a	-	a
1992	-	-	a	a	a	a	-	a
1993	-	31-Aug to 07-Sep	5	0	3	2	100.0%	2
1994	-	30-Aug to 10-Sep	7,846	0	5,477	2,369	100.0%	2,369

[a] Included in Seymour River estimate.

Appendix 2. Counts of live sockeye salmon, by date and reach, in the Seymour River, 1994.

Date	Reach 1	Reach 2	Reach 3	Reach 4	Reach 4a	Reach 5	Total
	Live sockeye count by reach						
22-Aug	-	287	123	330	47	297	1,084
26-Aug	1,375	3,049	1,245	2,510	609	809	9,597
28-Aug	640	2,750	1,140	5,790	837	1,150	12,307
30-Aug	1,250	3,760	1,190	10,020	1,840	1,450	19,510
1-Sep	2,835	7,150	1,584	8,135	2,150	3,485	25,339
6-Sep	2,230	6,290	1,530	3,203	1,270	2,360	16,883
Distribution at peak:	11%	28%	6%	32%	8%	14%	-

Appendix 3. Daily application of disk tags, by location and sex (field estimate and correction for sex identification error), to sockeye salmon in the Seymour River, 1994. [a]

Date	Reach	Number of sets	Original field estimate of sex composition: Male	Female	Jack	Corrected for sex identification error: Male	Female	Jack	Recaptures b: Male	Female	Total
18-Aug	5	1	0	0	0	0	0	0	0	0	0
19-Aug	5	2	1	0	0	1	0	0	0	0	0
20-Aug	5	4	0	0	0	0	0	0	0	0	0
21-Aug	5	4	1	0	0	1	0	0	0	0	0
22-Aug	5	3	3	0	0	3	0	0	0	0	0
23-Aug	5	3	1	1	1	1	1	1	0	0	0
24-Aug	5	4	0	0	0	0	0	0	0	0	0
25-Aug	4	c	84	34	0	86	32	0	0	0	0
26-Aug	4	c	70	22	2	71	21	2	0	0	0
27-Aug	4	c	55	21	0	56	20	0	3	0	0
28-Aug	4	c	53	27	1	54	26	1	12	4	0
29-Aug	4	c	46	34	1	47	33	1	1	0	0
30-Aug	4	c	64	38	1 [d]	65	37	1 [d]	7	0	0
31-Aug	4	c	26	9	0	27	8	0	1	1	0
	5	c	30	28	0	31	27	0	0	0	0
1-Sep	5	c	44	29	3 [d]	45	28	3 [d]	4	3	0
2-Sep	5	c	44	29	1 [d]	45	27 [e]	1 [d]	0	0	0
3-Sep	5	c	29	27	0	30	26	0	1	3	0
4-Sep	5	c	0	0	0	0	0	0	0	0	0
5-Sep	5	c	0	0	0	0	0	0	0	0	0
6-Sep	4	c	3	11	0	3	11	0	1	3	0
	5	c	20	16	0	20	16	0	0	0	0
7-Sep	4	c	12	14	1	12	14	1	4	0	0
8-Sep	4	c	5	7	0	5	7	0	0	3	0
	5	c	12	6	0	12	6	0	0	0	0
9-Sep	5	c	9	11	0	9	10 [e]	0	2	0	0
10-Sep	5	c	0	9	0	0	9	0	0	0	0
Total	4	-	418	217	6	426	209	6	29	11	0
	5	-	194	156	5	198	150	5	7	6	0
	Total	-	612	373	11	624	359	11	36	17	0

[a] See Methods for sex identification error correction procedure
[b] Three fish were recaptured twice.
[c] Number of sets was not recorded.
[d] Includes 1 female (jill).
[e] Excludes one fish with a short time out to recovery.

