Estimation of the 1995 Birkenhead River Sockeye Salmon *(Oncorhynchus nerka)* Escapement

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In 1995, the Department of Fisheries and Oceans conducted a mark-recapture study to estimate the sockeye salmon (*Oncorhynchus nerka*) escapement to the Birkenhead River. Sockeye were captured at two sites in the lower river; 1,862 were released with disk tags and secondary marks. The spawning grounds were surveyed through the period of spawning and die-off; 14,019 carcasses were recovered, of which 604 were marked. Analysis revealed that application was biased temporally, spatially and by sex, and that recovery was biased temporally, by sex and by size; however, because the 95% confidence intervals of the pooled Petersen estimates overlapped those of the spatially and temporally stratified estimators, it was concluded that the pooled Petersen population estimates were not seriously biased. The 1995 escapement was estimated, using the pooled Petersen estimator, at 19,838 adult males, 20,008 adult females and 3,139 jacks (age 3_2 and 4_3 males). Study design changes, including adjustments to the level and allocation of sampling effort, improved resurvey procedures and modified recovery procedures to improve the jack population estimate, are recommended.

RÉSUMÉ

Houtman, R., J.A. Tadey, and N.D. Schubert. 2000. Estimation of the 1995 Birkenhead River sockeye salmon (*Oncorhynchus nerka*) escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2534: 39 p.

En 1995, le ministère des Pêches et des Océans a mené une étude de marquage-recapture pour estimer l'échappée de saumon rouge (*Oncorhynchus nerka*) dans la rivière Birkenhead. Les saumons ont été capturés à deux stations du cours inférieur de la rivière; 1 862 spécimens ont été libérés après avoir été marqués avec des disques et des marques secondaires. Les frayères ont été surveillées pendant toute la période de fraye et de mortalité; 14 019 carcasses ont été récupérées, dont 604 étaient marquées. L'analyse a révélé que l'opération de marquage était biaisée temporellement, spatialement et par sexe, et que la récupération était biaisée temporellement, par sexe et par taille; toutefois, étant donné que les intervalles de confiance de 95 % des résultats obtenus avec l'estimateur multiple de Petersen chevauchaient ceux des estimateurs à stratification spatiale et temporelle, il a été conclu que les estimations Petersen de la population n'étaient pas gravement biaisées. L'échappée de 1995 a été estimée, à l'aide de l'estimateur multiple de Petersen, à 19 838 mâles adultes, 20 008 femelles adultes et 3 139 mâles précoces (âges 3_2 et 4_3). Il est recommandé d'apporter des modifications au plan d'étude, notamment des ajustements du niveau et de la répartition de l'effort d'échantillonnage, d'améliorer les procédures de deuxième relevé et de modifier les méthodes de récupération pour améliorer l'estimation de la population de mâles précoces.

INTRODUCTION

The Fraser River system supports the largest population of sockeye salmon (*Oncorhynchus nerka*) in the world (Northcote and Larkin 1989). Sockeye spawn in over 150 natal areas, ranging from small streams to large rivers and lakes, which are distributed throughout the accessible portion of the Fraser River system. The Department of Fisheries and Oceans estimates the stock-specific annual abundance of Fraser River sockeye spawners using a two-tiered system originally developed by the International Pacific Salmon Fisheries Commission. Stocks with forecasted escapements above 25,000 are assessed using enumeration fences or mark-recapture studies, while stocks with smaller escapements are assessed using visual techniques.

The Birkenhead River, located at the north end of Lillooett Lake (Fig. 1), supports a sockeye salmon population that has increased from an average escapement of 54,000 in the 1950's and 1960's to an average of over 143,000 in the 1980's and 1990's (Appendix 1). Stream surveys have been conducted in the Birkenhead River since at least 1905 following the construction of the Pemberton Hatchery (Bolton MS 1976); escapement estimates have been reported regularly since 1938. From 1939 to 1941, the Birkenhead River was the site of one of the first mark-recapture studies conducted on Fraser River sockeye salmon (Schaefer 1951). Mark-recapture studies have been used to estimate the escapement of this stock in most subsequent years. Escapements have been relatively consistent from year to year and, unlike many Fraser River stocks, exhibit little evidence of cyclic dominance (Cass 1989). The 1995 study was similar to that conducted in 1994 (Schubert and Tadey 1997), but included modifications designed to reduce sample selectivity and to facilitate assessment of tag loss and the effects of sub-acute and acute stress.

This report describes the study design, field methods and analysis of the study to estimate the escapement of sockeye salmon to the Birkenhead River, in 1995. Included are estimates of the adult age and length distributions, escapement by sex and age and average fecundities for the Birkenhead River population. As well, mark-recapture biases are evaluated, including a comparison of escapement estimates generated by alternative models. The report concludes with a discussion of the results and recommendations for the design of future studies.

STUDY AREA

The Birkenhead River originates in the Coast Mountains of southwest British Columbia and flows south for 54 km, entering the north end of Lillooet Lake near Pemberton (Fig. 1). The Birkenhead River is among the largest tributaries of the Harrison-Lillooet system, draining a 596 km^2, glaciated watershed (Brown *et al.* 1979). The river has a mean daily discharge of 24 m^{3}s^{-1} (1945-1971) with mean daily maxima (71 m^{3}s^{-1}) and minima (7 m^{3}s^{-1}) occurring in June and March, respectively (Environment Canada 1991).

The Birkenhead River flows for much of its length through a narrow valley bound by steep mountains. Spawning habitat is predominantly confined to mainstem and side channel areas. A 2 m falls in a deep bedrock canyon located 27.5 km upstream delineates the upper limit of fish passage (Koster MS 1976); however, sockeye salmon are seldom observed above Poole Creek (km 25.7) (Brown *et al.* 1979). Below the canyon, the river is characterized by long rapids and riffles, frequent deep pools and isolated braided areas. It flows onto the Lillooet River flood plain 8 km upstream of Lillooet Lake then turns east in a slow moving, meandering channel that drains into Lillooet Lake. Historically, the river flowed directly into the Lillooet River approximately 4.5 km upstream from Lillooet Lake. The channel was changed to its present course in 1946-1951 as part of a flood control program; changes included the construction of a series of dykes and cut-offs along the lower Birkenhead River and the dredging of the Lillooet Lake outlet to reduce the lake level by 2.5 m (Hamilton MS 1994).

The Birkenhead River was divided into eleven areas to facilitate the data aggregations required for bias testing. Areas were established based on three criteria: i) homogeneity of physical characteristics such as gradient, channel morphology and substrate type; ii) the ability of the crews to access and survey an area in one day; and iii) the existence of easily identifiable land marks to delineate the areas.

In areas 0-2, the river is characterized by a meandering channel with dense streamside vegetation. Area 0 (0 to km 3.7), extending from Lillooett lake upstream to a new road bridge, has a sand and mud substrate. Area 1 (km 3.7 to km 7.3), ending at a set of old bridge abutments, has

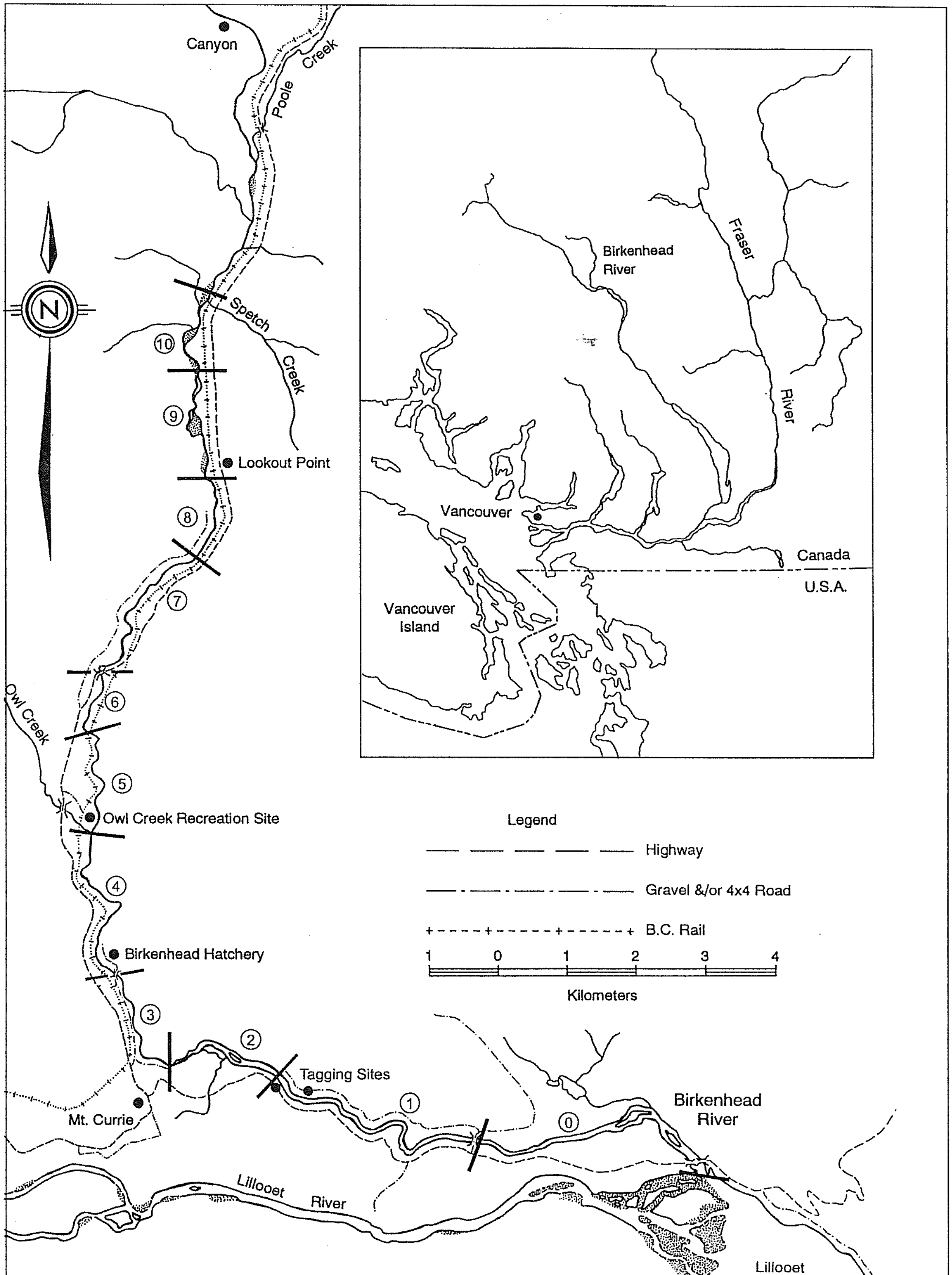

Figure 1. Birkenhead River study area location map

a sand and mud substrate in the lower 1 km and a gravel and sand substrate in the upper 2.5 km. Area 2 (km 7.3 to km 9.2), extending to a pumphouse on the southwest side of the river, is slightly braided with a sand and gravel substrate that changes to gravel and cobble.

Area 3 (km 9.2 to km 11.0) is a transition area where the river flows from the mountain valley onto the Lillooet River flood plain. The area, extending to the road bridge immediately below the Birkenhead Hatchery, is characterized by long riffles, isolated deep pools and a gravel and cobble substrate. The channel is moderately braided at higher water levels.

In areas 4-6, the river is characterized by a 2% gradient, frequent rapids and pools and a substrate of gravel and boulders. Area 4 (km 11.0 to km 13.8) extends from the bridge to the Owl Creek Recreation site on the west side of the river; Area 5 (km 13.8 to km 15.4) extends upstream to the B.C. Rail bridge; and Area 6 (km 15.4 to km 16.4) extends to the Mount Currie-Birken Highway Bridge.

Area 7 (km 16.4 to km 19.0) is a narrow gorge where the river flows over a series of small, passable falls. Long rapids, deep isolated pools and a substrate of mixed gravel, cobble and large boulders characterize this area.

Area 8 (km 19.0 to km 20.3) is typified by an unconstrained channel with long riffles and a gravel and cobble substrate. A small slough joins the mainstem from the west.

Area 9 (km 20.3 to km 22.1) extends to an electric transmission tower (No. 1074A) located adjacent to the river 1.3 km below Spetch Creek. The river flows across a broad valley with a gradient of less than 1% and is characterized by long riffles, deep pools, a heavily braided channel and a sand and gravel substrate. Extensive instream debris and undercut banks are common.

Area 10 (km 22.1 to km 23.4) extends upstream to Spetch Creek. The section is similar in character to Area 9.

FIELD METHODS

APPLICATION

Capture and tagging procedures were designed to distribute tags among adult males, females and jacks in a spatially and temporally representative manner. Sockeye were captured by beach seine at two sites located approximately 20 m ("Old Bridge" site) and 500 m ("Primary" site) below the upstream end of Area 1 (Fig. 1). Because an independent estimate of daily migrant abundance was unavailable, similar daily effort (number of beach seine sets) was to be applied throughout the run in an attempt to achieve temporally proportional tag application. Thus, on most days, three sets were made at the Primary site and 1 set was made at the Old Bridge site; this effort level was chosen as the maximum level that could be maintained, given crew size constraints, during the peak of the immigration. Experience tagging in this area of the river in previous years indicated that such a daily effort would also result in appropriate tagging rates.

Sockeye were captured by a three to five-person crew using a 46 m x 5 cm-mesh x 150 mesh deep beach seine net. The net was set from an inflatable boat in a downstream arc and withdrawn from the river to enclose an area of water along the riverbank. Captured fish were held in the net until removal for tagging. Previously tagged fish were identified upon recapture and immediately processed to avoid additional stress. The tag number was recorded and the tag checked; if damaged by recapture, it was retagged with the same disk. Other species and sockeye that were injured or showed advanced stages of maturation were released untagged.

