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A Comparison of Population Assessment Methods Employed to Estimate the Abundance of Sockeye Salmon *(Oncorhynchus nerka)* Returning to Henderson Lake, Vancouver Island During 1989

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1991

Canadian Technical Report of Fisheries and Aquatic Sciences 1798

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A COMPARISON OF POPULATION ASSESSMENT METHODS EMPLOYED TO ESTIMATE THE ABUNDANCE OF SOCKEYE SALMON (*Oncorhynchus nerka*) RETURNING TO HENDERSON LAKE, VANCOUVER ISLAND DURING 1989

by

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Cat. No. Fs 97-6/1798E ISSN 0706-6457

Correct citation for this publication:

Tschaplinski, P. J. and K. D. Hyatt. 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (Oncorhynchus nerka) returning to Henderson Lake, Vancouver Island during 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1798: 101 p.

ABSTRACT

Tschaplinski, P. J. and K. D. Hyatt. 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (Oncorhynchus nerka) returning to Henderson Lake, Vancouver Island during 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1798: 101 p.

Small numbers of sockeye first arrived at the Henderson Lake and Clemens Creek spawning grounds around 24 July shortly after they appeared in Barkley Sound. Spawning was not initiated until 5 October after the first seasonal rains increased stream discharge. Spawning activity peaked by 1 November and was completed by 2 December.

Several techniques were employed to estimate sockeye salmon escapements to Henderson Lake in 1989. Counts from fixed-wing aircraft generated a peak estimate of only 5,525 spawners. The peak number of live-plus-dead sockeye observed on one of seven ground-based visual surveys produced another minimum estimate of 18,556 fish. The highest estimates (64,979 and 48,734 sockeye) were derived from the area under a spawner abundance curve (AUC) combined with estimates of mean spawner residence times from tag-depletion curves either adjusted or unadjusted for tag-detection efficiencies. Simple and stratified Petersen estimates based on carcass recoveries were also biased high at 45,630 and 44,552 fish respectively. Intermediate estimates were generated from four other procedures including: (a) simple and stratified Petersen mark-recapture techniques based on counts of live, tagged fish; and, (b) AUC techniques combined with separate estimates of spawner residence time determined from the cumulative tag-day method and the interval between peak counts of live and dead spawners. Population estimates based upon these four independent techniques converged closely under near-ideal survey conditions. Techniques depending upon accurate recoveries of tagged sockeye were refined by adjusting recoveries on the basis of tag-detection efficiency studies specific for tag color and viewing conditions. The stratified Petersen mark recapture method based on live fish generated the preferred population estimate of 32,075 sockeye.

RÉSUMÉ

Tschaplinski, P. J. and K. D. Hyatt. 1991. A comparison of population assessment methods employed to estimate the abundance of sockeye salmon (Oncorhynchus nerka) returning to Henderson Lake, Vancouver Island during 1989. Can. Tech. Rep. Fish. Aquat. Sci. 1798: 101 p.

Les premiers saumons rouges sont arrivés en petit nombre aux frayères du lac Henderson et du ruisseau Clemens vers le 24 juillet peu de temps après leur apparition dans le bassin Barkley. La fraie n'a débuté que le 5 octobre après que les premières pluies automnales aient accru le débit du cours d'eau. Le gros de la fraie avait eu lieu le 1er novembre et elle etait terminée le 2 décembre.

Plusieurs techniques ont été utilisées pour estimer les échappées des saumons rouges vers le lac Henderson en 1989. Les dénumbrements effectués à bord d'un avion ont donné une estimation maximale de seulement 5,525 reproductuers. Le nombre le plus élevé de saumons rouges vivants et morts observés lors d'un dénombrement visuel au sol, dont sept ont été effectués au total, a donné une autre estimation peu élevée de 18,556 poissons. Les estimations les plus élevées (64,979 et 48,734 saumons rouges) ont été obtenues en conjuguant l'aire sous une courbe d'abondance des reproducteurs (AUC) à des estimations des temps de résidence moyens des reproducteurs fondées sur des courbes de diminution du nombre de poissons marqués, ajustées ou non en fonction de l'efficacité de repérage des étiquettes. Des estimations de Petersen, l'une simple et l'autre stratifiée fondées sur la récupération des carcasses, ont elles aussi été trop élevées, avec 45,630 et 44,552 poissons, respectivement. Des estimations intermédiaires ont été obtenues suivant quatre autre méthodes, dont: (a) des techniques de marquage-recapture de Petersen simples ou stratifiées fondées sur le dénombrement de poissons vivants et marqués; et (b) l'utilisation de courbes AUC, conjuguée à des estimations distinctes du temps de résidence des reproducteurs établies à partir de la méthode cumulative étiquettes-jours et de l'intervalle entre les dénombrements maximaux de reproducteurs morts et vivants. Les estimations de population obtenues au moyen de ces quatre techniques différentes étaient très semblables dans des conditions presque idéales pour la réalisation de ces travaux. Les techniques dépendantes du succès de recapture des saumons rouges étiquetés ont été améliorées par une correction des recaptures fondée sur des études de l'efficacité de repérage des étiquettes en fonction de leur couleur et des conditions de visibilité. La méthode de marquage-recapture stratifiée de Petersen prenant en considération les poissons vivants a donné l'estimation la plus satisfaisante, soit 32,075 saumons rouges.

INTRODUCTION

Adult sockeye salmon returning to Barkley Sound on the west coast of Vancouver Island spawn mainly in the Great Central, Sproat, and Henderson lake systems. Sockeye returning to Henderson Lake have been enumerated and sampled annually since 1980 to determine their population size, and age, sex, and length distributions (Tschaplinski and Hyatt 1990). The Biological Sciences Branch of the Canada Department of Fisheries and Oceans employs these data to determine the effects on sockeye production of annual additions of inorganic nutrients to British Columbia coastal lakes (Tschaplinski and Hyatt 1990).

The Henderson Lake sockeye stock is the smallest one in Area 23, annually forming between 2.1 - 16.9 % of the combined sockeye escapements to Great Central, Sproat, and Henderson lakes between 1980 and 1988 (Tschaplinski and Hyatt 1990). The larger Great Central and Sproat Lake stocks appear in Barkley Sound in May and begin their migrations upstream by late May - early June (Hyatt and Steer 1987). The later-returning Henderson Lake sockeye first appear in Barkley Sound in late June - mid-July, enter Henderson Lake usually in September, and begin migrating upstream in Clemens Creek (the main tributary to the lake) generally in late September (Fig. 1).

Most sockeye in the Henderson Lake system spawn in the lower 6.5 - 7.0 km of Clemens Creek, while some spawners use lakeshore reaches adjacent to the mouth of both Clemens and Ternan creeks (Fig. 2). Seasonal estimates of sockeye escaping to Henderson Lake have been made on the spawning grounds through either simple visual surveys (1980) or visual counts combined with Petersen mark-recapture techniques (Ricker 1975, Seber 1982). Simple Petersen estimates were made annually from 1981 - 1985, while stratified Petersen estimates have also been made since 1986. Visual counts of both tagged and untagged spawners made seasonally at different intervals provided an alternative to the Petersen estimates.

Sequential counts of tagged sockeye made throughout the spawning season have been employed to estimate spawner residence times using the cumulative tag-day and tag-depletion methods (Tschaplinski and Hyatt 1990). Residence times combined with seasonally integrated counts of sockeye spawners are ultimately used to estimate escapements using the area-under-the-curve (AUC) method (Ames 1984, Perrin and Irvine 1990). However, poor visibility associated with high discharges and turbidity in Clemens Creek have biased visual counts in most years. Poor viewing conditions have caused simple visual counts to underestimate spawning populations. Suboptimal viewing conditions, which reduce the numbers of live fish carrying tags which can be counted, also cause tag-loss (mortality) rates to be overestimated, mean residence times to be consequently biased low, and the subsequent AUC population estimate to be biased high (Tschaplinski and Hyatt 1990). Adverse environmental conditions affecting population surveys require that several techniques be employed each year to estimate the abundance of sockeye spawners in the Henderson Lake system because no single procedure can always be depended upon to provide an accurate estimate.

The objectives of the 1989 escapement studies at Henderson Lake were to employ a variety of methods to estimate the numbers of sockeye spawning in the system and to obtain representative samples of spawners to accurately describe some of the biological characteristics of the population. The length-frequency, age, and sex compositions of the spawning population will be described elsewhere (Tschaplinski and Hyatt 1991, in preparation). Methods used for the determination of the biological characteristics of the spawning population were consistent with those employed between 1980 and 1988 when 95 - 335 sockeye were sampled annually from the Henderson Lake system (Steer et al. 1988, Tschaplinski and Hyatt 1990).

The present report details the procedures employed to determine (a) the size of the sockeye spawning escapement to Henderson Lake and Clemens Creek in 1989, and (b) the effects of tag color and viewing conditions on visual detection efficiencies and subsequent population estimates which depend on accurate tag recoveries.

Separate estimates of population numbers were generated from surveys of the Clemens Creek and Henderson Lake spawning grounds made at intervals during September - early December by employing: (i) visual counts of live salmon made from fixed-wing aircraft; (ii) "ground-based" visual counts of live and dead sockeye; (iii) Petersen mark-recapture techniques for which sequential applications and subsequent visual enumerations of color-coded disc tags were made; and, (iv) a spawner-abundance curve (calculated from the seasonal series of visual counts of live sockeye) combined with three independent estimates of mean spawner residence time. Estimates of residence time were made by using the (i) interval between peak counts of live and dead spawners, (ii) cumulative tag-day method, and (iii) tag-depletion method (Tschaplinski and Hyatt 1990). All population estimates were compared and evaluated with respect to strengths and biases.

Accurate population estimates generated from both Petersen mark-recapture procedures and from techniques requiring estimates of spawner residence time depend upon the efficient detection of color-coded disc tags applied to the fish (Tschaplinski and Hyatt 1990). Visual detection efficiencies may vary according to the size and color of tags used (Tschaplinski and Hyatt 1990) as well as viewing conditions determined by turbidity, water depth, stream discharge, rainfall, and ambient light level. Given temporal variations in viewing conditions, tag-detection efficiencies can vary (i) among either tag colors or sizes within surveys and (ii) within colors or sizes among surveys conducted at different times in a year or in different years. Variations in tag-detection efficiencies directly affect the reliability of population estimates made by using mark-recapture and AUC methods.

Tag-detection efficiencies were investigated systematically in the present study during several population surveys spanning a variety of viewing conditions. Buoyant Petersen disc tags were placed in the stream in different locations for subsequent counting by observers. Percentages of each color of tag detected were determined under specific viewing conditions and then used to adjust visual recoveries of tagged sockeye made during population surveys conducted under similar viewing conditions. Petersen mark-recapture estimates and spawner residence times were adjusted according to the results of the tag-detection trials and then compared to survey results derived from unadjusted data. Implications for the refinement of population estimates made using mark-recapture and AUC techniques in previous years are discussed for Henderson Lake sockeye.

MATERIALS AND METHODS

Migration onto the Spawning Grounds, Spawning Activity, and Visual Counts of Live Sockeye

Seven visual surveys of sockeye escapements to Henderson Lake and Clemens Creek were made in 1989 between 20 September and 7 December. Surveys each spanned one to six days, were spaced at 6 - 12-d intervals, and were designated consecutively T-1 to T-7. During each trip, observations were made on spawning activity and the distribution of adult sockeye in both the stream and the lake. The date when sockeye first arrived on the spawning grounds was estimated from observations made by forest harvest and road construction personnel working in the Clemens Creek watershed during summer (Mars Industries Limited, Kildonan, BC). The final date of spawning was estimated by extending sockeye numbers to zero based upon the mean daily decrease in abundance derived from counts made on the two last trips of the year.

Visual counts of spawners were made along the lakeshore near the mouth of Clemens Creek and throughout seven similarly spaced reaches of the lower 7.0 km of the stream (Fig. 2). Three types of counts were employed to provide independent estimates of spawner abundance: total-section surveys, strip counts (Tschaplinski and Hyatt 1990), and aerial overflights. All sections of the stream were examined by at least one method on each survey of the spawning grounds. Sections were counted sequentially from the uppermost (section 7) to section 1 adjacent to the mouth of Clemens Creek.

(i) Total-Section Counts

For most surveys, two observers walked along the main channel and any secondary reaches in each section of Clemens Creek and enumerated all sockeye visible according to methods detailed by Tschaplinski and Hyatt (1990). The average between sums obtained separately by the two observers was accepted as the total count for each main-channel reach. Counts from secondary channels obtained by either observer were added to the main-channel averages to determine total sockeye abundance in each section. All live sockeye carrying color-coded, Petersen disc tags were tallied separately and the numbers of each color code were recorded for each stream section. Adult salmon of other species were also counted on all surveys.

Both tagged and untagged sockeye occurring along the beach adjacent to the mouth of Clemens Creek were counted by observers passing parallel to the shoreline in a small boat equipped with a 9.9-horsepower outboard motor. The boat was driven slowly (< 0.5 m/s) to avoid disturbing the fish. All sockeye sighted between the lakeshore and the 3 - 5-m depth limit of visibility were tallied.

Two days were generally required to complete each total-section survey. However, surveys T-3, T-5, and T-6 (beginning on 18 October, 15 November, and 29 November respectively), required rapid (one-day) coverage of the spawning grounds due to imminent bad weather. Stream sections were divided between observers on those dates; therefore, individual counts for each reach were pooled to derive the total-stream census.

(ii) Strip Counts

In addition to the seven main visual surveys, sections 1 - 6 of Clemens Creek were enumerated again on 1 and 15 November respectively (trips T-4 and T-5) by using the strip-count method (Tschaplinski and Hyatt 1990). Permanent strip-count stations were established at 30-m intervals in sections 1 - 6 of the stream. Stations in both main and secondary channels were marked with flagging ribbon and fluorescent paint, and numbered consecutively beginning at the downstream end of each section. A total of 213 stations were established along the main channel of Clemens Creek: each main-channel section contained from 22 - 45 stations. Additionally, there were 26 stations in the secondary reaches of sections 1, 4, and 6 combined. No stations were placed in section 7 because sockeye spawn only in the lower part of this steep-sloped reach which consists of numerous small channels.

Strip counts were undertaken by two observers in 1989 because these surveys were combined with recoveries and detailed observations of sockeye carcasses. On both surveys, one observer covered sections 1 - 4 while the other covered sections 5 and 6. The observers switched sections on the consecutive surveys. Sockeye occurring within a one-meter wide strip across Clemens Creek were enumerated at each counting station. For each section, the sum of all fish counted was expanded by methods detailed by Tschaplinski and Hyatt (1990) to derive the sectional estimate of live spawners. Separate expansions were made for each secondary channel within any section. Sectional population estimates were thus derived by adding estimates for the secondary channels to the main-channel total. The population numbers obtained by strip-count and total-section methods were compared directly: the speed and relative accuracy of the strip counting technique was then evaluated.

(iii) Aerial Overflights

Adult salmon on the Clemens Creek and Henderson Lake spawning grounds were counted by two observers passing overhead in a fixed-wing aircraft. One aerial survey was made on each trip to Henderson Lake if weather permitted. Counts were conducted at the beginning of each survey prior to ground-based surveys so that observers would not be biased by knowledge of the numbers of spawners actually present. The stream was surveyed sequentially from section 6 to the mouth. All near-shore areas of the lake known to be used by spawning sockeye were examined. Counts were made from altitudes between 45 and 90 m. Sockeye were estimated in multiples of fives, tens, hundreds, and thousands. The average between sums obtained separately by each observer was accepted as the final count for each stream section and lakeshore reach. Separate tallies were made for the lake at the mouth of Clemens Creek, beaches immediately east and west of the stream, and sites elsewhere in the lake.

Monitoring Physical Conditions in the Lake and Stream

Accurate visual counts of sockeye spawners could be obtained only when streamflows were relatively low and stable. Therefore, stream and lake levels were monitored during each population survey from staff gauges installed at the lakeshore adjacent to the field camp and in sections 1 and 5 of Clemens Creek. The lakeside and section 1 (S1) gauges were read once or twice daily. Multiple readings corresponded to morning and afternoon observations associated respectively with the start and finish of stream surveys or fish tagging. The gauge in section 5 was read at least once on all surveys except T-1.

The lakeside and section 5 gauges were located in the same positions as in previous years (Tschaplinski and Hyatt 1990). However, the gauge in section 1 was washed downstream during a freshet prior to the beginning of the 1989 escapement surveys. The original section 1 staff gauge was replaced in a new location on the opposite side of the stream about 220 m upstream from the old site. The staff was secured to a large tree root located in a low-velocity pool containing bedrock substrate. The elevation of the new gauge relative to positions in other years was determined by calibration against a linear regression between lakeshore and section 1 readings available for 1984 (Tschaplinski and Hyatt 1990; Table A-1).

Water temperatures (^{o}C) in the lake and stream were taken once or twice daily by using simple mercury thermometers. Temperatures were taken at or near each staff gauge site whenever water levels were examined. The time when each observation was made was also recorded.

Spawner Mortality and Recovery of Carcasses

During each survey of Clemens Creek, all dead sockeye of each sex were tallied separately from live ones and pitched up onto the stream banks. The numbers pitched in each section were then summed among observers and recorded. Carcasses carrying Petersen disc tags were counted separately from untagged individuals, and the total numbers of each color code were recorded for each stream section and the lake.

Observations were made to record the dates when sockeye carcasses (a) first appeared on the spawning grounds, and (b) were most abundant.

Tagging Procedures Used for Marking Henderson Lake Sockeye

Samples of adult sockeye were marked with Petersen disc tags on three occasions during the spawning season in order to estimate escapements by the Petersen mark-recapture method (Ricker 1975) and by techniques based upon estimates of mean residence time of sockeye on the spawning grounds (Perrin and Irvine 1990, Tschaplinski and Hyatt 1990). A total of 1 919 plastic disc tags were applied during surveys T-2, T-3, and T-4 combined (Table 1). The single-colored tags used were 25 mm in diameter and the same size as those employed in all previous years but 1988. Tagging was begun on 3 October when 289 white tags were applied prior to visual surveys. This procedure was repeated on 17 - 19 October by marking 737 fish with red tags. Finally, 893 pink tags were applied on 30 Oct - 3 Nov. About 46 % of all red tags and 80 % of all pink tags had been applied by 18 and 31 October respectively; therefore, these dates were used to identify the corresponding tagging sessions.

Sockeye were seined and tagged at a number of locations along the lowermost 100 - 150 m of Clemens Creek and along the adjacent lakeshore by methods detailed by Tschaplinski and Hyatt (1990; Fig. 2). No tag loss was observed among sockeye in the previous year; therefore, no secondary marks were applied. Before each sockeye was released, its sex was determined by examining its external morphology. The numbers of each sex tagged were tallied as were all other salmonid species caught incidentally.

Determination of Tag-Detection Efficiencies

(i) Counts of Tagged Sockeye One Day After Tagging

Counts of tagged sockeye were made the day after tagging in order to determine the proportion of newly tagged individuals visible under specific viewing conditions defined by streamflow, water depth, turbidity, rainfall, ambient light, and available cover. Given low mortality and emigration among tagged sockeye, counts on day 1 occasionally served as one measure of tag-detection efficiency. Counts were also used to indicate (i) the distribution and migration rate of tagged individuals in Clemens Creek shortly after tagging, and (ii) the proportion of tagged sockeye remaining in the stream and available for enumeration compared to those individuals which return to the lake after being handled. Tagged fish were enumerated at the same time that population surveys were conducted throughout the stream and nearby lakeshore.

(ii) <u>Tag Visibility Experiments</u>

Tag-detection efficiencies were also determined systematically by deploying variable numbers of buoyant tags of various colors for subsequent counting. Each set of tags consisted of two Petersen discs (25-mm diameter) tied together on one side with clear, monofilament line and separated by a central styrofoam disc of the same diameter and about 10-mm maximum thickness (Fig. 5). Discs were positioned at an angle that simulated their orientation on the dorsum of an adult salmon. Each set of tags was attached to a length of clear, monofilament line varying between 0.3 - 0.8 m long. The opposite end of each line was fastened to a lead fishing weight weighing either 57 or 85 g. When the weights were placed onto the stream bottom, each set of anchored tags was oriented such that they formed an inverted "V" (Fig. 5).