Appendix 4a. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among adult male sockeye examined at tag application in the Seymour River, 1994. [a]

Date	Number of adult males examined	Net marks		Lamprey marks		Hook marks		*F. columnaris* [b]	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
18-Aug	0	0	-	0	-	0	-	0	-
19-Aug	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
20-Aug	0	0	-	0	-	0	-	0	-
21-Aug	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
22-Aug	3	2	66.7%	0	0.0%	0	0.0%	0	0.0%
23-Aug	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
24-Aug	0	0	-	0	-	0	-	0	-
25-Aug	84	0	0.0%	2	2.4%	0	0.0%	0	0.0%
26-Aug	70	12	17.1%	4	5.7%	0	0.0%	0	0.0%
27-Aug	55	5	9.1%	10	18.2%	0	0.0%	0	0.0%
28-Aug	53	4	7.5%	16	30.2%	0	0.0%	0	0.0%
29-Aug	46	3	6.5%	17	37.0%	1	2.2%	0	0.0%
30-Aug	64	2	3.1%	24	37.5%	2	3.1%	0	0.0%
31-Aug	56	1	1.8%	20	35.7%	0	0.0%	0	0.0%
1-Sep	44	2	4.5%	16	36.4%	1	2.3%	0	0.0%
2-Sep	44	1	2.3%	8	18.2%	1	2.3%	0	0.0%
3-Sep	29	0	0.0%	9	31.0%	0	0.0%	0	0.0%
4-Sep	0	0	-	0	-	0	-	0	-
5-Sep	0	0	-	0	-	0	-	0	-
6-Sep	23	1	4.3%	3	13.0%	0	0.0%	0	0.0%
7-Sep	12	0	0.0%	3	25.0%	0	0.0%	0	0.0%
8-Sep	17	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9-Sep	9	0	0.0%	2	22.2%	0	0.0%	0	0.0%
10-Sep	0	0	-	0	-	0	-	0	-
Total	612	33	5.4%	135	22.1%	5	0.8%	0	0.0%

[a] Not corrected for sex identification error.

[b] Columnaris incidence was not recorded in 1994.

Appendix 4b. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among adult female sockeye examined at tag application in the Seymour River, 1994. [a]

Date	Number of females examined	Net marks		Lamprey marks		Hook marks		*F. columnaris* [b]	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
18-Aug	0	0	-	0	-	0	-	0	-
19-Aug	0	0	-	0	-	0	-	0	-
20-Aug	0	0	-	0	-	0	-	0	-
21-Aug	0	0	-	0	-	0	-	0	-
22-Aug	0	0	-	0	-	0	-	0	-
23-Aug	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
24-Aug	0	0	-	0	-	0	-	0	-
25-Aug	34	7	20.6%	0	0.0%	0	0.0%	0	0.0%
26-Aug	22	2	9.1%	0	0.0%	0	0.0%	0	0.0%
27-Aug	21	2	9.5%	1	4.8%	0	0.0%	0	0.0%
28-Aug	27	5	18.5%	3	11.1%	0	0.0%	0	0.0%
29-Aug	34	5	14.7%	8	23.5%	1	2.9%	0	0.0%
30-Aug	38	6	15.8%	5	13.2%	0	0.0%	0	0.0%
31-Aug	37	8	21.6%	9	24.3%	0	0.0%	0	0.0%
1-Sep	29	6	20.7%	9	31.0%	0	0.0%	0	0.0%
2-Sep	29	2	6.9%	5	17.2%	0	0.0%	0	0.0%
3-Sep	27	6	22.2%	2	7.4%	0	0.0%	0	0.0%
4-Sep	0	0	-	0	-	0	-	0	-
5-Sep	0	0	-	0	-	0	-	0	-
6-Sep	27	3	11.1%	2	7.4%	0	0.0%	0	0.0%
7-Sep	14	0	0.0%	2	14.3%	0	0.0%	0	0.0%
8-Sep	13	2	15.4%	2	15.4%	0	0.0%	0	0.0%
9-Sep	11	1	9.1%	0	0.0%	1	9.1%	0	0.0%
10-Sep	9	0	0.0%	3	33.3%	0	0.0%	0	0.0%
Total	373	55	14.7%	52	13.9%	2	0.5%	0	0.0%

[a] Not corrected for sex identification error.

