# KWINIUK RIVER SALMON COUNTING TOWER PROJECT REVIEW AND VARIANCE ESTIMATION

By:

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## ABSTRACT

This report 1) documents historical evolution of Kwiniuk River Tower escapement counting methodologies and total escapement estimation methodologies, 2) standardizes estimation methodologies for missing counts and total escapements, and 3) estimates variance of Kwiniuk River Tower escapement counts for chum salmon *Oncorhynchus keta*, pink salmon *Oncorhynchus gorbuscha*, chinook salmon *Oncorhynchus tshawytscha*, and sockeye salmon *Oncorhynchus nerka*. Range of coefficient of variation was 1-11 % (median 2%) for chum salmon, 1-33% (median 1.5%) for pink salmon, 2-4% (median 3.5%) for coho salmon, and 4-18% (median 6%) for chinook salmon. These estimates were consistent with presumed coefficient of variation, 10%.



**KEY WORDS:** Kwiniuk River Tower escapement, variance, chum salmon, *Oncorhynchus keta*, pink salmon, *Oncorhynchus gorbuscha*, chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon, *Oncorhynchus nerka*.

## INTRODUCTION

Kwiniuk River is located just east of Moses Point village, approximately 100 miles east of Nome. The river flows generally in a northeast direction for about 45 miles and in a southern direction for approximately 10 miles before draining into Norton Bay. Most of the river passes through a spruce forest area except for the lower 5 miles, which flows through flat tundra terrain. Kwiniuk River and Tubutulik River are the primary salmon spawning tributaries in Sub-district 3, often referred to as the Moses Point Subdistrict. Commercial salmon fishing has ocurred in the subdistrict since 1962.

Since 1965 the Alaska Department of Fish and Game has been operating a salmon counting tower on the Kwiniuk River (Bachelder 1978, Bue and Lean 1989, Bue and Merkouris 1988, Cunningham 1973, 1974, 1975, Geiger 1965, 1966, 1967, 1968, Lean 1981, 1982, 1985, 1989, 1990, 1994a, 1994b, 1994c, Lean and Merkouris 1987, Lebida 1969, Hurd 1970, 1971, Kohler 2000, Kohler and Knuepfer 2001, Kuhlman 1976, 1977, 1979, Rob 1996, 1997, 1998, 1999, Schaefer 1980, Trasky 1972). Objectives of the project are to obtain timely and accurate salmon escapement information including: 1) daily and seasonal estimates of the timing and magnitude of the salmon escapement by species, and 2) age, sex, and length (ASL) information. While daily and seasonal estimates of the salmon escapement have been reported in the past, no variance of these estimates has been reported.

Estimation of variance became highly significant in the light of determining biological escapement goals (BEG) for the Kwiniuk River and Tubutulik River chum salmon stocks (Clark 2001). Lack of variance estimates would cause underestimating the uncertainty of the BEG (Clark 2001). Clark (2001) assumed the coefficient of variation (CV) of tower counts would be less than 10 %.

The objective of this study is to estimate variance for historical daily and seasonal escapement estimates.

## VARIANCE ESTIMATION METHODS

Since initiation of the project, tower counting survey estimation methods of total run and missing counts methodologies have evolved. Before making variance estimates, past survey and total escapement estimation methodologies were documented, accuracies of archival count records were re-evaluated, and methodology of missing counts was standardized.

For methodology of estimating variance, the author adopted a simple random sample variance estimation method. The tower counting survey is considered a variation of systematic sampling, in which each sample (i.e., escapement) is collected consecutively at even intervals (e.g., every hour). Because the systematic sampling is a non-random sampling method, application of a simple random sample variance estimator to samples obtained by systematic sampling methods tends to provide a biased estimate. This bias is zero when magnitudes of sample elements (i.e., escapement) are in random order, positive when the magnitudes are ordered (e.g., increasing or decreasing trend) or cyclical (Scheaffer et al 1990). Kwiniuk River escapement counts tend to be cyclical, therefore application of a simple random sample variance estimator tends to provide a larger than actual variance estimate. The author considers overestimation of variance acceptable considering other uncounted errors are not included (e.g., measurement errors).

