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**ESTIMATION OF THE 1994 BIRKENHEAD RIVER  
SOCKEYE SALMON (*Oncorhynchus nerka*) ESCAPEMENT**

**by**

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## ABSTRACT

Schubert, N.D., and J.A. Tadey. 1997. Estimation of the 1994 Birkenhead River sockeye salmon (*Oncorhynchus nerka*) escapement. Can. Manuscr. Rep. Fish. Aquat. Sci. 2399: 35 p.

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

The Birkenhead River supports a major sockeye salmon stock which shows little evidence of cyclic dominance; escapements have exceeded 25,000 almost every year since 1940. Sockeye were captured while migrating through the Birkenhead River at a site near the lower limit of spawning; 1,808 were released with disk tags. The spawning grounds were surveyed through the period of spawning and die-off; 9,668 carcasses were recovered, of which 438 had disk tags. The 1994 escapement was estimated, using the pooled Petersen estimator, at 16,874 adult males, 22,360 adult females and 211 jacks (age 3<sub>2</sub> males).

The report identifies biases in the tag application and carcass recovery samples and discusses their potential impact on the population estimates. It concludes with recommendations for the improvement of study design, including improved allocation of sampling effort, resurvey procedures and the assessment of disk tag loss and handling stress.

## RÉSUMÉ

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En 1986, le ministère des Pêches et Océans (MPO) a accepté d'estimer l'échappée des saumons sockeye (*Oncorhynchus nerka*) pour le compte de la Commission internationale des pêcheries de saumon du Pacifique. Le MPO a adopté un système à deux niveaux permettant d'estimer les échappées importantes (plus de 25 000) à l'aide de clôtures de dénombrement ou d'études de marquage-recapture, et les petites échappées (moins de 25 000) à l'aide de techniques visuelles.

La rivière Birkenhead renferme un important stock de saumons sockeye qui ne présente guère une dominance cyclique; les échappées ont dépassé 25 000 presque chaque année depuis 1940. Les saumons sockeye ont été capturés pendant leur remontée dans la rivière Birkenhead à un endroit près de la limite inférieure de frai; 1 808 saumons ont été relâchés avec des étiquettes circulaires. Les frayères ont été étudiées pendant la période de frai et la période de mortalité; des 9 668 carcasses récupérées, 438 étaient munies d'une étiquette. Grâce à l'estimateur groupé de Petersen, l'échappée pour 1994 a été évaluée à 16 760 adultes mâles, 22 360 adultes femelles et 325 jeunes mâles (âgés de 3<sub>2</sub>).

Dans le rapport, on donne les biais relatifs à l'application des étiquettes et aux échantillons de récupération des carcasses et on examine l'impact qu'ils pourraient avoir sur les valeurs estimatives de population. On termine en formulant des recommandations relatives à l'amélioration du plan d'étude, y compris l'amélioration des opérations d'échantillonnage, des méthodes à appliquer lors d'un deuxième relevé et de l'évaluation des pertes d'étiquettes et du stress découlant de la manipulation.

## INTRODUCTION

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

Birkenhead River sockeye escapements have been relatively consistent from year to year and, unlike many Fraser River stocks, exhibit little evidence of cyclic dominance (Cass 1989). Spawner abundance has increased from an average of 54,000 in the 1950's and 1960's to an average of over 151,000 in the 1980's and 1990's (Appendix 1). Stream surveys have been conducted in the Birkenhead River system since at least 1905 following the construction of the Pemberton Hatchery (Bolton MS 1976); escapement estimates have been reported regularly since 1938. In 1939-1941, the Birkenhead 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.

The current report is the first published documentation of the Birkenhead River sockeye escapement estimation study since Schaefer's (1951) pioneering work. The report documents the study design, field methods, analytic techniques and results of the 1994 study. Included are estimates of the 1994 age and length of adult males, females and jacks, escapement by sex and age, and average fecundity for the Birken-

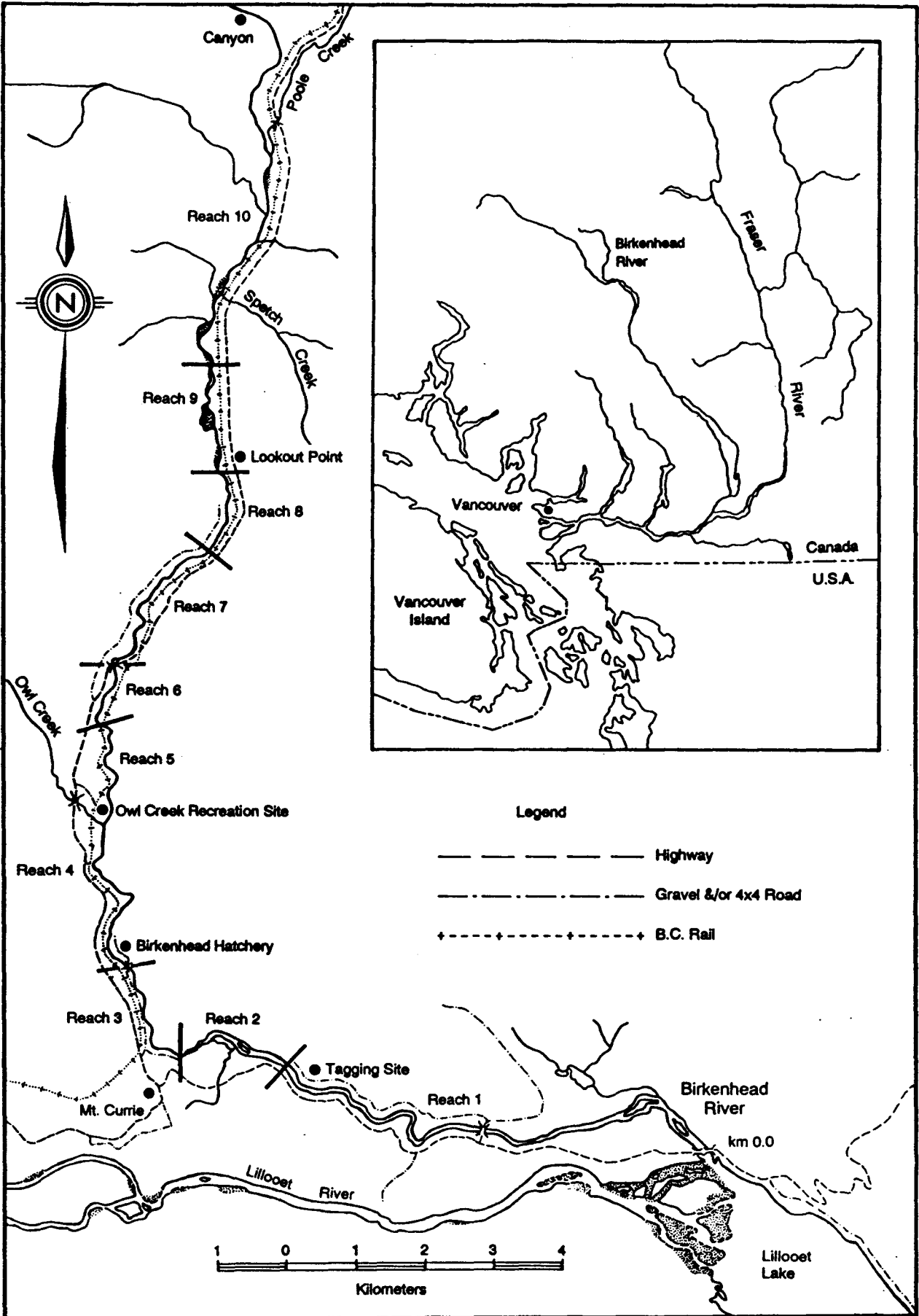
head River population. The report concludes with a discussion of the results and recommendations for the design of future studies.

## 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 is among the largest tributaries of the Harrison-Lillooet system, draining a 596 km<sup>2</sup> glaciated watershed (Brown *et al.* 1979). The river has a mean daily discharge of 24 m<sup>3</sup>s<sup>-1</sup> (1945-1971) with mean daily maxima (71 m<sup>3</sup>s<sup>-1</sup>) and minima (7 m<sup>3</sup>s<sup>-1</sup>) occurring in June and March, respectively (Environment Canada 1991).

The Birkenhead River flows for much of its length through a narrow valley bounded by steep mountains. Tributary streams enter from steep side valleys and generally flow directly into the main river. As a result, spawning habitat is confined to mainstem and side channel areas. The river is passable as far upstream as Taillefer Creek (34 km) (Koster MS 1976); however, a 2 m falls in a deep bedrock canyon located 27.5 km upstream delineates the upper limit of fish passage. Sockeye 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 from the mountains onto the Lillooet River flood plain 8 km upstream, then turns east in a slow moving, meandering channel which drains into Lillooet Lake. Historically, the river flowed directly into the Lillooet River 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 which included the construction of a series of dykes and cutoffs along the lower Birkenhead River and the dredging of the Lillooet Lake outlet to reduce the lake level by 2.5 m (Hamilton 1994). These activities increased the length of the Birkenhead River but reduced the potential spawning area.

The Birkenhead River was divided into ten reaches to facilitate the data aggregations required for bias testing. Reaches were established based on three criteria: homogeneity of physical characteristics such as gradient, channel morphology and substrate type; the ability of the



crews to access and survey a reach in one day; and the existence of easily identifiable land marks to delineate the reaches. The reaches are described below.

In reaches 1-2, the river is characterized by a meandering channel with dense streamside vegetation. Reach 1 (km 0 to km 7.3), extending from Lillooet Lake upstream to a set of old bridge abutments, has a sand and mud substrate in the lower 4.8 km and a gravel and sand substrate in the upper 2.5 km. The Mount Currie Indian Reserve borders most of the reach. The tagging site was located in Reach 1 at km 6.0. Reach 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 which changes to gravel and cobble.

Reach 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 reach, extending from 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 reaches 4-6, the river is characterized by a 2% gradient, frequent rapids and pools and a substrate of gravel and boulders. Reach 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; Reach 5 (km 13.8 to km 15.4) extends upstream to the B.C. Rail bridge; and Reach 6 (km 15.4 to km 16.4) extends to the Mount Currie-Birken highway bridge.

Reach 7 (km 16.4 to km 19.0) is a narrow gorge where the river flows over a series of small, passable falls. This reach is characterized by long rapids, deep isolated pools and a substrate of mixed gravel, cobble and large boulders.

Reach 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.

Reach 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.

Reach 10 (km 22.1 to km 28.0) extends upstream to the outlet of the Birkenhead Canyon. The lower 3 km is similar in character to the upper portions of Reach 9, above which the valley narrows and the gradient increases, resulting in a river morphology characterized by a single channel, rapids and a rubble substrate. The river is joined by two tributaries: Spetch Creek enters from the east at km 23.4; and Poole Creek enters from the east at km 25.7. Neither support significant sockeye spawning.