[b] Columnaris incidence was not recorded in 1994.

Appendix 4c. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among sockeye jacks examined at tag application in the Seymour River, 1994.

Date	Number of jacks examined	Net marks		Lamprey marks		Hook marks		*F. columnaris* [a]	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
18-Aug	0	0	-	0	-	0	-	0	-
19-Aug	0	0	-	0	-	0	-	0	-
20-Aug	0	0	-	0	-	0	-	0	-
21-Aug	0	0	-	0	-	0	-	0	-
22-Aug	0	0	-	0	-	0	-	0	-
23-Aug	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
24-Aug	0	0	-	0	-	0	-	0	-
25-Aug	0	0	-	0	-	0	-	0	-
26-Aug	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
27-Aug	0	0	-	0	-	0	-	0	-
28-Aug	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
29-Aug	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30-Aug	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
31-Aug	0	0	-	0	-	0	-	0	-
1-Sep	3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3-Sep	0	0	-	0	-	0	-	0	-
4-Sep	0	0	-	0	-	0	-	0	-
5-Sep	0	0	-	0	-	0	-	0	-
6-Sep	0	0	-	0	-	0	-	0	-
7-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8-Sep	0	0	-	0	-	0	-	0	-
9-Sep	0	0	-	0	-	0	-	0	-
10-Sep	0	0	-	0	-	0	-	0	-
Total	11	0	0.0%	1	9.1%	0	0.0%	0	0.0%

[a] Columnaris incidence was not recorded in 1994.

Appendix 5a. Daily sockeye carcass recoveries, by location, mark status and sex, in the Seymour River, 1994.

Date	Reach	Number of surveys	Disk tag present Male	Disk tag present Female	Disk tag present Jack	Untagged Male	Untagged Female	Untagged Jack	Total Male	Total Female	Total Jack
20-Aug	5	-	0	0	0	1	0	0	1	0	0
22-Aug	3	-	0	0	0	1	0	0	1	0	0
	4	-	0	0	0	1	0	0	1	0	0
23-Aug	5	-	0	0	0	0	1	0	0	1	0
27-Aug	4	-	0	0	0	1	0	0	1	0	0
30-Aug	4	-	0	0	0	1	0	0	1	0	0
31-Aug	4	-	0	0	0	4	1	0	4	1	0
	5	-	1	0	0	12	1	0	13	1	0
1-Sep	4	-	0	0	0	1	1	0	1	1	0
2-Sep	1	-	0	0	0	4	0	0	4	0	0
	2	-	0	1	0	42	10	0	42	11	0
	3	-	0	0	0	8	0	0	8	0	0
3-Sep	4	-	2	1	0	113	45	0	115	46	0
	5	-	1 [b]	0	0	54	21	0	55 [b]	21	0
5-Sep	4a	-	2	1	0	77	34	0	79	35	0
7-Sep	3	-	0	0	0	32	1	0	32	1	0
	4	a	0	6	0	145	91	0	145	97	0
8-Sep	1	-	0	0	0	12	6	0	12	6	0
	2	-	1	1	0	162	76	0	163	77	0
	4	a	5	4	0	192	90	0	197	94	0
	5	-	9	6	0	229	136	0	238	142	0
9-Sep	4	a	0	0	0	34	22	0	34	22	0
	4a	-	2	1	0	54	89	0	56	90	0
10-Sep	1	-	0	0	0	28	8	0	28	8	0
	2	-	1	0	0	105	43	0	106	43	0
	3	-	0	0	0	29	3	0	29	3	0
	4	a	3	1	0	129	86	0	132	87	0
	5	a	3	2	0	50	16	0	53	18	0
12-Sep	4	-	4	3	0	201	246	0	205	249	0
	4a	-	2	1	0	88	115	0	90	116	0
	5	-	5	8 [b]	0	197	223	0	202	231 [b]	0
13-Sep	1	-	0	0	0	22	21	0	22	21	0
	2	-	0	1	0	220	188	0	220	189	0
	3	-	0	0	0	16	2	0	16	2	0
14-Sep	4	-	0	0	0	31	30	0	31	30	0
	5	-	4	3	0	95	37	0	99	40	0
15-Sep	4	-	0	1	0	5	26	0	5	27	0
	5	-	1	2	0	81	84	0	82	86	0
17-Sep	1	-	0	1	0	17	18	0	17	19	0
	2	-	0	1	0	79	55	0	79	56	0
	3	-	0	0	0	5	13	0	5	13	0
	4	-	1	3	0	68	98	0	69	101	0
	4a	-	1	1	0	18	40	0	19	41	0
18-Sep	4	-	0	1	0	36	71	0	36	72	0
	5	-	1	0	0	54	148	0	55	148	0
19-Sep	1	-	0	0	0	3	12	0	3	12	0
	2	-	0	1	0	23	38	0	23	39	0
	3	-	0	1	0	8	4	0	8	5	0
	4	-	0	2	0	36	72	0	36	74	0
	4a	-	0	0	0	7	12	0	7	12	0
20-Sep	4	-	0	0	0	11	32	0	11	32	0
	5	-	1	0	0	34	112	0	35	112	0