Fish were tagged in a flexible plastic trough (12 x 20 x 100 cm) suspended in a wooden tray with a metre stick attached. In order to evaluate the susceptibility of this population to tagging-induced stress, standard and low stress tagging procedures were alternated every fish. Standard procedures entailed tagging the fish with the tray elevated from the water surface and releasing it by placing it in the water outside the net's cork line. Low stress procedures entailed tagging the fish with the tray immersed in approximately 15 cm of water and releasing it by lowering a section of the cork line; at no time was the fish removed from the water. The handling times for the two methods were not recorded, but no difference was noted. In addition, the following general fish handling guidelines were adopted in 1995 to reduce tagging-induced stress: crew activity within the net was minimized to reduce siltation; fish were removed from the water only when a tagger was ready and processed as quickly as possible; and, when removed from the water, the fish were cradled in two hands rather than dangled by the caudal peduncle.

The primary mark (disk tag) 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 disks, 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. Each tagged fish received a secondary mark to permit an assessment of tag loss. These consisted of one (males) or two (females) 7 mm diameter holes punched through the right operculum using a single hole punch. Care was taken to avoid gill tissue damage. If gill tissue was damaged, the fish was released with no disk tag and three holes punched in the right operculum. Date and location of capture, disk tag number, nose-fork (NF) length (±0.5 cm), sex, number of opercular holes punched, tagging method, and marks (gill net, lamprey and hook marks and predator 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

Recovery Survey

The carcass recovery surveys were designed to achieve equal recovery probabilities among strata. Thus, surveys began on the second day of application and continued until the die-off was virtually complete, both shores were examined entirely, complete surveys were performed at similar intervals (3-4 days) and each survey began immediately upon completion of the previous one. Surveys were conducted on foot by two-person crews with two crews required at the peak of die-off.

The crews were trained to recover carcasses independent of their tag status and, following recovery, to place a higher priority on the correct identification of tag and secondary mark status than on survey speed. All carcasses which were on shore or retrievable with a pe-ough by wading into the river to waist depth were enumerated (except predator kills, which were excluded from the survey), chopped in two with a machete and dropped on the shore. Carcass recoveries were recorded by date, area, sex, jack status (for males; based on morphology), tag and secondary mark status and carcass condition (fresh, tainted or rotten). Spawning success (0%, 50% or 100% spawned) was estimated, by incision, for each tagged female recovery, and typically one untagged female recovery following each tagged recovery. 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 reexamined through the recovery period to identify disk tagged carcasses that had been erroneously classified as untagged. The resurvey, conducted by experienced technicians only, recorded carcasses by date, area and mark status. Carcass sex and jack status could not be reliably identified because carcasses were too rotten. Schubert and Tadey (1997) identified deficiencies in the 1994 resurvey that were addressed by more frequent and extensive survey effort.

On the initial survey, tags were removed from carcasses identified as disk tagged, but those carcasses were not excluded from the resurvey. The number of fish with only secondary marks which were misclassified as unmarked, therefore, could not be determined.

BIOLOGICAL SAMPLING

Three hundred and sixty male and 180 female sockeye carcasses were sampled for post-orbital-hypural plate (POH) and nose-hypural plate (standard) lengths (±0.5 cm), otoliths and scales (one from each preferred region, as defined by Clutter and Whitesel (1956)). This sample (hereafter, "random carcass sample") was selected randomly with regard to carcass size and apparent jack status. Standard lengths and scale samples were also taken for 139 male carcasses identified as jacks. Carcasses for this "jack" sample were selected randomly throughout the recovery period during normal recovery surveys. The random carcass sample was collected at separate times from areas where jacks had not been removed for the jack sample (to avoid age-bias in the adult sample). Rotten carcasses were not included in either sample.

Near the peak of arrival, 25 randomly selected females were killed at the primary tagging site. Each was sampled as above, and the egg skeins and loose eggs were removed, placed in a cotton bag and preserved in a 10% formaldehyde solution. The number of eggs in each sample was estimated as the product of the total skein weight (grams) and the number of eggs per gram in a weighed subsample of the skein, plus a count of the loose eggs.

ANALYTIC PROCEDURES

Analytic procedures are presented in three sections. The first section describes the procedures by which the data were evaluated and corrected for sex, size class and tag identification error, tag loss, and acute stress effects. The second explains the procedure used to evaluate potential sampling biases. The results of this analysis were used to guide evaluation of bias in the resulting population estimates and the need to adopt stratified estimators. Finally, the third section describes the procedures used to calculate population estimates, and to evaluate alternative estimates.

DATA ADJUSTMENTS

Size Class Identification Error

Jack and adult males can have different recovery rates due to differences in size and behavior. This study was designed, therefore, to generate separate estimates for these two groups. Unfortunately, jack status of males could not be reliably determined at application; therefore, a NF length that separates jacks and adult males was determined from the combined jack and random male carcass samples. Those samples provided standard length distributions for jack and adult males. The NF length corresponding to the standard length that divides jack and adult males (hereafter, "NF_{Crit}") was estimated using a regression equation provided by the Pacific Salmon Commission.

The sizes of tagged recoveries were known from application. To estimate the number of untagged male carcasses in each size class, carcasses identified as jacks at recovery were considered to have been estimated as shorter than NF_{Crit}, and those identified as adult males to have been estimated as longer than NF_{Crit}. Tagged recoveries whose NF length (measured at application) did not match their size classification at recovery were treated as size class identification errors. The corrected total number of untagged male recoveries with NF ≥ NF_{Crit} was estimated as

$$U_m^* = \frac{U_m - \dfrac{U_t R_{m,j}}{R_j}}{1 - \dfrac{R_{m,j}}{R_j} - \dfrac{R_{j,m}}{R_m}} \quad ,$$

where:

- U_m = the field estimate of the number of untagged NF ≥ NF_{Crit} male sockeye recovered;
- U_t = the total number of untagged male sockeye recovered;
- $R_{m,j}$ = the number of tagged NF < NF_{Crit} male sockeye recoveries identified as NF ≥ NF_{Crit};
- $R_{j,m}$ = the number of tagged NF ≥ NF_{Crit} male sockeye recoveries identified as NF < NF_{Crit};
- R_j = the number of tagged male recoveries which were NF < NF_{Crit};
- R_m = the number of tagged male recoveries which were NF ≥ NF_{Crit}.

(Notice that this equation is equivalent to the sex identification error correction equation developed by Staley, 1990.)

The corrected number of untagged males with NF ≥ NF_{Crit} (hereafter, "males") recovered in stratum *i* was estimated as

$$U_{m_i}^* = \frac{U_m^*}{U_m} \times U_{m_i} \quad ,$$

where U_{m_i} is the field estimate of the number of untagged NF ≥ NF_{Crit} male sockeye recovered in that stratum. The corrected number of untagged males with NF < NF_{Crit} (hereafter, "jacks") recovered in that stratum was estimated as

$$U_{j_i}^* = U_{t_i} - U_{m_i}^* \quad ,$$

where U_{t_i} is the total number of untagged male sockeye recovered in the i^{th} stratum.

Sex Identification Error

The application data were corrected for sex identification error by comparing the sexes recorded at release and carcass recovery. All errors are assumed to be made at application, because the development of sexually dimorphic traits was less advanced at application, recording errors were more likely to occur during the hectic tagging process and carcasses of ambiguous sex could be incised and examined internally.

The corrected total number of males ($NF \geq NF_{Crit}$) tagged (M_m*) was estimated using an equation provided by Staley (1990). The corrected number of male sockeye tagged in a given application stratum was estimated by multiplying the fraction of all fish released as males that were released in that stratum by M_m*. The corrected number of females tagged in that stratum was estimated as the total number of males and females actually released minus M_m*.

Tag Recognition Error

Resurvey data were used to correct the carcass recovery totals for tags missed by the initial survey. The number of missed tags was estimated as the product of the tag incidence in the resurvey and the number of carcasses examined on the initial survey. For stratified population estimates, these recoveries were added to recovery strata in proportion to the fraction of total disk tagged carcasses recovered in each stratum.

Tag Loss

Because all fish released with a tag also received a permanent secondary mark, the rate of tag loss between application and carcass recovery equals the ratio of recoveries with only secondary marks to those with disk tags and/or secondary marks. The number of recoveries with disk tags and/or secondary marks was used to calculate the population estimate. For stratified population estimates, these recoveries were added to application strata in proportion to the fraction of the total application sample applied in each stratum.

Handling Stress

Tagging-induced stress can influence post-tagging behavior and the timing and probability of recovery. The data, adjusted for sex and size class errors, were evaluated to determine whether specific tags should be excluded. First, chi-square tests were used to test whether the proportion of tagged fish recovered was influenced by four potential stress factors: tagging method, release condition, the number of times tagged fish were recaptured in subsequent beach seine sets and time held in the net prior to tagging ("holding time"), stratified into 15 minute intervals. When a test result was significant, the high stress group was excluded from subsequent analyses. (In this report, significant ($P<0.05$) and highly significant ($P<0.005$) test results are indicated with a single and double asterisk, respectively.) Second, fish recovered less than five days after release were excluded from the remaining data. While five days is an arbitrary criterion, unusually short times between application and recovery are typically associated with poor spawning success and are assumed to result from tagging stress.

TESTS OF SAMPLING ASSUMPTIONS

Statistical tests were performed to assess whether application and recovery were proportional and whether complete mixing occurred (Seber 1982; p 434-9; Schwarz and Taylor 1998). The data were examined for temporal, spatial and fish sex biases at application and recovery. Application bias (non-proportional application and incomplete mixing) was assessed by stratifying the recovery sample (not corrected for missed tags) and comparing the mark incidence (the proportion of carcasses with disk tags and/or secondary marks) among strata. Similarly, recovery bias (non-proportional recovery and incomplete mixing) was assessed by stratifying the application sample and comparing the proportion recovered among strata. The data used for the recovery bias tests are adjusted for sex and size class identification errors and handling stress, but not for tag loss (the application stratum of fish with only a secondary mark could not be determined). Comparisons were made using chi-square tests (Sokal and Rohlf 1981).

For temporal bias tests, the application and recovery samples were stratified into five periods of approximately equal duration, total effort (numbers of sets or recovery surveys) and sample size. These three stratifications were used to examine the sensitivity of the tests to period start and end dates. For the spatial recovery bias test, the application sample was stratified by application site. Two spatial application bias tests were performed; one with five strata (areas 0, 1, 2, 3-6 and 7-10) and one with two strata corresponding to below and above the tagging sites (areas 0-1 vs. 2-10).

While size bias at application could not be assessed, because unmarked carcasses were not measured, the data were examined for a size bias at recovery, using several tests. First, the cumulative NF length frequency distributions of recovered and unrecovered portions of the application sample were compared using a Kolmogorov-Smirnov two-sample test (hereafter, "KS test"; Sokal and Rohlf 1981). For males, this test was done on the combined male and jack sample. If significant, separate KS tests were done for males and jacks to examine whether separating males into two size classes was effective at reducing size bias in recovery within each size class. Finally, recovery rates of jacks, small males (NF < 50 cm) and large males (NF ≥ 50 cm) were compared using chi-square tests.

Finally, spawning success of tagged and untagged female recoveries was compared. A 3-dimensional chi-square test (Zar 1984) was used to test for interactions among tag status, recovery section (areas 0-1 vs. 2-10) and spawning success (incomplete (0 or 50%) and complete). This test will indicate if spawning success depends on tag status and/or recovery area. Although an influence of tag status on spawning success could be due to sampling selectivity, tagging stress would most likely cause such an influence. For example, a study in coho salmon (*O. kisutch*) showed that spawning success was affected by electroshocking, a highly stressful capture technique (Schubert *et al.* 1994). Thus, this test is interpreted as indicating whether fish were stressed by tagging.

ESTIMATION OF SPAWNER POPULATION

Birkenhead River escapement was estimated using the simple or pooled Petersen estimator ("PPE"; Seber 1982) and two stratified estimators, the maximum likelihood Darroch estimator ("MLE"; Plante 1990; Arnason *et al.* 1996) and the Schaefer estimator (Seber 1982). The estimates were calculated using Stratified Population Analysis System software (Arnason *et al.* 1996), from mark-recapture data adjusted for sex and size class identification errors, tag recognition errors and handling stress effects.

Stratified population estimates were calculated using both temporal and spatial data arrays. The initial application and recovery strata were the same as those used in the bias tests (described above), for both temporal (periods of similar sample size) and spatial data arrays. Selected strata were then pooled when necessary to generate an estimate and satisfy assumptions of the MLE as assessed by Plante's goodness-of-fit test (Arnason *et al.* 1996). This selective pooling also permitted an evaluation of model sensitivity and stability. For temporally stratified data, only temporally 'adjacent' strata were pooled, and the stratum with the smallest number of tags applied or recovered was generally pooled. For spatially stratified data, the two application sites were pooled first (because of their proximity to each other, it was thought that fish tagged at the two sites would behave similarly). Then, recovery strata were pooled following the same guideline used for temporal strata. Population estimates were calculated after each pooling step.

Sampling biases were addressed in two ways. First, sex and size related biases (common in mark-recapture studies) were addressed by calculating separate population estimates for males, females and jacks. Second, spatial and temporal biases were evaluated by comparing the PPE and MLE estimates. The latter are considered most accurate, and therefore accepted, when the 95% confidence intervals of the two estimates did not overlap; otherwise, the PPE estimates are accepted, because their precision is generally higher. Schaefer estimates were only calculated for comparison; they were not considered for use as the final population estimates because precision estimates are unavailable.

The escapement of each age class was estimated using the age distribution in the carcass samples. The age distribution of all females in the random carcass sample was used for females. The age distribution of males in the random carcass sample with NF ≥ NF_{Crit} (NF lengths estimated from standard lengths using a regression equation provided by the Pacific Salmon Commission) was used for males. Finally, the age distribution among all carcasses shorter than NF_{Crit} in the jack and random carcass samples was used for jacks.