## FIELD METHODS

### TAG APPLICATION

The study objective was to apply tags to up to 5% of the sockeye as they migrated past the tagging site located in the lower river. Because an independent estimate of abundance was unavailable, proportional tag application was to be achieved by standardizing effort at six sets per day. Tagging began before abundance was high and continued until the run was virtually complete. Sockeye were captured using a 42 m x 7.5 m x 5 cm-mesh beach seine net. The net was set from an inflatable boat in a downstream arc and withdrawn from the river to enclose a small area of water along the river bank. Captured fish were held in the net until removal for tagging.

Sockeye which were damaged or showed advanced stages of maturation and other species were recorded and released untagged. For previously tagged fish, the tag number was recorded and the tag was checked; if loose, the fish was retagged with the same disk. The remainder were removed from the net and marked with Petersen disk tags in a wooden tray (12 cm x 20 cm x 100 cm) constructed with a flexible plastic bottom and a metre stick recessed in one side; the tray was set in a stand elevated above the water surface. The tags consisted of two red 15 mm diameter laminated cellulose acetate disks threaded through centrally punched holes onto a 77 mm long nickel pin. The pin was inserted with pliers through the musculature and pterygio-

phore bones approximately 12 mm below the anterior portion of the dorsal fin insertion. The disk tags, arranged with one on each side of the fish, were secured by twisting the pin into a double knot. One disk per pair was numbered with a unique code; no secondary marks were applied. Date of capture, disk tag number, nose-fork (NF) length ( $\pm 0.1$  cm), sex (fish with a NF length less than 50 cm were recorded as jacks) and marks (troll, gill net, lamprey or *Flexibacter columnaris* scars) were recorded for each fish released with a disk tag. Condition at release was recorded as 1 (swam away vigorously), 2 (swam away sluggishly) or 3 (required ventilation).

## SPAWNING GROUND SURVEYS

### Main Survey

The survey objective was to representatively sample sockeye carcasses from all Birkenhead River spawning areas throughout the die-off period. In practice, however, survey effort tended to be proportional to carcass abundance. The shores were surveyed on foot by a two person crew, with up to two crews required at the peak of die-off. The surveys were to begin after the first carcasses were observed; a complete survey required three to seven days.

All carcasses which were retrievable by wading into the river to waist depth were enumerated (except predator kills, which were excluded from the survey). To avoid recounting on later surveys, carcasses recovered in reaches 3-10 were thrown on the bank above the high water mark; those recovered in reaches 1-2 (residential areas) were cut in two with a machete. Carcass recoveries were recorded by date, reach, sex, mark status, carcass condition (fresh, tainted or rotten) and female spawning success (0%, 50% or 100% spawned). If a disk tag was present, it was retrieved and the tag number was recorded before the carcass was processed.

### Resurvey

Previously processed carcasses were resampled throughout the recovery period to estimate the number of tagged carcasses whose tag status had been incorrectly identified on the initial survey. The resurvey, conducted by an experienced technician, recorded carcasses by date, reach, sex and mark status.

## BIOLOGICAL SAMPLING

Biological samples were obtained following a protocol provided by the Pacific Salmon Commission. Twenty-six females, killed during the peak of arrival at the tagging site, were sampled for nose-hypural plate (standard) length ( $\pm 0.1$  cm), otoliths and scales (one from each preferred region, as defined by Clutter and Whitesel (1956)), and the egg skeins and loose eggs were removed and preserved in a 10% formaldehyde solution.

Male (including jacks) and female carcasses were randomly sampled as above for postorbital-hypural plate (POH) and standard lengths, otoliths and scales. Sixty females and 120 males were sampled ten days before, during and ten days after the peak die-off. All other jacks were sampled for standard length and scales.

## ANALYTIC PROCEDURES

### TESTS FOR SAMPLING SELECTIVITY

A bias profile was developed by evaluating five potential biases, temporal, spatial, fish size, fish sex and handling stress. Statistical tests were performed to assess whether the conditions of equal probability of capture, complete mixing, and simple random recovery sampling were violated (Seber 1982; p 434-39). Biases were treated in three ways. First, sex-related biases are common in mark-recapture studies and were addressed by stratifying the data by sex. Second, stress-related biases were treated by removing the high stress group from the application sample. Third, the severity of temporal or spatial biases was evaluated by comparing the simple or pooled Petersen estimates with those calculated using Darroch's (1961) and Schaefer's (Ricker 1975) stratified models. A stratified model was used if the confidence limits did not overlap.

### Period

Temporal bias was assessed using chi-square tests of the application and recovery data stratified by equal periods, approximately equal effort (number of sets or passes through the sampling area), and approximately equal numbers of sockeye tagged or recovered. Application sample bias (unequal probability of capture) was assessed by stratifying the recovery sample

as above and comparing the mark incidence among recovery strata, where mark incidence was the proportion of the fish marked with a disk tag. Recovery sample bias (nonrandom sampling in the recovery sample) was assessed by stratifying the application sample as above and comparing the proportions recovered among application strata.

**Location**

Spatial bias was similarly assessed using chi-square tests. Application sample bias was assessed by stratifying the recovery data into geographically discrete groups which allowed sufficient sample sizes in each stratum; mark incidences in each stratum were compared. Recovery bias could not be assessed because tags were applied at a single site.

**Fish Size**

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

**Fish Sex**

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

**Stress**

Potential bias resulting from handling and tagging stress was assessed in two ways. First, three tests were performed to determine whether specific tags should be excluded from the samples: a) fish with less than five days between tag application and recovery were removed from the samples; b) the sample was partitioned into fish which required ventilation at release and those which did not. If a chi-square test showed a significant difference in the proportions recover-

ed, the high stress group was removed from the samples; and c) an identical procedure was used to evaluate fish which were re-captured in subsequent beach seine sets.

Second, two chi-square tests were performed as general indicators of a stress problem: a) percent spawning success was compared between marked and unmarked spawning ground recoveries; and b) the recovery sample was partitioned into those recovered above and below (Reach 1) the tagging site. Disk tag incidence and the percent spawning success of tagged females was compared between each group. Unlike the first series of tests, these tests were not used to exclude specific data from the study. Rather, they provided an indicator of whether study design changes would be required in future studies to address a systemic stress problem.

**ESTIMATION OF SPAWNER POPULATION**

**Data Corrections**

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

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

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

where:

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

- $R_f$  = the number of adult females recovered with disk tags;  
 $R_m$  = the number of adult males recovered with disk tags.

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

$$M_f = M_t - M_m$$

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

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

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

where:

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

### Population Estimator

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

- 4) Estimated Birkenhead River sockeye escapement:

$$N_t = N_m + N_f + N_j$$

where:

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

**Pooled Petersen Estimator:** The pooled Petersen estimator was used to calculate the escapement unless biases were identified which required the stratification of the data set.

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

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

where:

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

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

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

$$V_t = V_m + V_f + V_j$$

= variance of the escapement estimate;

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

= variance of the adult male escapement estimate;

$$V_f = \text{variance of the female escapement estimate (as above);}$$

$$V_j = \text{variance of the jack escapement estimate (as above).}$$

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

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

**Stratified Estimators:** When spatial or temporal biases were identified, stratified estimates were calculated using Schaefer's and Darroch's estimators. The pooled Petersen was the preferred estimator because precision is generally higher; however, if the confidence intervals of the

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

Sex	Disk tags applied <sup>a</sup>	Carcasses examined	Marks recovered				Total	Percent recovered
			Disk tag and secondary mark <sup>b</sup>	Secondary mark only <sup>b</sup>	Disk tag only	Resurvey adjustment		
Male	721 <sup>c</sup>	3,620	0	0	145 <sup>d</sup>	9	154	21.4%
Female	1,059	6,011	0	0	270	14	284	26.8%
Jack	28	37	0	0	0	0	0	0.0%
Total	1,808	9,668	0	0	415	23	438	24.2%

<sup>a</sup>. Corrected for sex identification errors.

<sup>b</sup>. Secondary marks were not applied in 1994.

<sup>c</sup>. Excludes 9 males stressed by recapture.

<sup>d</sup>. Excludes 5 males stressed by recapture.

pooled and the stratified estimates did not overlap, the bias was judged to be severe and the stratified estimator was considered more appropriate. Variance estimation procedures have not been developed for the Schaefer estimator. The variance of the stratified Darroch estimator was calculated using the procedures described by Seber (1982; page 433).

#### Alternate Jack Population Estimator

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

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

where:

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

#### FECUNDITY ESTIMATION

Mean fecundities were calculated by age as follows:

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

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

where:

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

## RESULTS

### TAG APPLICATION

Disk tags were applied to 1,789 sockeye adults and 28 jacks from September 7 to October 4, 1994 (Appendix 2). These data were first adjusted for sex identification error. The sex of 0.7% (1) of the males and 0.4% (1) of the females was recorded incorrectly at the time of tagging. When adjusted for this error, an estimated 730 (40.8%) males, 1,059 (59.2%) females and 28 jacks were released with disk tags. The data were then tested to determine if specific tags should be excluded from subsequent analyses. First, fish with less than five days between tag application and recovery were re-

moved from the application sample. Although none were detected, we note that the delay between the start of tagging (September 7) and recovery (September 26) would have prevented the detection of such fish until late in the study. Second, the sample was partitioned into fish which required ventilation at release and those which did not. Thirty adults (1.7%) and five jacks (17.9%) required ventilation; however, the proportions of these groups recovered (33.3% and 0.0%, respectively) were not significantly different ( $P > 0.05$ ; chi-square) from the nonventilated fish (23.2% and 0.0%). Consequently, they were not removed from the application sample. Third, an identical procedure evaluated fish which were recaptured in subsequent beach seine sets. Tags were applied in the lower part of the spawning area. Consequently, the incidence of recaptures was relatively high: 159 adults and 6 jacks were recaptured once, 17 adults were recaptured twice and one adult was recaptured three times (Appendix 2; Table 2). While most (93%) were recaptured on the same day, some were recaptured up to 13 days after tagging. The proportions of the recaptured adult males and females which were later recovered as carcasses (22.4% and 33.7%) was higher than for the nonrecaptured fish (20.3% and 24.6%); however, the difference was not significant ( $P > 0.05$ ; chi-square). When the recaptured group was further divided into fish recaptured once and those recaptured two or more times, however, the difference was significant ( $P < 0.05$ ; chi-square) in the latter group among males. There was also a significant difference ( $P < 0.01$ ; t-test) in time out to recovery among males, with shorter times for fish which had been recaptured ( $15.1 \pm 1.0$  days) versus those which had not ( $18.5 \pm 0.4$  days). A similar pattern was noted in females ( $16.6 \pm 0.8$  days and  $17.2 \pm 0.8$  days, respectively); however, the difference was not significant ( $P > 0.10$ ; t-test). This suggests that the stress from multiple recaptures altered male behaviour and increased their recovery rate; consequently, these fish were removed from the application (nine disk tags) and recovery (five disk tags) samples. When adjusted for recapture stress, the final disk tag application sample totalled 721 males, 1,059 females and 28 jacks (Table 1).

The mean NF length of males, females and jacks was 64.4 cm, 60.2 cm and 38.5 cm; none were scale sampled. The incidence of net, lamprey and hook marks was 6%, 1% and 4% in

males, 17%, 1% and 2% in females, and 4%, 0% and 0% in jacks (Appendix 3).