One tag visibility trial was performed on each of surveys T-2 - T-5 (4, 16, and 30 October, and 18 November respectively). For each trial, one investigator deployed 20 - 25 white, 21 - 30 red, 25 - 35 pink, and 21 - 28 green tags (Σ = 100 - 110 tags) throughout a reach about 100 m long in section 1 of Clemens Creek in sites including riffles, runs, and pools frequented by adult sockeye. Tags were usually placed in water 0.5 - 1.5 m deep. The lower 450 m of stream was employed for these studies throughout the season. The number of tags deployed of each color was unknown to two observers who walked the stream and enumerated all tags visible. The average of the separate counts made by each observer was taken as the number detected for each color of tag. The final tallies excluded tags seen within 2 m of each observer and those first detected by either the lead weight or styrofoam center. These sightings were considered to be tags missed. Tags were recovered from the stream at the conclusion of each study. During each investigation, observations were recorded on stream discharge (S1 gauge heights), percent cloud cover, rain (light vs. moderate or heavy), and visibility through the stream surface (qualitative assessments with respect to turbidity, turbulence, or rainfall).

Mean percentages detected were determined (a) for all tags combined both within each study and seasonally among studies, and (b) for each color of tag over all studies.

Comparisons of tag-recovery percentages both within and among tag colors were made relative to specific viewing conditions available for the four tag-detection trials. These percentages provided separate indices of visual detection efficiency for each color of tag so that bias associated with tag counts made under different viewing conditions could be quantified. The numbers of tags observed in population surveys could then be accurately adjusted according to given conditions to compensate for differences between numbers detected and true numbers present.

Estimates of Sockeye Residence Time on the Spawning Grounds

The average residence time of adult sockeye on the Henderson Lake and Clemens Creek spawning grounds was determined from three techniques: (i) the time interval between peak counts of live and dead spawners, (ii) the cumulative tag-day method (Bocking et al. 1988, Tschaplinski and Hyatt 1990), and (iii) the tag-depletion method (Tschaplinski and Hyatt 1990). Both cumulative tag-day and tag-depletion methods were based upon counts of live, tagged sockeye made during population surveys throughout the spawning season. For each technique, residence times were generated both from (i) unadjusted tag-recoveries, and (ii) counts in which the numbers of tagged sockeye were adjusted upward according to the results of studies on tag-detection efficiencies. Tag recoveries in each population survey were adjusted separately for each tag color according to specific viewing conditions that corresponded most closely with those occurring during one of the four tag-detection trials.

(i) Cumulative Tag-Day Method

Spawner residence time was determined for all tags applied in each of the three tagging sessions from the following relationship:

$$\text{residence time} = (\Sigma \text{ tag-days} / \text{no. tags applied}).$$

Total tag-days were determined for each tag group by integrating the area under a tag abundance curve plotted from the numbers of tagged, live fish enumerated during visual surveys (Tschaplinski and Hyatt 1990). The first point on each curve (day 0) was the total number of tags applied. The second point was the day 1 count. Mean residence time (days) for each tag group was calculated by dividing the area under the curve (AUC) by the total number of tags initially applied (Bocking et al. 1988, Tschaplinski and Hyatt 1990). The population mean was then calculated by averaging residence times determined for the three sets of tags applied during the marking periods of 3, 18, and 31 October respectively.

(ii) Tag-Depletion Method

The seasonal decrease of the size of the spawning population was approximated linearly by the tag-depletion equation

$$\ln(\mathrm{Tags}+1) = a(DE) + b \ ,$$

where a = the slope of the line, b = the y-axis intercept, and DE = the number of days elapsed between tagging and recovery dates for each group of tags (Tschaplinski and Hyatt 1990). The natural logarithms of the numbers of tagged sockeye observed alive in each recovery period were correlated with the number of days elapsed between the tagging and recovery dates for each tag group. The elapsed time required to reach 50 % tag loss ($E_{TL}50$) was calculated from this relationship and considered to be an estimate of spawner residence time. Tag-recovery observations made one day after tagging constrained the y-axis intercept of the regression line for each set of tags. The initial point on each tag-depletion curve was thus the true number of tagged sockeye available for enumeration on the spawning grounds at the start of the study.

Separate $E_{TL}50$ values were determined for the three sets of tags applied on 3, 18, and 31 October respectively. Mean spawner residence time was averaged over all color groups for depletion curves based upon tag recoveries both adjusted and unadjusted for tag-detection efficiencies. Estimates of residence time were compared and evaluated between these two procedures, and among the methods respectively employing tag-depletion curves, corresponding cumulative tag-day data, and the interval between peak counts of live and dead sockeye.

Population Numbers Estimated From Simple Visual Counts, and From a Spawner Abundance Curve Plus Mean Residence Time

(i) Peak Count of Live-Plus-Dead Spawners

One estimate of the sockeye spawning escapement to Henderson Lake was derived simply by summing visual counts of both live and dead spawners. The seasonal population estimate was taken as the maximum sum of live-plus-dead fish derived from one of the seven population surveys made in 1989.

(ii) Spawner Abundance Curve Plus Mean Spawner Residence Time

A spawner abundance curve (Ames 1984, Bocking et al. 1988) was constructed by plotting the combined numbers of sockeye observed in Clemens Creek and Henderson Lake against time (days) spanning the estimated first day when fish entered the spawning grounds to the estimated last date when live sockeye were present. The area under the curve (total fish-days) was divided by the mean spawner residence time to yield the estimated total escapement (Tschaplinski and Hyatt 1990).

Petersen Mark-Recapture Estimates

Petersen mark-recapture estimates of the sockeye population in the Henderson Lake system were derived by employing procedures detailed by Tschaplinski and Hyatt (1990). Both simple and stratified Petersen estimates were made and were based alternatively on recoveries of live or dead sockeye. To estimate the population (N) by the simple Petersen method, the total number of tagged sockeye summed over all tagging periods was substituted for M; the total number of live or dead sockeye observed in subsequent visual surveys was substituted for C; and, the total number in sample C consisting of tagged individuals (all tag colors combined) was substituted for R in the formula

$$N = \frac{M \times C}{R},$$

where, M = the first sample of sockeye taken from population N, marked, then released back into N;
C = the second sample of sockeye consisting of the total numbers of either live or dead spawners visually surveyed and called the "captures"; and,
R = the numbers of sockeye bearing tags in the second sample and termed the "recaptures" (Ricker 1975, Seber 1982).

The upper and lower 95 % confidence limits for the estimate were found by substituting the observed number of recaptures (R) for the unknown term (x) in the formula

$$x + 1.92 \pm 1.96\ (x + 1.0)^{1/2},$$

and then by substituting the results into $N = (M \times C) / R$ (Ricker 1975).

An unbiased estimate of the total population is obtained by the simple Petersen method if either one of the samples marked or recovered is random (Ricker 1975). However, the estimate may be biased if both the original marking and the recovery samples are selective. To accommodate for potential bias, stratified Petersen estimates were employed in which the sets of uniquely colored tags applied respectively in marking periods denoted by i and recovered in periods denoted by j were treated as separate populations (Ricker 1975). The stratified technique is preferred whenever the successive "strata" marked and released maintain their separate identities due to incomplete mixing of marks among all spawners (Ricker 1975).

Sockeye marked in the three tagging sessions during October each represented a color-coded stratum denoted by M_i. Tagged live or dead sockeye enumerated during subsequent recovery surveys were denoted by R_i for each color code. The total number of tagged live or dead sockeye counted during each recovery period was denoted by R_j, while the total recoveries for each period (tagged-plus-untagged fish) were denoted by C_j. The total population was then determined by the stratified Petersen method by substituting these values into the formula

$$N = \Sigma N_{ij} = \Sigma \{R_{ij} \times \frac{M_i}{R_i} \times \frac{C_j}{R_j}\}$$

in which, C_j = the number of fish observed (tallied) in the jth period of recovery (ΣC_j is the total no. examined = C);

R_{ij} = the number of fish marked in the ith marking period which are recaptured (tallied) in the jth recovery period;

R_i = the total recaptures of fish in the ith period; and,

R_j = the total number of recaptures during the jth period (Ricker 1975).

Confidence limits for stratified Petersen estimates were calculated by methods similar to those used for simple estimates (Ricker 1975, Seber 1982).

Both simple and stratified estimates based upon live sockeye were generated alternatively from (i) unadjusted tag-recoveries, and (ii) counts in which the numbers of tagged sockeye were adjusted upward according to the results of studies on tag-detection efficiencies. Results were compared and evaluated between these two procedures, with Petersen estimates based upon sockeye carcasses, and with population estimates generated by other techniques.

RESULTS

Migration Onto the Spawning Grounds, Spawning Activity, and Visual Counts of Live Sockeye

(i) Main Surveys and Total-Section Counts

Forest harvest and road construction personnel observed small numbers of sockeye in sections 3 - 5 of Clemens Creek during the last week of July immediately following heavy rains. Therefore, some sockeye likely arrived at the Henderson Lake spawning grounds and in Clemens Creek around 24 July when lake levels and streamflows were high. Henderson Lake sockeye thus entered the stream shortly after the time this stock usually appears in Barkley Sound, about 40 - 50 days earlier than observed in most other years (Tschaplinski and Hyatt 1990). The same fish remained isolated in the deepest pools of sections 3 - 5 until early October (survey T-2) when 396 sockeye were counted in those reaches (Table 2). Low streamflows occurring throughout the period spanning late-July and early October probably restricted the movements of these fish. Therefore, the same numbers were concluded to be present in sections 3 - 5 during the first census of the season (survey T-1; 20 September) although only the lake and stream section 1 were surveyed in detail for that initial reconnaissance (Table 2).

Few sockeye occupied the spawning grounds prior to mid-October. The total population increased to only 851 fish from 593 between surveys T-1 and T-2 (Table 2, Fig. 3). Except for mid-summer migrants isolated in sections 3 - 5, and small numbers occurring near the stream mouth in section 1, no sockeye were found elsewhere in the creek during this period. Low lake levels and stream discharge (Table A-1) likely prevented large numbers of migrants from entering Clemens Creek until mid-October. Additionally, high water temperatures ranging between 17.9 - 19.9^{o}C in near-shore areas of Henderson Lake during the same period (Table A-2) may have limited populations along the lakeshore spawning sites near Clemens Creek to only 15 - 116 sockeye (Table 2).

About 30 redd-like depressions were observed in the lowermost pools of section 1 on 20 September; however, no spawning activity was observed among adult sockeye early in the season. Spawning activity was first observed on 5 October during survey T-2 after 76.2 mm of rain had increased stream discharge such that S1 gauge readings increased by 0.245 m over 48 h (Table A-1). Two females and one male were observed spawning in section 4 on that date. Increased streamflow had enabled sockeye to leave their pools and enter shallow riffles for the first time in the season.

Sockeye were not observed upstream of section 5 until survey T-3 in mid-October by which time their numbers had increased by nearly 16 fold to 13 354 during a 15-d period of increased streamflow (Tables 2 and A-1, Figs. 3 and 4). They were then distributed throughout sections 1 - 6 of Clemens Creek and along the lakeshore adjacent to the stream mouth (Table 2). Spawners had migrated upstream to section 7 by 29 October during survey T-4 (Table 2; 29 Oct - 1 Nov). Maximum spawner abundance and spawning activity occurred during that survey. Peak numbers of live sockeye were estimated for 1 November after 18 041 spawners had been enumerated (Table 2, Fig. 3). Population numbers declined rapidly after survey T-4 (Fig. 3). Spawning was last observed on 29 November during survey T-6 when only 455 fish remained. No spawning was observed among the 4 sockeye counted on the last trip of 6 December. The final date of spawning was thus interpolated to 2 December.

Virtually all sockeye counted in the system occurred either in Clemens Creek or near the lakeshore adjacent to Clemens and Ternan creeks. Only one sockeye was found elsewhere (near the camp beach during survey T-4). Nearly all spawners were adults. Jacks maximally formed only 0.24 % of the population when two individuals were observed during survey T-2. Only one jack was counted during survey T-4, and five were found during survey T-5 (0.03 % of the population).

Low-to-moderate streamflows, clear water, and bright daylight provided excellent conditions for visual counts throughout most of the season. Between surveys T-1 and T-6, S1 gauge readings (1984 equivalents) never exceeded 0.77 m (Fig. 4, Table A-1). Counts during all surveys but T-3 were made when streamflows were either stable or declining. Although late-season streamflows were relatively high (survey T-7; Fig. 4, Table A-1), visibility remained good to excellent because turbidity was low. Sporadic light rain during surveys T-4 and T-5 did not prevent accurate counts from being made. Intermittent light-to-moderate rain which occurred briefly during survey T-2 decreased visibility by about 50 % (measured as a proportion of the distance between stream banks). However, this reduction did not adversely affect counts because stream discharge and turbidity remained low. Rapidly increasing stream discharge, and heavy rain on 18 October (survey T-3) provided only fair viewing conditions when sections 7 - 5 were covered. Although S1 gauge readings increased by 3.5 fold, gauge heights remained below 0.6 m throughout the survey (Fig. 4, Table A-1); therefore, reliable sockeye counts were still possible. Sections 1 - 4 were surveyed efficiently on 19 October when no rainfall occurred and viewing conditions varied from very good to excellent in most locations.

(ii) Strip Counts Versus Total-Section Counts

Linear regression analysis based upon counts made in six stream sections demonstrated that total-section counts and estimates generated from expansions of strip counts were significantly correlated in 1989 ($r = 0.69$; $p < 0.05$; $n = 12$) and were related by the equation

Total Count = 0.771(Strip Count) + 579.11

(Tables 3 and A-3).

The low r^2 value for this relationship (0.47) indicates that high variances are associated with the regression. During survey T-4 when sockeye were most abundant, the estimate of 13 509 live spawners based on strip-count expansions was 22.6 % lower than the corresponding estimate based on total-section counts; by contrast, the population estimate based on strip counts exceeded that determined from total-section counts by 23.8 % for survey T-5 (Table 3). Large variations thus occurred in the relationship of the two types of counts between surveys. This variability was further illustrated by estimates of live-plus-dead sockeye which differed by 23.9 % between techniques for survey T-4, but converged to 6.0 % for survey T-5 (Table A-4).

Strip counts were performed rapidly in 1989 because permanent counting stations had been established. The counting procedure required about five hours for each of the two surveys. During survey T-4, this method achieved a 60 % saving in survey time (7.5 h) compared with the total-section method. Total-section counts in Clemens Creek spanned two days during the same census and required 12.5 h to complete.

(iii) Counts Made During Aerial Overflights

Five surveys of the spawning grounds were made from fixed-wing aircraft during trips T-1 - T-5 respectively. No overflights were possible on the last two surveys of the season due to adverse weather. Surveys were initiated in mid-day periods between 10:23 and 14:41. On average, about eight minutes were required to cover the stream and main spawning areas of the lake on each flight. Excellent conditions for counting were available on all overflights. Streamflows were low to moderate (Fig. 4, Table A-1), and bright sunshine was available for each survey but T-4 and T-3 when cloud cover varied respectively from 60 - 95 %. Despite favorable conditions, total counts of adult salmon during aerial surveys T-2 - T-5 were 3.3 - 5.7-fold lower than corresponding ground-based, total-section counts (Tables 2 and 4). Only 5 525 fish were estimated from the air during the peak of spawning on 29 October (Table 4). No fish in Clemens Creek were visible from the air during surveys T-1 and T-2 when only 578 - 735 sockeye were counted in the stream during ground-based surveys (Tables 2 and 4).

Aerial and ground-based counts of lake sockeye were highly correlated ($r^2 = 0.95$, $p < 0.05$, $n = 5$; Table 5) and coincided more closely than corresponding counts for spawners in the stream. Aerial estimates of lake sockeye varied between surveys from 2.9-fold lower to 1.9-fold higher than corresponding ground-based counts. Additionally, counts by air and ground differed only by about nine percent for survey T-4 (Tables 3 and 4). Adult salmon in all spawning areas of the lake were highly visible from the air. Regressions based upon individual counts from different lake sections (see Tables 3 and 4) were also highly correlated among all surveys and significant ($r^2 = 0.87$, $p < 0.001$, $n = 20$; Table 5).

In contrast with the lake, Clemens Creek was more difficult to survey because all of section 7 and large reaches of sections 4, 5, and 6 were obscured by shadows and the forest canopy. Consequently, aerial counts for Clemens Creek were 3.5 - 13.7-fold lower than corresponding ground-based totals. No fish were visible in the stream until survey T-3 after several thousand spawners had arrived (Tables 2 and 4). The differences between total-stream counts made from the air and ground varied about four fold among surveys. Therefore, the relationship between these counts was not significant ($p > 0.05$) although much of the variance between methods was accounted for by linear regression ($r^2 = 0.74$; Table 5). This relationship, based on only five observations, will likely improve given additional samples. For example, aerial and ground-based counts were significantly correlated ($p < 0.05$) when data from individual sections were used to compare the two techniques over all surveys ($n = 35$, Table 5). However, the high variances and low correlation coefficients ($r = 0.58$, $r^2 = 0.34$) associated with the regression suggest that aerial counts for several stream sections are susceptible to large variations in counting efficiency among surveys (Table 5).

When counting techniques were compared within stream sections across all surveys, significant relationships were found only for sections 5 and 6 (Table 5; $p < 0.05$). Aerial and ground-based counts were not correlated for sections 1 - 4 respectively (Table 5; all $p > 0.05$). The accuracy of aerial counts was reduced due to dark shadows cast upon open reaches of stream by trees and the banks. No fish could be seen wherever the stream surface was strongly shaded from sunlight. Shadows especially reduced counting efficiency in sections 1 and 4 early in the season whenever bright sunshine occurred. From September to mid-October, large numbers of fish in those densely-populated reaches often resided in deep, shaded pools along banks. Lack of correlation between aerial and ground-based counts within most stream sections likely resulted from the high variation which occurred in the amount of stream visible from the air among surveys.

Counts of Other Salmon Species

Between 15 and 250 coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and chum (*O. keta*) salmon were observed in Clemens Creek among the seven population surveys (Table A-5). Counts of each species for section 1 and the lake were supplemented with information from seine hauls made during sockeye tagging procedures if the number seined from a reach exceeded survey counts for the same area. The numbers of each species counted fluctuated widely among surveys. A maximum of 76 chum salmon were observed in the stream during survey T-4 (Table A-5). About 90 % were counted in section 1. Numbers of chum on all other surveys varied between 0 - 12. Eighty chinook jacks were estimated for the lakeshore reach adjacent to the mouth of Clemens Creek on survey T-2; however, few of these fish were seen again. Only two chinook were observed along the lakeshore during survey T-3, and a maximum of four adults and one jack were estimated for the stream (section 1) during survey T-4. No chinook were observed in the system after survey T-4.

Coho salmon were relatively abundant late in the season, especially during surveys T-5 and T-6 when their numbers ranged between 196 and 250 respectively (Table A-5). When peak numbers of coho were estimated during survey T-6, > 95 % of these fish were adults (Table A-5), and 96 % were distributed upstream in survey sections 4 - 6. No salmonid spawners other than sockeye and coho inhabited the stream at that time. Coho then formed nearly 55 % of all spawners in the study area because sockeye numbers had declined to only 455 (Table 2); however, the two species were easily distinguished because coho were larger and more darkly colored than sockeye. Similarly, when coho and chinook jacks were relatively abundant along the lakeshore during surveys T-1 and T-2, their dark green coloration allowed them to be readily distinguished from sockeye. However, coho and chinook jacks could be separated reliably only after they had been seined and examined.

During the main part of the sockeye spawning season, (surveys T-3 - T-5) live coho, chinook, and chum salmon together formed only 0.4 - 2.4 % of all spawners in the survey area (Tables 2 and A-5). Summed over the entire season, these species accounted for only 1.7 % of all individuals enumerated. The low numbers of salmon in Clemens Creek other than sockeye demonstrated that population estimates of sockeye spawners were not biased due to taxonomic misidentifications associated with the presence of other species.

Spawner Mortality and Recovery of Carcasses

Dead sockeye were first encountered on the spawning grounds on 18 October during survey T-3. The fewest carcasses (13) were counted and pitched both at that time and near the end of the spawning season (6 December; Table 6). Over 91 % of all carcasses were recovered between 14 and 29 November during surveys T-5 and T-6 (Table 6). Carcasses were most abundant during survey T-5 when 3 142 were enumerated. A total of 6 206 carcasses, including 2 930 males (47.2 %) and 3 276 females (52.8 %), were recovered throughout the season. This sex ratio was virtually identical to that of sockeye that were seined unselectively for tagging (Table 1).

