Chinook Salmon Escapement Estimation on the Campbell and Quinsam Rivers in 1984: Accuracy and Precision of Mark/Recapture Techniques Using Tagged Salmon Carcasses

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by

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Shardlow, T.F., T.M. Webb, and D.T. Lightly. 1986. Chinook salmon escapement estimation on the Campbell and Quinsam Rivers in 1984: accuracy and precision of mark/recapture techniques using tagged salmon carcasses. Can. Rep. Fish. Aquat. Sci. 1507: 52 p.

The chinook escapement to the Campbell and Quinsam Rivers in 1984 was estimated by using a simple carcass tagging method. Marked carcasses from the Quinsam hatchery were released on two occasions in each river and the proportion of these carcasses recovered in the dead pitch was used as an index of the effectiveness of the dead pitch. In this report, the theory behind the use of carcass tagging is examined and the expected levels of precision and the potentials for bias are assessed. Two different estimation methods are examined, one based on a Petersen approach and the other on the Schaefer method. The need for corrections for differences in the sex ratio between live sampling and dead sampling is discussed.

The escapements to the Campbell and Quinsam Rivers are estimated to be 1600 and 1385 respectively with a sex ratio of 59.7% male and 40.3% female, based on the Quinsam hatchery live sampling. It is estimated that the Quinsam hatchery contributes 50% of the escapement in the Campbell River and 58% in the Quinsam River.

RÉSUMÉ

Shardlow, T.F., T.M. Webb, and D.T. Lightly. 1986. Chinook salmon escapement estimation on the Campbell and Quinsam Rivers in 1984: accuracy and precision of mark/recapture techniques using tagged salmon carcasses. Can. Rep. Fish. Aquat. Sci. 1507: 52 p.

On a évalué la remonte de saumons quinnats dans les rivières Campbell et Quinsam en utilisant une méthode simple de marquage des carcasses. Des carcasses marquées provenant de la piscifacture de Quinsam ont été remises à l'eau à deaux reprises dans chaque rivière et la proportion de ces carcasses récupérées par rapport au nombre de poissons morts a été utilisée comme un indice de l'efficacité du dénombrement de poissons morts. Dans le présent rapport, on examine la théorie qui est derrière l'utilisation de l'étiquetage des carcasses et on évalue les niveaux escomptés de précision et les possibilités de déviation. On examine deux méthodes différentes d'estimation, l'une basée sur une approche de Peterson et l'autre sur la méthode de Schaefer. On discute de la nécessité d'apporter des corrections en ce qui concerne les différences dans le rapport des sexes entre l'échantillonnage de spécimens vivants et l'échantillonnage de spécimens morts.

On estime que la remonte dans les rivière Campbell et Quinsam est respectivement de 1600 et de 1385, le rapport des sexes étant de 59,7% de mâles et 40,3% de femelles à partir d'un échantillonnage de spécimens vivants à la piscifacture de Quinsam. On estime que la piscifacture de Quinsam contribue pour 50% de la remonte dans la rivière Campbell et pour 58% dans la rivière Quinsam.

INTRODUCTION

The development and assessment of effective management strategies for the rebuilding of chinook stocks along the west coast of British Columbia requires accurate estimates of escapement as well as estimates of the relative contributions of hatchery and natural production to that escapement. Therefore, the "key stream" program was designed as a means of monitoring escapement parameters in specific spawning areas. The chinook salmon of the Campbell/Quinsam river system have been designated as a "key" or "indicator" stock.

The purpose of this study is to estimate the size of the spawning population outside of the hatchery and to estimate the relative contribution of hatchery and wild/natural production to this escapement.

STUDY AREA

The general location of the study area is illustrated in Figure 1. The Campbell River flows northeast into Discovery Passage, just north of the city of Campbell River on Vancouver Island. The total drainage area is 1,460 km^2. Flows on the Campbell River are controlled by the John Hart Generating Station, 5.5 km from the mouth, and range from 1.2 m^3 /sec to 826.0 m^3 /sec with a mean of 96.0 m^3 /sec. Water is diverted from the Heber, Salmon, and Quinsam Rivers into Campbell River above the generating station, which is located just below Elk Falls, the upstream limit of all salmon migration.

The Quinsam River, a major tributary of the Campbell River system, drains an area of 265 km^2. The Quinsam flows north through a series of lakes to enter the Campbell River 3.8 km from its mouth. Flows range from 0.9 m^3 /sec to 21.6 m^3 /sec with mean of 9.0 m^3 /sec. The Quinsam Hatchery is located approximately 3.7 km south of the confluence of the Campbell and Quinsam Rivers. A fence is located just above the hatchery for brood stock collection.

Since 1947, estimates of chinook salmon returns to the

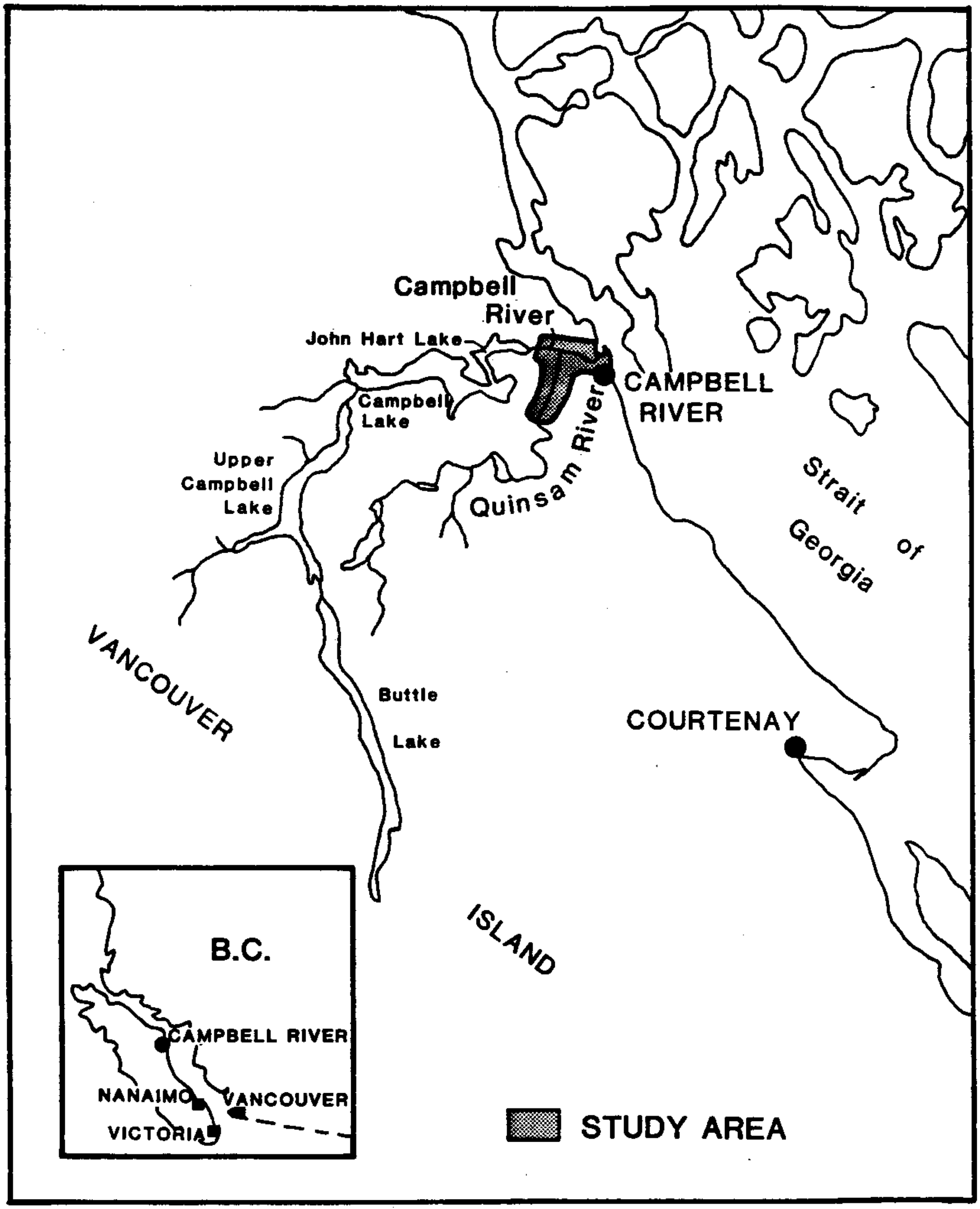

Figure 1. Location of study area.

Campbell River system have ranged from 750 to 8,000. Chinook returns to the Quinsam, negligible prior to the opening of Quinsam Hatchery in 1972, began in 1974 and estimates have averaged 1,000 - 2,000 in recent years. Approximately 27 km of the Quinsam are accessible for natural spawning but large numbers of chinooks do not normally migrate beyond the fence above the hatchery, preferring to spawn in the lower 4 km of the river.

ESTIMATION METHODS: THEORETICAL DEVELOPMENT

In this section, we briefly discuss the different methods available for the estimation of escapement, the circumstances under which each method is appropriate, and the rationale for using carcass tagging in the Campbell and Quinsam Rivers. This is followed with a more detailed analysis and discussion of methods of estimating escapement by using carcass tagging, and the levels of precision and accuracy that can be expected from tagging. A more wide ranging review of the different methods of escapement estimation and the history of the methods used for Pacific salmon can be found in Cousens et al. (1982).

There are seven major approaches to estimating the escapement of fish into a system:

1) counting live fish through a fishway or fence;
2) visual counts of live fish from observation towers and by photographic methods;
3) redd counts;
4) both complete and partial dead pitches and counts of carcasses;
5) estimates based on the tagging of live fish;
6) estimates based on the tagging of carcasses; and
7) the use of hydroacoustic equipment and electronic counters.