## SPAWNING GROUND SURVEYS

### Main Survey

The Birkenhead River was surveyed an average of 8 times (survey frequency varied between reaches) from September 26 to October 22 (Appendix 4), resulting in the recovery of 9,631 sockeye adults and 37 jacks (Table 1; Appendix 4). Of the adults, 38% were male and 62% were female, of which 4.0% and 4.5% had a disk tag. The jack disk tag incidence was 0.0%. The most important recovery areas were reaches 1 (50% of the total recovery), 2 (34%) and 3 (9%).

The average time between release and recovery for disk tagged males and females was 18 days and 17 days, respectively, and was longer among those tagged earlier in the study (Table 3). None were out for less than 5 days. Female spawning success averaged 99.8% and was consistently high throughout the study.

### Resurvey

Previously surveyed reaches were resurveyed an average of twice from October 6 to October 21 (Appendix 5), with most of the resurvey effort allocated to reaches 1 and 2; 811 males, 1,736 females and 0 jacks were reexamined, and 2, 4 and 0 disk tags were recovered. An estimated 9 (5.7%) and 14 (4.9%) disk tagged males and females processed during the main survey were not correctly identified as tagged fish (Table 1). When corrected for this error and adjusted for recapture stress, a total of 154 adult male and 284 female disk tags were recovered, for a disk tag incidence of 4.25% and 4.72%, respectively.

## BIOLOGICAL SAMPLING

Fecundity samples from 17 age 4<sub>2</sub> and 9 age 5<sub>2</sub> females were obtained at the tagging site (Appendix 6). Age 4<sub>2</sub> females had an average standard length of 53.8 cm (range 49.1 cm to 56.8 cm) and an average fecundity of 4,294 (range 3,485 to 5,218). Age 5<sub>2</sub> females had an average standard length of 58.8 cm (range 56.4 cm to 62.1 cm) and an average fecundity of 5,128 (range 4,294 to 5,738).

Table 2. Disk tag application and recovery for fish which were recaptured 0, 1, 2 and 3 times in subsequent beach seine sets in the Birkenhead River, 1994.

Recapture status	Disk tags applied <sup>a</sup>			Disk tags recovered			Percent recovered		
	Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Not recaptured	654	958	22	133	236	0	20.3%	24.6%	0.0%
Recaptures									
1 recapture	67	92	6	12	31	0	17.9%	33.7%	0.0%
2-3 recaptures	9	9	0	5	3	0	55.6%	33.3%	-
Total	76	101	6	17	34	0	22.4%	33.7%	0.0%
Chi-Square Test Result									
Not recaptured versus 1 recapture:							0.10	3.17	-
Not recaptured versus 2-3 recaptures:							4.72	0.05	-
Not recaptured versus all recaptures:							0.07	3.46	-
Critical Chi-Square (df = 1; $\alpha$ = 0.05):							3.84	3.84	-

<sup>a</sup> Corrected for sex identification errors.

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

Location	Section	Period <sup>a</sup>	Time out between tag application and carcass recovery (days)			Female spawning success
			Male	Female	Jack	
Birkenhead River	Tagging site	Early	18.4	19.6	-	99.7%
		Late	17.1	15.5	-	99.9%
		Total	17.7	16.9	-	99.8%
	Above tagging site	Early	21.2	19.5	-	99.5%
		Late	16.4	15.9	-	99.9%
		Total	18.7	17.4	-	99.8%
	Total	Early	19.7	19.0	-	99.6%
		Late	16.8	15.7	-	99.9%
		Total	18.1	17.2	-	99.8%

<sup>a</sup> Time out to recovery: early = 07-Sep to 20-Sep releases; late = 21-Sep to 04-Oct releases.

Female spawning success: early = 26-Sep to 08-Oct recoveries; late = 09-Oct to 22-Oct recoveries.

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

Recovery location	Sample type	Percent at age				POH length (cm) at age			
		3 <sub>2</sub>	4 <sub>2</sub>	5 <sub>2</sub>	6 <sub>3</sub>	3 <sub>2</sub>	4 <sub>2</sub>	5 <sub>2</sub>	6 <sub>3</sub>
Birkenhead River	Male	0.7%	61.1%	36.8%	1.4%	32.0	49.1	54.3	54.5
	Female	0.0%	55.6%	43.9%	0.6%	-	46.9	52.2	53.0
	Jack	96.8%	3.2%	0.0%	0.0%	32.6	-	-	-

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

Recovery period	Number of surveys <sup>a</sup>	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
26-Sep to 01-Oct	3	17	20	0	400	531	7	4.3%	3.8%	0.0%
02-Oct to 06-Oct	3	33	80	0	808	1,249	9	4.1%	6.4%	0.0%
07-Oct to 11-Oct	3	50	85	0	1,114	1,968	16	4.5%	4.3%	0.0%
12-Oct to 16-Oct	3	33	63	0	878	1,481	4	3.8%	4.3%	0.0%
17-Oct to 22-Oct	3	12	22	0	420	782	1	2.9%	2.8%	0.0%
Chi-Square Test Result:								2.33	16.78	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Average recovery effort in reaches 1-3; effort was not consistent between reaches.

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

Recovery period	Number of surveys <sup>a</sup>	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
26-Sep to 04-Oct	4	35	68	0	801	1,186	7	4.4%	5.7%	0.0%
05-Oct to 09-Oct	3	47	92	0	1,097	1,675	24	4.3%	5.5%	0.0%
10-Oct to 13-Oct	3	31	57	0	809	1,624	2	3.8%	3.5%	0.0%
14-Oct to 17-Oct	2	22	35	0	541	886	4	4.1%	4.0%	0.0%
18-Oct to 22-Oct	3	10	18	0	372	640	0	2.7%	2.8%	-
Chi-Square Test Result:								2.25	16.64	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Average recovery effort in reaches 1-3; effort was not consistent between reaches.

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

Recovery period	Number of surveys <sup>a</sup>	Carcasses recovered with disk tags			Total recovery			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
26-Sep to 04-Oct	4	35	68	0	801	1,186	7	4.4%	5.7%	0.0%
05-Oct to 08-Oct	2	32	55	0	790	1,139	16	4.1%	4.8%	0.0%
09-Oct to 11-Oct	2	33	62	0	731	1,423	9	4.5%	4.4%	0.0%
12-Oct to 14-Oct	2	25	52	0	697	1,146	4	3.6%	4.5%	0.0%
15-Oct to 22-Oct	5	20	33	0	601	1,117	1	3.3%	3.0%	0.0%
Chi-Square Test Result:								1.81	10.78	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Average recovery effort in reaches 1-3; effort was not consistent between reaches.

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

Sex	Application date	Recovery location of disk tagged carcasses <sup>a</sup>							
		Tagging site		Lower River		Middle River		Upper River	
		No.	%	No.	%	No.	%	No.	%
Male	07-Sep to 12-Sep	3	30%	5	50%	1	10%	1	10%
	13-Sep to 17-Sep	13	45%	12	41%	2	7%	2	7%
	18-Sep to 22-Sep	39	67%	18	31%	1	2%	0	0%
	23-Sep to 28-Sep	20	56%	12	33%	3	8%	1	3%
	29-Sep to 04-Oct	5	42%	7	58%	0	0%	0	0%
Female	07-Sep to 12-Sep	3	43%	3	43%	1	14%	0	0%
	13-Sep to 17-Sep	23	48%	12	25%	7	15%	6	13%
	18-Sep to 22-Sep	49	43%	49	43%	15	13%	0	0%
	23-Sep to 28-Sep	40	53%	26	34%	9	12%	1	1%
	29-Sep to 04-Oct	8	31%	13	50%	4	15%	1	4%

<sup>a</sup> Birkenhead River section definitions:

Tagging site: Reach 1;  
Lower: Reach 2;

Middle: reaches 3-6;  
Upper: reaches 7-10.

The male and female spawning ground samples consisted predominately of ages 4<sub>2</sub> and 5<sub>2</sub>, although a small proportion of age 3<sub>2</sub> and 6<sub>3</sub> fish was also noted (Table 4). Age composition varied between the three sample periods (Appendix 7a); however, the differences were not significant ( $P > 0.05$ ; chi-square). The jack sample consisted predominately of age 3<sub>2</sub> fish, although a small proportion of age 4<sub>2</sub> fish was also noted (Table 4; Appendix 7b).

## SAMPLING SELECTIVITY

### Period

Temporal bias in the application sample was examined by comparing disk tag incidences in five recovery periods which were stratified in three ways: equal periods; equal recovery effort; and equal numbers recovered (Table 5). Disk tag incidence in adults ranged from 2.7% to 6.4%, with a lower incidence later in the study. The difference was not significant ( $P > 0.05$ ; chi-square) in males; however, it was significant ( $P < 0.05$ ; chi-square) in all three stratifications in females. This test result indicates that the objective of proportional tag application across all run segments was not achieved in females. There is no indication that this bias impacted a particular group of

spawners because distribution patterns were relatively trendless after the second week of the study (Table 6).

Recovery bias was examined by comparing the proportions recovered from five application periods which were stratified in three ways: equal periods; equal application effort; and equal numbers applied (Table 7). The proportion of the adults recovered ranged from 11.0% to 33.2%, with a significant ( $P < 0.05$ ; chi-square) difference in males in all three stratifications and in females in two stratifications (equal application effort and equal numbers of total tags applied). The proportion recovered tended to be lower among those tagged earlier in the study.

### Location

Spatial bias in the application sample was examined by comparing the disk tag incidence in four recovery sections (Table 8). Tag incidence among adults ranged from 2.21% to 5.13%, with a lower incidence in the upper river spawners. These differences were not significant ( $P > 0.05$ ; chi-square), however, in either males or females. Recovery bias could not be examined because the tags were applied at a single site.

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

Application period	Number of sets	Disk tags applied <sup>a</sup>			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
07-Sep to 12-Sep	43	53	44	6	10	7	0	18.9%	15.9%	0.0%
13-Sep to 17-Sep	33	233	244	4	29	48	0	12.4%	19.7%	0.0%
18-Sep to 22-Sep	31	258	400	7	58	113	0	22.5%	28.3%	0.0%
23-Sep to 28-Sep	30	131	267	4	36	76	0	27.5%	28.5%	0.0%
29-Sep to 04-Oct	17	46	104	7	12	26	0	26.1%	25.0%	0.0%
Chi-Square Test Result:								14.92	9.33	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Corrected for sex identification error.

Table 7b. Proportion of the disk tag application sample recovered on the Birkenhead River spawning grounds, by application period and sex, 1994. Data are stratified by approximately equal application effort.

Application period	Number of sets	Disk tags applied <sup>a</sup>			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
07-Sep to 10-Sep	29	27	27	3	7	3	0	25.9%	11.1%	0.0%
11-Sep to 15-Sep	34	136	98	4	15	21	0	11.0%	21.4%	0.0%
16-Sep to 20-Sep	32	280	440	8	47	92	0	16.8%	20.9%	0.0%
21-Sep to 26-Sep	32	198	307	5	56	98	0	28.3%	31.9%	0.0%
27-Sep to 04-Oct	27	80	187	8	20	56	0	25.0%	29.9%	0.0%
Chi-Square Test Result:								18.90	17.29	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Corrected for sex identification error.