Visual Counts and Recoveries of Tagged Sockeye

(i) Live Spawners - Unadjusted Counts

Prior to adjusting recoveries to account for tag-detection efficiencies or spawner distribution, a total of 2 283 live sockeye bearing tags were enumerated among six recovery periods spanning surveys T-2 and T-7 (Table 7). Over 54 % of these recoveries consisted of tagged fish counted one day after tagging. During surveys T-2, T-3, and T-4, day 1 recoveries accounted respectively for 100, 45.5, and 62.6 % of the total numbers of tags counted (Table 7). Although day 1 counts for pink-tagged salmon were made on 1 November after only 714 pink tags had been applied, the 90.2 % recovery of these tags (644) was used to proportionally extrapolate a final recovery of 805 tags from a total of 893 applied by the end of survey T-4 (see footnotes, Table 7).

Tags were carried by 30.6, 2.9, 7.1, 4.2, and 0.9 % of the total numbers of live sockeye observed respectively on the first five recovery periods. Additionally, 7.8 and 5.9 % of live sockeye enumerated during strip-counting procedures on 1 and 15 November (T-4 and T-5) respectively were tagged (see

Tables A-3 and A-4). The declining percentage of tagged sockeye within the total live population from survey T-4 to T-6 suggests that a group of sockeye migrants had entered the spawning grounds after the final tagging session during the peak of spawning (survey T-4) and thus remained unmarked.

In all instances but one, fewer tagged, live sockeye of each color code were counted on successive stream surveys as mortality increased seasonally: no tags were seen on live fish during the last survey (6 December, T-7), and only 4 pink-tagged fish were counted in late November during survey T-6 (Table 7). However, low numbers of red-tagged fish (177) were initially counted during survey T-3 immediately after 737 red tags were applied. Day 1 counts indicated that most of the fish tagged had returned to Henderson Lake within hours after tag application during a period of rapidly increasing stream discharge (Table A-1). These individuals were thus unavailable for counting. Consequently, twice as many red-tagged sockeye were counted on the next survey after these fish had recovered from the combination of handling procedures and high streamflows and re-entered Clemens Creek (Table 7).

(ii) Determination of Tag-Detection Efficiencies

Four tag-detection trials performed between 4 October and 18 November (surveys T-2 - T-5) demonstrated that the mean detection efficiencies of white, red, and pink tags were not significantly different ($p > 0.05$; Table 8). Seasonal detection efficiencies for these tags varied between 77.7 - 81.1 % over a range of viewing conditions (see Table 8). By contrast, the detection efficiency of green tags was significantly lower than that of any other color and averaged 52.3 % seasonally. Green tags were only detected at approximately the same rate as the other colors during survey T-2 when stream discharge was minimal.

The detection efficiencies of all tags appeared to depend most strongly on stream discharge. When stream levels were minimal, detection efficiencies ranged from 86.0 - 97.6 % among the four colors and averaged 90.6 %. When higher water levels occurred, mean detection efficiencies for all tag colors combined were significantly lower (all $p < 0.05$) regardless of any other factor affecting visibility.

The detection efficiency of white tags was the least variable among studies and viewing conditions, and seasonally ranged between 75.0 and 86.0 %. Red and pink tags demonstrated intermediate changes in detectability among studies, whereas green tags were associated with the greatest changes. After stream levels increased from early-season minima, the detection efficiencies of green tags fell to 34.0 - 44.0 % (Table 8). White, red, and pink tags are clearly preferable to green ones for all studies requiring efficient visual detection of marked fishes in streams.

(iii) Live Sockeye - Adjusted Recoveries

Counts of tagged, live sockeye were adjusted upward according to the visual detection percentages determined for each color of tag in the tag-detection trials. Visual recoveries for surveys T-2, T-3, and T-4 were adjusted based on tag-detection efficiencies determined during the same respective surveys. However, adjustments for population survey T-5 were based upon tag-detection results from survey T-4 because viewing conditions were more similar between the respective dates of those two procedures than between the population census and tag-detection study of survey T-5. Finally, adjustments for tag recoveries made during survey T-6 were based upon tag-detection efficiencies determined during survey T-5.

Despite generally excellent conditions available for visual surveys, the total recovery of tagged, live sockeye increased by > 38 % to 3 158 after adjustments were made (Table 9). Tags were well represented in the spawning population in all main recovery periods. From surveys T-2 - T-5, the proportion of tagged sockeye within the spawning population was 34, 7.3, 8.2, 5.0, and 1.1 % respectively. A maximum of 1 482 tags were recovered during survey T-4 at the peak of spawner abundance (Table 9).

An additional adjustment to the day 1 recovery of red tags was made for survey T-3 when most red-tagged sockeye returned to the lake and were unavailable for counting. A constant loss (mortality) of about 17 sockeye per day was assumed for the 15 days between 18 October (the first day that large numbers of red tags were applied) to 2 November when 477 red-tagged sockeye were enumerated in the lake and the lower sections of Clemens Creek (Table 9). By this interpolation, about 720 red-tagged sockeye should have been alive on the survey date of 19 October. Because 166 of these fish were estimated to have been in the stream during survey T-3 (Table 9), 554 must have been in the lake.

(iv) Sockeye Carcasses

Seasonally, 261 of 6 206 carcasses recovered were tagged (4.2 %; Table 10). Females made up 60.9 % (159) of all tagged carcasses while males formed only 39.1 % (102) of the total. Therefore, female sockeye formed a greater proportion of the sample of tagged carcasses than of either the total number of carcasses recovered (52.8 %) or the number of sockeye initially tagged (52.2 %; Table 1). However, the sample of recovered, tagged carcasses was small relative to the other two groups; therefore, the difference in sex ratio between them likely does not represent a significant bias toward females in the sample of tagged carcasses recovered.

No tagged carcasses were observed until survey T-4 during the peak of spawning activity when 7.0 % of all carcasses enumerated had tags (Table 10). The proportion of carcasses carrying tags remained high at 5.6 % during the next survey (T-5) when sockeye mortality peaked and a maximum of 175 tagged carcasses were enumerated (Table 10). However, this proportion fell markedly to only 1.9 % by 29 November (survey T-6) at the same time that 40.7 % of all carcasses enumerated during 1989 were recovered (Tables 6 and 10). Although many tagged fish may have been removed from the spawning grounds by late-season freshets, the low ratio of tagged-to-untagged carcasses observed in late November indicated that a group of new sockeye migrants had entered Clemens Creek after the last tagging session (30 Oct - 3 Nov) and thus remained untagged.

Observations from a previous study indicated that tag loss rates are zero for all color codes (Tschaplinski and Hyatt 1990). In 1989, a small number of free tags were found lying on the spawning grounds in association with bear-damaged carcasses. Bears had clearly torn the tags from the salmon while capturing or feeding upon these fish; therefore, tag loss rates were again concluded to be negligible. Consequently, tag loss did not affect the ratios of tagged-to-untagged sockeye observed throughout the season or Petersen mark-recapture estimates which depend upon tag recoveries.

(v) <u>Distributions of Tagged Spawners</u>

Both tagged carcasses and live fish bearing tags were well mixed throughout most parts of the spawning grounds in 1989 (Fig. 6). Section 7, which maximally contained only four live spawners (Table 2), was the only reach where tagged sockeye were not found. Ranked in descending order, both live sockeye and carcasses were most abundant in sections 1, 4 and 5 respectively (Fig. 6). Counts accrued seasonally showed that 86.2 % of all sockeye carcasses, and 77.0 % of all live spawners were found in those sections combined. The numbers and distribution of both tagged carcasses and live, tagged sockeye followed virtually the same seasonal patterns: 86.6 %

of tagged carcasses and 79.6 % of live, tagged sockeye (from cumulative counts accrued between T-2 and T-7) were recovered in sections 1, 4, and 5 (Fig. 6). Recoveries of both tagged carcasses and live, tagged sockeye otherwise exhibited minor differences in distribution compared respectively with seasonally accrued counts of carcasses and live fish.

Although the distributions of tagged sockeye and the total sockeye population were similar, recoveries of tagged carcasses were biased toward section 1 (Fig. 6): 67.1 % of tagged carcasses occurred in that section compared with only 33.5 % of the total numbers of carcasses pitched. Tagged carcasses were undoubtedly abundant in section 1 due to the action of seasonal freshets which moved large numbers downstream toward the mouth of Clemens Creek. However, the observation that a much smaller proportion of the total number of carcasses pitched was found in the same area provides further evidence that recoveries were also biased because a number of late-season emigrants had entered the spawning grounds after early November and thus remained untagged.

In contrast with tagged carcasses, the distribution of tagged, live sockeye closely matched that of the total live population (Fig. 6). However, the recovery of tagged, live sockeye demonstrated a slight bias toward section 1. Seasonally, 44.0 % of the tagged, live sockeye were counted in that reach compared with 34.0 % for the total live count (Fig. 6). Nevertheless, the distribution of white-tagged fish was the only one consistently biased toward section 1. In the two surveys following tag application on trip T-2, 71.1 and 64.2 % of white-tagged sockeye were respectively recovered in that area (Table 9). By contrast, the distributions of red-tagged and pink-tagged fish in section 1 closely matched that of the total live population on surveys subsequent to those when tags were applied. Only 33.3 and 26.6 % of red-tagged fish remained in section 1 on the two trips following application of red tags, and only 35.7 % of pink-tagged sockeye remained there approximately two weeks after tagging (Table 9).

Both live, tagged fish and tagged carcasses were thus well represented among the main study reaches, establishing that (i) they were well mixed throughout the spawning population in Clemens Creek, and (ii) their distributions were not seriously biased despite relatively large numbers of tags recovered in section 1. The statistical validity of Petersen mark-recapture estimates depend partly upon the random distribution of recovered tags (Ricker 1975). The assumption of random tag distribution was not seriously violated by the recoveries of either live sockeye or carcasses in 1989.

Estimates of Sockeye Residence Time on the Spawning Grounds

(i) Time Interval Between Peak Counts of Live and Dead Sockeye

The greatest number of live sockeye was observed on the spawning grounds on 1 November (survey T-4; Table 2). Correspondingly, the largest number of sockeye carcasses was pitched from the stream by 18 November during the fifth trip of the season (Table 6). The seasonal distributions of the numbers of both live and dead sockeye appear approximately normal, have well-defined peaks, and are not markedly tailed in any direction (Fig. 7). The 17-day period spanning the peaks representing the maximum observed numbers of live and dead spawners respectively is thus an easily derived estimate of mean residence time on the spawning grounds (Fig. 7).

(ii) Cumulative Tag-Day Method - Unadjusted Tag Recoveries

Prior to adjusting tag recoveries to account for visual detection efficiencies, mean spawner residence times of marked sockeye decreased seasonally from 22.1 days for early migrants tagged on 3 October to 11.7 days for those tagged on 31 October (Table 11). The residence time calculated for red-tagged sockeye was only 10.4 days due to especially low visual recoveries one day after tags were applied on 18 October. This seasonal reduction in spawner residence time is consistent with that observed in previous years at Henderson Lake (Tschaplinski and Hyatt 1990) and with that reported elsewhere (Ames 1984). Sockeye entering the spawning grounds later in the season tend to spawn and die over a shorter period of time compared to early-season migrants. Seasonally, the mean spawner residence time based upon the unadjusted cumulative tag-day method was determined to be 14.7 days (Table 11).

Red-tagged sockeye were recovered in low numbers during survey T-3 because about 554 of these fish had emigrated from the spawning grounds one day after tagging. Consequently, the mean residence time calculated using the unadjusted cumulative tag-day method was 13.5 % (2.3 days) less than that determined from the interval between peak counts of live and dead sockeye.

(iii) Cumulative Tag-Day Method - Adjusted Tag Recoveries

Residence times based upon the cumulative tag-day method increased sharply when tag recoveries were adjusted upward according to (i) the results of the studies on tag-detection efficiency (see Table 8), and (ii) the numbers of red-tagged sockeye estimated to have temporarily emigrated from the spawning grounds soon after red tags were applied. Seasonal mean residence time increased by 27.9 % to 18.8 days (Table 12). Additionally, separate residence times calculated sequentially from the respective recoveries of white, red, and pink tags decreased progressively throughout the season from 25.6 - 13.2 days (Table 12).

(iv) Tag-Depletion Method - Unadjusted Recoveries

Averaged over all tag groups, the mean residence time for sockeye on the Henderson Lake spawning grounds was only 8.7 days based on tag-depletion regressions unadjusted for visual detection efficiencies (Table 13). Tag-loss regressions based on recoveries of white and pink tags were highly correlated ($r^2 = 0.893 - 0.943$) and statistically significant ($p < 0.01 - 0.05$; Table 13). However, the regression based upon red-tagged sockeye was not significant ($p > 0.05$) and poorly correlated due to low recoveries of red tags one day after tagging (Table 13).

(v) Tag-Depletion Method - Adjusted Recoveries

After tag recoveries were adjusted upward to account for tag-detection efficiencies (see Tables 8 and 9), the seasonal mean residence time based upon the tag depletion method increased by 33.3 % to 11.6 days (Table 13). Additionally, the $E_{TL}50$ value based upon red tags increased by 2.2 fold after recoveries were corrected for visibility and for tagged sockeye that had emigrated from the spawning grounds one day after tagging. Residence times calculated separately from the respective recoveries of white, red, and pink tags decreased progressively throughout the season from 16.0 - 7.8 days (Table 13). All regressions based on adjusted tag recoveries were highly correlated ($r^2 = 0.863 - 0.938$) and statistically significant (all $p < 0.01 - 0.05$; Table 13).

Despite adjustments to tag recoveries, estimates of sockeye residence time based on tag-depletion curves were clearly biased low relative to those generated by other techniques. For example, unadjusted and adjusted curves underestimated sockeye residence time by 40.8 and 38.3 % compared to those calculated from corresponding cumulative tag-day procedures. In 1989, mean spawner residence time for Henderson Lake sockeye was best estimated from the adjusted cumulative tag-day method. That estimate agreed within 9.6 % of the one derived from the interval between peak counts of live and dead spawners.

Population Numbers Estimated From Simple Visual Counts, and From a Spawner Abundance Curve Plus Mean Residence Time

(i) Peak Count of Live-Plus-Dead Spawners

The peak visual count of live-plus-dead spawners was made during survey T-4 when 18 556 sockeye were observed on the spawning grounds (Tables 14 and 15). This total consisted of 18 041 live sockeye and 515 carcasses (Table 14). Simple visual counts usually provide a minimum escapement estimate because no account is made for either the seasonal mortality of early sockeye migrants or the continuing immigration of new fish onto the spawning grounds (i.e., spawner turnover; Ames 1984, Tschaplinski and Hyatt 1990).

(ii) Spawner Abundance Curve Plus Mean Spawner Residence Time

The area under the spawner abundance curve represented approximately 565 315 fish-days (Fig. 3). This value divided by a mean spawner residence time of 18.8 days resulted in an estimated escapement of 30 070 fish. This estimate was 1.6-times greater than that determined from the peak count of live-plus-dead spawners. The additional numbers estimated from the spawner abundance curve likely reflect accurately the seasonal turnover of sockeye on the Henderson Lake spawning grounds because (a) the average sockeye residence period calculated from the adjusted cumulative tag-day method was consistent with residence times determined in other years (Tschaplinski and Hyatt 1990), and (b) was supported by the estimate based upon a 17-day residence time derived from the interval between peak counts of live and dead sockeye (Table 15).

When tag recoveries were not adjusted to represent 100 % tag-detection efficiency, mean residence time determined from the cumulative tag-day method was biased low and caused the corresponding escapement estimate to reach 38 457 fish (Table 15). This estimate was biased high by 27.9 % when compared to that determined from the same procedure when visual tag recoveries were adjusted (Table 15).

Spawner residence times based upon tag-depletion regressions generated escapement estimates that were strongly biased high. This bias varied according to the differences in spawner residence times estimated by the alternative tag-depletion techniques. The escapements of 48 734 and 64 979 sockeye estimated from regressions based respectively upon adjusted and unadjusted tag recoveries were 1.6 - 1.7-fold higher than those determined from the corresponding cumulative tag-day methods (Table 15).

Petersen Mark-Recapture Estimates

(i) Estimates Based on Counts of Live Sockeye

Simple and stratified Petersen mark-recapture estimates of sockeye escapement based on counts of live spawners plus adjusted recoveries of live fish bearing tags were 31 343 and 32 075 respectively (Tables 15, A-6, and A-7). These estimates were only 4.2 and 6.7 % higher than that determined from the AUC method combined with a mean spawner residence time of 18.8 days (Table 15). Simple and stratified Petersen estimates based on tag recoveries unadjusted for visual detection efficiencies were biased slightly high at 37 030 and 37 973 sockeye respectively, but converged closely with that determined from the AUC method given a spawner residence time of 14.7 days (unadjusted cumulative tag-days).

The close correspondence between the simple and stratified Petersen estimates demonstrated that tagged sockeye were well mixed throughout the spawning population despite the observation that the majority of the white-tagged spawners remained in section 1. However, any tag recoveries biased toward section 1 had little effect on mark-recapture estimates: simple and stratified estimates were not significantly different (Student's t, $p > 0.05$) and were within about 2.3 and 2.5 % for adjusted and unadjusted tag recoveries respectively.

(ii) Estimates Based on Recoveries of Sockeye Carcasses

Simple and stratified Petersen estimates of sockeye escapement based on carcass recoveries were 45 630 and 44 552 fish respectively (Tables 15 and A-8). These estimates were about 1.4 - 1.5-fold greater than those determined from either

(i) the AUC technique plus a spawner residence time calculated from the adjusted cumulative tag-day method, or (ii) simple and stratified Petersen methods based on adjusted recoveries of tagged, live fish. Petersen estimates based on carcasses were biased high mainly because only 1.9 % of the 2 5?3 dead sockeye recovered during survey T-6 carried tags. This low recovery in late November suggests that a proportion of the 1989 migration was not sampled for marking. Although tags were last applied during survey T-4 at the peak of spawner abundance, fish which entered the spawning grounds in early November were not represented by tags.

DISCUSSION

The ground-based peak count of 18 556 live-plus-dead sockeye provided one of the lowest estimates of sockeye escapement to Henderson Lake in 1989 (Fig. 8). This estimate does not account for spawner turnover due to seasonal mortality and immigration; therefore, it is undoubtedly biased low relative to the true seasonal escapement and should be considered a minimum estimate (Ames 1984, Tschaplinski and Hyatt 1990). Factors such as deep water, rainfall, or turbidity that reduce visibility will also cause simple visual counts to underestimate true escapements (Ames 1984, Tschaplinski and Hyatt 1990). Because temporal changes in these controlling factors can occur both within and between seasons, simple visual counts are often susceptible to poor precision as well as low accuracy.

Peak sockeye abundance occurred during a period of moderate streamflows when excellent visibility was available for spawner counts despite the occurrence of occasional light drizzle. Therefore, the peak count of live-plus-dead fish is likely an accurate estimate of the number of sockeye occurring on the spawning grounds during the period of maximum spawning activity in late October and early November. However, peak counts which are routinely used to assess salmon spawning escapements in British Columbia (Shardlow et al. 1987) clearly are biased low relative to true seasonal escapements (Fig. 8).

The peak count of live-plus-dead fish was based upon total-section enumerations which normally require two days to complete (about 12.5 h of survey time). The strip-count method clearly provides an alternate enumeration technique useful whenever rapid counts are required. On two occasions, observers using this method completed a census of six sections of Clemens Creek in only 7.5 h because permanent strip-count stations had been established. In 1988, population estimates based upon strip-count expansions were within seven percent of those derived from total-section counts (Tschaplinski and Hyatt 1990). However, present estimates diverged by > 20 % in each of two trials. During the peak of spawning activity, strip count expansions underestimated the total numbers of live spawners in the stream by nearly 23 %. However, strip-count expansions for survey T-5 exceeded the sum of total-section counts by nearly 24 %. Because strip counts generated estimates that were alternatively biased high and low, these results suggest that the error between methods is random. Further observations are clearly required on the relative behavior of the two techniques in order to improve the statistical relationships between them under different enumeration conditions. Given sound statistical relationships, strip-count expansions supplemented with surveys of lake-resident spawners can be more reliably employed as a substitute for total-section counts.

Aerial counts seriously underestimated sockeye populations in all instances despite near-optimum viewing conditions. During the peak of sockeye abundance, the aerial count of live spawners was nearly 3.3-times lower than the corresponding ground-based count, and generated the lowest escapement estimate for Henderson Lake sockeye (Fig. 8). Although aerial estimates were biased low, total counts by air were significantly correlated with ground-based estimates of live spawners. Therefore, aerial counts might provide useful annual indices of peak numbers for a given system if the relationship between aerial and ground based counts are first established over a wide range of viewing conditions.