Fishways and fence counts generally provide the most accurate and precise estimates of escapement. This approach is often not feasible, however, due to the constraints of resources and the configuration of the river system under consideration. For example, in some systems, fences are undesirable because of a high probability that floods will wash out the fence at critical times during the run, resulting in an underestimate of unknown proportions. Other problems with using fences are the possibility of confusing species in the count of spawners and errors in detecting and recording parameters such as sex and the occurrence of adipose clips. The relative desirability of the other methods depends on the characteristics of the system, the behaviour of the fish, and the resources available.

Frequently, the second best estimation method is considered to be a Petersen estimate based on the tagging of live fish and the sampling of carcasses for the tagged to untagged ratio. For this type of estimate to work well, two main conditions must be met:

1) tag loss and mortality must either not be a problem or be of known magnitudes; and

2) either the tag application or the recovery sampling, or both, must occur proportionally across the time of the whole escapement.

For chinook salmon, there is often a problem with mortality as a result of tagging since the un-ripe fish that move into spawning areas are quite sensitive to handling. In addition, the second criterion may be difficult to fulfill for two reasons. First, if tagging on the spawning grounds must take place after the fish have separated out among areas, then it will be difficult to apply tags so that fish throughout the escapement period are represented. Second, in systems with high flushing rates, access to all carcasses may be difficult to obtain.

Redd counts and visual counts of live fish both suffer from the subjective biases of the individuals doing the counting, as well as the effects of other variables such as turbidity. Calibrating individuals in particular conditions can address some of these problems and result in useful estimates (Shardlow et al. 1986).

Partial dead counts are useful only as indexes of total escapement unless there is an estimate of the proportion of the escapement that is pitched. This proportion can be estimated either from comparisons with other, more intensive methods over a number of years or through a carcass tagging program of the type described in this report.

METHODS OF ESTIMATION USING CARCASS TAGGING

There are two basic approaches for estimating populations using mark and recovery techniques: single census (Petersen) methods, in which no time component is considered in forming the estimate, and multiple census methods such as those proposed by Schaefer (1951a and b) and the Jolly-Seber method (Ricker 1975), where the time component is explicitly recognized.

The modified Jolly-Seber method, described in detail in Webb (1986), is the most appropriate approach when there is significant effort in tag application and recovery. It requires a minimum of 5 mark and recapture episodes into the population but works more effectively with more. This method will not be considered further here because the release of tagged carcasses only occurred twice in the Quinsam and Campbell River systems.

The two methods we will consider in some detail in the Results and Discussion section are the Petersen estimate and the Schaefer estimate (Ricker 1975). For both methods, the tagged carcasses can be supplied in one of two ways:

1) carcasses can be removed from the population and marked and replaced in the normal fashion for a mark and recovery estimate; or

2) tagged carcasses can be supplied from outside the population (e.g., from hatchery broodstock).

If carcasses are supplied from outside the estimated population, then the estimates produced by either method must be corrected by subtracting the total number of tagged carcasses added to the population.

Petersen Estimate

The Petersen estimate is made by making one or more releases of tagged carcasses into the population and then carrying out sampling for both tagged and untagged carcasses throughout the whole period that carcasses are available. This approach can be thought of as a method of calibrating a dead pitch to determine the proportion of carcasses sampled. The simplest approach to forming an estimate, with tagged carcasses supplied from outside the population, is thus:

$$N = \frac{M}{R} \cdot Cu \qquad (1)$$

Where: N = Population Estimate

M = Number of tagged carcasses added to the population

R = Number of tagged carcasses recovered

Cu = Number of untagged carcasses sampled

This can be rearranged in a more regular Petersen form with a correction for carcasses added from outside the population:

$$N = \left[\frac{M \cdot C}{R}\right] - M \qquad (2)$$

Where: C = Cu + R = The total number of carcasses sampled

Two other potential methods weight the recoveries from different release times:

1) take an arithmetic mean of the recovery rates formed from each of the releases; and

2) form a weighted mean of the recovery rates from each release using the estimated abundance of carcasses at the time of release (i.e., the number of carcasses pitched) for weights.

Monte Carlo simulations (discussed below in the Precision of Estimates section) of the above three approaches indicate that none of the elaborations perform consistently better than the simple approach; therefore, we will use the simple method here (Equation 2).

Approximate 95% confidence limits for N can be found by treating R as binomially distributed and obtaining limits from a chart of binomial confidence intervals (Ricker 1975). The lower and upper limits for R can then be substituted into Equation 2 to calculate the limits of confidence for N. This method is used later in this report in the analyses of unadjusted escapement estimates based on the charts in Pearson and Hartley (1976).

The Schaefer Method

The Schaefer method is appropriate when the population maintains a certain amount of stratification in the time of availability to tagging and recovery. The method has been used for escapement estimation using live tagging as fish move upstream past a certain point and are recovered later as carcasses on the spawning grounds. The method has been used for carcass tagging estimates of chinook escapement on the Tomki River in California (Brown 1977).

The estimate is formed by summing separate estimates of the number of individuals available for tagging at each interval and recovery at each subsequent interval. The basic equation used is:

$$N = N_{ij} = \left[\frac{R_{ij} \cdot M_i \cdot C_i}{R_i \cdot R_j} \right] \qquad (3)$$

The notation remains the same with the subscript 'i' indicating the tag release periods and the subscript 'j' indicating the recovery periods.

PRECISION OF ESTIMATES

The level of precision that can be expected from these carcass tagging methods was investigated using a Monte Carlo simulation model. This model was designed to simulate the random processes involved in inflow and washout of carcasses, application of tags, and sampling for tagged and untagged carcasses. The basic structure of the model is described in more detail in Webb (1986). To cover the different situations that might be relevant to the Quinsam and Campbell rivers, the model was run with a wide range of combinations of parameters. In all runs, 17 entries (an entry being one incidence of either tagging or recovering fish) were made into the system. One entry was made every other day for a total of 35 days. On most entries, only dead pitching and tag recovery were carried out, but on some days, releases of tagged fish were also made. The parameter ranges used were:

1) either 2, 4, or 8 tag releases were made into the system;

2) the carcasses present in the system at the time of entries were sampled at rates of 10 and 30 percent;

3) tags were supplied on either carcasses obtained from the sampling (internally), or from carcasses supplied externally;

4) internal carcasses were tagged at two rates: 25 and 75 percent of the sample taken;

5) externally supplied carcasses were put into the system at two rates: either 50 or 150 per entry;

6) two patterns of sampling were used, recoveries either were or were not made on the same days as tag release; and

7) two washout rates were applied to the runs with either 10 or 30 percent of the carcasses being washed out each day.

The basic scenario for all combinations of runs started with 10 carcasses present. Then carcasses entered the system at the rate of 14 per day for the first 10 days, 82 per day for the middle 15 days and 14 per day for the last 10 days. This inflow pattern resulted in a total of 1520 carcasses entering the pool during the course of the simulation.

Figures 2 and 3 show the results of plotting the coefficient of variation of the estimates against the mean number of tags recovered for each of the two estimation methods across all combinations. In addition, a reference curve is plotted, representing the inverse of the square root of the number of tags recovered. The results from both methods approximates the reference curve, although, in general, the Petersen method gives slightly better precision (the inverse of the variance) than the Schaefer method.

As a general rule of thumb, the inverse square root of the number of tags recovered seems to be a good indicator of the coefficient of variation of the estimate for a range of mark/recovery methods (including the Jolly-Seber method, Webb 1986).

ASSUMPTIONS AND BIASES

Both estimation methods are based on a number of assumptions; when these assumptions are violated, the resulting biases must be examined because they may be considerably more significant than the errors that are due to low precision. The major assumption of both methods is that all carcasses are exposed to sampling. If a sub-population of carcasses is flushed straight through the system, however, this will result in an underestimate with any method based on carcass surveys, unless a suitable correction factor can be estimated from elsewhere. For the estimation of chinook escapement, there are two cases where this is a concern:

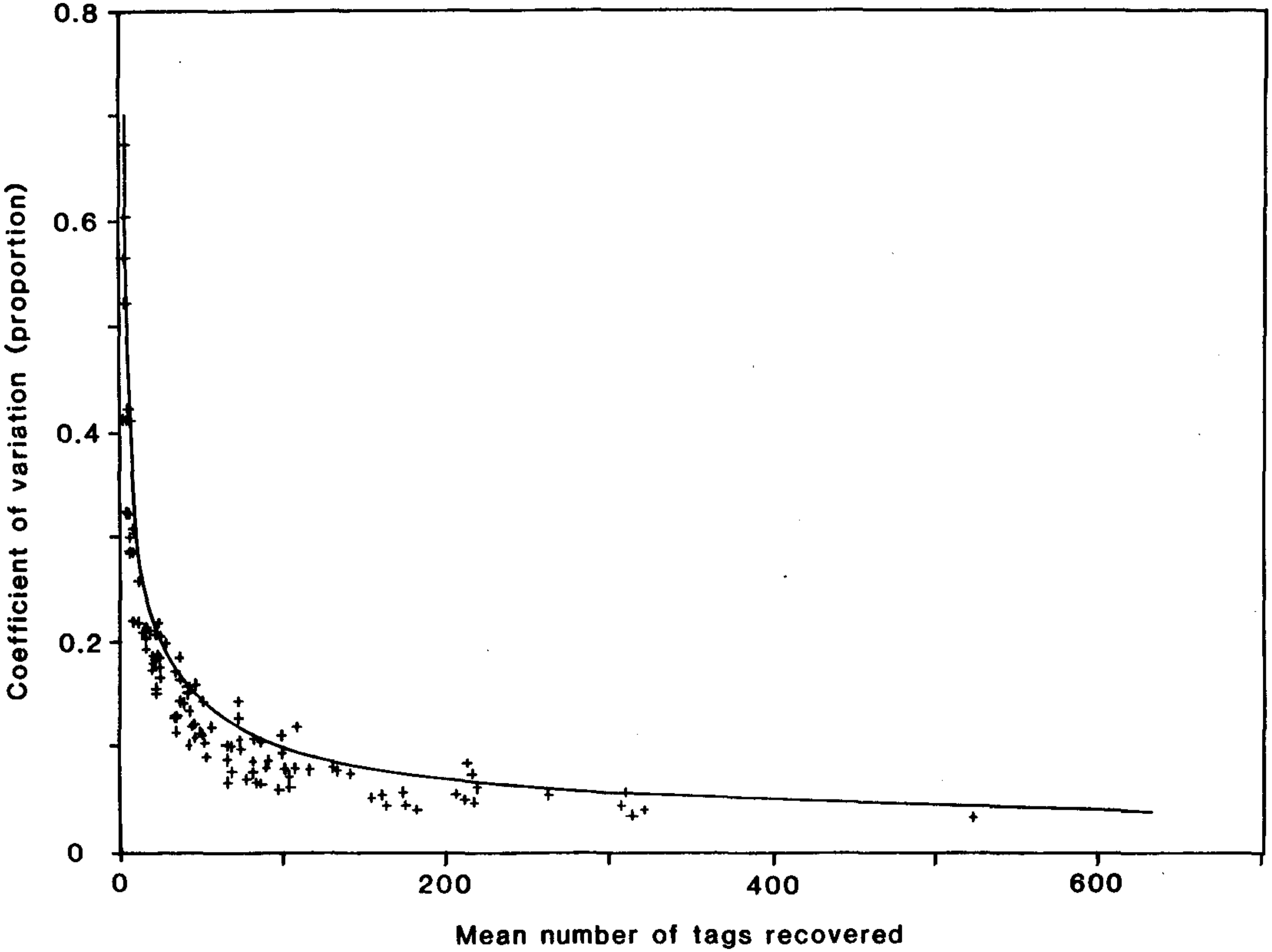

Figure 2. Plot of the coefficient of variation of estimates, derived from the Petersen method, versus the mean number of tags recovered.

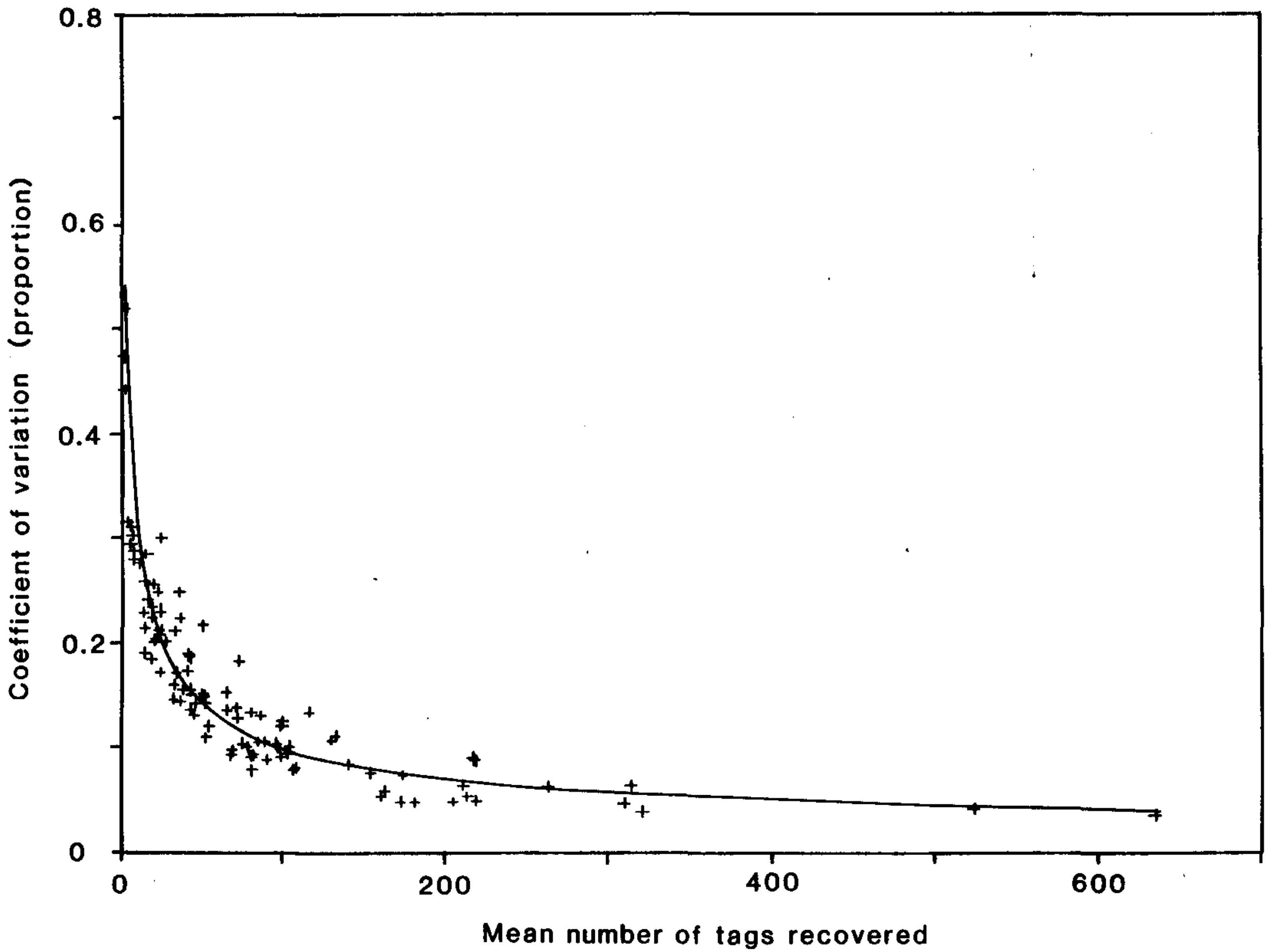

Figure 3. Plot of the coefficient of variation of estimates, derived from the Schaefer method, versus the mean number of tags recovered.

1) if carcasses from particular areas are either washed straight through the system (never moving into slower water near the banks where they are available for tagging), or get washed into deep pools where they are not available to the samplers; or

2) if certain fish (especially males) are washed out of the system in a moribund state and do not die until after they have left the study area.

The first possibility is always a concern with carcass tagging estimates and is very hard to test. The second possibility is an additional concern in the Quinsam and Campbell Rivers. Females normally hold over their eggs after spawning and tend to move into quiet water as they weaken. This behaviour makes them more recoverable than the males, which make no attempt to hold their position. A higher recoverability of females in spawning ground samples has been noted in sockeye by Petersen (1954), in pinks by Ward (1959), and in coho by Eames and Himo (1981) and Eames et al. (1981). It is highly probable that a similar bias occurs in spawning ground samples of chinook.

With the Petersen method, the whole population of carcasses must be available for dead pitching but not necessarily for tagging. If all sectors of the population are not exposed to tagging, then it is assumed that recovery rates are the same for the untagged and tagged sectors and an underestimate of the population is not necessarily automatic. With the Schaefer estimate, however, it is assumed that all sectors of the population are exposed to both tagging and recovery sampling. The estimate is formed from the sum of individuals available for tagging at 'i' and sampling at 'j'. Thus, if tagging does not occur right from the start of dieoff, then it is highly likely that the estimate will be negatively biased. This negative bias problem with the Schaefer estimate will also occur if the tag recovery rate is very low and no tags are recovered from certain releases. In this case, 'holes' will be evident in the matrix of sub-population estimates, resulting in an underestimation of the population.

An important feature of the population for the Petersen estimate is that it is not stationary but continually subjected to a loss or mortality of tagged and untagged carcasses and an influx of untagged carcasses. Consequently, the tagged ratio is continually changing over time; immediately following tagging, the rate is quite high, but as time passes until the next tag release, the ratio progressively drops. If sampling is carried out at regularly spaced intervals between tag releases, then a bias will not occur because the mean tagged ratio is still correct. If sampling is irregular, however, then the population may be either over or under estimated. The magnitude of this bias is a function of the washout rate: at high washout rates the tagged ratio varies a great deal and the potential for bias is high; at lower washout rates there is less concern.

One example of this problem with the Petersen estimate is when sampling is carried out both immediately before tagging and at evenly spaced intervals between tagging. In this example, the mean tagged ratio in the sampling is lower than the actual mean. as a result, the population will be overestimated. In the runs of the Monte Carlo model (described above), the resulting bias was approximately 10 percent with a washout rate of 10 percent per day, and 40 percent with a washout rate of 30 percent per day.

Both methods assume that tagged carcasses are basically the same as untagged carcasses. With externally supplied carcasses there is a concern that their rate of decomposition and buoyancy is different from naturally produced carcasses. With both types of tagged carcasses there is the problem of where to place carcasses in the system so they are most representative of the natural carcasses. These types of problems can give rise to biases of unknown magnitude that can only be checked by comparing these estimates with estimates formed by using different sets of assumptions (e.g., fence counts).

SELECTION OF THE MOST APPROPRIATE METHOD

From the discussion above it is clear that both the Schaefer and Petersen methods have advantages and disadvantages in different situations. If tagged carcasses were released from the start until the end of dieoff, and the dead pitch was also carried out throughout the period of carcass availability, then the Schaefer method would seem to be the best choice because it is less affected by the changing tag rate caused by washout of tagged carcasses. If, however, there are gaps in the pattern of tag releases or no recoveries from some releases, then there is a high probability that the Schaefer method will result in an underestimate. Therefore, the Petersen method is potentially the better choice.