Continued

Appendix 5a. Daily sockeye carcass recoveries, by location, mark status and sex, in the Seymour River, 1994, continued.

Date	Reach	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Total	1	6	0	1	0	86	65	0	86	66	0
	2	6	2	5	0	631	410	0	633	415	0
	3	7	0	1	0	99	23	0	99	24	0
	4	15	15	22	0	1,009	911	0	1,024	933	0
	4a	5	7	4	0	244	290	0	251	294	0
	5	11	26	21	0	807	779	0	833	800	0
	Total	-	50	54 [c]	0	2,876	2,478	0	2,926	2,532 [c]	0

[a] Partial survey.

[b] One disk tag recovery excluded because elapsed time between release and recovery was less than five days.

[c] Two disk tag recovery excluded because elapsed time between release and recovery was less than five days.

Appendix 5b. Daily sockeye live counts and carcass recoveries, by location, mark status and sex, in McNomee Creek, 1994.

Date	Live count	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
31-Aug	1,471	-	0	0	0	35	0	0	35	0	0
7-Sep	3,558	-	1	2	0	465	300	0	466	302	0
11-Sep	1,359	-	1	3	0	256	232	0	257	235	0
15-Sep	-	-	0	0	0	97	140	0	97	140	0
20-Sep	300	-	1	2	0	79	226	0	80	228	0
Total	-	5	3	7	0	932	898	0 [a]	935	905	0 [a]

[a] Excludes three fish which were field identified as jacks but scale identified as kokanee.

Appendix 6. Daily number of sockeye carcasses examined and disk tags recovered, by location and sex, during the re-survey of the Seymour River, 1994.

		Number of	Disk tag present			Total examined			Disk tag incidence		
Date	Reach	surveys	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
9-Sep	2	-	0	0	0	214	88	0	0.000	0.000	-
	3	-	0	0	0	20	0	0	0.000	-	-
	4	a	0	1	0	199	94	0	0.000	0.011	-
	4a	-	0	0	0	114	112	0	0.000	0.000	-
10-Sep	4	a	0	0	0	36	28	0	0.000	0.000	-
	5	-	0	0	0	296	120	0	0.000	0.000	-
11-Sep	McNomee	-	0	0	0	389	290	0	0.000	0.000	-
16-Sep	2	-	0	0	0	428	183	0	0.000	0.000	-
	3	-	0	0	0	13	2	0	0.000	0.000	-
	4	-	0	0	0	307	336	0	0.000	0.000	-
	4a	-	0	0	0	75	86	0	0.000	0.000	-
	5	-	0	0	0	312	295	0	0.000	0.000	-
19-Sep	1	-	0	0	0	5	7	0	0.000	0.000	-
Total	1	1	0	0	0	5	7	0	0.000	0.000	-
	2	2	0	0	0	642	271	0	0.000	0.000	-
	3	2	0	0	0	33	2	0	0.000	0.000	-
	4	2	0	1	0	542	458	0	0.000	0.002	-
	4a	2	0	0	0	189	198	0	0.000	0.000	-
	5	2	0	0	0	608	415	0	0.000	0.000	-
	McNomee	1	0	0	0	389	290	0	0.000	0.000	-
Total	-	-	0	1	0	2,408	1,641	0	0.000	0.001	-