Aerial counts are susceptible to further error resulting from the species composition of spawning escapements. Different species of salmon cannot be reliably distinguished from aircraft. Clearly, aerial overflights can only be used in systems similar to Henderson Lake where one species overwhelmingly dominates the spawning escapements, or in other systems where the species composition can be reliably determined by alternate methods.

All other methods employed to estimate sockeye escapements to Henderson Lake accounted for temporal spawner mortality and immigration onto the spawning grounds: most provided estimates preferable to simple visual counts, and all increased the estimated seasonal escapement relative to that determined from single counts of peak numbers.

Escapements estimated from the AUC method in which the mean spawner residence time was provided by the cumulative tag-day technique corresponded closely with both simple and stratified Petersen estimates based on live fish (Fig. 8). These three methods provided estimates varying between 30 070 and 32 075 sockeye after recoveries of tagged, live fish were adjusted upward to account for tag-detection efficiencies (Table 15). Additionally, these estimates were approximated by the 33 254 sockeye derived from the AUC method in which mean spawner residence time was estimated from the interval between peak counts of live and dead sockeye (Table 15, Fig. 8). That these four different techniques generated population estimates that converged closely suggests that the 1989 escapement to Henderson Lake was estimated relatively accurately by each of these methods.

Irrespective of technique employed, all methods which depended upon tag recoveries from live fish generated population estimates that were biased high when recoveries were not adjusted to reflect 100 % tag-detection efficiencies. Estimates then ranged between 37 973 and 38 457 spawners (Table 15). The AUC/cumulative tag-day method was the most sensitive of the three techniques to suboptimal visibilities that reduce tag recoveries. Based on unadjusted recoveries, escapements estimated by that method were biased high by 27.9 % compared to those based upon adjusted recoveries. By comparison, escapements determined from simple and stratified Petersen techniques increased by 18.1 and 18.4 % respectively when tag recoveries were not adjusted. These results clearly demonstrate that even modest reductions in counting efficiency can lead to substantial errors when populations are estimated from methods requiring accurate tag recoveries.

Excellent conditions for visual counts were available throughout most of the present study; however, studies of tag-detection efficiency illustrated that detection percentages for the white, red, and pink tags employed in 1989 varied seasonally between 77.7 and 81.1 % under nearly-ideal conditions. In most instances, viewing conditions can be expected to be inferior relative to that available on the Henderson Lake spawning grounds in 1989. Unless weighting factors accounting for reductions in tag visibility are available, escapement assessments based on methods requiring accurate recoveries of live, tagged fish can be seriously biased high (Tschaplinski and Hyatt 1990). Studies employing these techniques should account for sampling bias by determining visual detection efficiencies for disc tags of different colors over a wide range of viewing conditions defined by streamflow, rainfall, turbidity, and light intensity. The percentages of each color detected would allow: (i) the most easily observed colors to be identified and used for future field studies; and, (ii) the numbers of tags counted in visual surveys to be adjusted according to specific viewing conditions.

Additionally, the numbers of tagged fish available for counting on the spawning grounds can be determined from visual surveys conducted soon (e.g., one day) after tagging. Together with systematically determined tag-detection efficiencies, this information can be used to refine tag-recovery data for Petersen mark-recapture estimates, and improve the accuracy of mean spawner residence times generated from either the tag-depletion or cumulative tag-day methods. These procedural refinements were employed successfully for the present escapement study and ultimately resulted in the close convergence of population estimates generated from Petersen mark-recapture and AUC/cumulative tag-day methods.

Henderson Lake sockeye escapements for 1989 were thus estimated with equivalent accuracy from both live Petersen mark-recapture and AUC/cumulative tag-day methods because (a) surveys were conducted under good viewing conditions, (b) high-visibility tag colors were employed, (c) the entire spawning area was easily censused, (d) counts throughout the spawning season were scheduled on average at intervals no longer than the true residence time of the spawners, and (e) tag-recovery data could be adjusted according to quantified tag-detection efficiencies.

All three methods employed to estimate mean sockeye residence time in this investigation are sensitive to the frequency and timing of visual surveys (Tschaplinski and Hyatt 1990). Among them, the adjusted cumulative tag-day method may be the most accurate. Population estimates derived from this technique coincided closely with that derived independently from the Petersen mark-recapture method based upon live fish. Alternate techniques are more strongly associated with biases linked to survey timing or inherent mathematical limitations.

The interval between peak counts of live and dead spawners generated an estimate of spawner residence time (and corresponding population estimate) which agreed closely to that derived from the cumulative tag-day method. This agreement was a useful confirmation of the residence time estimate based upon cumulative tag-day techniques; however, the estimate derived from the interval between peak counts of live and dead spawners depends crucially upon the schedule of visual surveys. This estimate will be accurate only if the survey schedule coincides closely with the occurrence of peak numbers of live and dead salmon. The survey schedule for the present investigation was determined from prior knowledge of spawner residence times in Clemens Creek; nevertheless, peak abundances might be missed if they are temporally abrupt (Tschaplinski and Hyatt 1990). The assignment of spawner residence time is thus generally arbitrary, approximate, and fixed to actual survey dates. Given these disadvantages, the interval between peak counts should not be used preferentially to determinations based upon recoveries of tagged fish to estimate mean spawner residence time.

The tag-depletion method generated residence time estimates that are known to be strongly biased low because this technique employs logarithmic transformations of tag-recovery data to provide linear approximations of sockeye mortality (Tschaplinski and Hyatt 1990). Because this mortality follows a roughly sigmoidal pattern over time, tag-depletion regressions underestimate spawner residence times and thus overestimate population numbers (Tschaplinski and Hyatt 1990). Accordingly, the highest escapement estimates for Henderson Lake sockeye were based upon residence times generated by the tag-depletion technique (Fig. 8).

The tag-depletion technique also appears to be especially sensitive to tag-detection efficiencies. When tag recoveries were not adjusted for detection efficiencies, residence times based upon depletion curves decreased and corresponding population estimates increased by 33.3 %. Population estimates between adjusted and unadjusted AUC/tag-depletion methods differed by 16 245 fish (Table 15, Fig. 8). Despite drawbacks, tag-depletion regressions will also provide acceptable estimates of residence time and population abundance once a sufficient number of observations have been made so that inherent biases can be quantified and calibrated against preferred methods.

Survey schedules and visual counting efficiencies must be established carefully in order to estimate populations from residence-time techniques combined with spawner abundance curves (Tschaplinski and Hyatt 1990). Estimates derived from these methods are often difficult to use alone as absolute assessments of spawner abundance, and should be used cautiously as indices of true escapements unless (i) counting efficiencies are quantified and, (ii) the frequency and timing of visual surveys does not result in serious sampling bias.

Low recoveries and biased distributions of marked individuals frequently cause Petersen mark-recapture studies to overestimate true population numbers (Simpson 1984). Escapements of 45 630 and 44 552 sockeye determined respectively from simple and stratified mark-recapture techniques based upon carcass recoveries exceeded most other estimates and were undoubtedly biased high (Fig. 8). However, these high estimates cannot be linked to biased distributions of marked sockeye because tagged carcasses were well mixed throughout the spawning grounds (Fig. 6). The close correspondence between simple and stratified techniques ($p < 0.05$) also confirms that the distribution of tagged carcasses did not violate the assumption of random recoveries. Estimates based on carcasses were biased high mainly because less than two percent of > 2 500 carcasses recovered late in the spawning season bore tags.

Relatively low recoveries of tagged carcasses in previous years at Henderson Lake have resulted in mark-recapture estimates that were generally biased high irrespective of problems associated with the distribution of recovered carcasses (Tschaplinski and Hyatt 1990). This tendency appears to be a characteristic of this technique (see Simpson 1984) and must be recognized by investigators employing carcass recoveries for routine salmon stock assessments. Alternate estimates should preferably be available so that relative biases associated with Petersen mark-recapture can be revealed. Additionally, to reduce biases related to the mixing and distribution of tagged and untagged carcasses, stratified Petersen techniques should be employed and recovery efforts should be directly proportional to the spatial distribution of the fish (Andrews et al. 1988, Bocking et al. 1990).

The simple and stratified Petersen mark-recapture methods based on adjusted recoveries of live, tagged fish appeared to be relatively free from sampling bias. The present studies did not seriously violate the assumptions associated with either the mixing of tagged individuals within the population or the random recovery of tagged sockeye. All groups of live, tagged fish were well represented in all parts of the spawning grounds throughout the main part of the spawning season. Therefore, the simple and stratified Petersen estimates of 31 343 and 32 075 sockeye respectively are the preferred escapement estimates for the Henderson Lake stock in 1989. Although these estimates are similar, the stratified estimate which accounts for any incomplete mixing of tagged fish, is statistically more robust than the simple estimate and likely approximates the true sockeye escapement to Henderson Lake more closely. However, the simple estimate remains useful. It is directly comparable to similar estimates made in at least seven previous years for this stock provided that tag recoveries made in those years can be adjusted based upon the relationship between tag colors and viewing conditions determined from tag-detection efficiency studies.

This study illustrates that large variations can occur among escapement estimates generated by different methods even under nearly ideal conditions for population surveys. Independent techniques such as the AUC/cumulative tag-day and live Petersen mark-recapture methods generated escapement estimates that converged closely under conditions where visibility was good and large samples of sockeye were tagged and later enumerated. The effect of suboptimal visibilities on tag recoveries clearly revealed the biases associated with estimates based upon these techniques. Systematic compensation for these biases through tag-detection efficiency studies helped refine these estimates to better approximate true escapement levels.

Estimates based upon live mark-recapture and AUC/cumulative tag-day techniques were almost exactly intermediate between those derived from (i) peak live-plus-dead counts, which typically are biased low, and (ii) mark-recapture methods based upon carcasses, which are almost always biased high (Fig. 8). In contrast with 1989, estimates of sockeye escapements to Henderson Lake generated in previous years frequently showed different interrelationships under various survey conditions. For example, AUC estimates for previous years were frequently biased high and exceeded Petersen mark-recapture estimates (authors' unpublished data). Large variations in the behavior of a given technique can clearly occur among years. However, given that calibrations for tag-detection efficiencies are available for a suite of survey conditions, one source of bias among some enumeration techniques can be accounted for and reduced. Escapement estimates for previous years can then be interpreted and refined in relation to the results of the present investigation.

ACKNOWLEDGEMENTS

The work embodied in this report could not have been completed without the talent and dedication of several individuals working both in the field and the laboratory. We wish to thank: Mr. Ichio Miki for assistance in the field and for determining the ages of sockeye from samples of scales and otoliths; Mr. Ryan Cerniauskas and Mr. Pierre Dubeau for their participation in the field sampling program; and, Mr. Paul Rankin and Mr. Ron Traber for assistance in field mobilization and provision and maintenance of equipment.

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Table 1. Tags applied to adult sockeye to estimate population numbers in Henderson Lake and Clemens Creek in 1989.

		Number Applied		
Tagging Period	Color Code	Males	Females	Total
3 Oct	white	139 (48.1)	150 (51.9)	289
17 – 19 Oct	red	364 (49.4)	373 (50.6)	737
30 Oct - 3 Nov	pink	414 (46.4)	479 (53.6)	893
ALL	ALL CODES	917 (47.8)	1 002 (52.2)	1 919

Table 2. Visual counts of live sockeye made in seven total-section surveys of the Clemens Creek and Henderson Lake spawning grounds in 1989. Spawners in the stream were counted on foot: lake surveys were made by boat. Numbers with asterisks indicate counts extrapolated for sections not surveyed on trip T-1. Fish in sections 3 - 5 were isolated in deep pools due to low streamflows early in the season; therefore, extrapolated numbers were the same as those observed in the same sections during survey T-2. CM = lake at creek mouth; EB = beaches east of Clemens Creek; WB = beaches west of creek; OS = offshore parts of lake.

	Sockeye Numbers						
	T-1	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**
Survey Section	20 Sep	3 - 5 Oct	18 - 19 Oct	29 Oct - 2 Nov	15 Nov	28 - 29 Nov	6 Dec
Lake, CM	0	0	1 171	0	0	0	0
Lake, EB	0	75	0	0	0	0	0
Lake, WB	15	41	156	577	146	4	0
Lake, OS	0	0	0	1[a]	0	0	0
Lake Total	**15**	**116**	**1 327**	**578**	**146**	**4**	**0**
1	182	339	8 151	4 061	1 340	9	0
2	0	0	936	695	198	2	0
3	140*	140	880	1 215	261	22	0
4	238*	238	1 600	5 768	2 805	273	0
5	18*	18	414	3 856	2 557	126	4
6	0	0	46	1 864	935	19	0
7	0	0	0	4	0	0	0
Stream Total	**578**	**735**	**12 027**	**17 463**	**8 096**	**451**	**4**
ALL	**593**	**851**	**13 354**	**18 041**	**8 242**	**455**	**4**

[a] Observed near camp beach.

Table 3. Comparison of sockeye abundance estimated for Clemens Creek by total-section counts and within-section expansions based upon strip counts. Counts by both methods were made on surveys T-4 and T-5 respectively. The percentage of the total sockeye population estimated for the entire stream is given for each sectional estimate and count type. Strip counts include live fish only.

(A) Survey of 1 - 2 November 1989 (T-4)

Stream Section	Strip Count	Percent of Total	Complete Count	Percent of Total	Percent Difference
1	2 299	17.0	4 061	23.3	-43.4
2	178	1.3	695	4.0	-74.4
3	690	5.1	1 215	7.0	-43.2
4	3 030	22.4	5 768	33.0	-47.5
5	4 279	31.7	3 856	22.1	+9.9
6	3 029	22.4	1 864	10.7	+38.5
7	4*	0.03	4	0.02	0
ALL	**13 509**		**17 463**		-22.6

* Section 7 was counted completely and contained four live and one dead sockeye.

Counts made in small side channels and tributaries were added to strip count totals and included: 168 sockeye in section 5 and six fish in section 4.

Table 3. (continued).

(B) Survey of 15 November 1989 (T-5)

Stream Section	Strip Count	Percent of Total	Complete Count	Percent of Total	Percent Difference
1	2 699	25.4	1 340	16.6	+50.4
2	693	6.5	198	2.4	+71.4
3	304	2.9	261	3.2	+14.1
4	4 594	43.2	2 805	34.6	+38.9
5	1 699	16.0	2 557	31.6	-33.6
6	637	6.0	935	11.5	-31.9
7	0	0	0	0	0
ALL	**10 626**		**8 096**		**+23.8**

Counts made in small side channels and tributaries and added to strip count totals for 15 November included: 863 sockeye in section 5 and 88 fish in section 4.

Table 4. Visual counts of sockeye spawners made during aerial overflights of the Henderson Lake and Clemens Creek spawning grounds. Each overflight was made on the first day of each of the seven trips to Henderson Lake. The spawner count for each survey section is the average of counts made by two observers. Aerial surveys were not attempted on the last two trips of the season due to bad weather.

	Sockeye Numbers						
	T-1	T-2	T-3	T-4	T-5	T-6	T-7
Survey Section	20 Sep	2 Oct	16 Oct	29 Oct	14 Nov	27 Nov	6 Dec
Lake, CM	0	0	2 000	0	0	-	-
Lake, EB	0	0	500	0	0	-	-
Lake, WB	0	150*	0	525	50	-	-
Lake, OS	0	0	0	0	0	-	-
Lake Total	**0**	**150***	**2 500**	**525**	**50**	-	-
1	0	0	850	3 375	350	-	-
2	0	0	0	375	75	-	-
3	0	0	0	125	100	-	-
4	0	0	20	675	1 350	-	-
5	0	0	10	350	300	-	-
6	0	0	0	100	50	-	-
7	0	0	0	0	0	-	-
Stream Total	**0**	**0**	**880**	**5 000**	**2 225**	-	-
ALL	**0**	**150***	**3 380**	**5 525**	**2 275**	-	-

* Later observed to consist mainly of coho and chinook adults (nearly 73 %).

Table 5. Relationships between total-section counts and sockeye numbers estimated by observers in fixed-wing aircraft. Comparisons between techniques were made based on (i) total counts in the lake, stream, and total system (see Tables 2 and 4), (ii) individual-section counts among all surveys for these areas respectively, and (iii) counts within stream sections among all surveys.

Comparisons by Area Totals Among Surveys

Area	Regression	
Lake	Total Count = 0.50(Aerial Count) + 113.47	$p < 0.05$
	$r = 0.98$; $r^2 = 0.95$; $n = 5$	
Stream	Total Count = 3.01(Aerial Count) + 2907.89	$p > 0.05$
	$r = 0.86$; $r^2 = 0.74$; $n = 5$	
System	Total Count = 3.29(Aerial Count) + 766.23	$p < 0.01$
	$r = 0.99$; $r^2 = 0.99$; $n = 5$	

Comparisons by Section Counts Among Surveys

Area	Regression	
Lake	Total Count = 0.57(Aerial Count) + 16.82	$p < 0.001$
	$r = 0.93$; $r^2 = 0.87$; $n = 20$	
Stream	Total Count = 1.74(Aerial Count) + 709.61	$p < 0.05$
	$r = 0.58$; $r^2 = 0.34$; $n = 35$	
System	Total Count = 1.51(Aerial Count) + 436.40	$p < 0.001$
	$r = 0.55$; $r^2 = 0.30$; $n = 55$	

Table 5. (continued).

Comparisons Within Stream Sections Among Surveys

Section	Regression	
1	Total Count = 1.02(Aerial Count) + 1879.49 $r = 0.43$; $r^2 = 0.19$; $n = 5$	$p > 0.05$
2	Total Count = 1.05(Aerial Count) + 271.45 $r = 0.40$; $r^2 = 0.16$; $n = 5$	$p > 0.05$
3	Total Count = 3.83(Aerial Count) + 354.88 $r = 0.48$; $r^2 = 0.23$; $n = 5$	$p > 0.05$
4	Total Count = 2.33(Aerial Count) + 1177.80 $r = 0.60$; $r^2 = 0.37$; $n = 5$	$p > 0.05$
5	Total Count = 9.68(Aerial Count) + 94.55 $r = 0.98$; $r^2 = 0.97$; $n = 5$	$p < 0.05$
6	Total Count = 18.48(Aerial Count) + 14.75 $r = 1.00$; $r^2 = 1.00$; $n = 5$	$p < 0.05$

Table 6. Numbers of dead sockeye pitched from Clemens Creek during five visual surveys of the Henderson Lake spawning grounds in 1989. Carcasses were also enumerated for the lake. Because carcasses could not be pitched from the lake, only fresh carcasses were counted. No carcasses were observed on the spawning grounds prior to the survey of 16 October.

	Numbers of Dead Sockeye Pitched				
	T-3	T-4	T-5	T-6	T-7
Survey Section	18 - 19 Oct	29 Oct - 3 Nov	14 - 18 Nov	27 - 29 Nov	6 Dec
Lake CM	6	5	9	40	0
Lake EB	0	1	0	0	0
Lake WB	3	6	58	90	2
Lake OS	0	0	6	0	0
Lake Total	**9**	**12**	**73**	**130**	**2**
1	4	181	1 097	796	0
2	0	2	50	12	0
3	0	6	77	66	0
4	0	223	932	744	0
5	0	29	704	644	11
6	0	61	208	131	0
7	0	1	1	0	0
Stream Total	**4**	**503**	**3 069**	**2 393**	**11**
ALL	**13**	**515**	**3 142**	**2 523**	**13**

Table 7. Numbers of live sockeye bearing tags enumerated in six visual surveys of the spawning grounds in Clemens Creek, 1989. Counts are given separately for each tag color, stream survey section, and tag-recovery period. Numbers with asterisks indicate tagged fish enumerated one day after tag application. No adjustments to observed numbers were made to account for visual detection efficiencies or for fish known to be alive one day after tagging but distributed in the lake out of the sight of observers (see text).

		Numbers of Tagged, Live Sockeye Counted					
		T-2	T-3	T-4	T-5	T-6	T-7
Tag Color	Survey Section	3 - 5 Oct	18 - 19 Oct	29 Oct - 2 Nov	15 Nov	28 - 29 Nov	6 Dec
white	Lake	0	4	2	0	0	0
	1	260	150	62	4	0	0
	2	0	21	1	0	0	0
	3	0	2	9	0	0	0
	4	0	34	17	0	0	0
	5	0	1	5	0	0	0
	6	0	0	0	0	0	0
	7	0	0	0	0	0	0
	All	**260***a	**212**	**96**	**4**	**0**	**0**
red	Lake	-	58	29	0	0	0
	1	-	111	128	17	0	0
	2	-	3	26	3	0	0
	3	-	1	42	4	0	0
	4	-	4	87	14	0	0
	5	-	0	52	16	0	0
	6	-	0	21	10	0	0
	7	-	0	0	0	0	0
	All	-	**177***a	**385**	**64**	**0**	**0**
pink	Lake	-	-	1	12	0	0
	1	-	-	757	98	0	0
	2	-	-	23	12	0	0
	3	-	-	11	12	0	0
	4	-	-	11	101	3	0
	5	-	-	1	39	1	0
	6	-	-	1	2	0	0
	7	-	-	0	0	0	0
	All	-	-	**805***b	**276**	**4**	**0**
All Tags	**All**	**260**	**389**	**1 286**	**344**	**4**	**0**

Table 7. (continued).