In either case, the potential for the biases described above should be carefully considered as they can have a major effect on the accuracy of the estimate produced. If an intensive survey is proposed, then it is recommended that the Jolly-Seber approach be used in preference to either of these methods. The Jolly-Seber allows a more complete reconstruction of the pattern of dieoff and washout in addition to a more accurate assessment of some of the potential biases.

ESTIMATES OF CODED WIRE TAG ESCAPEMENT

The total escapement of chinooks marked with adipose clipped/coded wire tags (CWT) can be estimated in a similar manner to the overall escapement estimate using the Petersen method. (In this report "marked" carcasses refer to carcasses with CWT while "tagged" carcasses refer to fish with spaghetti tags applied for this study.) The number of adipose marks in the dead recovery is expanded according to the recovery rate for tagged carcasses, forming an estimate of the total escapement of marks to the system:

$$T = \frac{Rcwt}{R} \qquad (4)$$

Where: T = escapement of adipose/cwt chinooks
Rcwt = adipose/cwt chinooks in the dead recovery
r = recovery rate of carcass tags = R / M

METHODS

CARCASS TAGGING

Chinook carcasses from the Quinsam hatchery were used in the tagging study. The carcasses ranged from fresh to up to 5 days old. The male carcasses were round while the majority of the females had been cut during egg take. Many of the carcasses were frozen for up to a week prior to tagging.

Spaghetti tags, 35 cm long, were inserted through the dorsal surface near the adipose fin and tied over the back with a reef knot. Neutral colours were chosen so the tagged carcasses did not stand out from the untagged. One tag group was double tagged in an attempt to measure tag loss.

Tagged chinook carcasses were distributed in both rivers on two occasions. The guiding principle in distributing the carcasses was to place them in proportion to the natural spawning distribution. Carcasses were released into the current on or near the spawning grounds.

The number of tags and their distribution throughout the two rivers are shown in Tables 1 and 2, and Figure 4. A total of 215 tagged carcasses were released, 111 in the Campbell River and 104 in the Quinsam.

The distribution of tagged carcasses was done without the knowledge of the recovery crews. They were made aware that tagged carcasses would be distributed but not when and where they were placed, or how many to expect.

Table 1. Release dates and locations of spaghetti tagged chinook carcasses in the Campbell River in 1984. Numbers of single tagged (GREEN and GREEN/YELLOW) carcasses released for each sex are presented. Also see Figure 2 for a map of release locations.

Date	Area Released	Tag Colour	Total Release	Sex Distribution Male	Female	Jack
		GREEN				
Nov 03	Powerhouse			3	3	0
	Upper island			11	3	1
	Logging Bridge			3	3	1
	Intake Pool			7	7	3
	Highway bridge			4	3	0
	Foot of spruce			5	2	1
Subtotal			60	33	21	6
		GREEN/YELLOW				
Nov 13	Upper island			7	3	0
	Logging Bridge			11	4	0
	Intake Pool			2	3	0
	Highway bridge			7	5	3
	Foot of spruce			2	3	1
Subtotal			51	29	18	4
TOTAL			111	62	39	10

Table 2. Release dates and locations of spaghetti tagged chinook carcasses in the Quinsam River in 1984. The numbers of single tagged (GREY/GREEN) and double tagged (DOUBLE GREY) carcasses released for each sex are presented. Also see Figure 2 for a map of release locations.

Date	Area Released	Tag Colour	Total Release	Sex Distribution Male	Female	Jack
Nov 03	Fence	DOUBLE GREY		3	4	0
	Upper dyke			6	3	1
	Lower dyke			2	1	1
	Lower dyke			2	0	0
	Lower dyke			2	2	0
	Cold creek			4	4	0
	Lower park lot			4	2	0
	Washed out fence			3	1	3
	Campsite			3	0	0
	Logging bridge			3	1	0
Subtotal			54	34	18	2
Nov 13	Fence	GREY/GREEN		9	5	1
	Upper dyke			4	1	1
	Lower Dyke			5	1	0
	Cold creek			6	4	0
	Lower park lot			0	3	2
	Logging bridge			4	2	1
	Highway bridge			0	1	0
Subtotal			50	28	17	5
TOTAL			104	62	35	7

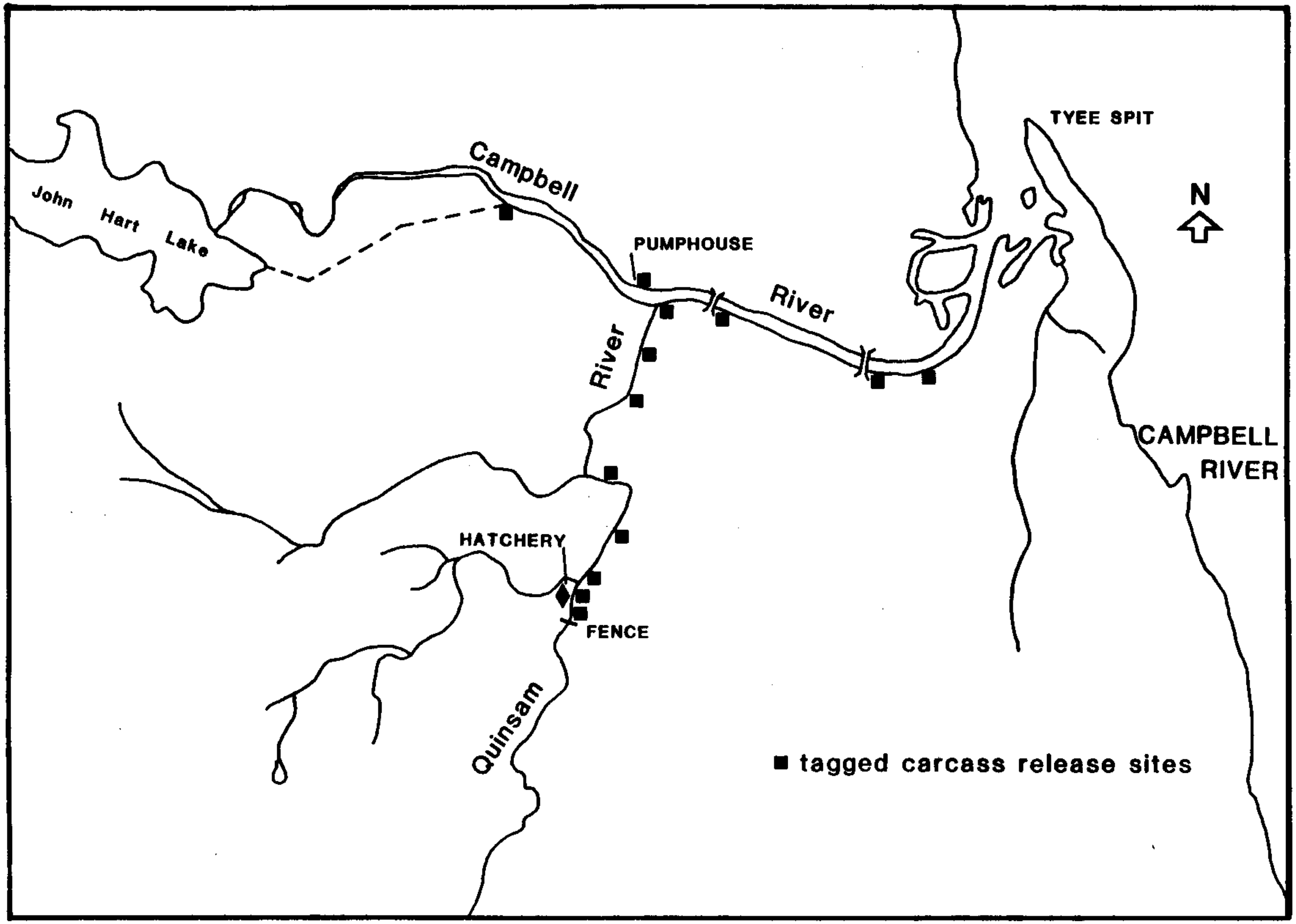

Figure 4. Tagged carcass release locations on the Campbell and Quinsam Rivers.

DEAD RECOVERY AND SAMPLING

Dead chinooks were recovered from the Campbell and Quinsam Rivers by two methods: (1) recovery crews combed the stream banks and shallow areas of the rivers; and (2) a scuba diver recovered carcasses from the lower reaches of the Campbell River and deep areas of the Quinsam River. As seen in Figure 5, the Campbell River was divided into eight recovery sections and the Quinsam into three sections.

All recovered chinook carcasses were cut in half to prevent repeat enumeration and sampling, and tags were removed from the carcasses. The following data were collected from the carcasses:

1) Sex of all chinooks (estimates made of the number of jacks, based on size).

2) Presence of carcass tags.

3) Presence of adipose marks.

4) All adipose clipped fish were sampled for length, their scales were removed, and the head was taken. Heads were removed with a cut behind the orbit, labelled with a head tag number, and frozen for later analysis. The coded wire tags were dissected and analyzed at the Quinsam hatchery.

5) Every tenth, unmarked chinook was sampled for length and scales were removed. Length measurements were from the back of the orbit to the hypural plate. Scale samples consisted of scrapings, stored in labelled plastic envelopes, that were later mounted. Scales from unmarked fish were read at the DFO scale lab in Vancouver.