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

Application period	Number of sets	Disk tags applied <sup>a</sup>			Carcasses recovered with disk tags			Percent recovered		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
07-Sep to 15-Sep	63	163	125	7	22	24	0	13.5%	19.2%	0.0%
16-Sep to 18-Sep	18	167	238	6	21	49	0	12.6%	20.6%	0.0%
19-Sep to 21-Sep	19	171	257	3	43	62	0	25.1%	24.1%	0.0%
22-Sep to 25-Sep	20	116	196	4	31	65	0	26.7%	33.2%	0.0%
26-Sep to 04-Oct	34	104	243	8	28	70	0	26.9%	28.8%	0.0%
Chi-Square Test Result:								19.20	13.35	-
Critical Chi-Square (df = 4; $\alpha$ = 0.05):								9.49	9.49	-

<sup>a</sup> Corrected for sex identification error.

Table 8. Proportion of the Birkenhead River sockeye salmon spawning ground recovery sample marked with disk tags, by recovery location and sex, 1994. <sup>a</sup>

Recovery river	Recovery Section	Carcasses recovered with disk tags			Total carcasses examined			Disk tag incidence		
		Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
Birkenhead	Tagging site	80	123	0	1,890	2,883	16	4.23%	4.27%	0.00%
	Lower	54	103	0	1,255	2,006	15	4.30%	5.13%	0.00%
	Middle	7	36	0	317	809	2	2.21%	4.45%	0.00%
	Upper	4	8	0	158	313	4	2.53%	2.56%	0.00%
Chi-Square Test Result:								4.10	5.01	-
Critical Chi-Square (df = 3; $\alpha$ = 0.05):								7.81	7.81	-

<sup>a</sup> See Table 6 for section definitions.

Table 9. Proportion of the disk tag application sample recovered on the Birkenhead River spawning grounds, by sex and 3 cm increments of nose-fork length, 1994.

Nose-fork length (cm)	Disk tags applied <sup>a</sup>			Carcasses recovered with disk tags			Percent recovered		
	Male <sup>b</sup>	Female	Total	Male <sup>c</sup>	Female	Total	Male	Female	Total
34-36.9	9	0	9	0	0	0	0.0%	-	0.0%
37-39.9	14	0	14	0	0	0	0.0%	-	0.0%
40-42.9	2	0	2	0	0	0	0.0%	-	0.0%
43-45.9	0	0	0	0	0	0	-	-	-
46-48.9	2	0	2	0	0	0	0.0%	-	0.0%
49-51.9	7	2	9	2	1	3	28.6%	50.0%	33.3%
52-54.9	17	55	72	1	8	9	5.9%	14.5%	12.5%
55-57.9	20	300	320	2	79	81	10.0%	26.3%	25.3%
58-60.9	73	284	357	17	67	84	23.3%	23.6%	23.5%
61-63.9	234	180	414	42	39	81	17.9%	21.7%	19.6%
64-66.9	178	189	367	33	55	88	18.5%	29.1%	24.0%
67-69.9	101	47	148	25	20	45	24.8%	42.6%	30.4%
70-72.9	82	1	83	21	1	22	25.6%	100.0%	26.5%
73-75.9	8	0	8	1	0	1	12.5%	-	12.5%
Kolmogorov-Smirnov 2-sample test Dmax (continuous data; see text):							0.087	0.092	-
Kolmogorov-Smirnov 2-sample test Dcritical ( $\alpha$ = 0.05):							0.126	0.096	-

<sup>a</sup> Corrected for sex identification error; excludes 2 males and 1 female which were not measured.

<sup>b</sup> Includes jacks.

<sup>c</sup> Excludes 1 male which was not measured at release.

Table 10. Sex composition of Birkenhead River sockeye adults in the disk tag application and spawning ground recovery samples, 1994. <sup>a</sup>

Sex	Application sample, by recovery status <sup>b</sup>				Recovery sample, by mark status			
	Sample size	Recovered	Not recovered	Total	Sample size	Marked	Unmarked	Total
Male	721	35.2%	42.3%	40.5%	3,620	35.2%	37.7%	37.6%
Female	1,059	64.8%	57.7%	59.5%	6,011	64.8%	62.3%	62.4%
Chi-Square Test Result:				6.60	Chi-Square Test Result:			
Critical Chi-Square (df = 1; $\alpha$ = 0.025):				5.02	Critical Chi-Square (df = 1; $\alpha$ = 0.05):			
					1.05			
					3.84			

<sup>a</sup> Data are from Table 1.

<sup>b</sup> Corrected for sex identification error.

### **Fish Size**

Size bias in the application sample could not be assessed because the length of untagged carcasses was not measured. Recovery bias was examined by partitioning the application sample into recovered and nonrecovered components and comparing the NF frequency distributions. There was no difference in either sex ( $P > 0.05$ ; Kolmogorov-Smirnov two sample test). Similar proportions recovered were also noted when the data were stratified in 3-cm NF groups (Table 9), except among the small males (jacks), none of which were recovered.

### **Fish Sex**

There was no difference ( $P > 0.05$ ; chi-square) in the sex ratio of the marked and unmarked spawning ground recoveries (Table 10). The application sample, therefore, was relatively unbiased with respect to sex.

The sex ratios of the recovered and nonrecovered components of the application sample were significantly different ( $P < 0.05$ ; chi-square), with a higher proportion of females in the recovered group (Table 10). A similar significant difference ( $P < 0.025$ ) was noted in the proportion of males (21.4%) and females (26.8%) released with disk tags and recovered on the spawning grounds (Table 1). The recovery sample, therefore, was biased toward females.

### **Stress**

Potential bias resulting from handling and tagging stress was assessed in two ways. First, three tests were performed to determine whether specific tags should be excluded from the application sample. The results of these tests were reported on pages 7-8; nine and five disk tagged males were removed from the application and recovery samples, respectively, due to recapture stress. Second, two tests were performed as general indicators of a stress problem: a) spawning success was compared between tagged (100.0%) and untagged (99.8%) females. The input data for this test of independence (number of recoveries which were 0%, 50% and 100% spawned) were collapsed into two groups (0%-50% and 100%) because of the low number of recoveries in the 50% group. No significant difference ( $P > 0.05$ ; chi-square) was noted; and

b) the recovery sample was partitioned into those recovered within and above the tagging site reach and the disk tag incidence and female spawning success were compared in each. Tag incidence at (4.25%) and above (4.36%) the tagging site reach was not significantly different ( $P > 0.05$ ; chi-square) in either sex (Table 8), and spawning success was identical in each (99.8%). We concluded, therefore, that with the exception of multiple recaptures in males, handling and tagging stress did not introduce substantial bias to this study.

### **SPAWNER POPULATION ESTIMATES**

The 1994 Birkenhead River system sockeye adult escapements are presented in Table 11 and are discussed below. The jack escapement, calculated using Equation 7 (page 7), was estimated at 218 fish.

#### **Petersen Estimator**

The pooled Petersen estimate was calculated from the data presented in Table 1. Escapement was estimated for adult males and females only; jack (NF length of less than 50 cm) abundance did not meet the minimum requirement for a mark-recapture estimate.

The 1994 sockeye adult escapement was estimated at 39,227 with 95% confidence limits of  $\pm 3,620$  (9.2%) (Table 11). The escapement of males and females was  $16,867 \pm 2,590$  (15.4%) and  $22,360 \pm 2,530$  (11.3%), respectively. The age-specific escapement by sex was calculated from the data in Appendix 7 (Table 11). Because the differences in age composition among the three sample periods were not significant ( $P > 0.05$ ; chi-square), escapement by age was calculated from the pooled sample data.

An overlap in the adult and jack NF-frequency distributions resulted in a misclassification of some age 4<sub>2</sub> (adult) fish as jacks (Table 11). When corrected for this error, the escapement was estimated at 16,874 adult males, 22,360 adult females, and 211 jacks.

#### **Stratified Estimators**

Because a temporal bias was identified in the sampling data, stratified estimates were calculated using the Schaefer and Darroch estimat-

Table 11. Escapement estimates and 95% confidence limits, by age and sex, for Birkenhead River sockeye adults and jacks, 1994. The symbol \* indicated the final study area escapement estimates (see text for jack misidentification correction).

Stratification type	Estimator	Sex	Escapement at age <sup>a</sup>					95% confidence limits on total escapement	
			3 <sub>2</sub>	4 <sub>2</sub>	5 <sub>2</sub>	6 <sub>2</sub>	Total	Lower	Upper
Pooled	Petersen	Male	0	10,385	6,253	229	16,867 *	14,277	19,456
		Female	0	12,422	9,814	124	22,360 *	19,831	24,890
		Total	0	22,807	16,067	354	39,227 *	35,607	42,847
		Jack	211	7	0	0	218 *	-	-
Temporal <sup>b</sup>	Schaefer	Male	-	-	-	-	16,690	-	-
		Female	-	-	-	-	22,095	-	-
	Darroch	Male	-	-	-	-	14,721	9,617	19,825
		Female	-	-	-	-	21,309	17,908	24,710

<sup>a</sup> Does not include 26 females which were killed for fecundity samples.

<sup>b</sup> Used a 3x4 matrix: 07-18 Sep, 19-21 Sep and 22 Sep to 04 Oct application; 26 Sep to 04 Oct, 05-08 Oct, 09-11 Oct, and 12-22 Oct recovery.

ors (Table 11). The data were initially stratified into five application periods, each with an approximately equal number of tags applied (Table 7c), and five recovery periods, each with an approximately equal number of carcasses recovered (Table 5c). The strata were collapsed into a 3x4 matrix to increase the number of recoveries per cell.

The stratified estimates of the male and female escapements ranged from -12.7% to -1.0% and -4.7% to -1.2% of the Petersen estimates, respectively. The stratified estimates were remarkably similar to the pooled Petersen estimate. All stratified estimates fell within the 95% confidence limits of the Petersen estimates. This suggests that the identified biases were not serious; therefore, the pooled Petersen was accepted as the most appropriate population estimator.

## DISCUSSION

### MARK-RECAPTURE ASSUMPTIONS

The Petersen mark-recapture technique is based on the principle that, by tagging a random sample of fish, permitting them to redistribute through the population, and by obtaining a second random sample of tagged and untagged individuals, the number of fish in the population

can be estimated with known precision. Even a very precise estimate, however, can be inaccurate. The accuracy of an escapement estimate depends on how well the assumptions underlying the technique have been addressed. These assumptions have been described in various forms by Ricker (1975), Otis *et al.* (1978), Eames *et al.* (1981) and Seber (1982) and are restated below in the context of the current study.