[a] Day 1 counts of both white and red tags were actually made late on the same day that tags were applied. Replicate counts of white tags made on day 1 were virtually identical to the first count made on day 0. The day 0 value was employed because this count, made under conditions of reduced visibility (light rain), was concluded to best represent the total number of tags available for enumeration during survey T-2. Day 0 counts were required for red tags during survey T-3 due to the need to complete all spawner enumerations as quickly as possible under conditions of rapidly increasing stream discharge.

[b] Recoveries were adjusted to reflect an equal proportion of the total number of tags applied during survey T-4 (893). Counts were made on 1 November after only 714 sockeye were tagged. A total of 644 pink-tagged fish were recovered including 605 in section 1, 18 in section 2, 9 each in sections 3 and 4, and 1 each in the lake and sections 5 and 6. This day 1 recovery of 90.2 % of the applied tags was factored against the 893 pink tags applied during the entire trip (179 additional sockeye were tagged on 3 November). Therefore, 805 tags would have been recovered had counts been made after all tagging was completed. The unadjusted recovery of 644 tags was used for Petersen mark-recapture determinations, while the adjusted recovery of 805 tags was used for cumulative tag-day and tag-depletion determinations of residence time.

Table 8. Visual detection efficiences for selected colors of Petersen disc tags. Tags were deployed in reaches of section 1 in a variety of depths and locations including riffles, pools, and runs frequented by adult sockeye. Tags were then counted by two observers during each of four trials. Counts were averaged for each tag color. Mean percentages detected (a) for all tags both within each study and over all studies, and (b) for each color of tag over all studies, are provided with ± standard errors. Additionally, stream and weather conditions affecting viewing efficiency are summarized.

A. Percentages of Deployed Tags Detected.

		Tag Colors				
Date		WHITE	RED	PINK	GREEN	Total
4 Oct (T-2)	No. Deployed	25	21	33	21	100
	Mean % Detected	86.0	97.6	90.9	88.1	90.6 ± 2.2
16 Oct (T-3)	No. Deployed	20	30	35	25	110
	Mean % Detected	80.0	60.0	64.3	34.0	59.6 ± 8.3
30 Oct (T-4)	No. Deployed	24	23	25	28	100
	Mean % Detected	83.3	76.1	82.0	42.9	71.1 ± 8.2
18 Nov (T-5)	No. Deployed	24	26	25	25	100
	Mean % Detected	75.0	76.9	76.0	44.0	68.0 ± 6.9
ALL	No. Deployed	93	100	118	99	410
	Mean % Detected	**81.1** ± 2.1	**77.7** ± 6.7	**78.3** ± 4.8	**52.3** ± 10.5	**72.3** ± 4.5

Table 8. (continued).

B. Viewing Conditions Available for Tag-Detection Experiments

	Stream Conditions and Weather				
Date	Stream Discharge	S1 Gauge Height (m)*	Percent Cloud	Rainfall	Stream Surface
4 Oct (T-2)	Very Low	0.510	100 (reduced light)	Light/ Moderate (76.2 mm/d)	Partly Obscured: Rippled by Rain
16 Oct (T-3)	Low	0.695	95 (reduced light)	None	Clear: Excellent Visibility
30 Oct (T-4)	Moderate	0.890	100 (reduced light)	Occasional Light Drizzle	Clear: Excellent Visibility
18 Nov (T-5)	Moderate	0.925	100 (reduced light; fog)	Intermittent Rain; Light/ Moderate	Partly Obscured: Rippled by Rain

* Direct readings of 1989 gauge.

Table 9. Counts of tagged, live sockeye adjusted to account for visual detection efficiences and for fish known to be alive one day after tagging but distributed in the lake out of the sight of observers. Counts made during six visual surveys of the spawning grounds in 1989 are given separately for each tag color, stream survey section, and tag-recovery period. Numbers with asterisks indicate tagged fish enumerated one day after tag application.

		Adjusted Counts of Tagged, Live Sockeye					
		T-2	T-3	T-4	T-5	T-6	T-7
Tag Color	Survey Section	3 - 5 Oct	18 - 19 Oct	29 Oct - 2 Nov	15 Nov	28 - 29 Nov	6 Dec
white	Lake	0	4	2	0	0	0
	1	289	180	72	5	0	0
	2	0	25	1	0	0	0
	3	0	2	11	0	0	0
	4	0	41	20	0	0	0
	5	0	1	6	0	0	0
	6	0	0	0	0	0	0
	7	0	0	0	0	0	0
	All	**289***	**253**	**112**	**5**	**0**	**0**
red	Lake	-	554	36	0	0	0
	1	-	155	159	21	0	0
	2	-	4	32	4	0	0
	3	-	1	52	5	0	0
	4	-	6	108	17	0	0
	5	-	0	64	20	0	0
	6	-	0	26	12	0	0
	7	-	0	0	0	0	0
	All	-	**720***	**477**	**79**	**0**	**0**
pink	Lake	-	-	1	14	0	0
	1	-	-	839	116	0	0
	2	-	-	25	14	0	0
	3	-	-	13	14	0	0
	4	-	-	13	119	4	0
	5	-	-	1	46	1	0
	6	-	-	1	2	0	0
	7	-	-	0	0	0	0
	All	-	-	**893*[a]**	**325**	**5**	**0**
All Tags	**All**	**289**	**973**	**1 482**	**409**	**5**	**0**

[a] Value adjusted for the total no. of tags applied during survey (see text).

Table 10. Numbers of dead sockeye bearing tags in five visual surveys of the spawning grounds in Clemens Creek, 1989. Tagged carcasses are tallied separately for each tag color, stream survey section, and tag-recovery period.

		Numbers of Tagged Carcasses Observed				
		T-3	T-4	T-5	T-6	T-7
Tag Color	Survey Section	18 - 19 Oct	29 Oct - 3 Nov	14 - 18 Nov	27 - 29 Nov	6 Dec
white	Lake	0	1	0	0	0
	1	0	6	12	3	0
	2	0	0	1	0	0
	3	0	0	0	0	0
	4	0	2	1	1	0
	5	0	0	1	0	0
	6	0	0	0	0	0
	7	0	0	0	0	0
	All	**0**	**9**	**15**	**4**	**0**
red	Lake	0	0	2	0	0
	1	0	18	25	4	0
	2	0	0	2	0	0
	3	0	0	4	1	0
	4	0	5	9	2	1
	5	0	2	6	2	0
	6	0	0	3	0	0
	7	0	0	0	0	0
	All	**0**	**25**	**51**	**9**	**1**
pink	Lake	0	0	4	2	0
	1	0	2	81	24	0
	2	0	0	3	0	0
	3	0	0	6	1	0
	4	0	0	10	5	0
	5	0	0	4	4	0
	6	0	0	1	0	0
	7	0	0	0	0	0
	All	**0**	**2**	**109**	**36**	**0**
All Tags	**All**	**0**	**36**	**175**	**49**	**1**

Table 11. Spawner residence time on the Henderson Lake and Clemens Creek spawning grounds based upon the cumulative tag-day method. Total tag-days were determined for each tag color by integrating the area under the curve formed from the numbers of tagged, live fish enumerated during visual surveys. Areas were determined separately for each survey interval and then summed. Observations one day after tagging are included. The first point on each curve (day 0) was the total number of tags applied. No adjustments to observed numbers were made to account for visual detection efficiencies or for fish known to be alive 1 - 2 days after tagging but distributed in the lake out of the sight of observers.

(i) WHITE TAGS

	Tags Applied	Tags Recovered					
	T-2	T-2	T-3	T-4	T-5	T-6	T-7
	3 Oct	4 Oct	19 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	289	260	212	96	4	0	0
Survey Interval (d)		1	15	12	14	14	7
Integrated AUC Interval (tag-d)		274.5	3540	1848	700	28	0

Cumulative tag-d: **6 390.5**
No. of Tags Applied: **289**

Residence Time (Σ tag-d / no. tags applied): **22.1 d**

Table 11. (continued).

(ii) RED TAGS

	Tags Applied	Tags Recovered				
	T-3	T-3	T-4	T-5	T-6	T-7
	18 Oct	19 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	737	177	385	64	0	0
Survey Interval (d)		1	13	14	14	7
Integrated AUC Interval (tag-d)		457	3653	3143	448	0

Cumulative tag-d: **7 701**
No. of Tags Applied: **737**

Residence Time (Σ tag-d / no. tags applied): **10.4 d**

(iii) PINK TAGS

	Tags Applied	Tags Recovered			
	T-4	T-4	T-5	T-6	T-7
	31 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	893	805	276	4	0
Survey Interval (d)		1	14	14	7
Integrated AUC Interval (tag-d)		849	7567	1960	28

Cumulative tag-d: **10 404**
No. of Tags Applied: **893**

Residence Time (Σ tag-d / no. tags applied): **11.7 d**

(iv) ALL TAGS **Mean Spawner Residence Time: 14.7 d**

Table 12. Spawner residence time on the Henderson Lake and Clemens Creek spawning grounds based upon the adjusted cumulative tag-day method. Total tag-days were determined for each tag color by integrating the area under the curve formed from the numbers of tagged, live fish enumerated during visual surveys. Areas were determined separately for each survey interval and then summed. Observations one day after tagging are included. The first point on each curve (day 0) was the total number of tags applied. Adjustments were made to observed numbers to account for visual detection efficiencies and for fish known to be alive one day after tagging but distributed in the lake out of the sight of observers.

(i) WHITE TAGS

	Tags Applied	Tags Recovered					
	T-2	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**
	3 Oct	4 Oct	19 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	289	289	253	112	5	0	0
Survey Interval (d)		1	15	12	14	14	7
Integrated AUC Interval (tag-d)		289	4065	2190	819	35	0

Cumulative tag-d: 7 398
No. of Tags Applied: **289**

Residence Time (Σ tag-d / no. tags applied): **25.6 d**

Table 12. (continued).

(ii) RED TAGS

	Tags Applied	Tags Recovered				
	T-3	T-3	T-4	T-5	T-6	T-7
	18 Oct	19 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	737	720	477	79	0	0
Survey Interval (d)		1	13	14	14	7
Integrated AUC Interval (tag-d)		728.5	7780.5	3892	553	0

Cumulative tag-d: 12 954
No. of Tags Applied: 737

Residence Time (Σ tag-d / no. tags applied): **17.6 d**

(iii) PINK TAGS

	Tags Applied	Tags Recovered			
	T-4	T-4	T-5	T-6	T-7
	31 Oct	1 Nov	15 Nov	29 Nov	6 Dec
	893	893	325	5	0
Survey Interval (d)		1	14	14	7
Integrated AUC Interval (tag-d)		893	8526	2310	17.5

Cumulative tag-d: 11 746.5
No. of Tags Applied: 893

Residence Time (Σ tag-d / no. tags applied): **13.2 d**

(iv) ALL TAGS **Mean Spawner Residence Time: 18.8 d**

Table 13. Mean stream residence time of sockeye spawners determined using the tag-depletion method. Residence time was defined as the estimated time (days) to reach 50 % tag loss ($E_{TL}50$), and was determined for each tag group using linear regressions in which the natural logarithm of visually recovered tags was correlated with the number of days elapsed (DE) since tag application. Mean stream residence times were determined both for unmodified observations and for visual recoveries adjusted for tag-detection efficiencies. Observations one day after tagging are included (constrained regressions). n = no. of tag-recovery observations.

(A) Constrained Regressions with Visual Recoveries Unadjusted for Tag-Detection Efficiencies

Tag Group	Tag-Depletion Regression	$E_{TL}50$ (d) (Stream Residence Time)
white (3 Oct)	Ln(Tags+1) = -0.107(DE) + 6.540 $r^2 = 0.893$; $p < 0.01$; n = 5	14.7
red (18 Oct)	Ln(Tags+1) = -0.128(DE) + 6.543 $r^2 = 0.725$; $p > 0.05$; n = 4	5.0
pink (31 Oct)	Ln(Tags+1) = -0.196(DE) + 7.348 $r^2 = 0.943$; $p < 0.05$; n = 4	6.3

Mean Stream Residence Time (Unmodified Regressions): **8.7 d**

Table 13. (continued).

(B) Constrained Regressions with Visual Recoveries Adjusted for Tag-Detection Efficiencies

Tag Group	Tag-Depletion Regression	$E_{TL}50$ (d) (Stream Residence Time)
white (3 Oct)	Ln(Tags+1) = -0.108(DE) + 6.706 $r^2 = 0.887$; $p < 0.01$; n = 5	16.0
red (18 Oct)	Ln(Tags+1) = -0.158(DE) + 7.642 $r^2 = 0.863$; $p < 0.05$; n = 4	11.0
pink (31 Oct)	Ln(Tags+1) = -0.201(DE) + 7.671 $r^2 = 0.938$; $p < 0.01$; n = 4	7.8

Mean Stream Residence Time (Modified Regressions): **11.6 d**

Table 14. Visual enumeration of live and dead sockeye at the Henderson Lake spawning grounds, 1989. Peak counts of live-plus-dead fish were estimated during survey T-4 for 1 November.

	Sockeye Numbers						
	T-1	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**
	20 Sep	3 - 5 Oct	18 - 19 Oct	29 Oct - 2 Nov	15 Nov	28 - 29 Nov	6 Dec
Live Sockeye	593	851	13 354	18 041	8 242	455	4
Dead Sockeye	0	0	13	515	3 142	2 523	13
Total Count	593	851	13 367	**18 556**	11 384	2 978	17

Table 15. Summary of escapement estimates for Henderson Lake sockeye, 1989. Some residence times were calculated after tag recoveries were adjusted upward to account for suboptimal visual detection efficiencies. AUC = integrated area under a spawner abundance curve.

Method	Adjustment for Tag Visibility	Residence Time (d)	Population Estimate
Peak Count Made from Fixed-Wing Aircraft	-	-	5 525
Peak Count of Live-Plus-Dead Sockeye from Strip-Count Expansions	-	-	13 667
Peak Count of Live-Plus-Dead Sockeye	-	-	18 556
AUC + Interval Between Peak Counts of Live and Dead Fish	-	17	33 254
AUC + Cumulative Tag-Days	Unadjusted	14.7	38 457
	Adjusted	18.8	30 070
AUC + Constrained Tag-Depletion Regressions	Unadjusted	8.7	64 979
	Adjusted	11.6	48 734
Petersen Mark-Recapture:			
(a) Live Fish/Simple	Unadjusted	-	37 030
	Adjusted	-	31 343
(b) Live Fish/Stratified	Unadjusted	-	37 973
	Adjusted		32 075
(c) Carcasses/Simple	-	-	45 630
(d) Carcasses/Stratified	-	-	44 552

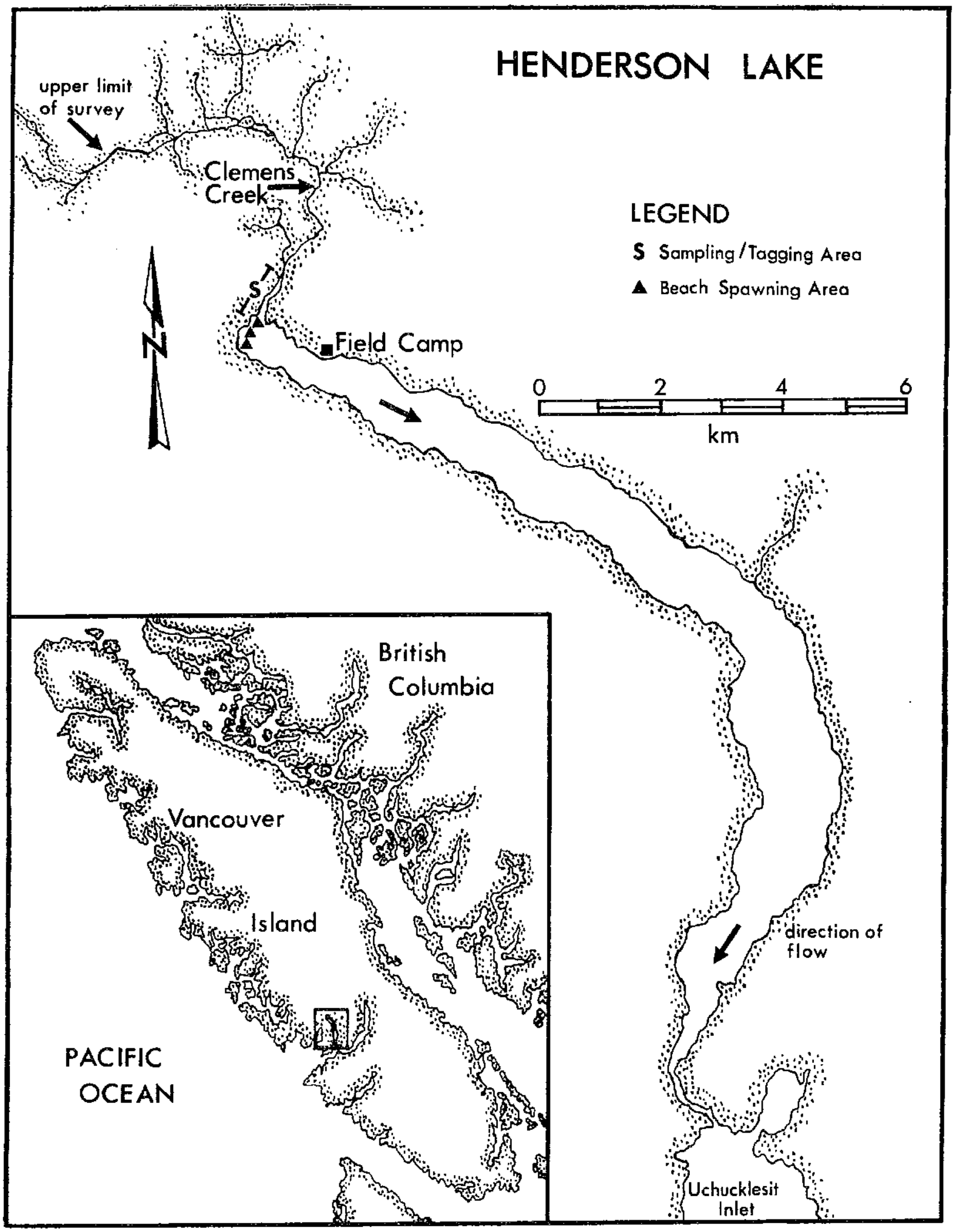


Fig. 1. Location of Henderson Lake and Clemens Creek study area adjacent to Barkley Sound, Vancouver Island.