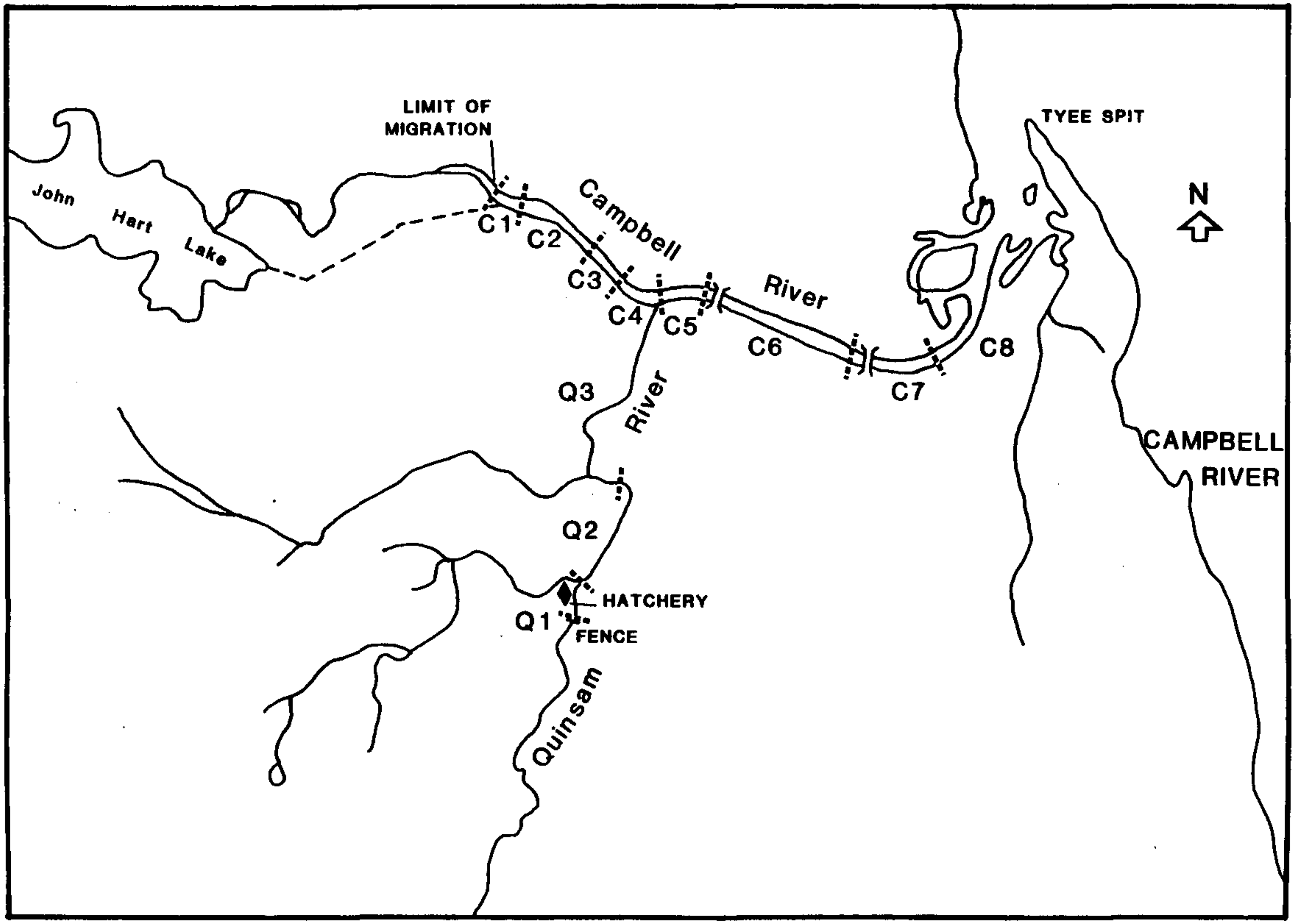

Figure 5. Recovery sections on the Campbell and Quinsam Rivers.

RESULTS AND DISCUSSION

RECOVERY OF CARCASSES

Recoveries of Spaghetti Tagged Carcasses

A total of 37 tagged carcasses were recovered from the Campbell River (Table 3) and 51 tagged carcasses from the Quinsam River (Table 4). No recoveries of tags released in the Quinsam River were made in the Campbell River. All recovered grey spaghetti tags were double, indicating no tag loss during this experiment.

The recovery rates for Campbell River carcasses are shown in Table 5 and the rates for the Quinsam River are shown in Table 6. Overall tag recovery rates were significantly higher in the Quinsam River than in the Campbell River (t-test comparing two proportions; $t = 2.20$; $p < 0.05$). Most of the difference between rivers occurred in the second recovery period (two-tailed t-test; $t = 2.50$; $p < 0.02$); recovery rates were insignificantly higher in the Quinsam for the first recovery period ($t = 0.45$; $p > 0.5$).

Within each river system, recovery rates for large male and female tagged carcasses were not significantly different (two-tailed t-tests; Quinsam: $t = 0.26$; Campbell: $t = 0.19$; $p > 0.5$ for both comparisons). In contrast, the recovery rates for jacks in each river were much lower than for large carcasses; however, sample sizes of released and recovered jack carcasses were too small to assess the significance of this difference. A discussion of the effects of these recovery rates on the escapement estimates are discussed below, after the presentation of estimates.

Recoveries of Untagged Carcasses

The recoveries of untagged carcasses from the Campbell River are presented by recovery area in Tables 7 and 8 and summarized in Table 9. For the Quinsam River, the recoveries by area are presented in Table 10 and summarized in Table 11. The numbers of carcasses with coded wire tags (marked) are also presented; these values are used later in forming

Table 3. Recovery dates and locations of spaghetti tagged carcasses in the Campbell River in 1984. Numbers are recovered tags of each colour (i.e., release date) for each sex.

Date	Recovery Area	Recovery of Green				Recovery of Yellow/Green			
		Male	Female	Jack	Total	Male	Female	Jack	Total
Nov 06	C8	0	0	1	1				
Nov 06	C4	1	3	0	4				
Nov 07	C8	1	1	0	2				
Nov 08	C8	2	1	0	3				
Nov 09	C8	1	1	0	2				
Nov 09	C4	0	1	0	1				
Nov 12	C8	1	1	0	2				
Nov 13	C6	1	0	0	1				
Nov 15	C8	2	0	0	2	2	0	0	2
Nov 15	C4					2	3	0	5
Nov 15	C6	0	1	0	1	3	1	0	4
Nov 16	C8	2	0	0	2	2	0	0	2
Nov 19	C8	0	1	0	1	0	1	0	1
Nov 19	C4					1	0	0	1
TOTAL		11	10	1	22	10	5	0	15

Table 4. Recovery dates and locations of spaghetti tagged carcasses in the Quinsam River in 1984. Numbers are recovered tags of each colour (i.e., release date) for each sex.

Date	Recovery Area	Recovery of Double/Grey				Recovery of Grey/Green			
		Male	Female	Jack	Total	Male	Female	Jack	Total
Nov 05	Q2	2	2	0	4				
Nov 05	Q3	2	1	0	3				
Nov 05	Q1	1	0	0	1				
Nov 08	Q2	4	3	0	7				
Nov 09	Q3	1	0	0	1				
Nov 12	Q2	1	1	0	2				
Nov 13	Q2	0	1	0	1				
Nov 14	Q1					5	1	0	6
Nov 14	Q2	3	0	0	3	6	1	1	8
Nov 14	Q3					3	2	0	5
Nov 15	Q2	1	0	0	1	2	3	0	5
Nov 20	Q1					0	1	0	1
Nov 20	Q2					0	1	0	1
Nov 22	Q2					1	1	0	2
TOTAL		15	8	0	23	17	10	1	28

Table 5. Recovery rates of spaghetti tagged carcasses in the Campbell River in 1984.

Tag Colour	Number Released				Number Recovered				Recovery Rate			
	M	F	J	Total	M	F	J	Total	M	F	J	Average
Green	33	21	6	60	11	10	1	22	.333	.475	.166	.367
Green/ Yellow	29	18	4	51	10	5	0	15	.345	.278	.000	.294
All	62	39	10	111	21	15	1	37	.339	.385	.100	.333

Table 6. Recovery rates of spaghetti tagged carcasses in the Quinsam River in 1984.

Tag Colour	Number Released				Number Recovered				Recovery Rate			
	M	F	J	Total	M	F	J	Total	M	F	J	Average
Double/ Grey	34	18	2	54	15	8	0	23	.441	.444	.000	.426
Grey/ Green	28	17	5	50	17	10	1	28	.607	.588	.200	.560
All	62	35	7	104	32	18	1	51	.516	.514	.143	.490

Table 7. Dead recoveries of unmarked and marked carcasses in Campbell River recovery areas above the confluence of the Quinsam River.

	Area C1						Area C2						Area C3						Area C4					
	Number Recovered			Number Marked			Number Recovered			Number Marked			Number Recovered			Number Marked			Number Recovered			Number Marked		
Date	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J
Oct 19																								
Oct 22																								
Oct 24																								
Oct 29							3	1																
Oct 30													2	7					7	3				
Oct 31													2	8					3	1				
Nov 1																								
Nov 2							2	3																
Nov 5																								
Nov 6													10	10	1	2	3	1	2	6				
Nov 7																								
Nov 8																								
Nov 9													6	11						2				
Nov 12																								
Nov 13													3	7										
Nov 15																				1				
Nov 16																								
Nov 19													5	9			1							
Nov 20							1	2																
Nov 23																								
Nov 27																								
TOTAL	0	0	0	0	0	0	6	6	0	0	0	0	28	52	1	2	4	1	12	13	0	0	0	0

Note: M = Male, F = Female, J = Jack

Area C1		Area C2		Area C3		Area C4	
Total Recovered	0	Total Recovered	12	Total Recovered	81	Total Recovered	25
Marks Recovered	0	Marks Recovered	0	Marks Recovered	7	Marks Recovered	0
Mark Rate	Ø	Mark Rate	0	Mark Rate	.09	Mark Rate	0

All areas of the Campbell River above the Quinsam:

	Male	Female	Jack	All
Total Recovered	46	71		118
Marks Recovered	2	4		7
Mark Rate	.0447	.0563	1.00	.0593

Table 8. Dead recoveries of unmarked and marked carcasses in Campbell River recovery areas below the confluence of the Quinsam River.