RESULTS

TAG APPLICATION

Tagging began on September 6, 1995, seven days after 2-6 sockeye were seen in areas 8-9 and at least 30 sockeye were seen entering the river mouth, and continued until the capture rate of untagged, non-spawning sockeye had dropped to nearly zero on October 9, 1995 (Appendix 2). Tags were applied to 763 males, 914 females and 199 jacks. The sex of three (1.5%) recovered males and five (1.4%) recovered females were recorded incorrectly at the time of tagging. After

Table 1. The influence of four potential stress factors on recovery rates; test data and results for Birkenhead River sockeye salmon, 1995.

	Disk tags applied [a,b]			Disk tags recovered [b]			Percent recovered		
Test of:	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Tagging method									
Standard	396.8	456.2	94	121	182	17	30.5%	39.9%	18.1%
Low stress	363.9	460.1	105	99	179	20	27.2%	38.9%	19.0%
Release condition [c]									
1	751.7	903.3	194	218	355	35	29.0%	39.3%	18.0%
2	4.0	9.0	4	1	3	2	25.1%	33.3%	50.0%
Number of recaptures									
0	681.9	840.1	178	195	329	34	28.6%	39.2%	19.1%
1	64.8	67.2	21	22	28	3	33.9%	41.7%	14.3%
2	6.0	3.0	0	3	2	0	50.2%	66.3%	-
3 or more	8.0	6.0	0	0	2	0	0.0%	33.2%	-
Holding time									
0-15 minutes	454.6	455.4	77	122	176	8	26.8%	38.6%	10.4%
15-30 minutes	232.3	320.7	79	76	127	20	32.7%	39.6%	25.3%
30-45 minutes	57.8	111.2	33	17	47	7	29.4%	42.3%	21.2%
45-60 minutes	13.0	25.0	8	3	10	0	23.1%	39.9%	0.0%
60-75 minutes	3.0	4.0	2	2	1	2	66.9%	24.9%	100.0%

Chi-square test results

	Male			Female			Jack		
Stress factor	χ^2	df	*P*	χ^2	df	*P*	χ^2	df	*P*
Tag application method	0.85 [d]	1	0.36	0.06 [d]	1	0.81	0.00 [d]	1	0.99
Release condition									
1 vs 2:	0.15 [d]	1	0.70 [e]	0.00 [d]	1	0.98 [e]	0.95 [d]	1	0.33 [e]
Number of recaptures									
0 vs 1 or more:	0.20 [d]	1	0.65	0.13 [d]	1	0.72 [e]	0.06 [d]	1	0.81
0 vs 3 or more:	1.93 [d]	1	0.17	0.01 [d]	1	0.90 [e]	-	-	-
Holding time	2.64	3	0.45	0.53	3	0.91	4.60	3	0.20
(last two periods pooled due to small sample size)									

[a] Corrected for sex identification errors.

[b] Includes fish recovered less than five days after tagging.

[c] Release condition was not recorded for 10 fish at application, 4 of which were recovered.

[d] χ^2 values are Yates corrected.

[e] Test result inaccurate due to small sample size in some cells.

correction for this error, an estimated 760.7 males and 916.3 females were marked.

The data were then examined for indications of fish that were excessively stressed by tag application. The proportion of tagged fish recovered in potential high-stress and corresponding low-stress groups did not differ significantly for any of the four potential stress factors examined: tagging method, release condition, number of recaptures and holding time (Table 1). Fish in these high-stress groups, therefore, were retained. Seven males, four females and three jacks were recovered less than five days after tag application. After these were removed from the application sample, the final disk tag applica-

Table 2. Sockeye tagged, total carcasses recovered and marked carcasses recovered, by sex, for Birkenhead River sockeye salmon, 1995.

			Marked sockeye carcasses recovered					
Sex	Disk tags applied [a]	Total recovery [b]	Both marks present	2° mark only	Resurvey adjustment	Total	Percent recovered	Mark incidence
Male	753.7 [7c]	5,598.2 [8c]	212 [8c]	0	0	212	28.1%	3.8%
Female	912.3 [4c]	7,864.0 [3c]	358 [3c]	0	0	358	39.2%	4.6%
Jack	196.0 [3c]	556.9 [3c]	34 [3c]	0	0	34	17.3%	6.1%
Total	1862.0 [14c]	14,019.0 [14c]	604 [14c]	0	0	604	32.4%	4.3%

[a.] Corrected for sex identification error.

[b.] Corrected for size class identification error.

[c.] Excludes fish recovered less than 5 days after release.

Numbers preceding notes indicate the number of fish to which notes apply.

tion sample included 753.7 males, 912.3 females and 196.0 jacks (Table 2).

The mean (S.D.) NF length for males, females and jacks in the application sample was 60.8 (6.0), 58.2 (3.8) and 39.2 (2.1) cm, respectively; ageing samples (*i.e.*, otoliths and/or scales) were not obtained for any tagged fish. The incidence of net, lamprey and hook marks and predator scars, was 11.9%, 0.4%, 0.4% and 7.4% in males, 23.8%, 0.1%, 0.0% and 8.5% in females and 7.1%, 0.0%, 0.0% and 5.1% in jacks, respectively (Appendix 3).

SPAWNING GROUND SURVEYS

Recovery Survey

The Birkenhead River was surveyed 11 times (frequencies varied between areas, and were highest in the lower river) between September 7 and October 16, 1995 (Appendix 4). A total of 5,509 male, 7,867 female and 657 jack carcasses were recovered. Most carcasses were recovered in areas 1 (39.0% of total recovery) and 2 (21.9%). Two tagged carcasses recovered as adult males (1.0%) measured NF < 46 cm at application, and five tagged carcasses recovered as jacks (13.5%) measured NF ≥ 46 cm at application (46 cm = NF_{Crit}; see below). After removal of fish recovered within 5 days of tagging, 209 male, 358 female and 37 jack tagged carcasses were recovered (Appendix 4). No secondary marked carcasses were found without disk tags (Table 2). After correction for size class identification errors, an estimated 5,598.2 male, 7,864.0 female and 556.9 jack carcasses were recovered, of which 212 males, 358 females and 34 jacks were tagged (Table 2). The sex ratio (male: female) among recovered carcasses was 41.6%: 58.4%.

Female spawning success averaged 93.1%, with lower success among early spawners (Table 3). A comparison of the proportion of incomplete spawners (0 or 50% spawning success) among early and late recoveries indicated that this difference was significant (p<0.005, chi-square). Spawning success also varied significantly (p<0.05, chi-square) by recovery area, and was lowest in Area 1 (90.6%) and highest in Area 0 (97.7%). Time between tagging and recovery averaged 15.9 days for males, 14.1 days for females and 12.0 days for jacks, and was significantly longer among those tagged earlier in the study (Table 3; p<0.005, t-test). Application and recovery location did not affect average time between tagging and recovery (p>0.05, ANOVA).

Resurvey

Areas 1, 2, and 3 were resurveyed 6, 4, and 2 times, respectively between September 29 and October 11, 1995; 2,814 carcasses were reexamined, and no disk tags were found (Appendix 5). Thus, no tag recognition error was detected and no correction was necessary. Resurveyed carcasses were usually placed in piles to distinguish them from un-resurveyed carcasses on subsequent resurveys. Rising water or scavengers occasionally dispersed some of the carcasses from these piles. The actual number of carcasses examined on the resurvey, therefore, is probably somewhat less than the number reported.

Table 3. Average elapsed time between tag application and recovery and female spawning success, by recovery section, period and sex, in Birkenhead River sockeye, 1995.

		Mean time (days) between tag application and carcass recovery [a]						Female spawning success		
Section	Period [b]	Male	(n)	Female	(n)	Jack	(n)	% [c]	(n_1)	(n_2)
Area 0	Early	15.4	(8)	16.0	(1)	11.0	(4)	75.0%	(2)	(20)
	Late	12.5	(4)	10.3	(3)	13.0	(1)	100.0%	(12)	(198)
	Total	14.4	(12)	11.8	(4)	11.4	(5)	97.7%	(14)	(218)
Area 1	Early	16.2	(61)	14.4	(88)	13.1	(12)	57.1%	(43)	(316)
	Late	12.8	(17)	11.1	(48)	6.5	(2)	94.6%	(317)	(2,651)
	Total	15.4	(78)	13.2	(136)	12.1	(14)	90.6%	(360)	(2,967)
Area 2	Early	18.2	(29)	15.6	(53)	13.0	(1)	66.7%	(15)	(209)
	Late	11.3	(11)	12.3	(22)	-	(0)	98.1%	(173)	(1,672)
	Total	16.3	(40)	14.6	(75)	13.0	(1)	94.6%	(188)	(1,881)
Area 3-6	Early	17.4	(17)	16.4	(27)	11.0	(1)	73.7%	(12)	(269)
	Late	-	(0)	11.4	(5)	-	(0)	95.3%	(71)	(1,068)
	Total	17.4	(17)	15.6	(32)	11.0	(1)	90.9%	(83)	(1,337)
Area 7-10	Early	17.4	(8)	16.5	(19)	-	(0)	100.0%	(11)	(514)
	Late	-	(0)	11.0	(1)	-	(0)	96.3%	(44)	(947)
	Total	17.4	(8)	16.2	(20)	-	(0)	97.6%	(55)	(1,461)
Total	Early	16.8	(123)	15.2	(188)	12.5	(18)	78.8%	(83)	(1,328)
	Late	12.2	(32)	11.5	(79)	8.7	(3)	96.0%	(617)	(6,536)
	Total	15.9	(155)	14.1	(267)	12.0	(21)	93.1%	(700)	(7,864)

a. Excluding carcasses recovered in 'rotten' condition and less than five days after release.

b. Time out to recovery: early= 6-Sep to 22-Sep releases. Female spawning success: early= 7-Sep to 26-Sep recoveries.

c. Mean of tagged and untagged carcasses sampled for percent spawning success (n_1), weighted by the number of tagged and untagged carcasses recovered (n_2).

BIOLOGICAL SAMPLING

Twenty-five females were sampled for fecundities between September 21 and 27, 1995. Of these, 16 were age 4_2 and averaged 52.0 cm standard length (range 50.1 to 55.2 cm), 8 were age 5_2 and averaged 58.2 cm standard length (range 53.7 to 61.5 cm) and one was sample could not be aged (Appendix 6). The average fecundities were 4,046 (range 3,214 to 5,326) for age 4_2 fish and 5,096 (range 4,539 to 5,964) for age 5_2 fish (Appendix 6).

The random carcass sample was collected throughout the period September 23 to October 6, 1995, predominantly from areas 1 and 9 (where road access facilitated transport of sampling gear). It consisted predominantly of age 4_2 and 5_2 fish, but included some fish aged 3_2, 4_3 and 5_3 (Appendix 7). The jack carcass sample consisted predominantly of age 3_2 males, but included a few males aged 4_2 and 4_3 (Appendix 7). Table 4 presents the age distributions (based on those in the random and jack carcass samples) used to estimate the escapement by age class.

The standard length distribution of the combined jack and random carcass sample males indicated that a male size class division at 41.5 cm, or approximately 46.0 cm NF length, provides essentially complete division of jack (ages 3_2 and 4_3) and adult (ages 4_2, 5_2 and 5_3) males.

SAMPLING ASSUMPTIONS

The application sample was temporally biased for males and females, for all three stratifications (Table 5). Mark incidences in these groups ranged from 0.0% to 6.3%, and were relatively low in the early strata. For jacks, mark incidences ranged from 0% to 10.0% and showed a similar pattern to that in males and females (Table 5). The recovery sample was only temporally biased for males (all three stratifications; Table 6).

Table 4. Percent at age and mean POH (adults) or standard (jacks) length at age of Birkenhead River sockeye carcasses sampled on the spawning grounds, 1995. Data included in each sex are described in the text.

		Male		Female		Jack	
Location	Age	%	POH (cm)	%	POH (cm)	%	Standard (cm)
Birkenhead	3_2	0.0%	-	0.0%	-	93.5%	36.8
River	4_3	0.0%	-	0.0%	-	6.5%	38.1
	4_2	68.9%	47.1	64.3%	46.1	0.0%	-
	5_2	30.7%	53.9	34.5%	51.6	0.0%	-
	5_3	0.3%	47.5	1.2%	44.6	0.0%	-

Table 5. Proportion of the Birkenhead River sockeye recoveries that were marked with disk tags and/or secondary marks, by recovery period and sex, in 1995, for the three stratifications used.

		Marked carcasses recovered			Total Recovery			Mark incidence		
Recovery period	Number of surveys	Male	Female	Jack	Male [a]	Female	Jack [a]	Male	Female	Jack
Equal recovery periods										
07-Sep to 14-Sep	1 [b]	0	0	0	66.2	55	21.8	0.0%	0.0%	0.0%
15-Sep to 22-Sep	3	9	19	4	632.9	666	85.1	1.4%	2.9%	4.7%
23-Sep to 30-Sep	2	62	107	12	1595.8	1817	186.2	3.9%	5.9%	6.4%
01-Oct to 08-Oct	3	77	142	10	1966.0	3326	162.0	3.9%	4.3%	6.2%
09-Oct to 16-Oct	3	64	90	8	1337.3	2000	101.7	4.8%	4.5%	7.9%
Similar recovery effort										
07-Sep to 19-Sep	3 [b]	0	3	1	286.0	276	62.0	0.0%	1.1%	1.6%
20-Sep to 26-Sep	2	23	39	5	1038.8	1052	104.2	2.2%	3.7%	4.8%
27-Sep to 02-Oct	2	56	99	10	1325.2	1718	141.8	4.2%	5.8%	7.1%
03-Oct to 08-Oct	2	69	127	10	1611.0	2818	147.0	4.3%	4.5%	6.8%
09-Oct to 16-Oct	3	64	90	8	1337.3	2000	101.7	4.8%	4.5%	7.9%
Similar total number of recoveries										
07-Sep to 26-Sep	5 [b]	23	42	6	1324.8	1328	166.2	1.7%	3.2%	3.6%
27-Sep to 01-Oct	2	51	89	10	1088.1	1403	135.9	4.7%	6.3%	7.4%
02-Oct to 05-Oct	1	38	78	8	990.7	1585	80.3	3.8%	4.9%	10.0%
06-Oct to 08-Oct	1	36	59	2	857.4	1548	72.6	4.2%	3.8%	2.8%
09-Oct to 16-Oct	3	64	90	8	1337.3	2000	101.7	4.8%	4.5%	7.9%

Chi-square test results

	Male			Female			Jack		
Stratification scheme	χ^2	df	*P*	χ^2	df	*P*	χ^2	df	*P*
Equal recovery periods	16.12	4	0.00 **	15.15	4	0.00 **	2.30	4	0.68
Similar recovery effort	23.76	4	0.00 **	15.17	4	0.00 **	3.39	4	0.50
Similar total number of recoveries	21.78	4	0.00 **	18.73	4	0.00 **	6.23	4	0.18

[a] Corrected for size class identification error.