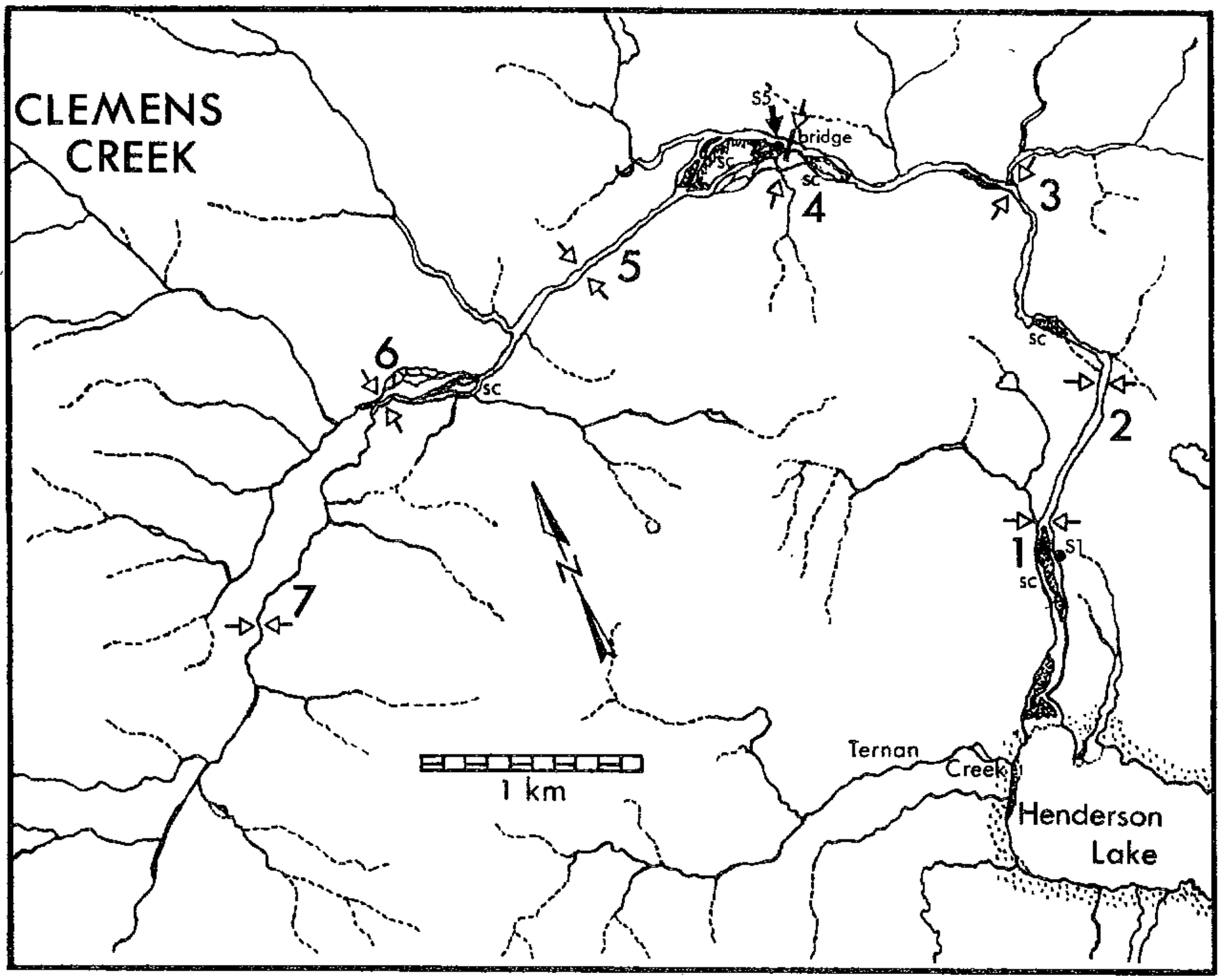


Fig. 2. Detailed map of the spawner survey sections in Clemens Creek. Numbers and arrows mark the upstream end of each study section. Sections were approximately 1 km long on average. Major side channels containing sockeye are denoted by sc. Sections 1 and 5 staff-guage locations are denoted by S1 and S5 respectively. Sockeye were enumerated separately in each section and along the lakehead beach of Henderson Lake.

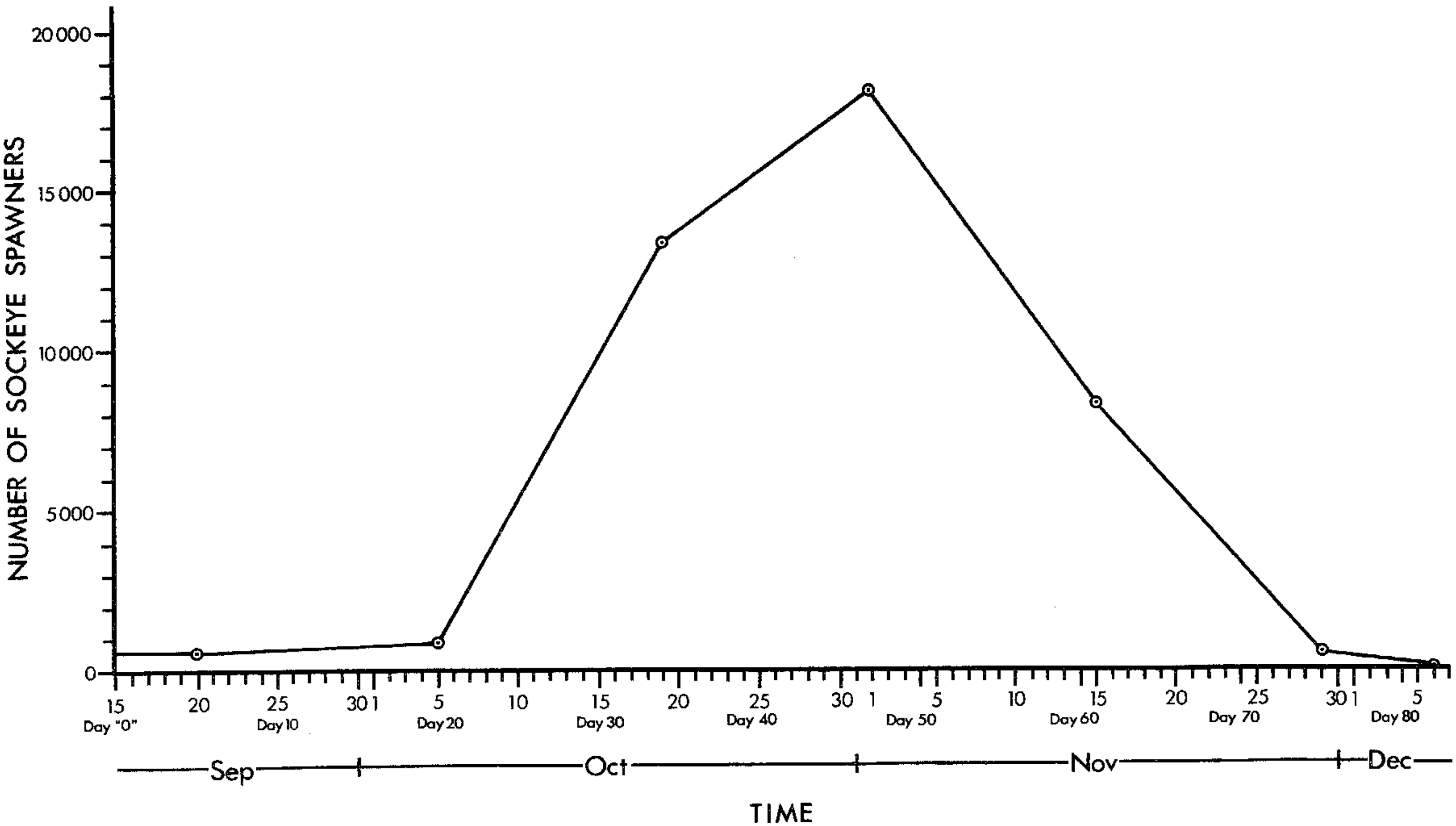


Fig. 3. Numbers of live, adult sockeye enumerated visually in six surveys of the Henderson Lake and Clemens Creek spawning grounds during 1988. Data points are plotted as the last day of each survey. Small numbers of adult sockeye which entered the stream during late July (and remained isolated in deep pools due to low discharges) caused the left-hand tail of the curve. The spawning season (and spawner abundance curve) was arbitrarily defined to begin on 15 September based on observations of sockeye migrations from previous years and because July migrants were not spawning throughout their early residence period in Clemens Creek.

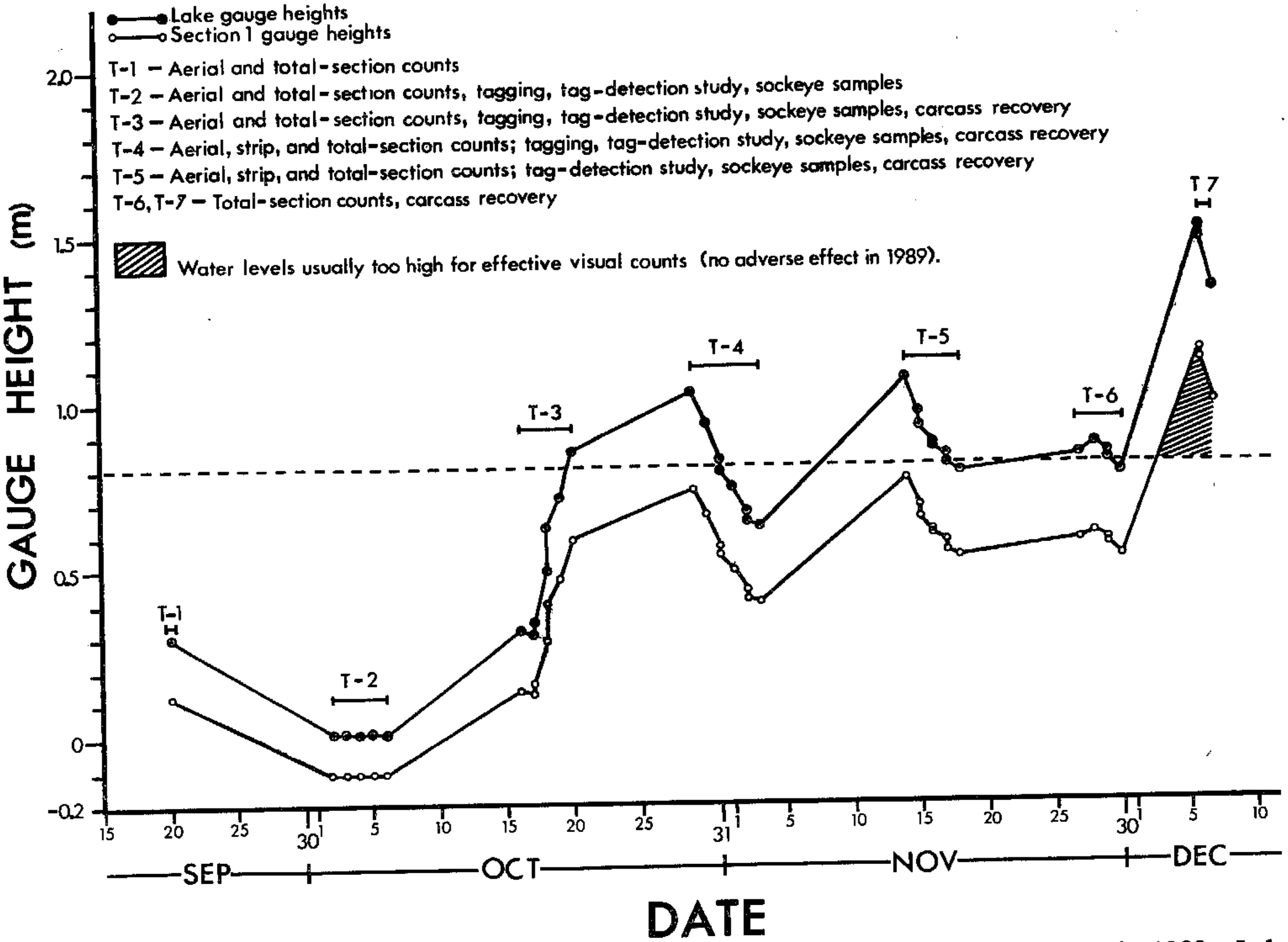


Fig. 4. Variations in staff gauge height (m) in Henderson Lake and Clemens Creek during surveys in 1989. Lake gauge heights are direct readings made in 1989. Stream gauge heights for 1989 are based on a regression between lake gauge and section 1 gauge heights developed in 1984 (see text, Appendix Table A-1). Durations of seven separate surveys of the spawning grounds are indicated as T-1 - T-7. High flows did not adversely affect counting efficiency during survey T-7 because turbidity was low.

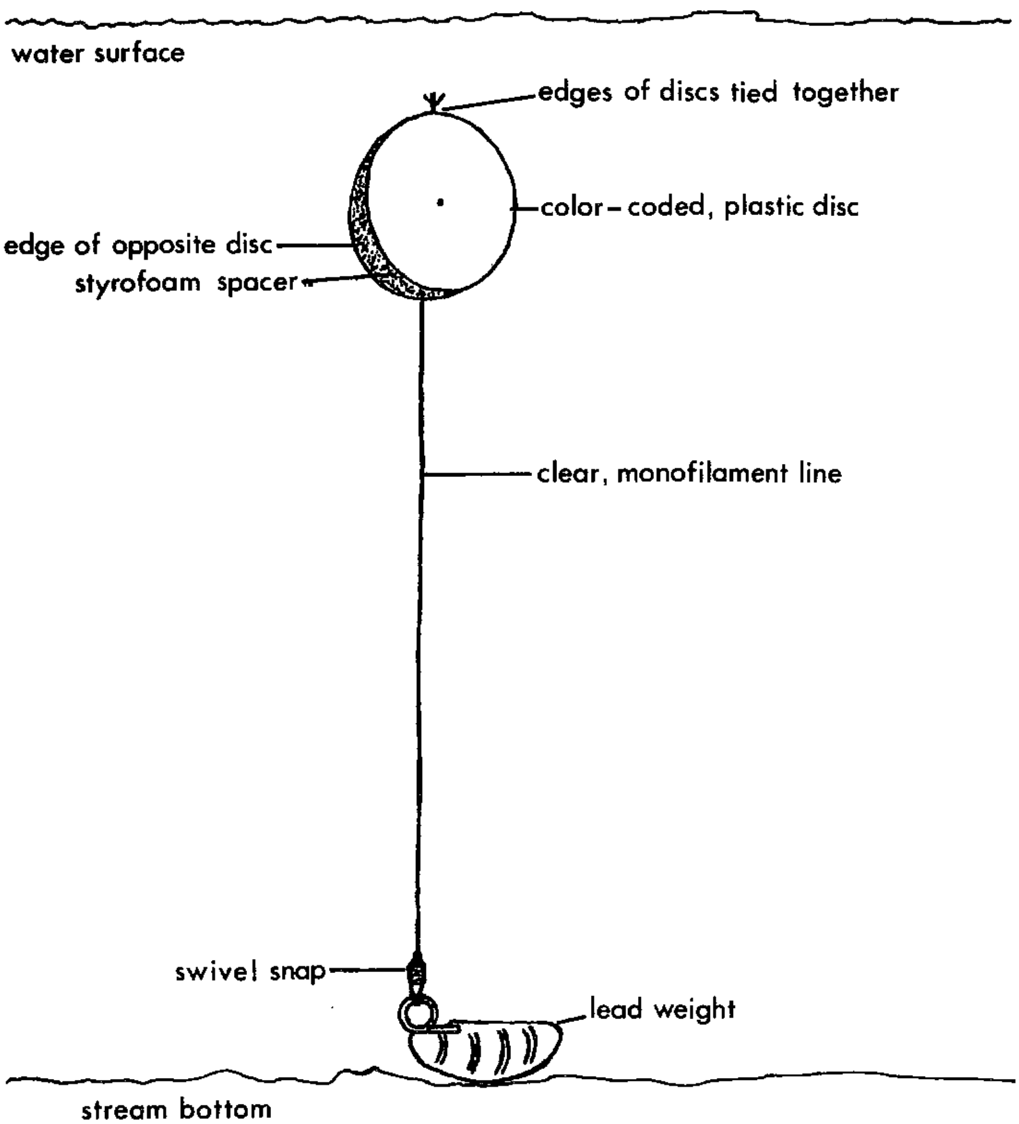
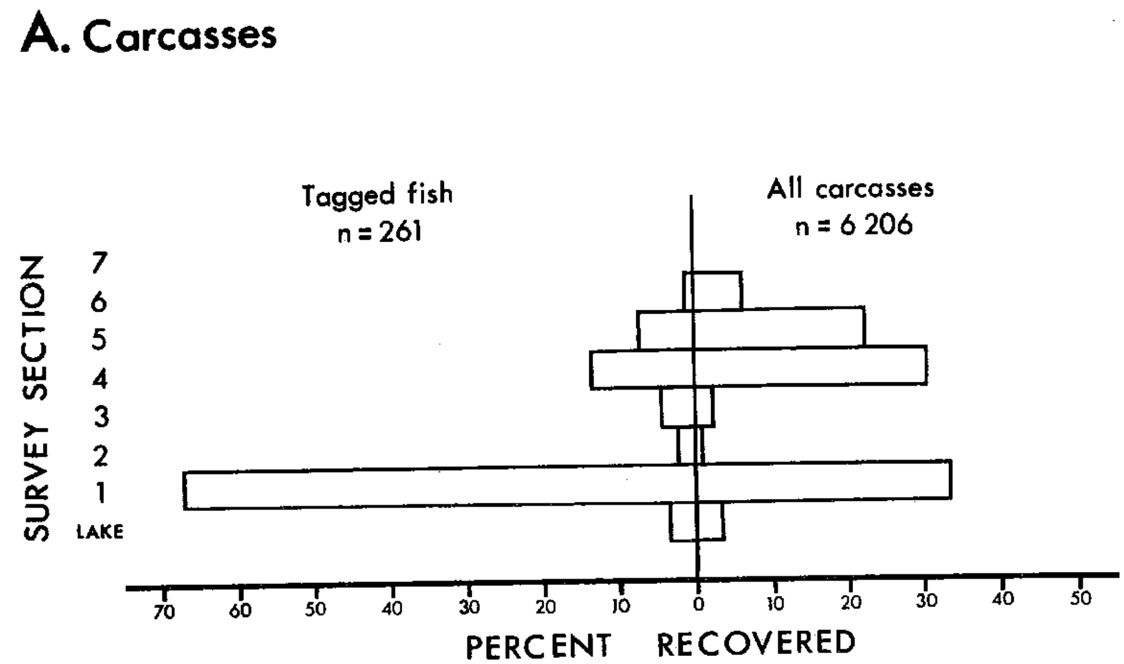


Fig. 5. Sketch of buoyant, styrofoam-centered, disc tags used to determine tag-detection efficiencies.



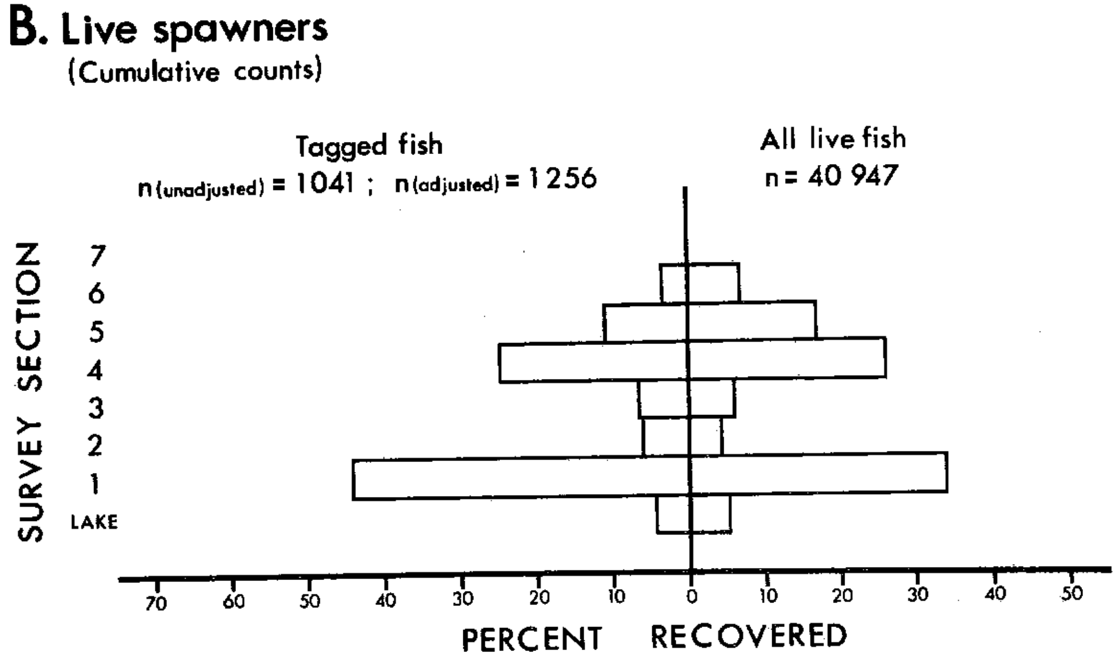


Fig. 6. Proportions of the total sample of recovered, tagged fish versus the total sockeye population in each survey section of the spawning grounds. The distributions of live fish and recovered carcasses are provided separately. Day 1 counts are excluded from the recovery data for tagged, live sockeye.