**Evolution of survey sampling methodologies, and total escapement and variance estimator (Tables 1, 2, 3)**

**1965-1969**

During the period 1965-1969, the run was counted continuously 60 minutes/hour for 24 hours.

Total run $T$ was enumerated as

$$T = \sum_{i} \sum_{j=0}^{23} C_{ij} \qquad (1)$$

where $C_{ij}$ is total number of fish counted during $j$-th hour period of $i$-th day.

Because all the run was counted, there was no variance estimation. Variance $\hat{V}(T) = 0$

**1970-1980**

During the period 1970-1980, the run was counted continuously 60 minutes/hour for 18 hours from 12:00 p.m. to 5:59 a.m. of the next day.

Total run $E[T]$ estimate is calculated as

$$E[T] = \sum_{i} \left( (1+\alpha) \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right) = (1+\alpha) \sum_{i} \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \qquad (2)$$

where $\alpha$ is "The average escapement for the hours from 6 a.m. until 12 noon for the years 1965-1969 was 2.1 percent (*i.e., $\alpha$=0.021*) of the total escapement for chums and 3.66 percent (*i.e., $\alpha$=0.0366*) for pink salmon." (Hurd 1970, 15). However, it was unclear how the number was calculated.

In this revision: $\alpha$ was estimated as

$$\alpha = \frac{\sum_{y=1965}^{1969} \sum_{i} \sum_{j=6}^{11} C_{yij}}{\sum_{y=1965}^{1969} \sum_{i} \sum_{j=0}^{23} C_{yij}} \tag{3}$$

with variance

$$\hat{V}[\alpha] = \left(\frac{1}{4}\right) \sum_{y=1965}^{1969} \left( \frac{\sum_{i} \sum_{j=6}^{11} C_{yij}}{\sum_{i} \sum_{j=0}^{5} \sum_{j=12}^{23} C_{yij}} - \alpha \right)^2 \tag{4}$$

Total run variance was estimated as

$$\hat{V}[T] = \hat{V}[\alpha] \left( \sum_{i} \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right)^2 \tag{5}$$

Based on re-constructed original data, $\alpha$ was estimated $\alpha$=0.0288 for chum salmon and $\alpha$=0.0377 for pink salmon, which was close to the reported values $\alpha$=0.021 and $\alpha$=*0.0366*, respectively.

### 1981-1986 periods

During the period1981-1987, the run was counted 60 minutes/hour for 18 hours from 12:00 p.m. to 5:59 a.m. of the next day, and once a week the run was counted 60 minutes/hour for 24 hours.

Instead of fixed α used in 1970-1980 studies, weekly $\alpha_i$ was estimated from the 24-hour counts.

$$\alpha_i = \frac{\sum_{j=6}^{11} C_{ij}}{\sum_{j=0}^{5} \sum_{j=6}^{23} C_{ij}} \tag{6}$$

This $\alpha_i$ was used for estimation of ± 3 days of the run counts, and total run $E[T]$ was calculated as

$$E[T] = \sum_i \left( (1+\alpha_i) \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right) \tag{7}$$

While this estimation method works reasonably well, this method faced some estimation difficulties. For instance, $\alpha_i$ is not estimable when no fish passed the tower during the weekly 24-hour count or when fish migrated only during the 6:00 am-12:00pm period. Also, $\alpha_i$ is estimated negative when more fish migrated down stream during 6:00 am-12:00pm period. Thus, instead of using $\alpha_i$, the author recommends using grand mean $\alpha$ calculated as

$$E[\alpha] = \frac{\sum_i \sum_{j=6}^{11} C_{ij}}{\sum_i \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij}} \tag{8}$$

with variance

$$\hat{V}[\alpha] = \left( \frac{1}{n_i - 1} \right) \sum_i^{n_i} (\alpha_i - E[\alpha])^2 \tag{9}$$

where $i$-th days excludes days when $\alpha_i < 0$ or $\alpha_i$ is not estimable

The total passage estimate was calculated as:

$$E[T] = \sum_i \left( (1+E[\alpha]) \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right) \tag{10}$$

$$\hat{V}[T] = \hat{V}[\alpha] \left( \sum_i \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right)^2 \tag{11}$$

**1987-1993**

During the period 1987-1993, run counting minutes were reduced from 60 minutes to 30 minutes per hour, while the weekly 24-hour count remained 60 minutes per hour. Further, a weekly day off (usually Monday) was introduced (Scheaffer, *et al.* 1990), and passage for the day off was estimated as an average of previous and following days.