	Area C5						Area C6						Area C7						Area C8					
	Number Recovered			Number Marked			Number Recovered			Number Marked			Number Recovered			Number Marked			Number Recovered			Number Marked		
Date	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J
Oct 19																				1				
Oct 22																			1					
Oct 24																			9	6			1	
Oct 29																								
Oct 30																			8	6				
Oct 31																								
Nov 1																			6	6	2	3	1	
Nov 2							1	3											2	4	1			
Nov 5													7	4										
Nov 6																			16	21	1			
Nov 7																			11	31		1	2	
Nov 8																			17	29	1		4	
Nov 9							3	2											4	14			2	
Nov 12																			4	8	2			
Nov 13							5	1		1	1								10	8	1			1
Nov 15							3	3											5	10		1		
Nov 16	6	1	1	1																3	1			1
Nov 19																				1			1	
Nov 20																								
Nov 23								1											2	5				
Nov 27																			5	9				
TOTAL	6	1	1	1	0	0	12	10	0	1	1	0	7	4	0	0	0	0	100	162	9	5	11	2

Note: M = Male, F = Female, J = Jack

	Area C5		Area C6		Area C7		Area C8
Total Recovered	8	Total Recovered	22	Total Recovered	11	Total Recovered	271
Marks Recovered	1	Marks Recovered	2	Marks Recovered	0	Marks Recovered	18
Mark Rate	.13	Mark Rate	.09	Mark Rate	0	Mark Rate	.07

All areas of the Campbell River below the Quinsam:

	Male	Female	Jack	All
Total Recovered	125	177	10	312
Marks Recovered	7	12	2	21
Mark Rate	.0560	.0678	.2000	.0673

Table 9. Summary of dead recoveries in the Campbell River over all areas.

Date	Number Recovered			Number Marked		
	Male	Female	Jack	Male	Female	Jack
Oct 19	0	1	0	0	0	0
Oct 22	1	0	0	0	0	0
Oct 24	9	6	0	0	1	0
Oct 29	3	1	0	0	0	0
Oct 30	17	16	0	0	0	0
Oct 31	5	9	0	0	0	0
Nov 1	6	6	2	3	1	0
Nov 2	5	10	1	0	0	0
Nov 5	7	4	0	0	0	0
Nov 6	28	37	2	2	3	1
Nov 7	11	31	0	1	2	0
Nov 8	17	29	1	0	4	0
Nov 9	13	29	0	0	2	0
Nov 12	4	8	2	0	0	0
Nov 13	18	16	1	1	1	1
Nov 15	8	14	0	1	0	0
Nov 16	6	4	2	1	0	1
Nov 19	5	10	0	0	2	0
Nov 20	1	2	0	0	0	0
Nov 23	2	6	0	0	0	0
Nov 27	5	9	0	0	0	0
TOTAL	171	248	11	9	16	3

	Male	Female	Jack	All
Total Recovered	171	248	11	430
Marks Recovered	9	16	3	28
Mark Rate	0.0526	0.0648	0.2727	0.0651

Table 10. Dead recoveries of unmarked and marked carcasses in Quinsam River recovery areas. Numbers of recovered carcasses marked with coded wire tags are also presented.

	Area Q1						Area Q2						Area Q3					
	Number Recovered			Number Marked			Number Recovered			Number Marked			Number Recovered			Number Marked		
Date	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J	M	F	J
Oct 22	4	16		1	1													
Oct 25	8	20		1														
Oct 26	9	9																
Oct 29	2	2																
Oct 30	10	11		2	2		3	5			1							
Oct 31	31	24	2	3		1	13	14		2								
Nov 2	2	2					2	7	2									
Nov 5	1	2			1		7	17		2	2		9	10		1	2	
Nov 6	2	3			1		1	2			1							
Nov 8	7	4		1			20	35	1	1	4	1						
Nov 9													2	3				
Nov 12	6	11		1	1		6	11		1								
Nov 13							6	2	1									
Nov 14	5	4					8	10			1		4	7			1	
Nov 15	15	25	3						1			1						
Nov 16														4				
Nov 20	1	10			2		6	10					3	1				
Nov 22	3	5						1			1							
TOTAL	106	148	5	9	8	1	72	114	5	6	10	2	18	25	0	1	3	0

Note: M = Male, F = Female, J = Jack

	Area Q1	Area Q2	Area Q3
Total Recovered	259	191	43
Marks Recovered	18	18	4
Mark Rate	0.07	0.09	0.09

Table 11. Summary of dead recoveries in the Quinsam River over all areas.

Date	Number Recovered			Number Marked		
	Male	Female	Jack	Male	Female	Jack
Oct 22	4	16		1	1	
Oct 25	8	20		1		
Oct 26	9	9				
Oct 29	2	2				
Oct 30	13	16		2	3	
Oct 31	44	38	2	5		1
Nov 2	4	9	2			
Nov 5	17	29		3	5	
Nov 6	3	5			2	
Nov 8	27	39	1	2	4	1
Nov 9	2	3				
Nov 12	12	22		2	1	
Nov 13	6	2	1			
Nov 14	17	21			2	
Nov 15	15	25	4			1
Nov 16		4				
Nov 20	10	21			2	
Nov 22	3	6			1	
TOTAL	196	287	10	16	21	3

	Male	Female	Jack	All
Total Recovered	196	287	10	493
Marks Recovered	16	21	3	40
Mark Rate	0.081	0.073	0.300	0.081

estimates of the contribution of hatchery chinook to the total escapement.

ESCAPEMENT ESTIMATES

A summary of the total number of carcasses recovered in both the Campbell and Quinsam Rivers is shown in Table 12. Note that these recovery numbers do not include the recoveries of carcasses with tags. The timing of tag releases and tagged and untagged carcass recoveries form the basis for the Schaefer escapement estimates presented below.

Table 12. Summary of chinook dead recovery results from the Campbell and Quinsam Rivers in 1984.

	Male	Female	Jack	Total
Campbell River	171	248	11	430
Quinsam River	196	287	10	493

In this section we examine three estimates of escapement derived from different methods. The first is a single census Petersen estimate of total escapement based on the total recovery rates of tagged carcasses. This method provides a single estimate of the total escapement. The second is a Schaefer estimate of total escapement using the timing of tag releases and recoveries to form the estimate. The third method attempts to correct for a negative bias in the dead recovery rate of males due to the behaviour of moribund fish. This correction is applied to the tag recovery rates for male carcasses, producing separate Petersen estimates of the total escapement of each sex.

<u>Petersen Estimate of Total Escapement</u>

The Petersen estimates of the numbers of chinooks spawning in the Campbell and Quinsam Rivers, derived from Equations 1 and 2 in the theory section, are shown in Table 13. The confidence limits are derived from binomial limits as described in the theory section. In interpreting the confidence limits in this table, and in all cases where confidence limits are given, considerable care should be exercised because these calculations presume that the assumptions of the method are not violated.

Table 13. Total escapement of chinook spawning on the Campbell and Quinsam Rivers in 1984 based on a Petersen estimate using total releases and recoveries. Confidence limits were determined from tables of the binomial distribution (see text for details).

	Campbell	Quinsam
Escapement	1,290	1,005
Upper 95% limit	1,757	1,349
Lower 95% limit	876	717

Schaefer Estimate of Total Escapement

Tables 14 and 15 show the calculations for the Schaefer estimates of escapement and Table 16 summarizes the results. The confidence limits were calculated using the rule of thumb discussed in the theory section. The coefficient of variation is estimated as the inverse of the square root of the number of tags recovered.

It is clear from Tables 14 and 15 that the periods of tagging do not encompass the entire period of carcass availability and therefore, as discussed in the theory section, the estimates are almost certain to be negatively biased. Due to this problem, the Schaefer estimates will not be considered further in this paper.

Table 16. Total escapement of chinook spawning on the Campbell and Quinsam Rivers in 1984 based on a Schaefer estimate using tag release and recovery dates.

	Campbell	Quinsam
Escapement	830	764
Upper 95% limit	1,093	974
Lower 95% limit	561	554

Table 14a. Release and recovery data used in the Schaefer escapement estimates for the Campbell River in 1984. C_j includes marked carcasses.

Dates of Recovery	Date of Tagging Nov 3	Nov 13	R_j	C_j	C_j/R_j
Oct 19			0	1	——
Oct 22			0	1	——
Oct 24			0	15	——
Oct 29			0	4	——
Oct 30			0	33	——
Oct 31			0	14	——
Nov 1			0	14	——
Nov 2			0	16	——
Nov 5			0	11	——
Nov 6	5		5	72	14.40
Nov 7	2		2	44	22.00
Nov 8	3		3	50	16.67
Nov 9	3		3	45	15.00
Nov 12	2		2	16	8.00
Nov 13	1		1	36	36.00
Nov 15	3	11	14	36	2.57
Nov 16	2	2	4	16	4.00
Nov 19	1	2	3	18	6.00
Nov 20			0	3	——
Nov 23			0	8	——
Nov 27			0	14	——

			$\Sigma C_j = 467$
R_i	22	15	
M_i	60	51	$\Sigma M_i = 111$
M_i/R_i	2.73	3.40	

Table 14b. Escapement estimates for the Campbell River in 1984 based on the Schaefer method.