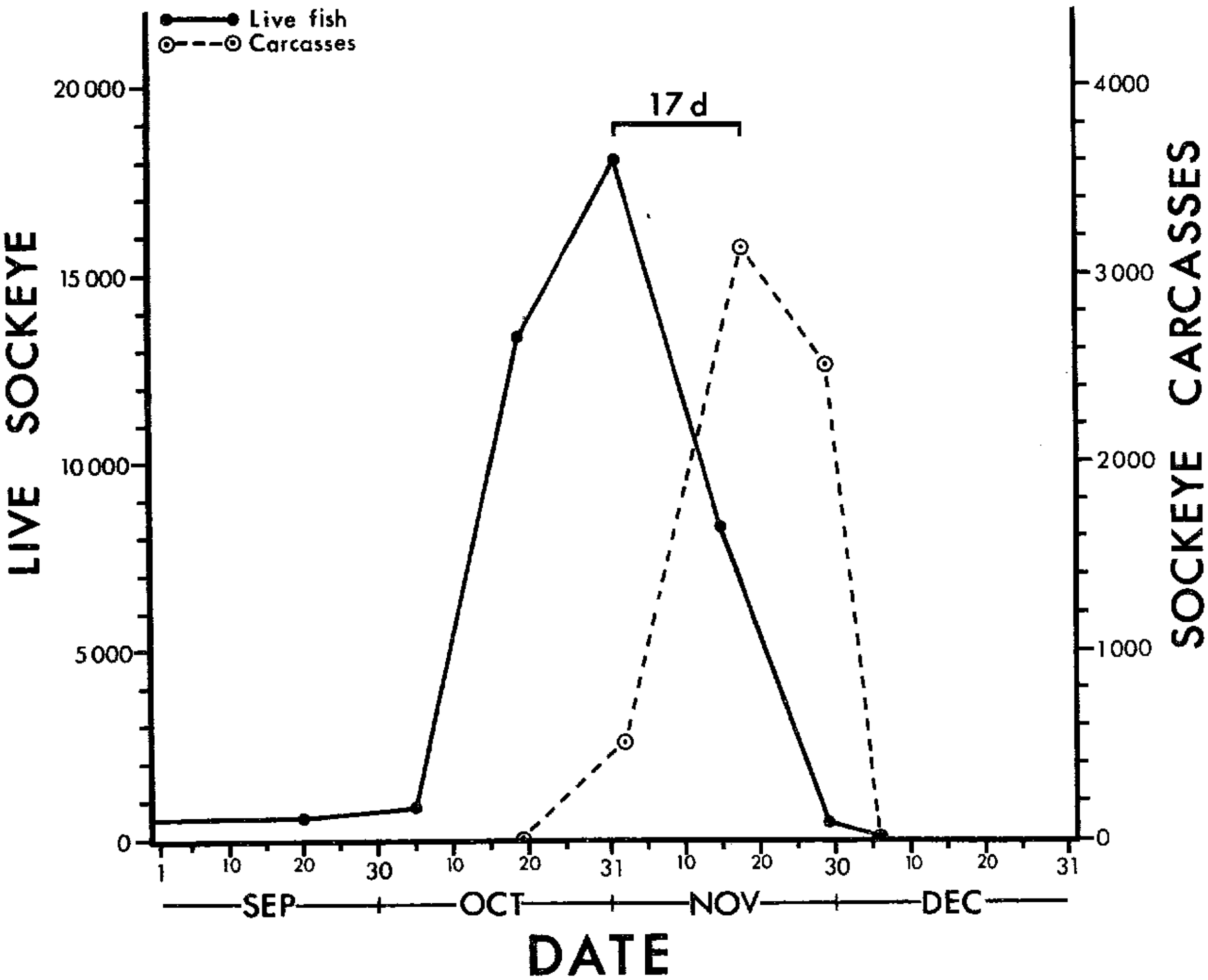
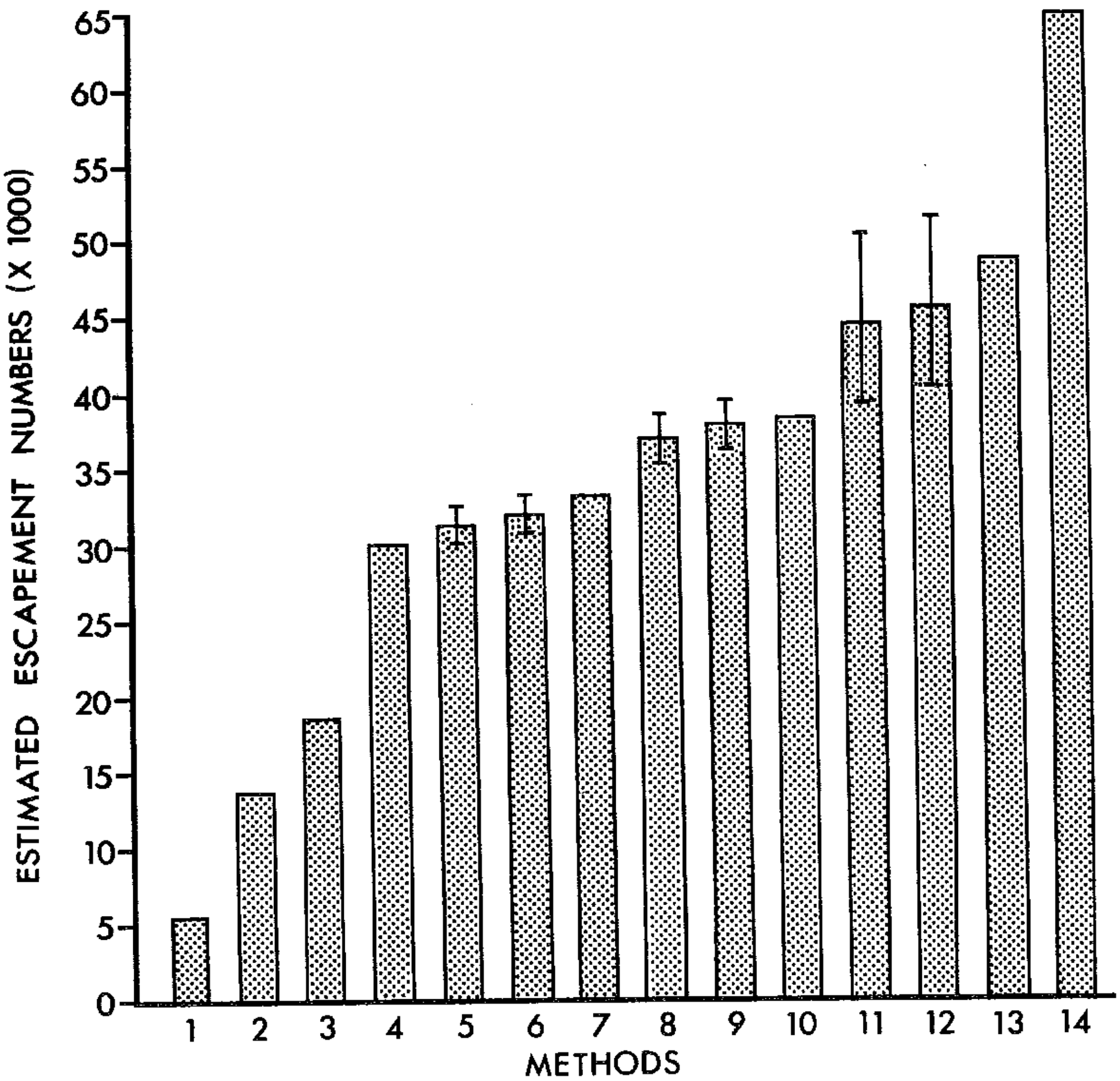


Fig. 7. Sequential estimates of live and dead sockeye used to determine mean spawner residence time from the interval between peak counts of live and dead fish.

Fig. 8. Array of population estimates generated by various assessment techniques for Henderson Lake sockeye in 1989. Petersen mark-recapture estimates are provided with $\pm$ 95% confidence limits.



1. Fixed-wing aerial overflight.
2. Peak count of live and dead fish from strip-count expansions.
3. Peak count of live and dead fish (complete counts).
4. AUC + Cumulative tag-days — tag recoveries adjusted.
5. Simple Petersen mark-recapture: live fish, tag recoveries adjusted.
6. Stratified Petersen mark-recapture: live fish, tag recoveries adjusted.
7. AUC + Interval between peak count of live and dead fish.
8. Simple Petersen mark-recapture: live fish, tag recoveries unadjusted.
9. Stratified Petersen mark-recapture: live fish, tag recoveries unadjusted.
10. AUC + Cumulative tag-days — tag recoveries unadjusted.
11. Stratified Petersen mark-recapture — carcasses.
12. Simple Petersen mark-recapture — carcasses.
13. AUC + Tag-depletion regressions — tag recoveries adjusted.
14. AUC + Tag-depletion regressions — tag recoveries unadjusted.

APPENDICES

Table A-1. Staff gauge readings (m) for relative water levels at Henderson Lake Camp and Clemens Creek stations (stream sections 1 and 5). Observation dates are grouped according to visual survey periods. Dual readings on some days indicate morning and afternoon data respectively.

Observation Date	Henderson Lake Gauge at Camp (Station)	Section 1 (Station)	Section 1; 1984 Gauge Equivalents[b] (Station)	Section 5 (Station)
20 Sep	0.314	-[a]	0.136	-
2 Oct	0.020	-[a]	-0.113	-
3 Oct	0.020	0.510	-0.113	-
3 Oct	0.020	0.510	-0.113	-
4 Oct	0.020	0.520	-0.113	-
5 Oct	0.025	0.755	-0.108	0.030
5 Oct	0.020	0.720	-0.113	-
6 Oct	0.020	0.640	-0.113	-
16 Oct	0.325	0.695	0.145	-
17 Oct	0.315	-	0.137	-
17 Oct	0.350	0.740	0.166	-
18 Oct	0.505	-	0.297	0.475
18 Oct	0.630	-	0.403	0.500
19 Oct	0.720	0.990	0.479	0.275
19 Oct	0.720	0.970	0.479	-
20 Oct	0.860	-	0.597	-
29 Oct	1.030	0.900	0.741	-
30 Oct	0.940	0.890	0.665	-
31 Oct	0.830	0.875	0.572	-
31 Oct	0.795	-	0.542	-
1 Nov	0.745	0.865	0.500	0.145
2 Nov	0.675	0.860	0.441	-
2 Nov	0.645	0.853	0.415	-
3 Nov	0.630	0.895	0.403	-
14 Nov	1.065	0.920	0.770	-
15 Nov	0.965	0.910	0.686	0.180
15 Nov	0.925	0.905	0.652	-
16 Nov	0.875	-	0.610	0.214
16 Nov	0.865	0.940	0.601	-
17 Nov	0.840	0.940	0.580	-
17 Nov	0.810	-	0.555	0.205
18 Nov	0.790	0.925	0.538	-

Table A-1. (continued).

Observation Date	Henderson Lake Gauge at Camp	Section 1	Section 1; 1984 Gauge Equivalents[b]	Section 5
	Station			
27 Nov	0.830	0.970	0.572	-
28 Nov	0.870	1.020	0.606	-
28 Nov	0.865	0.980	0.601	0.265
29 Nov	0.840	0.965	0.580	0.250
29 Nov	0.825	0.950	0.568	-
30 Nov	0.780	0.925	0.530	-
6 Dec	1.510	0.990	1.146	-
6 Dec	1.470	0.985	1.113	0.260
7 Dec	1.325	-	0.990	-

[a] Staff gauge in Section 1 was washed out by strong freshets prior to the 1989 survey season.

[b] Equivalent gauge heights for section 1 in 1984 were determined by linear regression between lake gauge heights (LkGH) and section 1 gauge heights (S1GH) for that year (Tschaplinski and Hyatt 1990):

S1GH (cm) + 100 = 0.845 X LkGH (cm) + 87.04 ($r^2 = 0.89$; $p < 0.001$; $n = 51$).

Table A-2. Water temperatures (^{o}C) determined at the Henderson Lake Camp and Clemens Creek stations (stream sections 1 and 5). Observation dates are grouped according to visual survey periods. Temperatures were taken at about 15 cm below the water surface.

Observation Date	Stations: Henderson Lake at Camp		Section 1		Section 5	
	Time	Temp.	Time	Temp.	Time	Temp.
20 Sep	11:00	18.0	11.10	–	–	–
2 Oct	15:00	19.0	–	–	–	–
3 Oct	09:20	17.9	12:25	10.0	–	–
3 Oct	16:30	19.0	–	–	–	–
4 Oct	18:10	18.0	11:50	10.0	–	–
5 Oct	09:30	18.0	09:50	10.0	13:10	11.1
5 Oct	18:15	18.0	–	–	–	–
6 Oct	09:10	19.9	09:20	10.0	–	–
16 Oct	14:00	16.5	15:19	9.0	–	–
17 Oct	08:50	15.5	16:47	9.0	–	–
17 Oct	17:43	15.5	–	–	–	–
18 Oct	08:31	15.5	–	–	16:13	9.0
18 Oct	18:00	15.0	–	–	–	–
19 Oct	08:30	15.0	11:36	9.5	12:41	9.5
19 Oct	17:15	15.0	17:04	9.5	–	–
20 Oct	08:46	15.0	09:07	9.5	–	–
29 Oct	15:52	12.5	17:12	7.5	–	–
30 Oct	08:30	12.5	09:45	7.0	–	–
31 Oct	08:10	12.5	11:21	7.0	–	–
31 Oct	17:41	12.5	–	–	–	–
1 Nov	08:17	12.5	08:53	6.0	15:22	7.0
2 Nov	08:26	12.0	08:56	7.0	–	–
2 Nov	17:07	12.0	14:40	7.5	–	–
3 Nov	08:05	12.0	11:14	7.5	–	–
14 Nov	14:47	10.5	17:17	6.0	–	–
15 Nov	08:14	10.0	09:11	6.0	10:06	6.5
15 Nov	17:10	10.0	15:08	6.0	–	–
16 Nov	08:23	10.0	15:32	6.0	09:25	6.5
16 Nov	17:15	10.0	–	–	–	–
17 Nov	08:19	10.0	10:33	6.0	15:58	7.0
17 Nov	17:15	10.0	–	–	–	–
18 Nov	08:18	10.0	08:57	7.0	–	–

Table A-2. (continued).

Observation Date	Stations					
	Henderson Lake at Camp		Section 1		Section 5	
	Time	Temp.	Time	Temp.	Time	Temp.
27 Nov	13:29	9.0	14:20	6.0	-	-
28 Nov	08:14	9.0	08:36	6.0	15:10	6.0
28 Nov	16:43	9.0	16:24	6.0	-	-
29 Nov	08:29	9.0	09:09	6.0	10:12	6.0
29 Nov	16:21	9.0	14:59	6.0	-	-
30 Nov	08:40	9.0	09:04	6.0	-	-
6 Dec	11:16	9.0	11:33	7.0	13:33	6.5
6 Dec	15:15	8.5	14:55	7.0	-	-
7 Dec	08:25	8.5	-	-	-	-

Table A-3. Numbers of live and dead sockeye enumerated by the strip-count method in six survey sections of Clemens Creek on 1 and 15 November 1989. Numbers of fish counted in each one-meter strip are included with observations of tagged, live fish and comments on visibility. The live-fish category refers to untagged sockeye. Tag colors employed: W = white, R = red, and P = pink. Section 7 of the stream contained few fish and was counted completely. Where strips were counted in two adjacent channels, M denotes the main channel and S denotes the side channel.

(A) **Survey of 1 November 1989 (T-4)**

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
1	1	0	0	0	0	
	2	0	0	0	0	
	3	0	0	0	0	
	4	1	0	0	1	
	5	3	0	0	3	
	6	4	0	4 P	8	
	7	0	0	0	0	Excellent
	8	4	0	6 P	10	visibility into
	9	5	0	1 P	6	deep pools of
	10	5	0	7 P	12	lower section 1.
	11	2	0	0	2	
	12	3	0	0	3	
	13	1	0	0	1	
	14	0	0	0	0	
	15	0	0	0	0	
	16	1	0	0	1	
	17	9	0	0	9	
	18	6	0	0	6	
	19	0	0	0	0	
	20M	4	0	0	4	
	20S	2	0	1 P	3	
	21M	1	0	0	1	
	21S	1	0	4 P	5	
	22M	0	0	0	0	
	22S	6	0	1R,1P	8	
	23M	1	0	0	1	
	23S	4	0	0	4	
	24M	0	0	0	0	
	24S	0	0	0	0	
	25	1	0	0	1	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
1	26	4	0	0	4	
	27	0	0	0	0	
	28	0	0	0	0	
	29	0	0	0	0	
	30	1	0	0	1	
	31	2	0	0	2	
	ALL	**71**	**0**	**1R, 24P**	**96**	
2	1	0	0	0	0	
	2	0	0	0	0	
	3	0	0	0	0	
	4	0	0	0	0	
	5	0	0	0	0	
	6	0	0	0	0	
	7	0	0	0	0	
	8	0	0	0	0	
	9	5	0	0	5	
	10	0	0	0	0	
	11	1	0	0	1	
	12	0	0	0	0	
	13	0	0	0	0	
	14	0	0	0	0	
	15	0	0	0	0	
	16	0	0	0	0	
	17	0	0	0	0	
	18	0	0	0	0	
	19	0	0	0	0	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	
	ALL	**6**	**0**	**0**	**6**	
3	1	1	0	0	1	
	2	5	0	1 P	6	
	3	3	0	0	3	
	4	0	0	0	0	
	5	0	0	0	0	
	6	0	0	0	0	
	7	0	0	0	0	
	8	0	0	0	0	
	9	0	0	0	0	
	10	0	0	0	0	
	11	0	0	0	0	
	12	0	0	0	0	
	13	0	0	0	0	
	14	0	0	0	0	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
3	15	0	0	0	0	
	16	0	0	0	0	
	17	1	0	1 R	2	
	18	2	0	0	2	
	19	4	0	1 R	5	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	
	23	0	0	0	0	
	24	0	0	0	0	
	25	0	0	0	0	
	26	0	0	0	0	
	27	0	0	0	0	
	28	0	0	0	0	
	29	0	0	0	0	
	30	0	0	0	0	
	31	0	0	0	0	
	32	1	0	0	1	
	33	0	0	0	0	
	34	0	0	0	0	
	35	0	0	0	0	
	36	0	0	0	0	Fish moving rapidly over strip 39 from adjacent deep pool.
	37	0	0	0	0	
	38	0	0	0	0	
	39	6	0	0	0	
	ALL	**23**	**0**	**2R,1P**	**26**	
4	1	3	0	0	3	Poor visibility into pool due to deep water (no strips crossed deep water).
	2	0	0	0	0	
	3	0	0	0	0	
	4	0	0	0	0	
	5	2	0	0	2	
	6	1	0	0	1	
	7	2	0	0	2	
	8	1	0	0	1	
	9	5	0	0	5	
	10M	0	0	0	0	
	10S	0	0	0	0	
	11M	0	0	0	0	
	11S	0	0	0	0	
	12M	1	0	0	1	
	12S	0	0	0	0	
	13M	0	0	0	0	
	13S	0	0	0	0	
	14M	6	1 R	0	7	
	14S	0	0	0	0	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
4	15	11	0	0	11	
	16	2	1 R	0	3	
	17	6	0	0	6	
	18	0	0	0	0	
	19	14	0	0	14	
	20	0	0	0	0	
	21	3	0	0	3	
	22	3	0	0	3	
	23	0	0	0	0	
	24	2	0	0	2	
	25	0	0	0	0	
	26M	1	0	0	1	
	26S	0	0	0	0	
	27M	0	0	0	0	
	27S	0	0	0	0	
	28M	0	0	0	0	
	28S	0	0	0	0	
	29M	0	0	0	0	
	29S	0	0	0	0	
	30	1	0	0	1	
	31	1	0	0	1	
	32	0	0	0	0	
	33	0	0	0	0	
	34	2	0	1 R	3	
	35	5	0	0	5	
	36	7	0	0	7	
	37	0	0	0	0	
	38	5	0	1 R	6	
	39	3	0	0	3	
	40	8	0	0	8	
	41	4	0	0	4	
	42	0	0	0	0	
	ALL	**99**	**2 R**	**2 R**	**103**	
5	1	14	0	1 R	15	
	2	0	0	0	0	
	3	6	0	0	6	
	4	4	0	1 R	5	
	5	0	0	0	0	
	6	0	0	0	0	
	7	1	0	0	1	
	8	3	0	0	3	
	9	0	0	0	0	
	10	0	0	0	0	
	11	2	0	0	2	
	12	1	0	0	1	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
5	13	1	0	0	1	
	14	4	0	0	4	
	15	0	0	0	0	
	16	2	0	0	2	
	17	1	0	0	1	
	18	7	0	1 R	8	
	19	13	0	0	13	
	20	14	0	0	14	
	21	23	0	1 R	24	
	22	5	0	0	5	
	23	3	0	1 R	4	
	24	3	0	0	3	
	25	3	0	0	3	
	26	1	0	0	1	
	27	1	0	0	1	
	28	2	0	0	2	
	29	2	0	0	2	
	30	0	0	0	0	
	31	2	0	0	2	Poor visibility available at strip 33 due to rapids.
	32	4	0	0	4	
	33	0	0	0	0	
	34	10	0	0	10	
	ALL	**132**	**0**	**5 R**	**137**	
6 Main Channel	1	1	0	0	1	
	2	1	0	0	1	
	3	3	0	0	3	
	4	1	0	0	1	
	5	1	0	0	1	
	6	3	0	1 R	4	
	7	0	0	0	0	
	8	4	0	0	4	
	9	0	0	0	0	
	10	4	0	0	4	
	11	0	0	0	0	
	12	3	0	0	3	
	13	5	0	0	5	
	14	0	0	0	0	
	15	0	0	0	0	
	16	4	0	0	4	
	17	1	0	0	1	
	18	1	0	0	1	
	19	5	0	0	5	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
6 Main Channel	23	1	0	0	1	
	24	0	0	0	0	
	25	0	0	1 R	1	
	26	5	0	0	5	
	27	0	0	0	0	
	28	1	0	0	1	
	29	9	0	0	9	
	30	1	0	0	1	
	31	2	0	0	2	
	32	5	0	0	5	
	33	0	0	0	0	
	34	4	0	0	4	
	35	2	0	0	2	
	36	1	0	0	1	
	37	7	0	1 R	8	
	38	5	0	0	5	
	39	0	0	0	0	
	40	0	0	0	0	
	41	0	0	0	0	
	42	0	0	0	0	
	43	1	0	0	1	
	44	0	0	0	0	
	45	1	0	1 R	2	
	ALL	**82**	**0**	**4 R**	**86**	
6 Side Channel	1	0	0	0	0	
	2	0	0	0	0	
	3	3	0	0	3	
	4	1	0	0	1	
	5	0	0	0	0	
	6	1	0	0	1	
	7	3	0	0	3	
	8	0	0	0	0	
	9	1	0	0	1	
	10	4	0	0	4	
	11	2	0	0	2	
	12	0	0	0	0	
	ALL	**15**	**0**	**0**	**15**	