Daily estimates of total counts $E[t_i]$ was estimated as

$$E[t_i] = 2 \cdot (1+\alpha_i) \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij} \tag{12}$$

where $c_{ij}$ is 30 minutes/hour passage count.

Total estimate was calculated as:

$$E[T] = \sum_i E[t_i] \tag{13}$$

For the same reason stated in the previous period, instead of using individual $\alpha_i$, the author recommends using grand mean $\alpha$ calculated as

$$E[\alpha] = \frac{\sum_i \sum_{j=6}^{11} c_{ij}}{\sum_i \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}}$$

with variance

$$\hat{V}[\alpha] = \left(\frac{1}{n_i - 1}\right) \sum_i^{n_i} (\alpha_i - E[\alpha])^2$$

where $i$-th days excludes days when $\alpha_i < 0$ or $\alpha_i$ is not estimable

Variance of daily passage estimate during the 18 hours was calculated as

$$\hat{V}'[t_i] = N_i^2 \left(\frac{N_i - n_i}{N_i}\right)\left(\frac{S^2}{n_i}\right) \tag{14}$$

$$S^2 = \frac{\sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}^2 - \frac{1}{n_i}\left(\sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}\right)^2}{n_i - 1}$$

where
$N_i$ = potential number of 30-minute counts in 18 hours = 36.
$n_i$ = number of 30-minute counts conducted in 18 hours.

Using Goodman's (1960) variance formula, daily passage variance is calculated as

$$\hat{V}[t_i] = \hat{V}'[t_i] + (E'[t_i])^2 \hat{V}[\alpha] + (E[\alpha])^2 \hat{V}'[t_i] - \hat{V}[\alpha]\hat{V}'[t_i] \tag{15}$$

where

$$E'[t_i] = 2 \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}$$

Note: $\hat{V}[t_i] = 0$ for weekly 24-hour counts.

Seasonal total run estimate $E[T]$ is

$$E[T] = 2\sum_i \left( (1 + E[\alpha]) \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij} \right) \tag{16}$$

with variance

$$\hat{V}[T] = \sum_i \hat{V}[t_i] \tag{17}$$

**1994-present**

Since 1994, weekly 24-hour counts were also reduced from 60 minutes per hour to 30 minutes per hour. Thus, $\alpha_i$ was estimated as

$$\alpha_i = \frac{\sum_{j=6}^{11} c_{ij}}{\sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}} \tag{18}$$

with daily run estimate as

$$E[t_i] = \left( \frac{N_i}{n_i} \right) \cdot (1 + \alpha_i) \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij} \tag{19}$$

where

$N_i$ = potential number of 30-minute counts in 18 hours = 36.

$n_i$ = number of 30-minute counts conducted in 18 hours.

In the revision, instead of using individual $\alpha_i$, the author recommends using grand mean $\alpha$ calculated as

$$E[\alpha] = \frac{\sum_i \sum_{j=6}^{11} c_{ij}}{\sum_i \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}} \tag{20}$$

with variance

$$\hat{V}[\alpha] = \left(\frac{1}{n_i - 1}\right)\sum_{i}^{n_i}(\alpha_i - E[\alpha])^2$$

where $i$-th days excludes days when $\alpha_i < 0$ or $\alpha_i$ is not estimable