[b] Regular surveys did not begin until 11-Sep.

Table 6. Proportion of disk tagged sockeye recovered in the Birkenhead River, by application period and sex, in 1995, for the three stratifications used.

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
Equal application periods										
06-Sep to 12-Sep	25	188.4	213.6	29	65	77	4	34.5%	36.1%	13.8%
13-Sep to 18-Sep	23	232.3	288.7	82	71	117	17	30.6%	40.5%	20.7%
19-Sep to 25-Sep	28	221.3	297.7	54	58	118	9	26.2%	39.6%	16.7%
26-Sep to 02-Oct	27	92.7	91.3	25	16	41	3	17.3%	44.9%	12.0%
03-Oct to 09-Oct	14	18.9	21.1	6	2	5	1	10.6%	23.7%	16.7%
Similar application effort										
06-Sep to 12-Sep	25	188.4	213.6	29	65	77	4	34.5%	36.1%	13.8%
13-Sep to 18-Sep	23	232.3	288.7	82	71	117	17	30.6%	40.5%	20.7%
19-Sep to 24-Sep	24	195.4	266.6	52	51	109	9	26.1%	40.9%	17.3%
25-Sep to 30-Sep	24	104.7	116.3	18	19	47	2	18.2%	40.4%	11.1%
01-Oct to 09-Oct	21	32.9	27.1	15	6	8	2	18.2%	29.5%	13.3%
Similar number of tags applied										
06-Sep to 11-Sep	21	148.5	163.5	24	53	61	3	35.7%	37.3%	12.5%
12-Sep to 15-Sep	15	138.6	163.4	49	44	63	9	31.8%	38.6%	18.4%
16-Sep to 18-Sep	12	133.6	175.4	38	39	70	9	29.2%	39.9%	23.7%
19-Sep to 22-Sep	16	140.6	208.4	41	41	79	7	29.2%	37.9%	17.1%
23-Sep to 09-Oct	53	192.4	201.6	44	35	85	6	18.2%	42.2%	13.6%

Chi-square test results

Stratification scheme	Male			Female			Jack		
	χ^2	df	*P*	χ^2	df	*P*	χ^2	df	*P*
Equal application periods	13.18	4	0.01 *	4.48	4	0.34	1.43	4	0.84
Similar application effort	11.61	4	0.02 *	2.55	4	0.64	1.57	4	0.81
Similar number of tags applied	14.64	4	0.01 *	1.20	4	0.88	1.92	4	0.75

[a] Corrected for sex identification error.

In this group, the proportion of tags recovered ranged from 10.6% to 35.7% and tended to decrease with application period. Recovery rates of jacks were highest in the middle periods, while no trend was present in females (Table 6).

The application sample was spatially biased for all sexes (Table 7). Mark incidence in recovered carcasses decreased moving upstream, and ranged from 0% to 11.3%. The proportion of tags recovered from the two application sites was very similar (Table 8), indicating no spatial bias in recovery (note that this test is relatively weak, since the two tagging sites were so close together).

Both the application and recovery samples were biased by sex (Table 9). The mark incidence among jack carcasses (6.1%) was significantly higher than among adults, and the mark incidence among females (4.6%) was significantly higher than among males (3.8%; Table 9). The proportion of tagged females recovered (39.2%) was significantly higher than that of males (28.1%), and the proportion of tagged adults recovered was significantly higher than that of jacks (17.3%; Table 9).

The KS test comparing size distributions of recovered and unrecovered tagged fish was significant for the combined male and jack samples but not for males or jacks separately, or for females (Table 10). The proportion of tags recovered tended to increase with male size, indicating that recovery was positively size-selective for

Table 7. Proportion of the Birkenhead River sockeye recoveries that were marked with disk tags and/or secondary marks, by recovery section and sex, in 1995.

	Marked carcasses recovered			Total Recovery			Mark incidence		
Recovery section	Male	Female	Jack	Male [a]	Female	Jack [a]	Male	Female	Jack
Area 0	19	6	6	301.9	218	53.1	6.3%	2.8%	11.3%
Area 1	116	187	25	2170.9	2967	336.1	5.3%	6.3%	7.4%
Area 2	45	96	2	1123.9	1881	66.1	4.0%	5.1%	3.0%
Area 3-6	20	42	1	894.3	1337	56.7	2.2%	3.1%	1.8%
Area 7-10	12	27	0	1107.1	1461	44.9	1.1%	1.8%	0.0%
Chi-square test results									
χ^2:		Males:	47.88		Females:	54.58		Jacks:	9.43
df:			4			4			4
P:			0.00 **			0.00 **			0.05 *

[a] Corrected for size class identification error.

Table 8. Proportion of disk tagged sockeye recovered in the Birkenhead River, by tag site location and sex, in 1995.

Tag site location	Number of sets	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Primary	90	652.0	711.0	84.0	183	271	15	28.1%	38.1%	17.9%
Old bridge site	27	101.7	201.3	112.0	29	87	19	28.5%	43.2%	17.0%
Chi-square test results										
χ^2:		Males:	0.00 [b]		Females:	1.51 [b]		Jacks:	0.00 [b]	
df:			1			1			1	
P:			0.97			0.22			0.98	

[a] Corrected for sex identification error.
[b] χ^2 values are Yates corrected.

males. Chi-square tests indicated that the proportion of tagged jacks recovered (17.3%) differed significantly from that of small (30.0%) and large males (28.1%), while the proportions of tagged small and large males recovered did not differ significantly (Table 10). In females, there was very little variation in recovery rates across size classes (Table 10).

The mean spawning success of marked and unmarked female recoveries was 92.5% and 91.9%, respectively. The proportion of incomplete spawners was not affected by either mark status or recovery section (areas 0-1 vs. 2-10; chi-square, p>0.05). All tests of sampling assumptions are summarized in Table 11.

SPAWNING POPULATION ESTIMATES

The 1995 Birkenhead River sockeye escapement estimates, based on the pooled (Table 2) and stratified (Table 12 and 13) data, are presented in Table 14. The sex-specific PPE estimates ± 95% confidence limits, excluding the females sampled for fecundities, are 19,838 ± 2,209 (11.1%) males, 20,008 ± 1,573 (7.9%) females and 3,139 ± 901 (28.7%) jacks. The PPE estimate of the total escapement, produced by summing the sex-specific estimates was 42,984 ± 2,587 (6.6%). The age-specific estimates (Table 14) are based on the age composition in the aged carcass sample (Table 4).

Table 9. Sex composition of Birkenhead River sockeye in the application and recovery samples, 1995.

	Application sample, by recovery status			Recovery sample, by mark status		
Sex	Disk tags applied [a]	Disk tags recovered	Percent recovered	Total recovery [b]	Marked recoveries	Mark incidence
Male	753.7	212	28.1%	5,598.1	212	3.8%
Female	912.3	358	39.2%	7,864.0	358	4.6%
Jack	196.0	34	17.3%	556.9	34	6.1%

Chi-square test results

	Recovery bias test			Application bias test		
Sexes compared:	χ^2	df	P	χ^2	df	P
All	46.03	2	0.00 **	9.19	2	0.01 *
Male and female	22.16 [c]	1	0.00 **	4.54 [c]	1	0.03 *

[a.] Corrected for sex identification error.

[b.] Corrected for size class identification error.

[c.] χ^2 values are Yates corrected.

Selective pooling of temporal strata (Table 12) provided stratifications in which the MLE model assumptions were satisfied, for males, females and jacks. The MLE estimates calculated for these stratifications differ from the PPE estimates by –7.2%, 1.4% and 1.8%, for males, females and jacks, respectively (Table 14). No spatial stratification passed Plante's (1990) goodness-of-fit test (see Arnason *et al.* 1996), for any sex. The MLE estimates reported for spatially stratified data differ from the PPE estimates by 0.3%, 0.2% and 2.3%, for males, females and jacks, respectively (Table 14).

Although Schaefer estimates were produced at all stratification scales, the reported values are those produced at the same scale as the reported MLE estimate. All Schaefer estimates differ by less than 2.3% from the PPE estimates.

The sex-specific PPE estimates are accepted, because the 95% confidence intervals of all six MLE estimates overlap those of the corresponding PPE estimates extensively and the discrepancies between the MLE and PPE estimates are relatively small in all cases where the MLE assumptions are met.

DISCUSSION

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 obtaining a second random sample of tagged and untagged individuals, the number of fish in the population can be estimated with known precision. The accuracy of an escapement estimate depends on how well the study meets the assumptions underlying the technique. These assumptions have been described in various forms by Ricker (1975), Otis *et al.* (1978), Eames *et al.* (1981), Seber (1982) and Arnason *et al.* (1996) and are discussed below in the context of the current study.

Population Closure

In a closed population the number of animals does not change during the study. The population did change during this study, through immigration, die-off and emigration; however, such factors will not violate the closure assumption if all components of the population are vulnerable to marking and/or carcass recovery, and death and emigration affect marked and unmarked fish equally (Arnason *et al.* 1996). The current study achieved the former condition. Temporally, although marking began late (at least seven days after sockeye first entered the river), recovery began one day after the first marked sockeye were released and ended when low recovery rates indicated die-off was complete. Spatially, although fish that never passed upstream of the tags sites would not have been vulnerable to tagging, essentially all areas of the Birkenhead River with spawning sockeye were included in recovery surveys.

Table 10. Proportion of disk tagged sockeye recovered in the Birkenhead River, by sex and nose-fork length-class, 1995.

Nose-fork length (cm)	Disk tags applied [a]			Carcasses recovered with disk tags			Percent recovered		
	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
2 cm size increments									
32-33.9	-	0.0	1.0	-	0.0	0.0	-	-	0.0%
34-35.9	-	0.0	11.0	-	0.0	0.0	-	-	0.0%
36-37.9	-	0.0	41.0	-	0.0	10.0	-	-	24.4%
38-39.9	-	0.0	81.0	-	0.0	10.0	-	-	12.3%
40-41.9	-	0.0	44.0	-	0.0	9.0	-	-	20.5%
42-43.9	-	0.0	14.0	-	0.0	2.0	-	-	14.3%
44-45.9	-	0.0	4.0	-	0.0	3.0	-	-	75.0%
46-47.9	8.0	1.0	-	2.0	0.0	-	25.1%	0.0%	-
48-49.9	21.9	2.1	-	7.0	2.0	-	31.9%	96.8%	-
50-51.9	25.9	12.1	-	4.0	3.0	-	15.4%	24.8%	-
52-53.9	40.9	63.1	-	9.0	23.0	-	22.0%	36.4%	-
54-55.9	45.9	179.1	-	10.0	71.0	-	21.8%	39.6%	-
56-57.9	37.9	258.1	-	11.0	104.0	-	29.0%	40.3%	-
58-59.9	85.7	161.3	-	20.0	59.0	-	23.3%	36.6%	-
60-61.9	171.5	56.5	-	48.0	25.0	-	28.0%	44.2%	-
62-63.9	126.6	69.4	-	43.0	33.0	-	34.0%	47.6%	-
64-65.9	56.8	76.2	-	13.0	26.0	-	22.9%	34.1%	-
66-67.9	31.9	28.1	-	12.0	12.0	-	37.6%	42.7%	-
68-69.9	53.8	5.2	-	16.0	0.0	-	29.7%	0.0%	-
70-71.9	32.9	0.1	-	11.0	0.0	-	33.4%	0.0%	-
72-73.9	12.0	0.0	-	5.0	0.0	-	41.8%	0.0%	-
74-75.9	1.0	0.0	-	1.0	0.0	-	100.0%	0.0%	-
3 size classes of males									
33 - 45.9	196.0	-	-	34	-	-	17.3%	-	-
46 - 49.9	30.0	-	-	9	-	-	30.0%	-	-
50 - 75.9	723.7	-	-	203	-	-	28.1%	-	-

Test results

Kolmogorov-Smirnov 2-sample test:	Dmax	Dcritical ($\alpha = 0.05$)	*P*
Males:	0.083	0.106	>0.05
Females:	0.015	0.085	>0.05
Jacks:	0.095	0.252	>0.05
Males & jacks combined:	0.107	0.097	<0.05 *

Chi-square test comparing recovery rates of males between:	χ^2 value	df	*P*
All three size classes:	9.48	2	0.01 *
46-50 cm versus $\geq$50cm:	0.00	1	0.98
<46 cm versus $\geq$46cm:	8.87	1	0.00 *

[a] Corrected for sex identification error.

Table 11. Bias profile for the 1995 Birkenhead River sockeye escapement estimation study.