[a] Partial surveys.

Appendix 7. Fecundity sampling results and analytic details for sockeye salmon captured in the Seymour River, 1994.

Sample number	Age	POH length (cm)	Skein weight (g)	Skein sub-sample Weight (g)	Skein sub-sample Egg count	Estimated fecundity	Actual fecundity	Misc. eggs	Adjusted fecundity
1	4_2	53.0	322.6	171.8	1,959	3,679		2	3,681
2	4_2	48.0	322.9	127.6	1,361	3,444		0	3,444
3	4_2	44.5	272.8	110.9	1,134	2,789		0	2,789
4	4_2	52.5	246.1	112.4	1,528	3,346		0	3,346
5	4_2	50.0	386.2	148.8	1,489	3,865		3	3,868
6	4_2	46.5	353.4	158.8	1,678	3,734	3,757	1	3,735
7	4_2	51.0	314.1	182.0	2,273	3,923	3,941	1	3,924
8	4_2	48.0	389.2	149.7	1,534	3,988		1	3,989
9	4_2	46.5	407.5	155.8	1,498	3,918		3	3,921
10	4_2	49.5	392.2	210.6	1,982	3,691		4	3,695
11	4_2	48.5	332.4	153.7	1,334	2,885	2,887	5	2,890
12	4_2	51.0	361.2	140.4	1,291	3,321		1	3,322
13	4_2	50.0	334.8	133.9	1,235	3,088		2	3,090
14	4_2	47.0	450.9	170.6	1,515	4,004		1	4,005
15	4_2	49.5	354.7	138.2	1,377	3,534		7	3,541
16	4_2	49.0	269.9	140.6	1,608	3,087	3,096	14	3,101
18	4_2	50.5	296.6	119.2	1,209	3,008		15	3,023
19	4_2	50.5	352.7	137.7	1,297	3,322		11	3,333
20	4_2	47.0	391	150.4	1,395	3,627		12	3,639
22	4_2	46.0	326.4	129.7	1,208	3,040		15	3,055
23	4_2	46.0	404	154.8	1,691	4,413		16	4,429
24	4_2	48.5	334.9	132.7	1,439	3,632		12	3,644
25	4_2	47.0	339.6	133.2	1,322	3,371		10	3,381
17	n/r	50.5	237.2	104.0	669	1,526		11	1,537
21	n/r	49.0	354.5	210.1	2,083	3,515	3,528	13	3,528
Mean	4_2	48.7	345.9	146.2	1,494	3,509	3,420	6	3,515

Appendix 8. Proportion at age and mean length (Standard and POH) at age, by location, sex and sample period, from the adult sample of sockeye carcasses recovered on the Seymour River spawning grounds, 1994. [a]

Location	Sex	Sampling Period	Age	Sample size	Percent	Standard length (cm) Mean	Standard length (cm) Standard deviation	POH length (cm) Mean	POH length (cm) Standard deviation
Seymour River	Male	Total	4_2	115	100.0%	-	-	49.3	1.7
			Unaged	5	-	-	-	50.8	4.2
						-	-		
	Female	Total	4_2	116	96.7%	-	-	47.4	2.3
			Unaged	4	-	-	-	48.0	0.8

[a] Mean lengths and standard deviations were calculated from length data rounded to the nearest centimeter.