Daily total estimate is calculated as

$$E[t_i] = \left(\frac{N_i}{n_i}\right) \cdot (1 + E[\alpha])\sum_{j=0}^{5}\sum_{j=12}^{23} c_{ij} \quad (21)$$

with variance

$$\hat{V}[t_i] = \hat{V}'[t_i] + (E'[t_i])^2\hat{V}[\alpha\ ] + (E[\alpha_i])^2\hat{V}'[t_i] - \hat{V}[\alpha\ ]\hat{V}'[t_i]$$

where

$$E'[t_i] = \left(\frac{N_i}{n_i}\right) \cdot \sum_{j=0}^{5}\sum_{j=12}^{23} c_{ij}$$

$$\hat{V}'[t_i] = N_i^2\left(\frac{N_i - n_i}{N_i}\right)\left(\frac{S^2}{n_i}\right)$$

$$S^2 = \frac{\sum_{j=0}^{5}\sum_{j=6}^{23} c_{ij}^2 - \frac{1}{n_i}\left(\sum_{j=0}^{5}\sum_{j=6}^{23} c_{ij}\right)^2}{n_i - 1}$$

$N_i$ = potential number of 30-minute counts in 18 hours = 36.
$n_i$ = number of 30-minute counts conducted in 18 hours.

for 24 hour count dates

$$S^2 = \frac{\sum_{j=0}^{23} c_{ij}^2 - \frac{1}{n_i}\left(\sum_{j=0}^{23} c_{ij}\right)^2}{n_i - 1}$$

Seasonal passage and variance estimates are the same as 1987-1993.

## Missing Counts and Expansion Methods

During the survey period, some counts were missed (Table 4), though reports did not include causes of missing counts. Those missing counts consisted of single hour periods, consecutive hour periods, and days. Starting time of the first day counts used to be at 0:00; however, it was moved to 12:00 pm in recent years. In some years, the missing counts between 0:00-11:00 were estimated from aerial survey, but in other years, no estimations were made. Similarly, in some years, estimation methodology of the missing counts was reported, while in other years, no description was available. Despite attempts to locate the original field notes for the 1970s and 1980s, none were found. Those were deemed lost because of the flood.

Following is a list of correction methodologies described in the reports.

1965-1977:

No missing counts correction methodology was recorded.

1978: (Bachelder 1978)

In an effort to better estimate the number of salmon that may have passed the tower prior to July 4, the following determinations were made:

1. Individual missing counts were expanded by averaging the last complete hourly count with the next complete hourly count.

2. If several consecutive counts were missing, they were expanded by using hourly migration figures from Tables 2 and 3.

These calculations indicate an adjusted total of 10,957 and 69,719 chum and pink salmon migrated past the tower between 7/4 and 7/22 (Table 4). Expanded escapements totaled 11,187 chum and 72,270 pink salmon (Appendix Tables 2 and 3).

Daily salmon migration totals for 1965-1977 were plotted against 1978 tables in an effort to determine the proportion of fish that may have passed the tower before and after counting operations were conducted (Figures 4 and 5: *Missing from the report* Hamazaki). Chum salmon escapements appear to have peaked about two days earlier than average. Approximately 25-35% of the chum salmon escapement may have passed the tower prior to 7/4, while only 2-3% migrated upstream after 7/22 (Table 5). This results in a total chum salmon escapement range estimate of 13,696-15120 fish and point estimate of 14,408 fish. Virtually all the early pink salmon escapement appears to have been counted, but about 9% of the escapement may not have been estimated after 7/22. This results in a total pink salmon escapement estimate of 75,993 fish.

1979: (Kuhlman 1979)

In an effort to determine the number of fish not counted before 7/8 and after 7/22, daily counts were expanded:

1. Individual missing counts were expanded by averaging the last complete hourly count with the next complete hourly count.

2. If several consecutive counts were missing, they were expanded by using hourly migration figures from Tables 2 and 3.

1980: (Schaefer 1980)

Counts were adjusted to account for missed hours using two nearest complete sample days.

(i.e., $E[t_{ji}]$ was estimated by averaging the counts of ± 1or 2 days. $E[t_{ji}] = \frac{1}{2}(E[t_{ji-1}] + E[t_{ji+1}])$

1983: (Lean 1983)

Counts were adjusted to account for missed hours using two nearest complete sample hours(?). Counts were adjusted to account for missed half hours using previous half hour multiplied by 2.