Bias type	Test of	Between	Test result [a]
Application sample			
Temporal	Tagged: untagged recoveries	Equal recovery periods	Mid/late period bias: M, F
		Periods of similar recovery effort	Mid/late period bias: M, F
		Periods of similar total recoveries	Mid/late period bias: M, F
Spatial	Tagged: untagged recoveries	Five recovery sections	Lower section bias: all sexes
Fish sex	Tagged: untagged recoveries	Adult males and females	Bias for females
Stress	Recovery of a tag less than 5 days after release:	-	Removed 14 disk tags
	Recovered: unrecovered tags	Application method	No bias
	Recovered: unrecovered tags	Release condition 1 vs 2 [b]	No bias
	Recovered: unrecovered tags	0 vs $\geq$1 and vs $\geq$3 recaptures	No bias
	Recovered: unrecovered tags	Different 'holding times'	No bias
	Spawning success:	Tagged vs untagged and recovery section	No bias
Recovery sample			
Statistical	Minimum recovery of 5 tags:	-	No bias
Temporal	Recovered: unrecovered tags	Equal application periods	Early/mid bias in males
		Periods of similar application effort	Early/mid bias in males
		Periods of similar applications	Early/mid bias in males
Spatial	Recovered: unrecovered tags	Two application sites	No bias
Fish sex	Recovered: unrecovered tags	Adult males and females	Bias for females
Fish size	Recovered: unrecovered tags	Across size-frequency distrib.	Bias for larger males
	Recovered: unrecovered tags	Three male size classes	Bias against males <46cm

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

b. See text for description of release conditions.

Sockeye can become unavailable to recovery (emigrate from the study area) by several mechanisms, including carcass decomposition, predator activity and fishing, and flushing downstream. Few carcasses were excluded due to decomposition because typical inter-survey intervals were 3-4 days. Native fisheries, which took place at the river mouth (gill net) and in Area 7 (the canyon; dip net) and predators removed some fish (likely a small proportion of the population) from the study area; however, it is unlikely that marked fish were disproportionately affected by these mechanisms. Finally, the proportion of the population that flushed out of the river is probably quite small, because little spawning occurred in Area 0 (Tadey, pers. obs.), and carcasses from upstream would rarely flush through this area because of its length (3.7 km) and low water velocities. The population closure assumption, therefore, appears to have been met in this study.

Correct Identification of Tag Status

If uncorrected, misidentification of carcasses with a disk tag and/or secondary mark as unmarked results in an overestimate of escapement. Surveyor inexperience, fatigue or assigning a higher priority to recovery speed than to thoroughness can all contribute to this error. In the current study, no disk tags were found in a resurvey of 20% of the recovered carcasses, indicating that no disk tagged carcasses had been misidentified as unmarked on the initial survey. This error rate was low relative to many studies (*e.g.* Schubert 1998), including the previous Birkenhead River study (5.3%; Schubert and Tadey 1997). This difference may be due to the implementation of recommendations made by Schubert and Tadey (1997), including emphasizing to crews the importance of complete accuracy in identification of

Table 12. Temporally stratified tag application-recovery matrices, for the 1995 Birkenhead River sockeye mark-recapture study. The finest scale stratifications are shown; bracketed strata were aggregated to produce an ML Darroch estimate and attempt to meet the assumptions of the ML Darroch model. Total male and jack recoveries are corrected for size class identification error.

Male

Application period	Tags applied	[7-Sep to 26-Sep	27-Sep to 1-Oct]	2-Oct to 5-Oct	6-Oct to 8-Oct	9-Oct to 16-Oct	Total recovered
		Recovery period					
06-Sep to 11-Sep	148.5	17	19	7	3	7	53
12-Sep to 15-Sep	138.6	3	16	12	4	9	44
16-Sep to 18-Sep	133.6	2	12	6	10	9	39
19-Sep to 22-Sep	140.6	1	4	11	12	13	41
23-Sep to 09-Oct	192.4	0	0	2	7	26	35
Total tags:	753.7	23	51	38	36	64	212
Total recovered:		1324.8	1088.1	990.7	857.4	1337.3	5598.1

Female

Application period	Tags applied	[7-Sep to 26-Sep	27-Sep to 1-Oct]	2-Oct to 5-Oct	6-Oct to 8-Oct	9-Oct to 16-Oct	Total recovered
		Recovery period					
06-Sep to 11-Sep	163.5	29	24	7	1	0	61
12-Sep to 15-Sep	163.4	11	29	11	4	8	63
16-Sep to 18-Sep	175.4	2	21	17	11	19	70
19-Sep to 22-Sep	208.4	0	14	33	14	18	79
23-Sep to 09-Oct	201.6	0	1	10	29	45	85
Total tags:	912.3	42	89	78	59	90	358
Total recovered:		1328.0	1403.0	1585.0	1548.0	2000.0	7864.0

Jack

Application period	Tags applied	[7-Sep to 26-Sep	27-Sep to 1-Oct]	2-Oct to 5-Oct	[6-Oct to 8-Oct	9-Oct to 16-Oct]	Total recovered
		Recovery period					
[06-Sep to 11-Sep	24.0	2	0	1	0	0	3
12-Sep to 15-Sep	49.0	2	4	2	0	1	9
16-Sep to 18-Sep]	38.0	2	4	2	0	1	9
[19-Sep to 22-Sep	41.0	0	2	2	2	1	7
23-Sep to 09-Oct]	44.0	0	0	1	0	5	6
Total tags:	196.0	6	10	8	2	8	34
Total recovered:		166.2	135.9	80.3	72.6	101.7	556.9

carcass tag status; thus, these procedures should be continued.

The estimated number of missed tags may not be very accurate, because the resurvey was small and unrepresentative: only 20% of previously processed carcasses were resurveyed, all of the resurvey was performed in areas 1, 2 and 3, and the resurvey began 22 days after recovery began and ended 5 days before the recovery ended (Appendix 5). Unfortunately, the only available method for incorporating the variance of the missed tag estimate into the population variance (Rajwani and Schwarz 1997) was not applicable to this study, because carcasses identified as tagged on the initial survey were included in the resurvey. (Note, however, that if no tags are found on the resurvey, no variance estimate can

Table 13. Spatially stratified tag application-recovery matrices, for the 1995 Birkenhead River sockeye mark-recapture study. The finest scale stratifications are shown; bracketed strata were aggregated to produce an ML Darroch estimate and attempt to meet the assumptions of the ML Darroch model. Total male and jack recoveries are corrected for size class identification error.

Male

Tag site	Tags applied	Recovery section: Area 0	Area 1	Area 2	[Areas 3-6	Areas 7-10]	Total recovered
[Primary	652.0	15	98	39	19	12	183
Old bridge site]	101.7	4	18	6	1	0	29
Total tags:	753.7	19	116	45	20	12	212
Total recovered:		301.9	2170.9	1123.9	894.3	1107.1	5598.1

Female

Tag site	Tags applied	Recovery section: [Area 0	Area 1]	Area 2	[Areas 3-6	Areas 7-10]	Total recovered
[Primary	711.0	5	140	73	31	22	271
Old bridge site]	201.3	1	47	23	11	5	87
Total tags:	912.3	6	187	96	42	27	358
Total recovered:		1328.0	1403.0	1585.0	1548.0	2000.0	7864.0

Jack

Tag site	Tags applied	Recovery section: Area 0	Area 1	[Area 2	Areas 3-6	Areas 7-10]	Total recovered
[Primary	84.0	3	10	1	1	0	15
Old bridge site]	112.0	3	15	1	0	0	19
Total tags:	196.0	6	25	2	1	0	34
Total recovered:		53.1	336.1	66.1	56.7	44.9	556.9

be calculated using the method of Rajwani and Schwarz (1997).) The precision of the population estimates, therefore, is overestimated (*i.e.,* the 95% confidence intervals reported are too small). In future studies, carcasses identified on the recovery survey as marked should be excluded from the resurvey, so that the variance estimation procedures of Rajwani and Schwarz (1997) can be applied. This can be easily achieved either by making such carcasses identifiable (*e.g.,* by chopping them in three, with chops in front and behind the dorsal fin) or by throwing them far up the bank.

No Undetected Tag Loss

Undetected loss of disk tags between application and recovery results 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. In the current study, tag loss was assessed by applying an opercular punch as a permanent secondary mark. No tag loss was detected. This value probably underestimates true tag loss, for two reasons. First, opercular punch holes could effectively be lost, since they could be distorted and enlarged by fungus, decomposition and predator activity, making carcasses with missing disk tags indistinguishable from untagged carcasses with holes in their opercula. Second, the surveyors could have missed non-disfigured opercular punches on carcasses that had lost disk tags. No estimate of this error was possible because disk

Table 14. Escapement estimates and 95% confidence limits, by age and sex, for Birkenhead River sockeye, 1995. Asterisks indicate accepted estimates.

		Escapement at age [a]						95% confidence limits on total	
Estimator	Sex	3_2	4_3	4_2	5_2	5_3	Total	Lower	Upper
Pooled Petersen	Male	0	0	13,677	6,094	68	19,838 *	17,629 *	22,047 *
	Female	0	0	12,870	6,903	234	20,008 *	18,435 *	21,581 *
	Adult total [b]	0	0	26,547	12,997	302	39,846 *	37,134	42,557
	Jack	2,934	205	0	0	0	3,139 *	2,238 *	4,039 *
	Total [b]	2,934	205	26,547	12,997	302	42,984 *	40,127 *	45,842 *
Application and recovery stratified temporally									
ML Darroch	Male [c, d]	-	-	-	-	-	18,416	15,955	20,876
	Female [c, d]	-	-	-	-	-	20,296	16,482	24,111
	Jack [c, d]	-	-	-	-	-	3,195	2,240	4,150
Schaefer	Male [d]	-	-	-	-	-	19,443	-	-
	Female [d]	-	-	-	-	-	20,008	-	-
	Jack [d]	-	-	-	-	-	3,203	-	-
Application and recovery stratified spatially									
ML Darroch	Male [d]	-	-	-	-	-	19,902	17,675	22,130
	Female [d]	-	-	-	-	-	20,040	18,459	21,621
	Jack [d]	-	-	-	-	-	3,210	2,260	4,161
Schaefer	Male [d]	-	-	-	-	-	19,902	-	-
	Female [d]	-	-	-	-	-	20,040	-	-
	Jack [d]	-	-	-	-	-	3,210	-	-

a. Excludes 25 females which were killed for fecundity samples.

b. Sum of sex specific estimates. Confidence intervals calculated as in Schubert and Tadey (1997).

c. Model assumptions are satisfied (passes Plante's goodness-of-fit test (Arnason *et al.* 1996)).

d. Stratifications used to produce estimates are indicated in Tables 12 and 13.

tags, but not secondary marks, were removed during the initial surveys. In future studies, the incidence of missed secondary marks can be determined if carcasses identified as disk tagged and/or secondary marked are excluded from the resurvey. Further, alternate secondary marks should be evaluated and available for use should the accurate detection of opercular punches prove inadequate.

Equal Catchability

Recovery probabilities across strata (hereafter, 'average' recovery probabilities) of marked and unmarked sockeye must be equal for the PPE estimate to be unbiased. For stratified models to be unbiased, average recovery probabilities of these two groups can differ, but recovery probabilities within strata must be equal (Arnason *et al.* 1996). Note that even when recovery probabilities are equal within each stratum, unequal average recovery probabilities can exist unless one or more of the following three conditions exist: i) proportional application, ii) proportional recovery, and iii) complete mixing. If recovery probabilities differ within strata, average recovery probabilities will rarely be equal.

Tagging stress effects and selective application sampling can both influence where and when tagged carcasses become recoverable, potentially causing unequal recovery probabilities of tagged and untagged fish. Stress can influence the distance and duration of movements by impairing swimming ability and causing earlier death; application can favour fish with specific spawning ground distributions or spawning schedules. While the application bias tests should detect such differences, they do not distinguish their cause. Application bias will not induce unequal recovery probabilities of marked and unmarked fish, however, if the recovery sample is unbiased or has an independent source of bias (Junge 1963; Seber 1982).

In the current study, tag application was designed to minimize tagging stress (see above). Only 13 (0.8%) fish did not swim away vigorously upon release, suggesting that application was reasonably stress-free. As well, tagged fish were excluded from the analysis if there were indications that they were stressed by application. Because the proportion of tagged fish recovered was not affected by any of the four stress factors examined, fish in the (potentially) high-stress groups were retained. Fourteen fish recovered less than five days after tagging were excluded, because of the likelihood that they suffered acute stress. These procedures, however, probably did not fully eliminate the influence of tagging stress on tagged fish.

The sampling methods were also designed to minimize selectivity, through proportional application and recovery. To achieve application proportionality, fish were captured using a gear known to minimize selectivity, and a standardized daily tagging effort was applied throughout the run. Expending application effort evenly may not achieve proportional application, however, due to variability in river conditions, the proportion of the fish which migrate at night, daily set times, the technique used during each set and the daily size of the migration (large migrations may exceed the tagging capacity of the crew). Also, fish migrating at night (and other periods of the day in which application did not occur) may have differed in behavior, sex ratio, size distribution and/or other aspects, leading to application selectivity for these attributes. Similarly, although the recovery survey effort was applied relatively equally (spatially and temporally) throughout the die-off, sample selectivity may have persisted for a variety of reasons, including variable river conditions.

Here, evidence regarding the likelihood that recovery probabilities of tagged and untagged sockeye were equal (at either level) is examined. In this study, no data were collected to provide a direct test of this assumption at the within-stratum level. In future, consideration should be given to recovering carcasses from deep pools and other sites where substantial numbers of carcasses would be unavailable to normal recovery. Comparison of the tag incidence among such carcasses with that among standard recoveries provides evidence of whether recovery probabilities of tagged and untagged carcasses were the same within a limited (spatially and temporally) stratum (*e.g.*, Houtman and Schubert 2000).

The chi-square test indicated that tag status did not influence female spawning success. This indicates that the behavior of tagged and untagged females was similar, increasing the likelihood that the two groups had similar recovery probabilities. This result also suggests that tagging procedures were relatively unstressful, since spawning success is known to be sensitive to stress in salmon (Schubert *et al.* 1994).