### Population Closure

A closed population is one where the number of animals does not change during the study. In spawning salmon populations, this implies that there is neither recruitment nor immigration, and that death and emigration affect tagged and untagged fish equally. Functionally, closure also implies that all components of the population will be vulnerable to either capture or recapture. The Birkenhead study addressed the closure assumption through temporal and spatial design elements. Temporally, the study was designed to encompass virtually the entire period of immigration, spawning and die-off. Spatially, the study included the entire accessible portion of the river and efforts were made to ensure that all fish would be vulnerable to the application or recovery surveys. Emigration from the study area to the Lillooet River system was possible; however, it was not a serious concern because sockeye

populations in those areas are known from previous surveys to be small.

### Identification of Tag Status

The failure to correctly identify the tag status of a carcass is common in mark-recapture studies. It generally results from surveyor inexperience, fatigue, or from assigning a higher priority to the speed of carcass processing than to the thoroughness of carcass examination. If uncorrected, this type of error results in an underestimate of the proportion of tags in the population and an overestimate of escapement. In the current study, the proportion of the tags missed by the initial survey was evaluated by resurveying 26% of the carcasses in previously surveyed areas; the proportion of the tags missed was 5.3% or 23 tags. This proportion was small relative to other 1994 studies (Schubert 1996); however, it still represents a serious deficiency in the execution of field procedures because the daily number of carcasses processed by an individual was small (less than 500) throughout the study. Two procedural changes are recommended to reduce the missed tag incidence in future studies: staff training should reemphasize the importance of carefully examining each carcass; and the crew chief, through more frequent resurveys, should provide immediate feedback and retraining to staff who are missing tags.

We have three concerns with the design of the resurvey sample and the analytic treatment of the resurvey data. First, the resurveys were relatively unsystematic, i.e. they were less frequent than the initial surveys and did not representatively sample all spatial and temporal components of the run. For example, the resurveys began well after the start of the initial surveys, and were much less frequent in the middle and upper river areas relative to the lower river. Unsystematic resurveys could introduce error in the population estimate if the missed tag rate was not uniform during the study. This could occur if the proportion of tags missed was related to the daily number of fish processed, to surveyor fatigue, or to the physical characteristics of the survey area. While stratification is an option, it was not considered in the current study because sample size was inadequate in several spatial and temporal cells. This issue should be addressed in future studies by a more representative resurvey. Second, as with the sex identifica-

tion error correction, there is no variance estimator for the resurvey sampling stage. Consequently, the precision of the population estimate was overstated. This should be addressed in the analytic design of future studies. Third, if estimator variance is to be minimized, simulation studies are required to determine the optimal allocation of effort between the initial and resurvey sampling stages.

### Tag Loss

The undetected loss of disk tags between tag application and recovery would result in an underestimate of the proportion of the population with tags and an overestimate of escapement. Tag loss can result from poor tag application technique, tangling of the tag in the net when recaptured, or the fighting which is common among males during spawning. It can be easily evaluated (although with an incremental labour cost) by applying a secondary tag, or a mark such as an opercular punch or fin clip, in addition to the primary tag. Tag loss in the current study could not be assessed because secondary marks were not used. A 1989 tag loss study, however, reported an average 3.5% (range 0% to 9.7%) loss of the primary tag in seven Fraser river sockeye stocks (DFO, unpublished). Studies of Fraser River chinook (Schubert *et al.* 1994a) and coho (Schubert *et al.* 1994b) also reported levels of tag loss which varied annually within about the same range. If tag loss in the current study was similar to that reported in the 1989 studies, the 1994 escapement would have been overestimated by 3.6% or 1,400 sockeye (range 0 to 3,800). Clearly, tag loss could introduce a substantial bias in the population estimate and its assessment should be an integral part of all future mark-recapture studies. We note, however, that a positive bias of the same relative magnitude would also have occurred in past years because tag loss corrections were not incorporated in the escapement estimates produced by any previous mark-recapture study.

### Tagging Effects

Tagging can influence subsequent catchability if, for example, a tagged fish becomes more vulnerable to a fishery, to technicians or to predators. This type of tagging effect had little impact on the current study because: there were no fisheries upstream from the tagging site; the

capture net was the only net used in the river, and the recapture data were examined for evidence of stress; the technicians were trained to recover carcasses independent of their tag status; and, although there was no indication that predators differentially removed tagged fish, predator recoveries were excluded from the sample.

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

There are a number of stress-related tagging effects which are of potential concern in the current study. First, stress could impair the ability of an affected fish to swim in stronger currents. In a subacute case, the ability of a stressed fish to hold position in faster currents could be impaired, forcing it to spawn in slower flowing water along the river periphery. This could increase the probability that the fish would wash ashore and could result in a higher recovery rate among the stressed group, a violation of the equal probability of recapture assumption. In a more severe case, the ability of the fish to move beyond the tagging site could be impaired, resulting in a higher probability of recovery downstream. In an extreme case, such fish could be flushed from the study area, a violation of the closure assumption. Second, stress may impair the ability of a fish to spawn successfully, resulting in a measurable reduction in spawning success. Lower spawning success among disk tagged fish could indicate a subacute stress, while lower success below the tagging site could indicate a more severe, acute stress. By itself, differential spawn-

ing success does not violate the basic mark-recapture assumptions; however, it does demonstrate behavioural differences which could violate the assumptions in a way which would be undetectable using current study techniques. Such differential spawning success should be treated as an indicator that the study stock may be highly susceptible to stress; low stress study techniques should be considered. Third, the time span between release and death could be shorter among stressed fish. Shorter time spans among tagged fish in general could indicate a subacute stress which would violate the assumption of random mixing. The detection of such a stress, however, requires an independent estimate of the time between migration past the tagging site and death for untagged fish; such an assessment was unavailable in the current study. In contrast, acute stresses should be detectable because behaviour was assessed immediately after release.

In the current study, we attempted to minimize handling stress by ensuring that the capture and tagging processes were as stress-free as possible. This was done by selecting a tagging site proximal to the main spawning areas, where fast water would not stress the fish being held for tagging, and by minimizing the holding and handling time. These conditions were intended to minimize stress induced mortality while at the same time permit the complete mixing of tagged and untagged fish. With the exception of the multiple recapture stress in males, which was addressed by removing those fish from the data set, our evaluation procedures did not detect any subacute or acute stress effects in 1994 (Table 12). As noted above, however, we were unable to assess time out to recovery of tagged versus untagged fish. Furthermore, the late start of the recovery surveys (19 days after the start of tagging), impaired our ability to detect shorter life spans among fish tagged early in the study.

In summary, none of our tests demonstrated a serious concern with stress-induced tagging effects in the 1994 Birkenhead study. We were unable to discount the possibility that sub-acute and acute stresses did not bias the population estimate, however, and we recommend several design changes to permit such an assessment in the future: a) to evaluate the Birkenhead stock's susceptibility to stress and the potential impact of sub-acute stress on the study results, high and

Table 12. Bias profile for the 1994 Birkenhead River sockeye escapement estimation study. <sup>a</sup>

Sample	Bias type	Test of	Between	Test result	
Application	Temporal	Tag incidence:	Equal recovery periods	Early/mid period bias in females	
			Equal recovery effort	Early/mid period bias in females	
			Equal numbers of recoveries	Early/mid period bias in females	
	Spatial	Tag incidence:	Five recovery areas	No bias	
	Fish sex	Sex ratio:	Marked/unmarked recoveries	No bias	
	Stress	Recovery rate:	Recovery of a tag within 5-days of rel:	Ventilated/nonventilated releases	No bias
				-	No bias
		Recovery rate:	Live recaptured/not recaptured	Multiple recapture bias in males	
		Spawning success:	Tagged/untagged recoveries	No bias	
		Spawning success:	Tagging site/above site	No bias	
Tag incidence:		Tagging site/above site	No bias		
Recovery	Statistical	Minimum recovery of 5 tags:	-	No bias	
	Temporal	Recovery rate:	Equal application periods	Late period bias in males	
			Equal application effort	Late period bias in both sexes	
			Equal numbers applied	Late period bias in both sexes	
	Fish size	Size-frequency distrib:	Recovered/nonrecovered tags	No bias	
Fish sex	Sex ratio:	Recovered/nonrecovered tags	Bias to females		

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

low stress tag application techniques should be developed; and b) to permit a more thorough assessment of acute tagging effects, surveys of the river above and below the tagging site should begin immediately after the start of tagging.

### Sampling Selectivity

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

of tag status. When nonrepresentative sampling occurs, it can be at least partially addressed by using a stratified population estimator.

The design of the current study attempted to address this assumption by making both tag application and recovery as representative as possible. Daily tagging effort was standardized and the fish were captured using a gear (beach seine net) known to minimize selectivity. Standardized effort can still fail to provide a representative sample of migrating sockeye, however, due to variability in: river conditions; the proportion of the fish which migrate at night; daily set times; and the technique used during each set. The spawning ground surveys were planned to cycle on a fixed number of days regardless of carcass abundance. Again, standardized effort can be compromised by variable river conditions or staff

levels. Areas where the study design could not be fully implemented are discussed below.

We could not definitively test sample representativeness because the true population parameters were not known. Instead, we constructed a bias profile by examining the samples for five potential biases, temporal, spatial, fish size, fish sex and stress, as indicators of weaknesses in the study design (Table 12). Three biases were detected in the application and recovery samples: a) a temporal application bias which resulted in a lower tag incidence among later spawning females; b) a temporal recovery bias which resulted in lower recovery rates among early spawners; and c) and a recovery bias toward females in general. The latter bias was easily treated by stratifying the data by sex and calculating independent population estimates. The other biases are potentially more serious and are discussed below in greater detail.

The temporal biases reflected staff levels which were adequate to conduct the application or recovery surveys individually, but which did not permit a consistent level of effort during the period of concurrent surveys. There were two effects. First, there was a 50% reduction in application effort, from six to three sets per day, in the last week of the study (Appendix 2). This would be expected to cause an overall reduction in tag incidence among late spawners and, because females generally arrive on the spawning grounds later than males (Killick 1955), a disproportionate reduction in tag incidence among females during the last week of the study. Both were noted in 1994. Second, the start of the recovery survey was delayed until 19 days after the start of tagging. Because the average time out to recovery was 17-18 days, this delay would reduce the recovery rate among fish tagged early in the study because at least some of the tags applied at the start of the study would have been unavailable for recovery. Future studies must address these issues by ensuring that: a) recovery begins shortly after the start of tagging; and b) staff levels are sufficient to permit consistent effort in both the application and recovery surveys throughout the study.

Although we did not detect a spatial bias in the application sample, we are concerned that the disk tag incidence in the upper river was about half that of the lower river (Table 8). This

was unexpected because these fish apparently migrated past the tagging site early in the study (Table 6) when application effort was high. While there was no indication from the catch per set (Appendix 2) that a significant number of fish had moved into the system before the start of tagging, visual surveys of reaches 8-9 on September 7 reported at least some (30+) spawners in the upper river. We were unable to conclude, therefore, whether this bias reflected: a late start of tagging; a differential vulnerability to capture of the earlier, upper river fish resulting from some unidentified behavioural characteristic; or handling stress. Future studies should consider two changes: a) increasing application effort early in the study; and b) establishing a second tagging site, perhaps at the lower end of Reach 7, which would differentially capture upper river fish.