1984-6:

Expanded counts in this report were calculated by first assigning a value for all missed hours during the standard 18 hour count. This was done by finding the mean of the two nearest daily counts of the missing time block. If more than one hour was missing, then an equal number of hours on either side of the missing block was used to find a mean for the missing block.

1989: (Bue and Lean 1989)

6/30: Expanded daily total derived from both aerial survey and hourly expansion. On July 3, counts from 1600 to 24000 = 63% of the total day resulting in an estimated count of 140 chum. The aerial survey counted 2178 chum before 1200, therefore the daily total = 140+2178 = 2318.

7/01: Expanded daily total derived by estimating the missing time block. On July 3 counts from 0000 to 2100 = 88% of the daily total, therefore, the actual count of 367 divided by 12% = 3133.

7/02: Expanded daily total derived by estimating the missing time block. On July 3 counts from 0000 to 1500 = 37% of the daily total, therefore, the actual count of 134 divided by 63% = 213.

1990: (Lean 1990)

Additional expansion was necessary to estimate missed time blocks during the initial tower set up. Fish passage was estimated by first identifying the time block during the closest 24-our count that corresponded with the counted period during the partial day. The percent of fish counted during that period of the daily total was calculated, and expansion for the partial count day was made accordingly.

1994 : (Rob 1996)

Counts adjusted to account for missed hours using two nearest complete sample days.
(i.e., $E[t_{ji}]$ was estimated by averaging the counts of ± 1or 2 days.
$E[t_{ji}] = \frac{1}{2}(E[t_{ji-1}] + E[t_{ji+1}])$

1995: (Rob 1996)

Count adjusted at 1100 hours 6/22 by aerial survey. Previous counts omitted in totals.
Counts adjusted to account for missed hours using two nearest complete sample days.
(i.e., $E[t_{ji}]$ was estimated by averaging the counts of ± 1or 2 days.
$E[t_{ji}] = \frac{1}{2}(E[t_{ji-1}] + E[t_{ji+1}])$

1996: (Rob 1997)

Aerial survey counts above the tower.
Counts adjusted to account for missed hours using two nearest complete sample days.
(i.e., $E[t_{ji}]$ was estimated by averaging the counts of ± 1or 2 days.
$E[t_{ji}] = \frac{1}{2}(E[t_{ji-1}] + E[t_{ji+1}])$

1997-:

No expansions on the first day counts.
Counts adjusted to account for missed hours using two nearest complete sample days.
(i.e., $E[t_{ji}]$ was estimated by averaging the counts of ± 1or 2 days.
$E[t_{ji}] = \frac{1}{2}(E[t_{ji-1}] + E[t_{ji+1}])$

In this revision the following procedure was adopted:

Missing day counts was estimated as an average of previous and following day counts:

$$E[t_{ji}] = \frac{1}{2}(E[t_{\text{[illegible]}}] + E[t_{ji+1}])$$

Counts of missing hours of a partial day counts were estimated by multiplying the partial day counts with the seasonal ratio of the count of the missing hours to the count of the partial day counts.

$$\hat{E}[c_{ji}] = \frac{\sum_j c_{ji} \cdot \sum_i c_{ji}}{\sum_j \sum_i c_{ji}}$$

where

$\sum_j c_{ji}$ : total run counts of the i-th period throughout season

$\sum_i c_{ji}$ : partial day run counts of the j-th day.

$\sum_j \sum_i c_{ji}$ : total partial day run counts throughout season.

## RESULTS AND DISCUSSION

Median CV was 0.02 for chum salmon, 0.015 for pink salmon, 0.035 for coho salmon, and 0.06 for chinook salmon (Table 5). This translates to a 95% Confidence Interval of approximately ± 3-12% of the total passage estimate, which is consistent with Clark's (2001) contention that CV is about 10 %.