Examination of the application and recovery samples indicated several biases. Both samples were biased by sex; however, because separate PPE estimates were calculated for females and males, these biases should not affect the accuracy of the estimates. Also, the recovery sample was biased toward larger males, and whether or not the application sample was biased could not be determined (because untagged recoveries were not measured). Pooled Petersen estimates on combined male and jack data could therefore have been biased (if these biases led to unequal average recovery probabilities). The calculation of separate PPE estimates for two size classes of males, each with no (detectable) recovery size bias, reduces the likelihood that size biases induced bias in the population estimate.

In males, both application and recovery samples were also biased temporally. Thus, the male PPE estimate is potentially biased. As expected, the deviation between the PPE and MLE estimates was greatest in this case (-7.2%; Table 14); however, for the reasons discussed above, the PPE estimate was accepted. Obviously, the male population estimate should be considered more uncertain than should those for females and jacks.

GENERAL DISCUSSION

The design of future studies should be modified, if possible, to avoid the temporal and spatial biases encountered in this study. Here, possible causes of these biases are examined, and corresponding solutions are suggested. The application bias toward middle and late period recoveries, in all sexes, was likely due to the late start of application. Clearly, future studies should start immediately after the first sockeye are sighted in the lower areas. The spatial application bias, with tag incidence decreasing upstream in all sexes, was almost certainly due to tag application sites being near important spawning areas (a similar but non-significant trend was shown in 1994; Schubert and Tadey 1997). A relatively high proportion of fish tagged were likely going to spawn near the tagging sites. One solution to this would be to move the tag sites downstream so that only migrating fish (the ideal described by Schaefer 1951) are tagged; however, no viable tagging sites have been found downstream of the current ones. Alternatively, the addition of one or more upstream tagging sites should be considered to reduce the spatial application bias; this technique has succeeded in other systems, such as the Seymour River (Houtman and Schubert 2000). The late start of tag application probably contributed to the spatial application bias, since earlier migrants tended to spawn further upstream (as indicated by peak recovery in areas 8-10 occurring on October 6, five days earlier than in areas 0-3; Appendix 4). An earlier start of application should, therefore, also help reduce this bias. The temporal bias in male recoveries involved decreasing tag recovery rates with application date. This was probably caused, at least in part, by increasing water levels over the last 6-8 days of recovery (J. Tadey, pers. obs.), and by ending recovery before recovery rates dropped to near zero (see Appendix 4); however, such causes would be expected to produce similar patterns regardless of sex and size. While a similar pattern was shown in jacks, no pattern was evident in females.

In this study, the overall tag incidence was 4.3%, and the average recovery rate was 32.4%. These values, while substantially higher than those typical for contemporary Fraser River sockeye mark-recapture studies, are similar to those achieved in Birkenhead River mark-recapture studies in 1994 (Schubert and Tadey 1997), 1996 and 1997 (unpublished data). Consequently, precision estimates in these studies, ranging from 8% to 15% of the population estimates (male and female populations between 16,867 and 30,287), have also been substantially higher than those typical of contemporary studies with similar population sizes. Tagging at these high rates (approximately 4 times the 1% goal in other systems) has been considered desirable because floods are more likely to occur in this system during the study, which would reduce recovery rate and thus precision.

The use of alternative tagging sites, however, would likely result in reduced tagging rates (given similar crew sizes) and consequent precision. To examine the consequences of such reductions, a simulation was used to calculate the expected precision for a given population size, tagging rate and recovery rate (and assuming proportional recovery of tagged and untagged carcasses). For a population size of 20,000, and a recovery rate of 25%, reducing tagging rate from 4% to 2% causes (expected) 95% confidence intervals to increase from 11.7% to 16.6%. When recovery rate is reduced to 20%, the same change in tagging rate increases the 95% confidence intervals from 13.5% to 19.1%. Further, when the population size is doubled, the effect of reduction in tagging rate on precision is much reduced. Thus, future studies can afford to achieve somewhat reduced tagging rates without unacceptably large reduction in precision, especially in years of larger expected run sizes.

RECOMMENDATIONS

The 1995 study was similar to that conducted in 1994 (Schubert and Tadey 1997), but included modifications designed to reduce sample selectivity and to facilitate assessment of tag loss and the effects of sub-acute and acute stress. Future studies should build on the 1995 study design, with the following modifications.

1. The following changes will improve the estimation of tag-status identification error rate:

- To allow for incorporation of the uncertainty in the misidentification error rate into population estimates (Rajwani and Schwarz 1997), carcasses identified as disk tagged and/or secondary marked on the recovery survey should be excluded from the resurvey, by chopping them in three (with chops in front and behind the dorsal fin). This change will also enable an estimation of the rate at which carcasses which had lost a disk tag but retained a secondary mark were misidentified as unmarked on the initial survey;
- The resurvey should be more spatially and temporally representative;
- Resurveyed carcasses must either be thrown out of the recovery area or chopped to distinguish them from un-resurveyed recoveries;
- The sex of resurveyed carcasses should be recorded when possible.

2. This stock has a high proportion of jacks relative to other Fraser River sockeye. To improve estimation of jack and adult male popula-

tion sizes, both tagged and untagged male carcasses should be separated into two NF length categories, with the categories divided at a length that will tend to separate jacks and adult males.

3. The following changes would help to reduce the severity of spatial application bias:

- Addition of a tagging site below the current ones, if possible at a holding area between spawning areas, if any viable sites exist;
- Addition of a tagging site in upper area 2 or in area 3, at a holding area between spawning areas;
- Starting tagging at the start of immigration.

4. In order to provide data that will help test important assumptions of the model, the following additions should be considered:

- For areas in which tag application occurs, carcass recovery records should distinguish recoveries made above and below tagging sites. For areas in which several nearby tagging sites are used, records should identify three recovery locations: i) below the furthest downstream tagging site, ii) above the furthest upstream site and iii) the remainder of the area. This minor change will allow more extensive testing to ensure that tagging stress (or potentially, but less likely, application selectivity) is not severe enough to affect the distribution and mortality schedules of tagged fish;
- Carcasses in selected deep pools and other areas unavailable to standard recoveries should be recovered to provide a test of the assumption that tagged and untagged carcasses were equally likely to be recovered. These collections should be made as representative as possible.

5. The rate of sex-identification errors is estimated from the recovery sample (only a subsample of the application sample). The uncertainty in this estimate contributes to the uncertainty in the population estimates; currently, this contribution is unaccounted for. Analytical methods should be developed to allow for the variance in these error rate estimates to be incorporated into the variance of the population estimates.

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APPENDICES

Appendix 1. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the effective number of female spawners, in the Birkenhead River, 1938-1995.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
1938	-	-	11,100	150	2,894	8,056	95.0%	7,653
1939	10-Sep	Oct 01-Oct 05	15,435	155	6,112	9,168	95.0%	8,710
1940	29-Aug	Sep 20-Sep 26	29,580	5,810	11,110	12,660	94.8%	12,007
1941	-	-	46,490	18,320	10,090	18,080	95.0%	17,176
1942	8-Sep	Oct 01-Oct 05	93,099	1,257	24,271	67,571	98.1%	66,253
1943	1-Sep	Sep 27-Oct 02	50,668	2,112	21,491	27,065	93.3%	25,252
1944	2-Sep	Sep 27-Oct 02	69,111	22,164	21,196	25,751	94.1%	24,237
1945	6-Sep	Oct 01-Oct 05	96,664	8,632	29,270	58,762	95.5%	56,088
1946	31-Aug	Sep 29-Oct 03	93,243	5,874	20,346	67,023	98.8%	66,246
1947	25-Aug	Sep 29-Oct 03	123,627	36,240	34,693	52,694	93.2%	49,095
1948	1-Sep	Sep 27-Oct 02	122,424	38,637	24,509	59,278	92.4%	54,755
1949	5-Sep	Oct 04-Oct 08	74,085	3,581	25,882	44,622	97.1%	43,328
1950	1-Sep	Oct 01-Oct 05	72,567	8,127	19,956	44,484	93.0%	41,370
1951	1-Sep	Oct 01-Oct 05	42,063	20,767	6,839	14,457	94.0%	13,589
1952	28-Aug	Sep 25-Sep 30	77,386	30,345	18,362	28,679	86.3%	24,744
1953	20-Aug	Sep 24-Sep 25	55,823	13,332	19,074	23,417	69.6%	16,287
1954	30-Aug	Sep 25-Sep 27	40,453	22,240	8,493	9,720	88.8%	8,635
1955	7-Sep	Sep 23-Sep 25	24,450	9,897	5,944	8,609	95.1%	8,185
1956	2-Sep	[a]	57,899	8,145	18,828	30,926	87.8%	27,156
1957	4-Sep	Sep 25-Sep 28	24,168	9,632	7,041	7,495	94.3%	7,068
1958	5-Sep	Sep 26-Sep 29	33,055	17,889	9,030	6,136	89.8%	5,510
1959	1-Sep	Sep 23-Sep 28	38,604	12,445	13,476	12,683	89.8%	11,388
1960	28-Aug	Sep 24-Sep 26	39,848	3,010	15,376	21,462	89.5%	19,198
1961	25-Aug	Sep 24-Sep 28	49,627	17,946	15,322	16,359	64.5%	10,550
1962	5-Sep	Sep 22-Sep 28	52,146	25,777	10,322	16,047	89.2%	14,311
1963	1-Sep	Sep 21-Sep 25	67,151	18,258	17,425	31,468	66.0%	20,769
1964	29-Aug	Sep 19-Sep 21	69,939	21,031	20,271	28,637	97.7%	27,978
1965	21-Aug	Sep 16-Sep 23	30,008	13,778	5,587	10,643	91.8%	9,769
1966	2-Sep	Sep 20-Sep 23	81,134	61,018	5,569	14,547	92.5%	13,462
1967	1-Sep	Sep 18-Sep 22	58,036	18,160	17,078	22,798	77.1%	17,580
1968	13-Aug	Sep 22-Sep 24	83,750	25,803	16,995	40,952	75.8%	31,042
1969	25-Aug	Sep 23-Sep 26	64,527	27,145	14,624	22,758	62.9%	14,324
1970	3-Sep	Sep 24-Sep 26	72,760	42,104	9,847	20,809	92.5%	19,252
1971	9-Sep	Sep 22-Sep 25	32,672	8,043	7,831	16,798	96.1%	16,143
1972	28-Aug	Sep 23-Sep 26	113,097	58,581	25,009	29,507	88.8%	26,202
1973	1-Sep	Sep 23-Sep 26	139,295	82,642	25,942	30,711	92.4%	28,374
1974	1-Sep	Sep 26-Oct 01	173,463	53,826	31,224	88,413	96.7%	85,495
1975	-	Sep 23-Sep 28	92,928	31,390	24,919	36,619	63.7%	19,653
1976	1-Sep	Sep 23-Sep 28	108,121	30,816	25,962	51,343	97.4%	50,023
1977	1-Sep	Sep 21-Sep 28	43,139	19,294	9,660	14,185	90.2%	12,799
1978	1-Sep	Sep 26-Sep 29	99,857	5,075	46,382	48,400	99.5%	47,158
1979	-	Sep 24-Sep 29	78,088	17,100	21,712	39,276	90.3%	35,168
1980	5-Sep	Sep 21-Sep 27	90,922	12,309	35,009	43,604	75.2%	32,786

Continued

Appendix 1. Annual date of sockeye salmon arrival and peak spawning, jack and adult escapement by sex, percent spawning success and the effective number of female spawners, in the Birkenhead River, 1938-1995.

Year	Arrival	Period of peak spawning	Escapement Total	Jacks	Males	Females	Percent spawning success	Effective females
Continued								
1981	1-Sep	Sep 23-Sep 30	65,495	16,472	20,576	28,447	95.5%	27,175
1982	29-Aug	Sep 20-Sep 30	128,771	9,033	46,350	73,388	98.6%	72,355
1983	-	Sep 20-Sep 29	48,841	4,812	20,156	23,873	88.4%	21,069
1984	1-Sep	Sep 21-Sep 28	42,849	2,604	15,893	24,352	95.4%	23,226
1985	10-Sep	Sep 18-Sep 23	37,612	25,707	5,845	6,060	95.0%	5,757
1986	4-Sep	Oct 03-Oct 10	348,294	12,664	135,411	200,219	98.8%	197,841
1987	4-Sep	Oct 01-Oct 10	168,841	3,992	71,262	93,587	95.6%	89,429
1988	29-Aug	Sep 21-Sep 26	177,327	10,736	77,390	89,201	84.7%	75,537
1989	31-Aug	Sep 22-Sep 29	46,703	17,369	13,426	15,908	98.9%	15,690
1990	25-Aug	Sep 29-Oct 06	170,262	3,489	69,300	97,473	99.6%	97,108
1991	Early Sep	Oct 01-Oct 07	316,469	22,843	138,913	154,713	98.3%	152,077
1992	Early Sep	Sep 27-Oct 01	218,533	32,625	91,464	94,444	98.9%	93,455
1993	Early Sep	Late Sep	250,425	5,471	93,434	151,520	99.7%	151,089
1994	Early Sep	Sep 25-Oct 01	39,445	211	16,874	22,360	99.8%	22,315
1995	Early Sep	Late Sep	42,985	3,139	19,838	20,008	93.1%	18,632

[a] Two peaks: Sep 18-Sep 21 and Oct 02-Oct 05.

Appendix 2. Number of sockeye salmon marked, and the number of recaptures of previously marked sockeye, by date, location and sex, in the Birkenhead River, 1995. Values are not corrected for sex identification errors.