Dates of Recovery	Date of Tagging Nov 3	Nov 13	Total
Oct 19	0	0	0
Oct 22	0	0	0
Oct 24	0	0	0
Oct 29	0	0	0
Oct 30	0	0	0
Oct 31	0	0	0
Nov 1	0	0	0
Nov 2	0	0	0
Nov 5	0	0	0
Nov 6	196.4	0	196.4
Nov 7	120.0	0	120.0
Nov 8	136.4	0	136.4
Nov 9	122.7	0	122.7
Nov 12	43.6	0	43.6
Nov 13	98.2	0	98.2
Nov 15	21.0	96.2	117.2
Nov 16	21.8	27.2	49.0
Nov 19	16.4	40.8	57.2
Nov 20	0	0	0
Nov 23	0	0	0
Nov 27	0	0	0
Total	776.5	164.2	940.7

Actual estimate 941 -111 = 830

Table 15a. Release and recovery data used in the Schaefer escapement estimates for the Quinsam River in 1984. C_j includes marked carcasses.

Dates of Recovery	Date of Tagging Nov 3	Date of Tagging Nov 13	R_j	C_j	C_j/R_j
Oct 22			0	20	—
Oct 25			0	28	—
Oct 26			0	18	—
Oct 29			0	4	—
Oct 30			0	29	—
Oct 31			0	84	—
Nov 2			0	15	—
Nov 5	8		8	46	5.75
Nov 6			0	10	—
Nov 8	7		7	74	10.57
Nov 9	1		1	5	5.00
Nov 12	2		2	37	18.50
Nov 13	1		1	9	9.00
Nov 14	3	19	22	40	1.82
Nov 15	1	5	6	45	7.50
Nov 16			0	4	—
Nov 20		2	2	33	16.50
Nov 22		2	2	10	5.00

$\Sigma C_j = 511$

	Nov 3	Nov 13	
R_i	15	28	
M_i	54	50	$\Sigma M_i = 104$
M_i/R_i	3.60	1.79	

Table 15b. Escapement estimates for the Quinsam River in 1984 based on the Schaefer method.

Dates of Recovery	Date of Tagging Nov 3	Nov 13	Total
Oct 22	0	0	0
Oct 25	0	0	0
Oct 26	0	0	0
Oct 29	0	0	0
Oct 30	0	0	0
Oct 31	0	0	0
Nov 2	0	0	0
Nov 5	165.6	0	165.6
Nov 6	0	0	0
Nov 8	266.4	0	266.4
Nov 9	18.0	0	18.0
Nov 12	133.2	0	133.2
Nov 13	32.4	0	32.4
Nov 14	19.6	61.7	81.3
Nov 15	27.0	67.0	94.0
Nov 16	0	0	0
Nov 20	0	58.9	58.9
Nov 22	0	17.9	17.9
Total	662.2	205.5	867.7

Actual estimate 868 - 104 = 764

Petersen Estimates of Escapement of Males and Females

The spawning escapements of males, females, and jacks may be calculated separately by substituting the appropriate values for M, R, and C into the formulas for the Petersen estimates. These estimates and their confidence limits are shown in Table 17.

Table 17. Unadjusted escapement estimates for each sex in the Campbell and Quinsam Rivers in 1984 based on the Petersen method. Confidence limits were determined from tables of the binomial distribution (see text for details).

	Campbell			Quinsam		
	Males	Females	Jacks	Males	Females	Jacks
Escapement	505	645	110	380	558	70
Upper 95% limit	873	1017	4766	539	752	1745
Lower 95% limit	372	313	16	274	289	12

The total of these individual estimates gives an escapement of 1,260 chinooks for the Campbell River and 1,008 for the Quinsam, values very similar to the estimates for the sexes combined (Table 15).

While tagged male and female carcasses showed similar recovery rates in this study, the escapement estimates of males, using these recovery rates and the number of dead recoveries, are potentially biased due to the behaviour of male spawners prior to death. The differences between the behaviour of males and females on the spawning grounds were previously described in the Assumptions and Biases section. The consequences of these differences are that both spawning females and tagged carcasses "die" on or near the spawning grounds, while males may move considerable distances downstream in a moribund state. This supposition is supported by frequent observations of spent, but live, male chinooks in estuaries or adjacent inlets. Thus, it can be argued that carcass tagging best approximates the behaviour of the spawning females and will tend to result in an underestimate of the number of males. In addition, the recovery rate of carcass tagged jacks was low compared to the other two groups. The small size of jacks may make them less likely to settle to the bottom and they may be flushed from the system more readily.

The sex ratios observed in the dead recoveries and in the seining for hatchery broodstock are shown in Table 18. For the reasons outlined above, the sex ratio of chinooks seined for broodstock in the Quinsam River adjacent to the hatchery, is probably a better indication of the sex ratio of the spawning population than the dead recovery estimates.

Table 18. Sex ratios observed in the dead recoveries on the Campbell and Quinsam Rivers and in the Quinsam Hatchery broodstock.

	% Male	% Female	% Jack
Campbell dead recovery	39.7	57.7	2.6
Quinsam dead recovery	39.8	58.2	2.0
Quinsam hatchery seining	59.7	40.3	-

Using the assumptions that the hatchery sex ratio best estimates the spawning ground sex ratio, and that the carcass tag recovery rate is a good estimator of the recovery rate for spawning females, adjustments to the population estimates are possible using the following equations. We apply the female carcass tag recovery rate to the female dead recoveries to give a spawning escapement estimate for females. The number of males is then estimated using the hatchery sex ratio as follows:

$$P' = \frac{Pm}{1 - Pm} \qquad (5)$$

$$Nm = Nf\ (P') \qquad (6)$$

Where: Pm = proportion of males in the spawning population (estimated from hatchery recoveries)

Nm = escapement estimate for males

Nf = escapement estimate for females

In order to calculate the variance of the escapement estimate for females (as opposed to the confidence limits on the estimate), we used the equation (Ricker 1975):

$$\mathrm{Var(Nf)} = \frac{M^2 \cdot Cf \cdot (Cf - R)}{R^3} \qquad (7)$$

Where: Nf = escapement estimate for females

Mf = number of carcass tags applied to females

Rf = number of carcass tags recovered from females

Cf = number of females in dead pitch including tagged carcasses

The variance of the escapement estimate for males is found as follows. First, the variance of the proportion of males in the spawning population is estimated by assuming a binomial distribution and using:

$$\mathrm{Var(Pm)} = \frac{Pm\ (1 - Pm)}{n} \qquad (8)$$

Where: Pm = proportion of males in the spawning population

n = number of carcasses examined for sex

Next, the variance of P' is estimated by using the equations for the variance of ratios (Cochran 1963):

$$\mathrm{Var(P')} = \frac{\mathrm{Var(Pm)}}{(1 - Pm)^4} \qquad (9)$$

Finally, the variance of the number of spawning males can be estimated as the variance of the products of Nf and P' (using the formulas of Goodman 1960):

$$Var(Nm) = ((Nf)^2 . Var(P')) + (P'^2 . Var(Nf)) - (Var(P') . Var(Nf)) \quad (10)$$

The adjusted population estimates for both river systems using these equations are shown in Table 19 (for the Campbell) and Table 20 (for the Quinsam). The confidence limits for the total population are also calculated based on the variance for females.

Table 19. Adjusted escapement estimates for chinook spawning in the Campbell River in 1984.

	Male	Female	Total
Escapement	955	645	1600
Upper 95% limit	1484	981	2033
Lower 95% limit	427	309	1169

Table 20. Adjusted escapement estimates for chinook spawning in the Quinsam River in 1984.

	Male	Female	Total
Escapement	827	558	1385
Upper 95% limit	1246	824	1675
Lower 95% limit	407	292	1095

To summarize, we have two different estimates of the number of males in the escapement; one is based on the sex ratio in the dead pitch and one is based on the sex ratio in the hatchery. In the calculations that follow, we use the estimate based on the hatchery sex ratio because the true sex ratio will likely exhibit a preponderance of males. Nonetheless, the hatchery sex ratio is probably biased to some unknown degree and the overall estimate based on carcass tagging is subject to some unquantifiable biases (i.e., the questionable representativeness of carcasses for all sexes and the proportion of all carcasses available for dead pitch). Thus, the confidence limits shown in Tables 19 and 20 may be somewhat conservative.

AGE STRUCTURE

The results of the scale sampling from the unmarked dead recoveries in the Campbell and Quinsam are shown in Tables 21 and 22, respectively. The results of the scale sampling from the unmarked hatchery broodstock are shown in Table 23.

Using the population estimates for males, females, and jacks, and the age compositions from the dead recovery, the escapements of each age class by sex can be estimated (Tables 24 and 25). No jacks were included in the scale sample, but the estimates based on their frequency in the dead recovery are included. This separation was based on size and may include some small 3 year old fish. The confidence intervals in these tables are based on variances calculated in the following way. First, the variances on the estimates of the numbers of males and females were calculated using Equations 7 through 10 above. Then the variance of the proportion of fish in each age class was calculated using the same method as in Equation 8 above. The variances were combined using the following equation for the variance of products:

$$Var(N_{ij}) = ((N_i)^2 \cdot Var(P_{ij})) + ((P_{ij})^2 \cdot Var(N_i)) - (Var(P_{ij}) \cdot Var(N_i)) \quad (11)$$

Where: N_{ij} = escapement estimate for sex i and age j

N_i = escapement estimate for the sex i

P_{ij} = proportion of sex i in age group j

Table 21. Age composition and mean lengths of dead recoveries from the Campbell River in 1984.