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

## RECOMMENDATIONS

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

- Staff training must emphasize the importance of thoroughly examining each carcass for a disk tag;
- Crew chiefs should resurvey the recovery areas more frequently, and provide immediate feedback and retraining to crew members who miss disk tags;
- The resurvey should be made spatially and temporally more representative;
- Analytic methods should be developed to permit incorporating the variance of the resurvey sampling stage into the variance of the population estimator;
- Simulation studies are required to determine

the optimum allocation of effort between the initial and resurvey sampling stages.

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

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

- To evaluate the Birkenhead stock's susceptibility to stress and the potential impact of sub-acute stress on the study results, low stress tag application techniques should be developed and compared with current methods;
- To permit a more thorough assessment of acute tagging effects, surveys of the river above and below the tagging site should begin immediately after the start of tagging;
- Consistent techniques should be developed to estimate spawning success in disk tagged versus untagged females;
- Because the stress from holding a fish in the net before tagging may increase with time, holding time should be recorded for all tagged fish.

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

- Live capture should begin as soon as sockeye are observed in the river and application effort should be increased in the early component of the run;
- To permit a more proportional application of disk tags to the upper river spawners, the feasibility of establishing a second tagging site, possible at the lower end of Reach 7, should be investigated;

- To ensure that application and recovery effort are consistent over the respective periods of immigration and die-off, staff levels must be increased during the coincidental sampling periods.

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

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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 number of females which had spawned effectively in the Birkenhead River, 1938-1994.

Year	Arrival	Period of peak spawning	Escapement			Percent spawning success	Effective females	
			Total	Jacks	Males			Females
1938	-	-	11,100	150	2,894	8,056	95.0%	7,653
1939	Sep 10	Oct 01-Oct 05	15,435	155	6,112	9,168	95.0%	8,710
1940	Aug 29	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	Sep 08	Oct 01-Oct 05	93,099	1,257	24,271	67,571	98.1%	66,253
1943	Sep 01	Sep 27-Oct 02	50,668	2,112	21,491	27,065	93.3%	25,252
1944	Sep 02	Sep 27-Oct 02	69,111	22,164	21,196	25,751	94.1%	24,237
1945	Sep 06	Oct 01-Oct 05	96,664	8,632	29,270	58,762	95.5%	56,088
1946	Aug 31	Sep 29-Oct 03	93,243	5,874	20,346	67,023	98.8%	66,246
1947	Aug 25	Sep 29-Oct 03	123,627	36,240	34,693	52,694	93.2%	49,095
1948	Sep 01	Sep 27-Oct 02	122,424	38,637	24,509	59,278	92.4%	54,755
1949	Sep 05	Oct 04-Oct 08	74,085	3,581	25,882	44,622	97.1%	43,328
1950	Sep 01	Oct 01-Oct 05	72,567	8,127	19,956	44,484	93.0%	41,370
1951	Sep 01	Oct 01-Oct 05	42,063	20,767	6,839	14,457	94.0%	13,589
1952	Aug 28	Sep 25-Sep 30	77,386	30,345	18,362	28,679	86.3%	24,744
1953	Aug 20	Sep 24-Sep 25	55,823	13,332	19,074	23,417	69.6%	16,287
1954	Aug 30	Sep 25-Sep 27	40,453	22,240	8,493	9,720	88.8%	8,635
1955	Sep 07	Sep 23-Sep 25	24,450	9,897	5,944	8,609	95.1%	8,185
1956	Sep 02	*	57,899	8,145	18,828	30,926	87.8%	27,156
1957	Sep 04	Sep 25-Sep 28	24,168	9,632	7,041	7,495	94.3%	7,068
1958	Sep 05	Sep 26-Sep 29	33,055	17,889	9,030	6,136	89.8%	5,510
1959	Sep 01	Sep 23-Sep 28	38,604	12,445	13,476	12,683	89.8%	11,388
1960	Aug 28	Sep 24-Sep 26	39,848	3,010	15,376	21,462	89.5%	19,198
1961	Aug 25	Sep 24-Sep 28	49,627	17,946	15,322	16,359	64.5%	10,550
1962	Sep 05	Sep 22-Sep 28	52,146	25,777	10,322	16,047	89.2%	14,311
1963	Sep 01	Sep 21-Sep 25	67,151	18,258	17,425	31,468	66.0%	20,769
1964	Aug 29	Sep 19-Sep 21	69,939	21,031	20,271	28,637	97.7%	27,978
1965	Aug 21	Sep 16-Sep 23	30,008	13,778	5,587	10,643	91.8%	9,769
1966	Sep 02	Sep 20-Sep 23	81,134	61,018	5,569	14,547	92.5%	13,462
1967	Sep 01	Sep 18-Sep 22	58,036	18,160	17,078	22,798	77.1%	17,580
1968	Aug 13	Sep 22-Sep 24	83,750	25,803	16,995	40,952	75.8%	31,042
1969	Aug 25	Sep 23-Sep 26	64,527	27,145	14,624	22,758	62.9%	14,324
1970	Sep 03	Sep 24-Sep 26	72,760	42,104	9,847	20,809	92.5%	19,252
1971	Sep 09	Sep 22-Sep 25	32,672	8,043	7,831	16,798	96.1%	16,143
1972	Aug 28	Sep 23-Sep 26	113,097	58,581	25,009	29,507	88.8%	26,202
1973	Sep 01	Sep 23-Sep 26	139,295	82,642	25,942	30,711	92.4%	28,374
1974	Sep 01	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	Sep 01	Sep 23-Sep 28	108,121	30,816	25,962	51,343	97.4%	50,023
1977	Sep 01	Sep 21-Sep 28	43,139	19,294	9,660	14,185	90.2%	12,799
1978	Sep 01	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	Sep 05	Sep 21-Sep 27	90,922	12,309	35,009	43,604	75.2%	32,786
1981	Sep 01	Sep 23-Sep 30	65,495	16,472	20,576	28,447	95.5%	27,175
1982	Aug 29	Sep 20-Sep 30	128,771	9,033	46,350	73,388	98.6%	72,355
1983	-	-	4,312	4,312	0	0	-	0
1984	Sep 01	Sep 21-Sep 28	42,849	2,604	15,893	24,352	95.4%	23,226
1985	Sep 10	Sep 18-Sep 23	37,612	25,707	5,845	6,060	95.0%	5,757

\* Two peaks: Sep 18-Sep 21 and Oct 02-Oct 05.

Continued

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

Year	Arrival	Period of peak spawning	Escapement			Percent spawning success	Effective females	
			Total	Jacks	Males			Females
1986	Sep 04	Oct 03-Oct 10	348,294	12,664	135,411	200,219	98.8%	197,841
1987	Sep 04	Oct 01-Oct 10	168,841	3,992	71,262	93,587	95.6%	89,429
1988	Aug 29	Sep 21-Sep 26	177,327	10,736	77,390	89,201	84.7%	75,537
1989	Aug 31	Sep 22-Sep 29	46,703	17,369	13,426	15,908	98.9%	15,690
1990	Aug 25	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%	93,445
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

Appendix 2. Daily application of disk tags, by location and sex (field estimate and correction for sex identification error), to sockeye salmon in the Birkenhead River, 1994. <sup>a</sup>

Date	Reach	Number of sets	Original field estimate of sex composition			Corrected for sex identification error			Recaptures <sup>b</sup>		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
7-Sep	1	8	3	3	0	3	3	0	0	0	0
8-Sep	1	6	6	7	0	6	7	0	0	1	0
9-Sep	1	8	8	6	3	8	6	3	0	0	0
10-Sep	1	7	10	11	0	10	11	0	1	1	0
11-Sep	1	8	22	11	1	22	11	1	1	0	0
12-Sep	1	6	4	6	2	4	6	2	0	0	0
13-Sep	1	6	33	29	1	33	29	1	2	1	0
14-Sep	1	8	13	8	0	13	8	0	0	1	0
15-Sep	1	6	64	44	0	64	44	0	2	4	0
16-Sep	1	7	66	80	1	66	80	1	4	8	0
17-Sep	1	6	60	83	2	57 <sup>c</sup>	83	2	11	8	0
18-Sep	1	5	44	75	3	44	75	3	2	4	1
19-Sep	1	7	50	90	1	50	90	1	9	10	0
20-Sep	1	7	63	113	1	63 <sup>d</sup>	112	1	5	11	0
21-Sep	1	5	58	55	1	58	55	1	5	5	0
22-Sep	1	7	43	68	1	43	68	1	2	6	0
23-Sep	1	6	43	72	3	42 <sup>d</sup>	72	3	8	8	2
24-Sep	1	0	0	0	0	0	0	0	0	0	0
25-Sep	1	7	33	56	0	31 <sup>e</sup>	56	0	10	9	0
26-Sep	1	7	25	56	0	24 <sup>d</sup>	56	0	4	8	0
27-Sep	1	7	28	64	1	27 <sup>d</sup>	64	1	9	13	1
28-Sep	1	3	7	19	0	7	19	0	1	3	0
29-Sep	1	3	7	18	2	7	18	2	0	3	1
30-Sep	1	3	18	20	1	18	20	1	3	4	1
1-Oct	1	3	4	35	1	4	35	1	1	1	0
2-Oct	1	3	8	14	1	8	14	1	1	2	0
3-Oct	1	3	7	12	2	7	12	2	3	0	0
4-Oct	1	2	2	5	0	2	5	0	1	0	0
Total	-	-	729	1,060	28	721	1,059	28	85	111	6

<sup>a</sup> See Methods for sex identification error correction procedure

<sup>b</sup> Seventeen fish were recaptured twice and 1 was recaptured three times.

<sup>c</sup> Excludes 3 which were removed due to recapture stress.

<sup>d</sup> Excludes 1 which was removed due to recapture stress.

<sup>e</sup> Excludes 2 which were removed due to recapture stress.