Date	Tagging site	Number of sets	Sockeye marked			Recaptures		
			Male	Female	Jack	Male	Female	Jack
6-Sep	Primary	3	42	53	7	6	6	0
7-Sep	Primary	3	14	10	5	2	0	0
8-Sep	Primary	3	29	13	0 [1a]	3	1	0
	Old bridge	1	5	8	3	0	0	0
9-Sep	Primary	2	12	3	3	0	0	0
	Old bridge	1	1	4	0	0	0	0
10-Sep	Primary	3	16	33	3	0	2	1
	Old bridge	1	1	3	0	0	0	0
11-Sep	Primary	3	26	34	2 [1a]	4	2	1
	Old bridge	1	3	2	1	0	0	0
12-Sep	Primary	3	31	29 [1c]	0	2	2	0
	Old bridge	1	9 [1b]	21	5	0	3	1
13-Sep	Primary	3	20	20	1	2	6	0
	Old bridge	1	12 [2a]	19	5	2	2	1
14-Sep	Primary	2	17	13 [1a,1c]	8	1	1	2
	Old bridge	1	13	14	8	1	0	1
15-Sep	Primary	3	29 [1a]	38 [1c]	8	5	4	2
	Old bridge	1	8	9	14	2	0	1
16-Sep	Primary	3	24	34	6	2	2	1
	Old bridge	1	3	4	8 [1a]	0	0	0
17-Sep	Primary	3	47	53	2	9	4	0
	Old bridge	1	8 [1a,2b]	24	11	0	2	1
18-Sep	Primary	3	43 [1a]	52	4	4	5	1
	Old bridge	1	9	8 [1a]	7	0	1	1
19-Sep	Primary	3	29 [1a]	58	2	2	5	0
	Old bridge	1	8	20	14	0	2	4
20-Sep	Primary	3	25	31	2	2	4	0
	Old bridge	1	6	22	11	0	2	1
21-Sep	Primary	3	23	25	5	0	2	0
	Old bridge	1	1	3	1	0	0	0
22-Sep	Primary	3	44	40 [1a]	4	8	7	0
	Old bridge	1	5	9	2	1	0	1
23-Sep	Primary	3	28	18 [1a]	5	4	2	0
	Old bridge	1	1	3	2	0	0	0
24-Sep	Primary	3	25	28	3	2	4	0
	Old bridge	1	1	9	1	0	0	0
25-Sep	Primary	3	25 [1b]	25	1	3	1	1
	Old bridge	1	1	6	1	0	0	0
26-Sep	Primary	3	18	17	4	2	0	0
	Old bridge	1	2	4	4	0	0	0
27-Sep	Primary	3	13	11	0	3	0	0
	Old bridge	1	1	2	2	0	0	0
28-Sep	Primary	3	22	28	4	2	1	0
	Old bridge	1	1	1	0	0	0	0
29-Sep	Primary	3	9 [1a]	8	1	2	2	0
	Old bridge	1	0	0	1	0	0	0
30-Sep	Primary	3	12	13	0	1	0	0
	Old bridge	1	1	1	0	0	0	0

Continued

Appendix 2. Number of sockeye salmon marked, and the number of recaptures of previously marked sockeye, by date, location and sex, in the Birkenhead River, 1995. Values are not corrected for sex identification errors.

Date	Tagging site	Number of sets	Sockeye marked			Recaptures		
			Male	Female	Jack	Male	Female	Jack
Continued								
1-Oct	Primary	3	7	3	0	0	0	0
	Old bridge	1	1	0	8	0	0	0
2-Oct	Primary	3	6	3	1	0	1	0
3-Oct	Primary	3	8 [1b]	7	1	1	0	0
4-Oct	Primary	3	8	7	1	1	0	0
	Old bridge	1	0	2	1	0	0	0
5-Oct	Primary	2	0	1	1	0	0	0
7-Oct	Primary	1	0	1	0	0	0	0
	Old bridge	1	0	2	2	0	0	0
9-Oct	Primary	2	2	0	0	0	0	0
	Old bridge	1	1	1	0	0	0	0
Total	Primary	90	654 [4a,2b]	709 [3a,3c]	84 [2a]	73	64	9
	Old bridge	27	102 [3a,3b]	201 [1a]	112 [1a]	6	12	12
	Total	117	756 [7a,5b]	910 [4a,3c]	196 [3a]	79	76	21

[a] Fish excluded because elapsed time between release and recovery was less than 5 days.

[b] Fish identified as female at recovery.

[c] Fish identified as male at recovery.

Numbers preceding notes indicate the number of fish to which notes apply.

Appendix 3a. Incidence of net, lamprey and hook marks, predator scars and *Flexibacter columnaris* lesions among adult male sockeye examined during tag application in the Birkenhead River, 1995. Values are not corrected for sex identification errors.

Date	Number examined	Net marks	Lamprey marks	Hook marks	Predator scars	*F. columnaris* [a]
6-Sep	42	9.5%	0.0%	2.4%	9.5%	-
7-Sep	14	14.3%	0.0%	0.0%	0.0%	-
8-Sep	34	17.6%	2.9%	0.0%	2.9%	-
9-Sep	13	7.7%	0.0%	0.0%	0.0%	-
10-Sep	17	0.0%	0.0%	5.9%	0.0%	-
11-Sep	29	17.2%	0.0%	0.0%	3.4%	-
12-Sep	40	10.0%	0.0%	0.0%	10.0%	-
13-Sep	32	12.5%	0.0%	0.0%	0.0%	-
14-Sep	30	10.0%	0.0%	0.0%	13.3%	-
15-Sep	37	10.8%	0.0%	0.0%	2.7%	-
16-Sep	27	11.1%	0.0%	0.0%	0.0%	-
17-Sep	55	14.5%	0.0%	0.0%	10.9%	-
18-Sep	52	7.7%	0.0%	0.0%	7.7%	-
19-Sep	37	5.4%	0.0%	0.0%	0.0%	-
20-Sep	31	12.9%	0.0%	0.0%	9.7%	-
21-Sep	24	12.5%	0.0%	0.0%	8.3%	-
22-Sep	49	6.1%	0.0%	0.0%	8.2%	-
23-Sep	29	13.8%	3.4%	0.0%	0.0%	-
24-Sep	26	11.5%	0.0%	3.8%	11.5%	-
25-Sep	26	11.5%	3.8%	0.0%	11.5%	-
26-Sep	20	35.0%	0.0%	0.0%	15.0%	-
27-Sep	14	21.4%	0.0%	0.0%	7.1%	-
28-Sep	23	13.0%	0.0%	0.0%	21.7%	-
29-Sep	9	11.1%	0.0%	0.0%	0.0%	-
30-Sep	13	23.1%	0.0%	0.0%	15.4%	-
1-Oct	8	12.5%	0.0%	0.0%	12.5%	-
2-Oct	6	16.7%	0.0%	0.0%	16.7%	-
3-Oct	8	12.5%	0.0%	0.0%	25.0%	-
4-Oct	8	0.0%	0.0%	0.0%	12.5%	-
9-Oct	3	0.0%	0.0%	0.0%	0.0%	-
Total	756	11.9%	0.4%	0.4%	7.4%	-

[a] Incidence was not recorded in 1995.

Appendix 3b. Incidence of net, lamprey and hook marks, predator scars and *Flexibacter columnaris* lesions among adult female sockeye examined during tag application in the Birkenhead River, 1995. Values are not corrected for sex identification errors.

Date	Number examined	Net marks	Lamprey marks	Hook marks	Predator scars	*F. columnaris* [a]
6-Sep	53	11.3%	0.0%	0.0%	7.5%	-
7-Sep	10	20.0%	0.0%	0.0%	10.0%	-
8-Sep	21	9.5%	4.8%	0.0%	4.8%	-
9-Sep	7	28.6%	0.0%	0.0%	0.0%	-
10-Sep	36	33.3%	0.0%	0.0%	0.0%	-
11-Sep	36	27.8%	0.0%	0.0%	5.6%	-
12-Sep	50	34.0%	0.0%	0.0%	6.0%	-
13-Sep	39	41.0%	0.0%	0.0%	2.6%	-
14-Sep	27	33.3%	0.0%	0.0%	7.4%	-
15-Sep	47	14.9%	0.0%	0.0%	12.8%	-
16-Sep	38	23.7%	0.0%	0.0%	2.6%	-
17-Sep	77	29.9%	0.0%	0.0%	11.7%	-
18-Sep	60	28.3%	0.0%	0.0%	6.7%	-
19-Sep	78	29.5%	0.0%	0.0%	7.7%	-
20-Sep	53	13.2%	0.0%	0.0%	13.2%	-
21-Sep	28	25.0%	0.0%	0.0%	10.7%	-
22-Sep	49	24.5%	0.0%	0.0%	12.2%	-
23-Sep	21	14.3%	0.0%	0.0%	0.0%	-
24-Sep	37	18.9%	0.0%	0.0%	5.4%	-
25-Sep	31	19.4%	0.0%	0.0%	3.2%	-
26-Sep	21	14.3%	0.0%	0.0%	9.5%	-
27-Sep	13	15.4%	0.0%	0.0%	0.0%	-
28-Sep	29	17.2%	0.0%	0.0%	6.9%	-
29-Sep	8	25.0%	0.0%	0.0%	62.5%	-
30-Sep	14	21.4%	0.0%	0.0%	14.3%	-
1-Oct	3	33.3%	0.0%	0.0%	33.3%	-
2-Oct	3	33.3%	0.0%	0.0%	33.3%	-
3-Oct	7	14.3%	0.0%	0.0%	0.0%	-
4-Oct	9	11.1%	0.0%	0.0%	22.2%	-
5-Oct	1	0.0%	0.0%	0.0%	100.0%	-
7-Oct	3	33.3%	0.0%	0.0%	66.7%	-
9-Oct	1	0.0%	0.0%	0.0%	0.0%	-
Total	910	23.8%	0.1%	0.0%	8.5%	-

[a] Incidence was not recorded in 1995.

Appendix 3c. Incidence of net, lamprey and hook marks, predator scars and *Flexibacter columnaris* lesions among jack sockeye examined during tag application in the Birkenhead River, 1995. Values are not corrected for sex identification errors.

Date	Number examined	Net marks	Lamprey marks	Hook marks	Predator scars	*F. columnaris* [a]
6-Sep	7	0.0%	0.0%	0.0%	14.3%	-
7-Sep	5	20.0%	0.0%	0.0%	0.0%	-
8-Sep	3	0.0%	0.0%	0.0%	0.0%	-
9-Sep	3	0.0%	0.0%	0.0%	0.0%	-
10-Sep	3	0.0%	0.0%	0.0%	0.0%	-
11-Sep	3	0.0%	0.0%	0.0%	0.0%	-
12-Sep	5	0.0%	0.0%	0.0%	20.0%	-
13-Sep	6	0.0%	0.0%	0.0%	0.0%	-
14-Sep	16	0.0%	0.0%	0.0%	0.0%	-
15-Sep	22	0.0%	0.0%	0.0%	22.7%	-
16-Sep	14	7.1%	0.0%	0.0%	0.0%	-
17-Sep	13	7.7%	0.0%	0.0%	0.0%	-
18-Sep	11	9.1%	0.0%	0.0%	0.0%	-
19-Sep	16	12.5%	0.0%	0.0%	0.0%	-
20-Sep	13	7.7%	0.0%	0.0%	0.0%	-
21-Sep	6	0.0%	0.0%	0.0%	0.0%	-
22-Sep	6	16.7%	0.0%	0.0%	0.0%	-
23-Sep	7	0.0%	0.0%	0.0%	14.3%	-
24-Sep	4	25.0%	0.0%	0.0%	0.0%	-
25-Sep	2	0.0%	0.0%	0.0%	0.0%	-
26-Sep	8	0.0%	0.0%	0.0%	0.0%	-
27-Sep	2	50.0%	0.0%	0.0%	50.0%	-
28-Sep	4	25.0%	0.0%	0.0%	0.0%	-
29-Sep	2	0.0%	0.0%	0.0%	0.0%	-
1-Oct	8	12.5%	0.0%	0.0%	0.0%	-
2-Oct	1	100.0%	0.0%	0.0%	0.0%	-
3-Oct	1	0.0%	0.0%	0.0%	100.0%	-
4-Oct	2	50.0%	0.0%	0.0%	0.0%	-
5-Oct	1	0.0%	0.0%	0.0%	0.0%	-
7-Oct	2	0.0%	0.0%	0.0%	0.0%	-
Total	196	7.1%	0.0%	0.0%	5.1%	-

[a] Incidence was not recorded in 1995.

Appendix 4. Daily sockeye salmon carcass recoveries, by recovery area, mark status and sex, in the Birkenhead River, 1995. Values are not corrected for size class identification errors.