	MALES			
	Number	Percent	Mean length	S.D. length
Age 2 *	2	6.4	0	0
Age 3	0	0.0	0	0
Age 4	10	32.3	729	53
Age 5	17	54.8	848	75
Age 6	2	6.5	830	14
All Ages	31	100.0	806	86

	FEMALES			
	Number	Percent	Mean length	S.D. length
Age 2	0	0.0	0	0
Age 3	0	0.0	0	0
Age 4	6	13.0	811	90
Age 5	32	69.6	847	46
Age 6	8	17.4	896	51
All Ages	46	100.0	851	58

- 15 scale samples from this location were unreadable
- scale readings indicated all fish were ocean type
- length measurements are post-orbital hypural lengths in mm

* No jacks were included in the scale samples but their contribution to the age composition is estimated based on the dead recovery results. This probably greatly underestimates their actual escapement.

Table 22. Age composition and mean lengths of dead recoveries from the Quinsam River in 1984.

	MALES			
	Number	Percent	Mean length	S.D. length
Age 2 *	3	4.8	0	0
Age 3	5	7.9	605	25
Age 4	34	54.0	715	55
Age 5	20	31.7	822	62
Age 6	1	1.6	900	0
All Ages	63	100.0	745	87
	FEMALES			
	Number	Percent	Mean length	S.D. length
Age 2	0	0.0	0	0
Age 3	0	0.0	0	0
Age 4	18	36.7	737	43
Age 5	27	55.1	816	47
Age 6	4	8.2	828	41
All Ages	49	100.0	788	59

- 15 scale samples from this location were unreadable

- scale readings indicated all fish were ocean type

- length measurements are post-orbital hypural lengths in mm

* No jacks were included in the scale samples but their contribution to the age composition is estimated based on the dead recovery results. This probably greatly underestimates their actual escapement.

Table 23. Age composition and mean lengths of unmarked chinooks from the Quinsam Hatchery holding pond in 1984.

	MALES			
	Number	Percent	Mean length	S.D. length
Age 2	0	0.0	0	0
Age 3	27	18.7	573	38
Age 4	94	65.3	727	47
Age 5	23	16.0	821	61
Age 6	0	0.0	0	0
All Ages	144	100.0	713	89
	FEMALES			
	Number	Percent	Mean length	S.D. length
Age 2	0	0.0	0	0
Age 3	0	0.0	0	0
Age 4	129	62.3	738	42
Age 5	77	37.2	818	42
Age 6	1	0.5	878	0
All Ages	207	100.0	767	58

- 69 scale samples from this location were unreadable
- scale readings indicated all fish were ocean type
- length measurements are post-orbital hypural lengths in mm

Table 24. Chinook escapement estimates by age class and sex for the Campbell River in 1984.

	Male			Female		
		95% limits			95% limits	
Age	Number	Upper	Lower	Number	Upper	Lower
2	61	101	21	0	-	-
3	0	-	-	0	-	-
4	308	483	130	84	132	36
5	523	816	230	449	684	214
6	62	102	22	112	175	50

Table 25. Chinook escapement estimates by age class and sex for the Quinsam River in 1984.

	Male			Female		
		95% limits			95% limits	
Age	Number	Upper	Lower	Number	Upper	Lower
2	40	65	15	0	-	-
3	65	103	27	0	-	-
4	447	676	218	205	305	105
5	262	399	125	307	456	160
6	13	24	2	46	70	20

CODED WIRE TAG ESCAPEMENT ESTIMATES

The recovery of adipose marked fish is summarized on the dead recovery tables (Tables 7-11). A total of 27 marks were recovered from the Campbell River and 40 from the Quinsam. The mark rates are fairly consistent throughout the recovery areas; overall mark recovery rates are not significantly different for recovered carcasses on the Campbell or the Quinsam (Campbell: 0.063; Quinsam: 0.081: $t = 1.24$; $p > 0.20$). In addition, the recovery rates of marks from the Campbell River above and below the confluence with the Quinsam are not significantly different (Campbell: 0.059; Quinsam: 0.067; t = 0.08; p > 0.5).

The estimates of the escapement of adipose clipped/coded wire tagged fish are shown below in Table 26. A tag from the 1980 brood at Puntledge Hatchery (02/19/48) was recovered on the Campbell River but was not included in this analysis. Estimates are based on the overall adjusted Petersen escapement estimates shown in Tables 19 and 20. Confidence limits were calculated using the mark rates for the two rivers (see Tables 9 and 11) and the same set of equations as for the age composition analysis above.

Table 26. Escapement estimates for adipose clipped/ coded wire tagged chinooks to the Campbell and Quinsam Rivers in 1984.

	Campbell	Quinsam
Escapement of adipose/CWT's	104	112
Upper 95% limit	147	152
Lower 95% limit	61	72

The results of the analysis of the coded wire tags recovered from the Campbell and Quinsam Rivers are in Tables 27 and 28 respectively.

To breakdown the estimate of the escapement to the two rivers into hatchery and naturally produced components, an assumption must be made about the rate of adipose clipped/coded wire tagged fish in the hatchery produced component. If we assume that marked fish return at the same rate as when they were released, these estimates can be made as follows. The estimated escapement of marks is totalled for each brood year, with tags not seen (no pin, lost pin, or lost head) assigned proportionally. The mark rate at release for the tag codes involved is then used to estimate the total return of hatchery fish from that brood year. These estimates for the Campbell and Quinsam Rivers are shown in Tables 29 and 30.

Table 27. Coded wire tag analysis from the Campbell River dead recovery.

Brood Year	Tag Code	Number Male	Number Female	Total
82	08/21/10	1	0	1
81	08/21/26	1	0	1
	08/21/30	1	0	1
	08/21/38	1	0	1
80	02/16/57	3	1	4
	02/19/43	1	1	2
79	02/17/57	0	6	6
	02/17/58	1	1	2
78	02/17/59	1	2	3
Total Readings		10	11	21
	no pin/lost pin	0	5	5
	other			1
Total		10	16	27

Table 28. Coded wire tag analysis from the Quinsam River dead recovery.

Brood Year	Tag Code	Number Male	Number Female	Total
82	08/20/57	1	0	1
	08/21/01	1	0	1
81	08/21/24	1	0	1
	08/21/35	1	0	1
	08/21/40	1	0	1
	08/21/41	1	0	1
80	02/17/57	3	3	6
	02/19/43	4	6	10
	02/19/50	1	1	2
79	02/17/57	1	5	6
	02/17/58	0	2	2
78	02/17/59	0	1	1
Total Readings		15	18	33
	no pin/lost pin	2	3	5
	other	2	0	2
Total		19	21	40

Table 29. Estimated hatchery contribution to the 1984 Campbell River chinook escapement.

Age	Percentage of Tags in Sample	Escapement of marks	Mark Rate at Release	Estimated Hatchery Contribution Number	%
2	4.7	5	0.976	5	8.1
3	14.3	14	0.930	15	-
4	28.6	29	0.131	221	56.4
5	38.1	38	0.095	400	41.2
6	14.3	14	0.093	151	86.8
TOTAL		100		792	49.6

Table 30. Estimated hatchery contribution to the 1984 Quinsam River chinook escapement.

Age	Proportion of Tags in Sample	Escapement of marks	Mark Rate at Release	Estimated Hatchery Contribution Number	%
2	6.1	7	0.986	7	17.5
3	12.1	14	0.984	14	21.5
4	54.6	61	0.137	445	68.2
5	24.2	27	0.087	310	54.4
6	3.0	3	0.115	26	44.8
TOTAL		112		802	57.4

The hatchery contribution to the Campbell River escapement is estimated at 50% of the total, based on the adjusted estimate of escapement. The total hatchery contribution to the Quinsam River escapement is estimated at 58%. These estimates, shown separately for each brood year in Tables 29 and 30, are uncertain for two reasons. First, because the number of CWT recoveries used is relatively small, the estimates may lack precision. Second, controversy exists over which mark rate is appropriate for estimating the hatchery contribution to escapement. If the adipose clipped/coded wire tagged chinooks are returning at a lower rate than their unmarked broodmates, then the above method will underestimate hatchery contribution to the overall escapement.

SUMMARY AND CONCLUSIONS

This report has outlined the methods that were used to estimate the chinook salmon escapement to the Campbell and Quinsam Rivers in 1984. The results represent our best estimate of the escapement and hatchery contribution based on the available data. Nonetheless, there are a number of potential biases that cannot be quantified at present. These biases include questions such as:

1) are all carcasses available for sampling or is some proportion rapidly washed out of the system and therefore not included in the estimate;

2) are the tagged carcasses representative of the untagged carcasses that die naturally in the system;

3) what is the appropriate mark rate to use in estimating hatchery contribution to the escapement; and

4) what is the best sex ratio to use in forming the overall estimates of escapement.

These questions represent a serious problem when any carcass tagging method is used for estimating escapement. As in the present case, however, the alternatives may not be any better. In order to make this method more useful and the estimates more defensible, the methods should be assessed in situations where the estimates produced can be checked against other well tested methods.

Given the remaining potentials for bias, the estimates produced for these two rivers in 1984 are:

- the escapements for the Campbell and Quinsam Rivers are estimated to be 1600 and 1385 respectively;

- the best estimate of the sex ratio is that seen at the hatchery, 59.7% males and 40.3% females;
- the contribution of hatchery fish to the escapement in the Campbell and Quinsam systems is estimated to be 50% and 58% respectively;
- in the Campbell River the predominant age classes for males were 4 and 5 (32% and 55%) and for females 5 (70%);
- in the Quinsam River the predominant age classes for males were 4 and 5 (54% and 32%) and for females 4 and 5 (37% and 55%).

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