Appendix 3a. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among adult male sockeye examined at tag application in the Birkenhead River, 1994. <sup>a</sup>

Date	Number of adult males examined	Net marks		Lamprey marks		Hook marks		<i>F. columnaris</i> <sup>b</sup>	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
7-Sep	3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8-Sep	6	0	0.0%	0	0.0%	0	0.0%	0	0.0%
9-Sep	8	1	12.5%	0	0.0%	0	0.0%	0	0.0%
10-Sep	10	0	0.0%	1	10.0%	0	0.0%	0	0.0%
11-Sep	22	1	4.5%	2	9.1%	0	0.0%	0	0.0%
12-Sep	4	0	0.0%	0	0.0%	0	0.0%	0	0.0%
13-Sep	33	2	6.1%	1	3.0%	1	3.0%	0	0.0%
14-Sep	13	1	7.7%	0	0.0%	0	0.0%	0	0.0%
15-Sep	64	8	12.5%	0	0.0%	0	0.0%	0	0.0%
16-Sep	66	1	1.5%	0	0.0%	1	1.5%	0	0.0%
17-Sep	60	3	5.0%	0	0.0%	0	0.0%	0	0.0%
18-Sep	44	2	4.5%	0	0.0%	1	2.3%	0	0.0%
19-Sep	50	6	12.0%	0	0.0%	1	2.0%	0	0.0%
20-Sep	63	3	4.8%	0	0.0%	3	4.8%	0	0.0%
21-Sep	58	4	6.9%	1	1.7%	3	5.2%	0	0.0%
22-Sep	43	2	4.7%	0	0.0%	5	11.6%	0	0.0%
23-Sep	43	2	4.7%	0	0.0%	1	2.3%	0	0.0%
24-Sep	0	0	-	0	-	0	-	0	-
25-Sep	33	3	9.1%	0	0.0%	5	15.2%	0	0.0%
26-Sep	25	1	4.0%	0	0.0%	3	12.0%	0	0.0%
27-Sep	28	2	7.1%	0	0.0%	1	3.6%	0	0.0%
28-Sep	7	1	14.3%	0	0.0%	0	0.0%	0	0.0%
29-Sep	7	0	0.0%	0	0.0%	1	14.3%	0	0.0%
30-Sep	18	1	5.6%	0	0.0%	1	5.6%	0	0.0%
1-Oct	4	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2-Oct	8	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3-Oct	7	0	0.0%	0	0.0%	0	0.0%	0	0.0%
4-Oct	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
Total	729	44	6.0%	5	0.7%	27	3.7%	0	0.0%

<sup>a</sup>. Not corrected for sex identification error.

<sup>b</sup>. Columnaris incidence was not recorded in 1994.

Appendix 3b. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among adult female sockeye examined at tag application in the Birkenhead River, 1994. <sup>a</sup>

Date	Number of females examined	Net marks		Lamprey marks		Hook marks		<i>F. columnaris</i> <sup>b</sup>	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
7-Sep	3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
8-Sep	7	1	14.3%	0	0.0%	0	0.0%	0	0.0%
9-Sep	6	2	33.3%	1	16.7%	0	0.0%	0	0.0%
10-Sep	11	3	27.3%	2	18.2%	0	0.0%	0	0.0%
11-Sep	11	1	9.1%	2	18.2%	0	0.0%	0	0.0%
12-Sep	6	0	0.0%	1	16.7%	0	0.0%	0	0.0%
13-Sep	29	9	31.0%	2	6.9%	1	3.4%	0	0.0%
14-Sep	8	0	0.0%	0	0.0%	0	0.0%	0	0.0%
15-Sep	44	11	25.0%	0	0.0%	1	2.3%	0	0.0%
16-Sep	80	12	15.0%	0	0.0%	1	1.3%	0	0.0%
17-Sep	83	18	21.7%	0	0.0%	1	1.2%	0	0.0%
18-Sep	75	11	14.7%	0	0.0%	0	0.0%	0	0.0%
19-Sep	90	15	16.7%	0	0.0%	1	1.1%	0	0.0%
20-Sep	113	20	17.7%	1	0.9%	3	2.7%	0	0.0%
21-Sep	55	8	14.5%	0	0.0%	0	0.0%	0	0.0%
22-Sep	68	13	19.1%	0	0.0%	4	5.9%	0	0.0%
23-Sep	72	14	19.4%	0	0.0%	0	0.0%	0	0.0%
24-Sep	0	0	-	0	-	0	-	0	-
25-Sep	56	9	16.1%	0	0.0%	0	0.0%	0	0.0%
26-Sep	56	8	14.3%	0	0.0%	1	1.8%	0	0.0%
27-Sep	64	11	17.2%	0	0.0%	2	3.1%	0	0.0%
28-Sep	19	2	10.5%	0	0.0%	1	5.3%	0	0.0%
29-Sep	18	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30-Sep	20	3	15.0%	0	0.0%	0	0.0%	0	0.0%
1-Oct	35	7	20.0%	0	0.0%	0	0.0%	0	0.0%
2-Oct	14	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3-Oct	12	2	16.7%	0	0.0%	0	0.0%	0	0.0%
4-Oct	5	1	20.0%	0	0.0%	0	0.0%	0	0.0%
Total	1,060	181	17.1%	9	0.8%	16	1.5%	0	0.0%

<sup>a</sup> Not corrected for sex identification error.

<sup>b</sup> Columnaris incidence was not recorded in 1994.

Appendix 3c. Incidence of net, lamprey and hook marks and of *Flexibacter columnaris* lesions among sockeye jacks examined at tag application in the Birkenhead River, 1994.

Date	Number of jacks examined	Net marks		Lamprey marks		Hook marks		<i>F. columnaris</i> <sup>a</sup>	
		Number	Percent	Number	Percent	Number	Percent	Number	Percent
7-Sep	0	0	-	0	-	0	-	0	-
8-Sep	0	0	-	0	-	0	-	0	-
9-Sep	3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
10-Sep	0	0	-	0	-	0	-	0	-
11-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
12-Sep	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
13-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
14-Sep	0	0	-	0	-	0	-	0	-
15-Sep	0	0	-	0	-	0	-	0	-
16-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
17-Sep	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
18-Sep	3	0	0.0%	0	0.0%	0	0.0%	0	0.0%
19-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
20-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
21-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
22-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
23-Sep	3	1	33.3%	0	0.0%	0	0.0%	0	0.0%
24-Sep	0	0	-	0	-	0	-	0	-
25-Sep	0	0	-	0	-	0	-	0	-
26-Sep	0	0	-	0	-	0	-	0	-
27-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
28-Sep	0	0	-	0	-	0	-	0	-
29-Sep	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
30-Sep	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1-Oct	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
2-Oct	1	0	0.0%	0	0.0%	0	0.0%	0	0.0%
3-Oct	2	0	0.0%	0	0.0%	0	0.0%	0	0.0%
4-Oct	0	0	-	0	-	0	-	0	-
Total	28	1	3.6%	0	0.0%	0	0.0%	0	0.0%

<sup>a</sup> Columnaris incidence was not recorded in 1994.

Appendix 4. Daily sockeye carcass recoveries, by location, mark status and sex, in the Birkenhead River, 1994.

Date	Reach	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
26-Sep	1	-	1	0	0	38	41	0	39	41	0
	2	-	2	1	0	41	36	3	43	37	3
	3	-	0	1	0	7	14	0	7	15	0
27-Sep	5	-	0	0	0	2	4	0	2	4	0
	6	-	0	0	0	1	2	0	1	2	0
28-Sep	2	-	1	1	0	38	36	0	39	37	0
	3	-	0	0	0	2	0	0	2	0	0
	4	-	1	1	0	6	12	0	7	13	0
29-Sep	10	-	0	0	0	0	2	0	0	2	0
	1	-	3	4	0	110	104	0	113	108	0
	9	-	0	0	0	3	9	0	3	9	0
30-Sep	1	-	7	2	0	53	101	0	60	103	0
	5	-	0	0	0	2	8	0	2	8	0
	6	-	0	1	0	2	1	0	2	2	0
	7	-	0	0	0	1	2	0	1	2	0
1-Oct	8	-	2	3	0	22	52	1	24	55	1
	1	-	0	6	0	48	67	2	48	73	2
	4	-	0	0	0	7	16	1	7	16	1
2-Oct	7	-	0	0	0	0	4	0	0	4	0
	1	-	2	7	0	58	87	0	60	94	0
	3-Oct	1	-	5	8	0	77	139	0	82	147
4-Oct	1	-	5	18	0	94	154	0	99	172	0
	2	-	6 <sup>a</sup>	12	0	121	185	0	127 <sup>a</sup>	197	0
	3	-	0	3	0	33	42	0	33	45	0
5-Oct	7	-	0	0	0	3	2	0	3	2	0
	8	-	0	2	0	33	45	0	33	47	0
	9	-	1	1	0	10	8	0	11	9	0
	10	-	0	0	0	7	2	0	7	2	0
6-Oct	1	-	9	11	0	119	262	7	128	273	7
	2	-	4	12	0	152	152	1	156	164	1
	3	-	1 <sup>a</sup>	5	0	50	41	1	51 <sup>a</sup>	46	1
	4	-	0	1	0	8	30	0	8	31	0
	5	-	0	0	0	7	12	0	7	12	0
	6	-	0	0	0	3	8	0	3	8	0
7-Oct	9	-	0	0	0	0	0	1	0	0	1
	1	-	11 <sup>a</sup>	7	0	162	264	4	173 <sup>a</sup>	271	4
8-Oct	2	-	6 <sup>a</sup>	11	0	177	196	2	183 <sup>a</sup>	207	2
	3	-	0	5	0	27	62	0	27	67	0
	1	-	0	5	0	75	84	0	75	89	0
9-Oct	2	-	15	28	0	199	355	8	214	383	8
	3	-	0	4	0	18	60	0	18	64	0
	1	-	5	3	0	59	59	1	64	62	1
10-Oct	2	-	4	5	0	95	244	0	99	249	0
	3	-	1	3	0	20	76	0	21	79	0
	8	-	0	0	0	19	49	0	19	49	0
	9	-	0	1	0	7	12	0	7	13	0
11-Oct	1	-	7 <sup>a</sup>	10	0	187	371	0	194 <sup>a</sup>	381	0
	4	-	0	1	0	10	29	0	10	30	0
	5	-	0	1	0	5	10	0	5	11	0
	6	-	1	1	0	4	12	0	5	13	0
12-Oct	1	-	5	10	0	161	223	0	166	233	0
	2	-	2	7	0	56	91	0	58	98	0
	3	-	1	3	0	23	62	0	24	65	0

Continued

Appendix 4. Daily sockeye carcass recoveries, by location, mark status and sex, in the Birkenhead River, 1994, continued.

Date	Reach	Number of surveys	Disk tag present			Untagged			Total		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
13-Oct	2	-	5	10	0	86	184	0	91	194	0
	3	-	0	2	0	28	97	0	28	99	0
	8	-	0	0	0	8	26	1	8	26	1
	9	-	0	0	0	10	22	0	10	22	0
14-Oct	1	-	11	16	0	278	326	2	289	342	2
	4	-	0	4	0	6	32	0	6	36	0
	7	-	1	0	0	16	31	1	17	31	1
15-Oct	2	-	4	1	0	62	46	0	66	47	0
16-Oct	1	-	2	4	0	54	118	0	56	122	0
	2	-	1	6	0	50	121	0	51	127	0
	3	-	1	0	0	7	39	0	8	39	0
17-Oct	2	-	1	3	0	17	51	1	18	54	1
	3	-	1	0	0	14	48	0	15	48	0
	7	-	0	1	0	8	14	0	8	15	0
	8	-	0	0	0	5	17	0	5	17	0
18-Oct	9	-	0	0	0	2	8	0	2	8	0
	1	-	2	7	0	118	179	0	120	186	0
	2	-	3	1	0	64	110	0	67	111	0
19-Oct	2	-	0	2	0	11	50	0	11	52	0
	3	-	0	0	0	11	21	0	11	21	0
	5	-	0	0	0	3	2	0	3	2	0
	6	-	0	0	0	2	10	0	2	10	0
20-Oct	1	-	3	4	0	91	143	0	94	147	0
21-Oct	3	-	0	0	0	2	23	0	2	23	0
22-Oct	1	-	2	1	0	28	38	0	30	39	0
	2	-	0	3	0	32	46	0	32	49	0
Total	1	18	80	123	0	1,810	2,760	16	1,890	2,883	16
	2	15	54	103	0	1,201	1,903	15	1,255	2,006	15
	3	13	5	26	0	242	585	1	247	611	1
	4	5	1	7	0	37	119	1	38	126	1
	5	5	0	1	0	19	36	0	19	37	0
	6	5	1	2	0	12	33	0	13	35	0
	7	5	1	1	0	28	53	1	29	54	1
	8	5	2	5	0	87	189	2	89	194	2
	9	6	1	2	0	32	59	1	33	61	1
	10	2	0	0	0	7	4	0	7	4	0
Total	-	-	145	270	0	3,475	5,741	37	3,620 <sup>b</sup>	6,011	37

<sup>a</sup>. Excludes 1 disk tag which was removed due to recapture stress.