(B) Survey of 15 November 1989 (T-5)

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
1	1	0	0	0	0	
	2	1	1 R	0	2	
	3	2	0	1 P	3	
	4	5	0	2 P	7	
	5	9	0	0	9	Excellent visibility into deep pools of lower section 1.
	6	0	0	0	0	
	7	0	1	0	1	
	8	2	0	0	2	
	9	4	0	0	4	
	10	3	1	0	4	
	11	1	0	0	1	
	12	4	0	0	4	
	13	1	1	0	2	
	14	7	0	0	7	
	15	0	0	0	0	
	16	0	0	0	0	
	17	3	0	0	3	
	18	6	0	0	6	
	19	0	0	1 P	1	
	20M	2	0	0	2	
	20S	6	0	1 P	7	
	21M	0	0	0	0	
	21S	6	0	0	6	
	22M	0	0	0	0	
	22S	4	0	1 P	5	
	23M	0	0	0	0	
	23S	5	0	0	5	
	24M	0	0	0	0	
	24S	9	0	0	9	
	25	0	0	0	0	
	26	0	0	1 P	1	
	27	1	0	0	1	
	28	0	0	0	0	
	29	0	0	0	0	
	30	1	0	0	1	
	31	0	0	1 P	1	
	ALL	**82**	**3;1R**	**8 P**	**94**	
2	1	0	0	0	0	
	2	1	0	2 P	3	
	3	3	0	0	3	
	4	0	0	0	0	
	5	0	0	1 P	1	
	6	1	1	0	2	
	7	3	0	0	3	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
2	8	5	0	0	5	
	9	3	0	0	3	
	10	1	0	0	1	
	11	1	0	0	1	
	12	0	0	0	0	
	13	0	0	0	0	
	14	0	0	0	0	
	15	0	0	0	0	
	16	0	0	0	0	
	17	0	0	0	0	
	18	0	0	0	0	
	19	0	0	0	0	
	20	0	0	0	0	
	21	1	0	0	1	
	22	1	1	0	2	
	ALL	**20**	**2**	**3 P**	**25**	
3	1	0	0	0	0	
	2	3	0	0	3	
	3	0	0	0	0	
	4	0	0	0	0	
	5	0	0	0	0	
	6	0	0	0	0	
	7	0	1	0	1	
	8	0	0	0	0	
	9	0	0	0	0	
	10	0	0	0	0	
	11	0	0	0	0	
	12	0	0	0	0	
	13	0	0	0	0	
	14	2	0	0	2	
	15	0	0	0	0	
	16	0	0	0	0	
	17	0	0	0	0	
	18	4	1	0	5	
	19	1	1	0	2	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	
	23	0	0	0	0	
	24	0	0	0	0	
	25	0	0	0	0	
	26	0	0	0	0	
	27	0	0	0	0	
	28	0	0	0	0	
	29	0	0	0	0	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
3	30	0	0	0	0	
	31	0	0	0	0	
	32	0	1	0	1	
	33	0	0	0	0	
	34	0	0	0	0	
	35	0	0	0	0	
	36	0	0	0	0	
	37	0	0	0	0	
	38	0	0	0	0	
	39	0	0	0	0	
	ALL	**10**	**4**	**0**	**14**	
4	1	0	0	0	0	
	2	2	0	0	2	
	3	0	0	0	0	
	4	0	1	0	1	
	5	4	2	0	6	
	6	4	0	1 P	5	
	7	1	2	0	3	
	8	0	0	0	0	
	9	0	1	0	1	
	10M	0	0	0	0	
	10S	2	1	0	3	
	11M	0	0	0	0	
	11S	2	0	0	2	
	12M	0	0	0	0	
	12S	2	0	0	2	
	13M	4	0	0	4	
	13S	0	2	0	2	
	14M	5	0	0	5	
	14S	2	0	0	2	
	15	11	1	0	12	
	16	7	1	1 P	9	
	17	12	0	1 P	13	
	18	8	2	0	10	
	19	7	0	1 P	8	
	20	0	3	0	3	
	21	0	0	0	0	
	22	2	0	0	2	
	23	4	0	0	4	
	24	7	0	0	7	
	25	0	0	0	0	
	26M	0	0	0	0	
	26S	4	0	1 R	5	
	27M	0	1	0	1	
	27S	7	8	0	15	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
4	28M	0	0	0	0	
	28S	0	0	0	0	
	29M	1	1	0	2	
	29S	0	1	0	1	
	30	0	0	0	0	
	31	0	0	0	0	
	32	0	0	0	0	
	33	0	0	0	0	
	34	1	0	0	1	
	35	2	4	0	6	
	36	5	0	1 R	6	
	37	6	0	0	6	
	38	9	0	0	9	
	39	5	0	0	5	
	40	6	0	0	6	
	41	8	0	0	8	
	42	4	0	0	4	
	ALL	**144**	**31**	**4P;2R**	**181**	
5	1	3	0	0	3	
	2	0	0	0	0	
	3	0	0	0	0	
	4	3	0	0	3	
	5	0	0	0	0	
	6	0	0	0	0	
	7	0	0	0	0	
	8	0	0	0	0	
	9	0	1	0	1	
	10	0	0	0	0	
	11	0	0	0	0	
	12	0	0	0	0	
	13	1	0	0	1	
	14	1	0	0	1	
	15	0	0	0	0	
	16	0	0	0	0	
	17	0	0	0	0	
	18	2	0	0	2	
	19	6	0	0	6	
	20	4	0	0	4	
	21	3	0	0	3	
	22	0	0	0	0	
	23	1	0	0	1	
	24	0	0	0	0	
	25	0	0	0	0	
	26	0	0	0	0	
	27	0	0	0	0	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
5	28	0	0	0	0	
	29	0	0	0	0	
	30	0	0	0	0	
	31	1	0	0	1	Poor visibility at strip 33 due to rapids.
	32	1	0	0	1	
	33	0	0	0	0	
	34	2	0	0	2	
	ALL	**28**	**1**	**0**	**29**	
6 Main Channel	1	0	0	0	0	
	2	0	0	0	0	
	3	0	0	0	0	
	4	1	0	0	1	
	5	0	0	0	0	
	6	1	0	0	1	
	7	0	0	0	0	
	8	0	0	0	0	
	9	0	0	0	0	
	10	0	0	0	0	
	11	0	0	0	0	
	12	0	0	0	0	
	13	1	0	0	1	
	14	0	0	0	0	
	15	2	0	0	2	
	16	0	0	1 P	1	
	17	0	0	0	0	
	18	1	0	0	1	
	19	0	0	0	0	
	20	0	0	0	0	
	21	0	0	0	0	
	22	0	0	0	0	
	23	0	0	0	0	
	24	0	0	0	0	
	25	0	0	0	0	
	26	0	0	0	0	
	27	0	0	0	0	
	28	0	0	0	0	
	29	0	0	0	0	
	30	0	0	0	0	
	31	1	0	0	1	
	32	2	0	0	2	
	33	0	0	0	0	
	34	0	0	0	0	
	35	0	0	1 R	1	
	36	1	0	0	1	
	37	4	0	0	4	

Table A-3. (continued).

Stream Section	Strip No.	Live Fish	Dead Fish	Tagged Sockeye	Total No. Observed	Comments
6 Main Channel	38	0	0	0	0	
	39	0	0	0	0	
	40	0	0	0	0	
	41	0	0	0	0	
	42	0	0	0	0	
	43	0	0	0	0	
	44	0	0	0	0	
	45	0	0	0	0	
	ALL	14	0	1R;1P	16	
6 Side Channel	1	0	0	0	0	
	2	1	1	0	2	
	3	0	0	0	0	
	4	0	0	0	0	
	5	2	0	0	2	
	6	0	0	0	0	
	7	2	0	0	2	
	8	0	0	0	0	
	9	0	0	0	0	
	10	0	0	0	0	
	11	0	0	0	0	
	12	0	0	0	0	
	ALL	5	1	0	6	

Table A-4. Determination of numbers of live-plus-dead sockeye in six survey sections of Clemens Creek from strip-count data collected on 1 and 15 November 1989. Actual section lengths were determined by multiplying the distance between strips (30 m) by the no. of strips per section. Total fish/m was determined for each section by dividing the total number of fish observed by the total number of one-meter strips surveyed. Fish numbers in each section were then calculated by multiplying the total fish/m by the total-section length. M = main channel, S = side channel, R = red tags, P = pink tags.

(A) Survey of 1 November 1989 (T-4)

Section	Length (m)	No. of Strips	No. of Sockeye Observed: Live	Dead	Tagged[a]	Total	Total Fish/m	Total Fish/ Section
1 M	930	31	58	0	18 P	76	2.45	2 279
1 S	150	5	13	0	1R; 6P	20	0.13	20
2	660	22	6	0	0	6	0.27	178
3	1 170	39	23	2 R 1 P	0	26	0.67	784
4 M	1 260	42	99	2 R	2 R	103	2.45	3 087
4 S1	150	5	0	0	0	0	0	0
4 S2	120	4	0	0	0	0	0	0
5	1 020	34	132	0	5 R	137	4.03	4 111
6 M	1 350	45	82	0	4 R	86	1.91	2 579
6 S	360	12	15	0	0	15	1.25	450
	Totals	239	428	5	36	469		13 488

Total estimate including complete counts in section 7 (5) and small side channels and tributaries (178): 13 667

Table A-4. (continued).

(B) **Survey of 15 November 1989 (T-5)**

Section	Length (m)	No. of Strips	No. of Sockeye Observed: Live	Dead	Tagged[a]	Total	Total Fish/m	Total Fish/ Section
1 M	930	31	52	3;1R	6 P	62	2.00	1 860
1 S	150	5	30	0	2 P	32	6.40	960
2	660	22	20	2	3 P	25	1.14	752
3	1 170	39	10	4	0	14	0.36	421
4 M	1 260	42	125	19	1R; 4P	149	3.55	4 473
4 S1	150	5	8	3	0	11	2.20	330
4 S2	120	4	11	9	1 R	21	5.25	630
5	1 020	34	28	1	0	29	0.85	867
6 M	1 350	45	14	0	1R; 1P	16	0.36	486
6 S	360	12	5	0	0	5	0.42	151
Totals		239	303	42	19	364		**10 930**

Total estimate including complete counts in section 7 (0) and small side channels and tributaries (951): **11 881**

[a] Data include live fish only.

Table A-5. Counts of salmonid species on the Clemens Creek and Henderson Lake spawning grounds excluding sockeye. Estimates were derived from visual surveys supplemented with information from seine catches made in section 1 and the lakeshore during tagging procedures (surveys T-2 - T-4). Fifteen unidentified jacks observed in lake section CM (near the mouth of Clemens Creek) during trip T-1, and 14 unidentified jacks observed in the same area during trip T-2, were assigned to species from the proportions of 95 jacks positively identified as chinook and coho during trip T-2. Counts include carcasses where indicated. J = jack, A = adult.

	Salmon Counts						
	T-1	T-2	T-3	T-4	T-5	T-6	T-7
Lake (CM)							
chinook (J)	11	80	0	0	0	0	0
chinook (A)	0	0	2	0	0	0	0
All chinook	11	80	2	0	0	0	0
coho (J)	4	29	0	0	0	0	0
coho (A)	0	2	5	0	0	0	0
All coho	4	31	5	0	0	0	0
chum (A)	0	0	2	0	0	0	0
Total CM	**11**	**111**	**7**	**0**	**0**	**0**	**0**
Clemens Creek							
chinook (J)	0	1	0	1	0	0	0
chinook (A)	0	0	0	4	0	0	0
All chinook	0	1	0	5	0	0	0
coho (J)	0	0	0	3	1	11[2]	2
coho (A)	0	0	1	17	195	239[3]	62
All coho	0	0	1	20	196	250	64[4]
chum (A)	0	0	11	51[1]	4	0	0
Total Creek	**0**	**1**	**12**	**76**	**200**	**250**	**64**

Table A-5. (continued).

	Salmon Counts						
	T-1	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**
Total System							
Chinook	11	81	2	5	0	0	0
Coho	4	31	6	20	196	250	64
Chum	0	0	11	51	4	0	0
All Species	**15**	**112**	**19**	**76**	**200**	**250**	**64**

[1] Includes eight carcasses and 43 live fish.
[2] Includes two carcasses and nine live jacks.
[3] Includes 23 carcasses and 216 live adults.
[4] Sections 1 - 3, 6, and 7 were not surveyed for coho.

Table A-6. Petersen Mark-Recapture estimates of escapements to Henderson Lake in 1989 based on visual recovery data for live sockeye. The spawning population was estimated by both simple and stratified Petersen methods. The three weeks of tagging are represented by the tag applications of 3, 18, and 31 October respectively. The six weeks of recovery are represented by consecutive surveys beginning on 4, 19, and 29 October, 15 and 29 November, and 6 December, when tagged and untagged sockeye were enumerated on the spawning grounds. No adjustments were made to the numbers of tagged, live sockeye observed to account for visual detection efficiencies (see text).

		Weeks of Tagging			Tagged Fish Recovered	Total Fish Recovered	
		1	2	3	(R_j)	(C_j)	C_j/R_j
Weeks of Recovery	1	260	0	0	260	851	3.27
	2	212	177	0	389	13 354	34.33
	3	96	385	644	1 125	18 041	16.04
	4	4	64	276	344	8 242	23.96
	5	0	0	4	4	455	113.75
	6	0	0	0	0	4	0
Tagged Fish Recovered (R_i)		572	626	924			
Total Tagged Sockeye (M_i)		289	737	893			
M_i/R_i		0.51	1.18	0.97			

Simple Petersen Estimate: $(\Sigma M_i \times \Sigma C_j)/\Sigma R_{ij}$ = 37 030

Ninety-five Percent Confidence Interval: +1 613, -1 539

Upper 95 % Confidence Limit = N + 1 613 = **38 643**
Lower 95 % Confidence Limit = N - 1 539 = **35 491**

Table A-6. (continued).

Stratified Petersen Estimate: 37 973

		Weeks of Tagging (i)			
		1	2	3	Total Sockeye Estimated Per Period (j)
Weeks of Recovery (j)	1	430	0	0	430
	2	3 677	7 154	0	10 831
	3	778	7 269	9 981	18 028
	4	48	1 805	6 391	8 244
	5	0	0	440	440
	6	0	0	0	0
Total Sockeye Estimated Per Period (i)		4 933	16 228	16 812	37 973

Ninety-five Percent Confidence Interval: +1 613, -1 539

Upper 95 % Confidence Limit = N +1 613 = 39 586
Lower 95 % Confidence Limit = N -1 539 = 36 434

Table A-7. Petersen Mark-Recapture estimates of escapements to Henderson Lake in 1989 based on visual recovery data for live sockeye. Adjustments were made to the numbers of tagged, live sockeye observed to account for visual detection efficiencies (see text).

		Weeks of Tagging 1	2	3	Tagged Fish Recovered (R_j)	Total Fish Recovered (C_j)	C_j/R_j
Weeks of Recovery	1	289	0	0	289	851	2.94
	2	253	248	0	501	13 354	26.65
	3	112	477	714	1 303	18 041	13.85
	4	5	79	325	409	8 242	20.15
	5	0	0	5	5	455	91.00
	6	0	0	0	0	4	0
Tagged Fish Recovered (R_i)		659	804	1 044			
Total Tagged Sockeye (M_i)		289	737	893			
M_i/R_i		0.44	0.92	0.86			

Simple Petersen Estimate: $(\Sigma M_i \times \Sigma C_j)/\Sigma R_{ij}$ = 31 343

Ninety-five Percent Confidence Interval: +1 254, -1 201

Upper 95 % Confidence Limit = N + 1 248 = 32 591
Lower 95 % Confidence Limit = N - 1 201 = 30 142

Table A-7. (continued).

Stratified Petersen Estimate: 32 075

		Weeks of Tagging (i)			
		1	2	3	Total Sockeye Estimated Per Period (j)
Weeks of Recovery (j)	1	373	0	0	373
	2	2 957	6 060	0	9 017
	3	680	6 054	8 456	15 190
	4	44	1 460	5 602	7 106
	5	0	0	389	389
	6	0	0	0	0
Total Sockeye Estimated Per Period (i)		4 054	13 574	14 447	32 075

Ninety-five Percent Confidence Interval: +1 254, -1 201

Upper 95 % Confidence Limit = N +1 254 = 33 329
Lower 95 % Confidence Limit = N -1 201 = 30 874

Table A-8. Petersen Mark-Recapture estimates of escapements to Henderson Lake, 1989 based on recovery data for sockeye carcasses. The spawning population was estimated by both simple and stratified Petersen methods. The three weeks of tagging are represented by the tag applications of 3, 18, and 31 October respectively. The five weeks of recovery are represented by consecutive surveys beginning on 18 and 29 October, 14 and 27 November, and 6 December, when dead sockeye were counted and pitched from the spawning grounds.

		Weeks of Tagging			Tagged Fish Recovered	Total Fish Recovered	
		1	2	3	(Rj)	(Cj)	Cj/Rj
Weeks of Recovery	1	0	0	0	0	13	0
	2	9	25	2	36	515	14.31
	3	15	51	109	175	3 142	17.95
	4	4	9	36	49	2 523	51.49
	5	0	1	0	1	13	13.00
Tagged Fish Recovered (R_i)		28	86	147			
Total Tagged Sockeye (M_i)		289	737	893			
M_i/R_i		10.32	8.57	6.07			

Simple Petersen Estimate: $(\Sigma M_i \times \Sigma C_j)/\Sigma R_{ij}$ = **45 630**

Ninety-five Percent Confidence Interval: +5 883, -5 210

Upper 95 % Confidence Limit = N + 5 883 = **51 513**
Lower 95 % Confidence Limit = N - 5 210 = **40 420**

Table A-8. (continued).

Stratified Petersen Estimate: 44 552

		Weeks of Tagging (i)			
		1	2	3	Total Sockeye Estimated Per Period (j)
Weeks of Recovery (j)	1	0	0	0	-
	2	1 329	3 065	174	4 568
	3	2 779	7 847	11 889	22 515
	4	2 126	3 971	11 261	17 358
	5	0	111	0	111
Total Sockeye Estimated Per Period (i)		6 234	14 994	23 324	44 552

Ninety-five Percent Confidence Interval: +5 883, -5 210

Upper 95 % Confidence Limit = N +5 883 = 50 435
Lower 95 % Confidence Limit = N -5 210 = 39 342