			Disk tag and/or secondary mark present			Unmarked			Total		
Date	Area	Number of surveys	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
7-Sep	1	-	0	0	0	2	0	0	2	0	0
9-Sep	1	-	0	0	0	4	3	2	4	3	2
10-Sep	1	-	0	0	0	0	0	0	0	0	0
	2	-	0	0	0	5	4	1	5	4	1
	3	-	0	0	0	4	5	2	4	5	2
11-Sep	1	-	0	0	0 [1a]	5	4	5	5	4	5
12-Sep	2	-	0	0	0	3	6	4	3	6	4
	3	-	0	0	0	3	1	0	3	1	0
	8	-	0	0	0	4	2	0	4	2	0
	9	-	0	0	0	5	2	0	5	2	0
13-Sep	5	-	0	0	0	2	2	0	2	2	0
	6	-	0	0	0	5	2	0	5	2	0
14-Sep	0	-	0	0	0	0	3	0	0	3	0
	1	-	0 [3a]	0	0 [1a]	23	21	9	23	21	9
15-Sep	9	-	0	0	0	3	4	1	3	4	1
	10	-	0	0	0	0	1	0	0	1	0
16-Sep	1	-	0	0	0 [1a]	4	4	3	4	4	3
	2	-	0	1	0	24	16	6	24	17	6
	3	-	0	0	0	8	3	0	8	3	0
	4	-	0	0	0	2	10	2	2	10	2
	7	-	0	0	0	7	3	0	7	3	0
17-Sep	0	-	0	0	0	0	0	0	0	0	0
	1	-	0 [1a]	1	0	24	31	14	24	32	14
	5	-	0	0	1	10	2	3	10	2	4
	6	-	0	0	0	4	5	1	4	5	1
18-Sep	8	-	0	0	0	24	30	2	24	30	2
	9	-	0	0	0	38	29	2	38	29	2
	10	-	0	1	0	1	3	0	1	4	0
19-Sep	4	-	0	0	0	8	14	2	8	14	2
	5	-	0	0	0	5	10	1	5	10	1
	6	-	0	0	0	7	14	3	7	14	3
	7	-	0	0	0	47	39	3	47	39	3
20-Sep	0	-	1	0	1	5	14	2	6	14	3
	1	-	4 [3a]	8 [1a]	2	72	80	28	76	88	30
	2	-	3	3	0	85	92	5	88	95	5
	3	-	0	1	0	20	16	1	20	17	1
21-Sep	8	-	0	0	0	28	34	0	28	34	0
	9	-	0	0	0	70	62	2	70	62	2
	10	-	0	0	0	2	4	0	2	4	0
22-Sep	4	-	0	2	0	21	30	2	21	32	2
	5	-	0	1	0	22	24	4	22	25	4
	6	-	0	0	0	17	27	1	17	27	1
	7	-	1	1	0	55	46	4	56	47	4
23-Sep	1	-	7	4 [1a]	1	91	84	13	98	88	14
	2	-	0	5	0	100	82	7	100	87	7
	3	-	1	1	0	27	21	4	28	22	4
24-Sep	0	-	1	0	0	18	3	5	19	3	5
	1	-	4	8	1	79	68	19	83	76	20

Continued

Appendix 4. Daily sockeye salmon carcass recoveries, by recovery area, mark status and sex, in the Birkenhead River, 1995. Values are not corrected for size class identification errors.

			Disk tag and/or secondary mark present			Unmarked			Total		
Date	Area	Number of surveys	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Continued											
25-Sep	8	-	0	2	0	57	52	4	57	54	4
	9	-	0	0	0	84	98	4	84	98	4
	10	-	0	0	0	2	3	0	2	3	0
26-Sep	4	-	0	0	0	16	11	5	16	11	5
	5	-	0	0	0	24	27	3	24	27	3
	6	-	0	2	0	21	38	3	21	40	3
	7	-	1	1	0	82	97	1	83	98	1
27-Sep	0	-	3	0	1 [1c]	22	9	9	25	9	10
	1	-	12	16 [1a]	4	136	139	28	148	155	32
	2	-	2	9	1	110	146	9	112	155	10
	3	-	1	1	0	39	39	5	40	40	5
28-Sep	8	-	0	2	0	63	59	9	63	61	9
	9	-	0	2	0	46	83	2	46	85	2
	10	-	0	0	0	1	6	1	1	6	1
29-Sep	4	-	1	2	0	28	28	0	29	30	0
	5	-	0	1	0	24	26	1	24	27	1
	6	-	2	1	0	26	30	3	28	31	3
	7	-	2	2	0	43	36	3	45	38	3
30-Sep	0	-	1	0	2	15	5	6	16	5	8
	1	-	11	33	7 [4c]	234	312	46	245	345	53
	2	-	6	13	0	96	163	10	102	176	10
	3	-	2	2	0	23	45	1	25	47	1
1-Oct	8	-	2	1	0	40	76	6	42	77	6
	9	-	1	2	0	71	101	4	72	103	4
	10	-	0	2	0	2	11	1	2	13	1
2-Oct	4	-	1	2	0	59	48	1	60	50	1
	5	-	0	4	0	35	56	2	35	60	2
	6	-	1	3	0	53	106	4	54	109	4
	7	-	3	1	0	81	95	3	84	96	3
3-Oct	0	-	2	2	1	27	20	4	29	22	5
	1	-	11 [1a,1b]	36	6	286	448	43	297	484	49
	2	-	15	21	0	136	295	15	151	316	15
	3	-	1	0	0	27	50	0	28	50	0
4-Oct	8	-	0	1	0	33	55	1	33	56	1
	9	-	0	0	0	12	33	2	12	33	2
	10	-	0	0	0	8	7	0	8	7	0
5-Oct	4	-	1	1	0	29	63	2	30	64	2
	5	-	2	3	0	38	47	4	40	50	4
	6	-	0	0	0	33	81	2	33	81	2
	7	-	2	4	0	79	103	6	81	107	6
6-Oct	0	-	4	0	0	50	45	11	54	45	11
	1	-	19 [1b]	34	1	389	643	50	408	677	51
	2	-	10	17	0	197	404	14	207	421	14
	3	-	2	3	0	34	73	0	36	76	0
7-Oct	8	-	0	2	0	10	56	0	10	58	0
	9	-	0	1	0	14	33	1	14	34	1
	10	-	0	0	0	0	1	0	0	1	0

Continued

Appendix 4. Daily sockeye salmon carcass recoveries, by recovery area, mark status and sex, in the Birkenhead River, 1995. Values are not corrected for size class identification errors.

Date	Area	Number of surveys	Disk tag and/or secondary mark present			Unmarked			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Continued											
8-Oct	4	-	0	0	0	14	30	0	14	30	0
	5	-	1	0	0	28	55	4	29	55	4
	6	-	1	1	0	47	70	4	48	71	4
	7	-	0	1	0	24	79	1	24	80	1
9-Oct	0	-	2	0	2	76	78	13	78	78	15
	1	-	27	27	4	361	541	63	388	568	67
	2	-	6	18	1	208	365	8	214	383	9
	3	-	1	3	0	27	69	1	28	72	1
10-Oct	8	-	0	0	0	6	7	0	6	7	0
	9	-	0	0	0	12	28	1	12	28	1
	10	-	0	0	0	0	1	0	0	1	0
11-Oct	4	-	0	1	0	11	17	0	11	18	0
	5	-	1	0	0	12	17	0	13	17	0
	6	-	0	0	0	10	8	0	10	8	0
	7	-	0	1	0	10	19	0	10	20	0
12-Oct	0	-	2	2	0	50	28	2	52	30	2
	1	-	17	16	1	228	321	20	245	337	21
	2	-	2	7	0	77	168	1	79	175	1
	3	-	1	2	0	15	33	0	16	35	0
13-Oct	8	-	0	0	0	5	15	0	5	15	0
	9	-	0	0	0	4	14	0	4	14	0
	10	-	0	0	0	0	1	0	0	1	0
14-Oct	4	-	0	0	0	3	11	0	3	11	0
	5	-	0	0	0	3	6	0	3	6	0
	6	-	0	0	0	4	6	0	4	6	0
	7	-	0	0	0	3	6	0	3	6	0
15-Oct	0	-	1	0	0	5	1	0	6	1	0
	1	-	0	0	0	23	19	1	23	19	1
	2	-	0	0	0	10	23	3	10	23	3
	3	-	0	3	0	5	8	0	5	11	0
16-Oct	0	-	1	2	0	10	6	0	11	8	0
	1	-	2	4	0	58	62	3	60	66	3
	2	-	1	2	0	9	21	0	10	23	0
	3	-	0	2	0	6	11	0	6	13	0

Continued

Appendix 4. Daily sockeye salmon carcass recoveries, by recovery area, mark status and sex, in the Birkenhead River, 1995. Values are not corrected for size class identification errors.

Date	Area	Number of surveys	Disk tag and/or secondary mark present			Unmarked			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Continued											
Total	0	12	18	6	7 [1c]	278	212	52	296	218	59
	1	18	114 [8a,2b]	187 [3a]	27 [3a,4c]	2,019	2,780	347	2,133	2,967	374
	2	13	45	96	2	1,060	1,785	83	1,105	1,881	85
	3	13	9	18	0	238	374	14	247	392	14
	4	10	3	8	0	191	262	14	194	270	14
	5	11	4	9	1	203	272	22	207	281	23
	6	11	4	7	0	227	387	21	231	394	21
	7	10	9	11	0	431	523	21	440	534	21
	8	10	2	8	0	270	386	22	272	394	22
	9	11	1	5	0	359	487	19	360	492	19
	10	10	0	3	0	16	38	2	16	41	2
	Total	-	209 [8a,2b]	358 [3a]	37 [3a,5c]	5,292	7,506	617	5,501	7,864	654

[a] Fish excluded because elapsed time between release and recovery was less than 5 days.

[b] Fish with NF length <46 cm. [c] Fish with NF length $\geq$46 cm.

Numbers preceding notes indicate the number of carcasses to which notes apply.

Appendix 5. Number of sockeye salmon carcasses examined and disk tags recovered, by date and recovery area, in the resurvey of the Birkenhead River, 1995. Sex and age class of recoveries was not recorded

Date	Area	Number of surveys	Disk tag present	Total examined	Disk tag incidence
29-Sep	1	-	0	227	0.000
	3	-	0	35	0.000
1-Oct	1	-	0	345	0.000
2-Oct	2	-	0	239	0.000
5-Oct	1	-	0	502	0.000
	2	-	0	62	0.000
6-Oct	1	-	0	222	0.000
7-Oct	1	-	0	505	0.000
	2	-	0	274	0.000
10-Oct	2	-	0	119	0.000
	3	-	0	14	0.000
11-Oct	1	-	0	270	0.000
Total	1	6	0	2,071	0.000
	2	4	0	694	0.000
	3	2	0	49	0.000
Total	-	-	0	2,814	0.000

Appendix 6. Fecundity sampling results and analytic details for sockeye salmon captured in the Birkenhead River, 1995.

Age	Standard length (cm)[a]	Skein weight (g)	Skein sub-sample Weight (g)	Skein sub-sample Egg count	Estimated fecundity	Actual fecundity	Loose eggs	Adjusted fecundity
4_2	50.1	374.7	126.2	1,249	3,708		8	3,716
4_2	50.8	319.9	108.7	1,206	3,549		0	3,549
4_2	51.0	355.7	120.1	1,214	3,596		3	3,599
4_2	51.0	375.5	168.0	1,990	4,448	4,465	3	4,468
4_2	51.2	354.7	120.9	1,092	3,204		10	3,214
4_2	51.5	380.0	172.2	1,760	3,884	3,888	10	3,898
4_2	51.5	389.6	131.6	1,358	4,020		11	4,031
4_2	51.7	376.5	127.8	1,346	3,965		0	3,965
4_2	51.9	407.5	137.4	1,459	4,327		10	4,337
4_2	52.1	378.3	128.4	1,392	4,101		10	4,111
4_2	52.3	363.7	123.1	1,339	3,956		0	3,956
4_2	52.4	399.1	135.7	1,350	3,970		10	3,980
4_2	53.3	369.1	125.1	1,342	3,959		10	3,969
4_2	53.7	434.4	146.8	1,563	4,625		4	4,629
4_2	55.2	428.4	143.1	1,266	3,790		12	3,802
4_2	n/r	643.8	217.2	1,797	5,326		0	5,326
5_2	53.7	467.1	157.1	1,554	4,620		10	4,630
5_2	56.0	454.0	218.1	2,389	4,973	5,006	12	5,018
5_2	58.0	556.3	187.7	1,623	4,810		1	4,811
5_2	58.3	513.1	172.5	1,618	4,813		1	4,814
5_2	59.3	567.1	192.7	1,842	5,421		10	5,431
5_2	59.4	519.4	175.4	1,724	5,105		4	5,109
5_2	59.5	422.2	143.1	1,344	3,965		574	4,539
5_2	61.5	551.3	290.9	3,148	5,966	5,963	1	5,964
n/r	53.6	418.9	208.1	1,967	3,960	3,993	4	3,997
Means								
4_2 (n=16)	52.0	396.9	139.5	1,420	4,040	4,177	6	4,046
5_2 (n=8)	58.2	506.3	192.2	1,905	5,019	5,485	77	5,096

[a] Not adjusted for shrinkage that occurs in carcass recoveries.

Appendix 7. Proportion at age and mean length (Standard and POH) at age, by sex, from the random and jack sockeye carcass samples collected on the Birkenhead River, 1995.

Location	Sex	Sampling date	NF length [a]	Age	Sample size	Percent	Standard length (cm) Mean	Standard length (cm) Standard deviation	POH length (cm) Mean	POH length (cm) Standard deviation
Random carcass sample										
Birkenhead River	Male	Total	<46cm	3_2	36	92.3%	35.8	1.7	32.0	1.6
				4_3	3	7.7%	37.6	1.2	33.3	0.2
				Unaged	8	-	36.3	2.0	32.2	1.7
			≥46cm	4_2	202	68.9%	54.6	3.5	47.1	2.8
				5_2	90	30.7%	62.6	2.3	53.9	1.9
				5_3	1	0.3%	54.8	-	47.5	-
				Unaged	17	-	53.5	5.8	46.3	4.5
	Female	Total	≥46cm	4_2	110	64.3%	51.0	1.8	46.1	1.6
				5_2	59	34.5%	57.3	2.4	51.6	2.2
				5_3	2	1.2%	49.3	0.3	44.6	0.4
				Unaged	9	-	50.9	3.8	45.7	3.0
Jack sample [b]										
Birkenhead River	Male	Total	<46cm	3_2	93	93.9%	37.1	1.5	33.5	-
				4_3	6	6.1%	38.3	1.5	-	-
				Unaged	18	-	37.6	1.5	34.6	0.7
			≥46cm	3_2	2	12.5%	41.6	0.1	-	-
				4_2	14	87.5%	45.9	2.0	-	-
				Unaged	5	-	47.1	1.5	-	-

[a] NF lengths were not measured in the PSC sample. However, carcasses with standard length>41.5 cm were estimated to have NF length>46cm.

[b] In the jack sample, POH lengths were only measured on one age 3_2 and two unaged carcasses.