<sup>b</sup>. Excludes 5 disk tags which were removed due to recapture stress.

Appendix 5. Daily number of sockeye carcasses examined and disk tags recovered, by location and sex, during the re-survey of the Birkenhead River, 1994.

Date	Reach	Number of surveys	Disk tag present			Total examined			Disk tag incidence		
			Male	Female	Jack	Male	Female	Jack	Male	Female	Jack
6-Oct	1	-	0	1	0	173	355	0	0.000	0.003	-
9-Oct	1	-	0	1	0	143	283	0	0.000	0.004	-
	2	-	0	0	0	74	135	0	0.000	0.000	-
11-Oct	1	-	0	0	0	15	19	0	0.000	0.000	-
	2	-	0	1	0	71	136	0	0.000	0.007	-
	4	-	0	0	0	1	7	0	0.000	0.000	-
	5	-	0	0	0	4	6	0	0.000	0.000	-
	6	-	0	0	0	2	9	0	0.000	0.000	-
18-Oct	1	-	0	0	0	40	97	0	0.000	0.000	-
	2	-	1	0	0	106	186	0	0.009	0.000	-
20-Oct	1	-	1	0	0	64	158	0	0.016	0.000	-
	2	-	0	0	0	64	190	0	0.000	0.000	-
	3	-	0	1	0	28	94	0	0.000	0.011	-
21-Oct	1	-	0	0	0	24	48	0	0.000	0.000	-
	7	-	0	0	0	0	2	0	-	0.000	-
	8	-	0	0	0	1	9	0	0.000	0.000	-
	9	-	0	0	0	1	2	0	0.000	0.000	-
Total	1	6	1	2	0	459	960	0	0.002	0.002	-
	2	4	1	1	0	315	647	0	0.003	0.002	-
	3	1	0	1	0	28	94	0	0.000	0.011	-
	4	1	0	0	0	1	7	0	0.000	0.000	-
	5	1	0	0	0	4	6	0	0.000	0.000	-
	6	1	0	0	0	2	9	0	0.000	0.000	-
	7	1	0	0	0	0	2	0	-	0.000	-
	8	1	0	0	0	1	9	0	0.000	0.000	-
	9	1	0	0	0	1	2	0	0.000	0.000	-
Total	-	-	2	4	0	811	1,736	0	0.002	0.002	-

Appendix 6. Fecundity sampling results and analytic details for sockeye salmon captured in the Birkenhead River, 1994.

Sample number	Age	Standard length (cm) <sup>b</sup>	Skein weight (g)	Skein sub-sample		Estimated fecundity	Actual fecundity	Misc. eggs	Adjusted fecundity
				Weight (g)	Egg count				
1	4 <sub>2</sub>	55.7	487.5	182.5	1,604	4,285		1	4,286
2	4 <sub>2</sub>	52.4	357.2	139.0	1,356	3,485		0	3,485
3	4 <sub>2</sub>	53.8	353.6	137.8	1,456	3,736		0	3,736
4	4 <sub>2</sub>	55.2	471.4	177.3	1,771	4,709		0	4,709
5	4 <sub>2</sub>	55.1	383.9	147.9	1,605	4,166		0	4,166
6	4 <sub>2</sub>	53.9	453.1	171.0	1,701	4,507		0	4,507
7	4 <sub>2</sub>	54.4	437.1	165.7	1,521	4,012		7	4,019
8	4 <sub>2</sub>	51.3	280.0	113.8	1,483	3,649		2	3,651
9	4 <sub>2</sub>	55.0	481.5	181.0	1,961	5,217		1	5,218
10	4 <sub>2</sub>	54.6	423.3	225.3	2,234	4,197	4,231	10	4,207
11	4 <sub>2</sub>	53.6	447.3	169.1	1,475	3,902		10	3,912
12	4 <sub>2</sub>	53.5	475.2	178.4	1,888	5,029		12	5,041
13	4 <sub>2</sub>	54.2	442.3	241.4	2,656	4,866	4,934	10	4,876
14	4 <sub>2</sub>	49.1	364.6	141.5	1,439	3,708		14	3,722
15	4 <sub>2</sub>	54.5	440.5	166.8	1,934	5,107		11	5,118
16	4 <sub>2</sub>	56.8	478.8	179.6	1,627	4,337		17	4,354
17	4 <sub>2</sub>	52.1	379.4	146.4	1,539	3,988		0	3,988
1	5 <sub>2</sub>	57.8	548.9	275.1	2,873	5,732	5,761	6	5,738
2	5 <sub>2</sub>	57.0	554.9	301.9	2,801	5,148	5,193	1	5,149
3	5 <sub>2</sub>	62.1	626.4	228.8	1,908	5,224		0	5,224
4	5 <sub>2</sub>	56.4	479.2	179.7	1,853	4,941		1	4,942
5	5 <sub>2</sub>	58.8	484.9	220.1	2,131	4,695	4,712	1	4,696
6 <sup>a</sup>	5 <sub>2</sub>	57.8							
7	5 <sub>2</sub>	60.3	575.4	211.9	1,641	4,456		12	4,468
8	5 <sub>2</sub>	58.6	591.4	217.3	2,099	5,713		11	5,724
9	5 <sub>2</sub>	60.2	537.7	200.0	1,888	5,076		10	5,086
Mean	4 <sub>2</sub>	53.8	421.0	168.5	1,721	4,288	4,583	6	4,294
	5 <sub>2</sub>	58.8	549.9	229.4	2,149	5,123	5,222	5	5,128

<sup>a</sup>. Sample lost.

<sup>b</sup>. Actual measurements; not adjusted for shrinkage which occurs in carcass recoveries.

Appendix 7a. Proportion at age and mean length (Standard and POH) at age, by location, sex and sample period, from the adult sample of sockeye carcasses recovered on the Birkenhead River spawning grounds, 1994. <sup>a</sup>

Location	Sex	Sampling Period	Age	Sample size	Percent	Standard length (cm)		POH length (cm)	
						Mean	Standard deviation	Mean	Standard deviation
Birkenhead River	Male	2-Oct to 3-Oct	6 <sub>3</sub>	0	0.0%	-	-	-	-
			5 <sub>2</sub>	21	35.0%	63.6	2.1	54.2	1.7
		3-Oct	4 <sub>2</sub>	39	65.0%	57.1	3.8	48.9	3.1
			3 <sub>2</sub>	0	0.0%	-	-	-	-
		Unaged		0	-	-	-	-	-
				0	-	-	-	-	-
		10-Oct to 12-Oct	6 <sub>3</sub>	4	3.4%	63.3	1.7	54.5	1.9
			5 <sub>2</sub>	40	33.9%	63.5	2.3	54.3	1.6
		12-Oct	4 <sub>2</sub>	73	61.9%	57.2	2.8	48.9	2.3
			3 <sub>2</sub>	1	0.8%	35.0	-	31.0	-
		Unaged		2	-	59.0	1.4	50.5	2.1
				2	-	59.0	1.4	50.5	2.1
	15-Oct to 16-Oct	6 <sub>3</sub>	0	0.0%	-	-	-	-	
		5 <sub>2</sub>	48	40.7%	63.5	2.0	54.3	1.7	
	16-Oct	4 <sub>2</sub>	69	58.5%	57.5	2.8	49.3	2.3	
		3 <sub>2</sub>	1	0.8%	36.9	-	32.7	-	
	Unaged		2	-	52.0	0.0	48.0	1.4	
			2	-	52.0	0.0	48.0	1.4	
	Total		6 <sub>3</sub>	4	1.4%	63.3	1.7	54.5	1.9
			5 <sub>2</sub>	109	36.8%	63.5	2.1	54.3	1.7
			4 <sub>2</sub>	181	61.1%	57.3	3.1	49.1	2.5
			3 <sub>2</sub>	2	0.7%	36.0	1.4	32.0	1.4
			Unaged	4	-	58.0	1.4	49.6	2.1
	Female	2-Oct to 3-Oct	6 <sub>3</sub>	0	0.0%	-	-	-	-
5 <sub>2</sub>			31	51.7%	58.4	1.7	52.2	1.4	
4 <sub>2</sub>			29	48.3%	52.3	2.0	47.0	1.7	
Unaged			0	-	-	-	-	-	
			0	-	-	-	-	-	
10-Oct to 12-Oct		6 <sub>3</sub>	1	1.7%	58.6	-	53.0	-	
		5 <sub>2</sub>	22	36.7%	59.0	1.8	52.8	1.6	
12-Oct		4 <sub>2</sub>	37	61.7%	51.9	1.9	46.6	1.5	
		Unaged	0	-	-	-	-	-	
15-Oct to 16-Oct		6 <sub>3</sub>	0	0.0%	-	-	-	-	
		5 <sub>2</sub>	26	43.3%	57.5	2.2	51.7	1.8	
16-Oct		4 <sub>2</sub>	34	56.7%	52.6	1.7	47.2	1.4	
	Unaged	0	-	-	-	-	-		
Total		6 <sub>3</sub>	1	0.6%	58.6	-	53.0	-	
		5 <sub>2</sub>	79	43.9%	58.2	2.0	52.2	1.6	
		4 <sub>2</sub>	100	55.6%	52.3	1.9	46.9	1.5	
		Unaged	0	-	-	-	-	-	

<sup>a</sup> Mean lengths and standard deviations were calculated from length data rounded to the nearest centimeter.

Appendix 7b. Proportion at age and mean length (Standard and POH) at age, by location and sample period, from the jack sample of sockeye carcasses recovered on the Birkenhead River spawning grounds, 1994. <sup>a</sup>

Location	Sex	Sampling Period	Age	Sample size	Percent	Standard length (cm)		POH length (cm)	
						Mean	Standard deviation	Mean	Standard deviation
Birkenhead River	Jack	Study period to 3-Oct	4 <sub>2</sub>	1	3.2%	42.0	-	-	-
			3 <sub>2</sub>	30	96.8%	36.1	2.4	32.6	1.0
		Unaged	3	-	35.3	4.9	-	-	

<sup>a</sup> Mean lengths and standard deviations were calculated from length data rounded to the nearest centimeter.