While $\alpha = 0.021$ for chum salmon and $\alpha = 0.0366$ for pink salmon were used during 1970-1980, recalculations of $\alpha$ from the original 1965-1969 data produced $\alpha = 0.0273$ for chum salmon and $\alpha = 0.0294$ for pink salmon. Thus, runs for 1970-1980 were recalculated using the new $\alpha$ values.

The numbers also slightly differ from the ones previously reported (Bachelder 1978, Bue and Lean 1989, Bue and Merkouris 1988, Cunningham 1973, 1974, 1975, Geiger 1965, 1966, 1967, 1968, Lean 1981, 1982, 1985, 1989, 1990, 1994a, 1994b, 1994c, Lean and Merkouris 1987, Lebida 1969, Hurd 1970, 1971, Kohler 2000, Kohler and Knuefer 2001, Kuhlman 1976, 1977, 1979, Rob 1996, 1997, 1998, 1999, Schaefer 1980, Trasky 1972). This difference is because the presented numbers standardized the missing data calculations and corrected calculation/transcription errors found in the previous reports.

Review of historical data and reports revealed that the authors often omitted any description about the survey conditions, reasons for missing tower counts, and distinction between zero (0) and missing tower counts (especially during 1970s and 1980s). Original field notes and data from those years were not located and are assumed to be lost during the flood suffered at the Nome office. Future reports should include a description of the survey conditions and reasons for missing tower counts. Inclusion of detailed information about survey conditions would be of significant value for later analyses.

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Table 1: Evolution of Kwiniuk River Tower counting methodology.

| Years | Survey Hours | Hourly Counting Minutes | Day off | 24 hours count | Species Counted/Reported |
|---|---|---|---|---|---|
| 1965-1969 | 24 hours<br>First Day Starting time:<br>0:00 | 60min | None | N/A | Chum salmon,<br>Pink salmon,<br>Chinook salmon |
| 1970-1980 | 18 hours 12:00 - 05:59<br>First Day Starting time:<br>0:00 (1970-1979),<br>12:00 (1980) | 60min | None | None | Chum salmon,<br>Pink salmon |
| 1981-1986 | 18 hours 12:00 - 05:59<br>First Day Starting time:<br>12:00 | 60min | None | 1/week | Chum salmon,<br>Pink salmon,<br>Chinook salmon (1985-86) |
| 1987-1993 | 18 hours 12:00 - 05:59<br>First Day Starting time:<br>12:00<br>0:00 (1988) | 30 min. | 1/week | 1/week<br>60min/hour | Chum salmon,<br>Pink salmon,<br>Chinook salmon,<br>Coho salmon (1989) |
| 1994-present | 18 hours 12:00 - 05:59<br>First Day Starting time:<br>12:00<br>0:00 (1996-98) | 30 min. | 1/week | 1/week<br>30min/hour | Chum salmon,<br>Pink salmon,<br>Chinook salmon,<br>Coho salmon (1994-1996) |

Table 2: Evolution of total escapement count methodology

| Years | Estimation Methodology |
|---|---|
| 1965-1969 | $E(T)=\sum_i \sum_j C_{ij}$ |
| 1970-1980 | $E(T)=\sum_i \left( (1+\alpha)\cdot \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right)$ ($\alpha = 0.021$ for chum salmon, $\alpha = 0.0366$ pink salmon). |
| 1981-1986 | $E(T)=\sum_i \left( (1+\alpha_i)\cdot \sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij} \right) \quad \alpha_i = \frac{\sum_{j=6}^{11} C_{ij}}{\sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij}}$ |
| 1987-1993 | $E(T)=2\cdot \sum_i \left( (1+\alpha_i) \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij} \right) \quad \alpha_i = \frac{\sum_{j=6}^{11} C_{ij}}{\sum_{j=0}^{5} \sum_{j=12}^{23} C_{ij}}$ |
| 1994-present | $E(T)=2\cdot \sum_i \left( (1+\alpha_i) \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij} \right) \quad \alpha_i = \frac{\sum_{j=6}^{11} c_{ij}}{\sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}}$ |

Table 3: Revised total and variance estimating methodology

| Years | Estimation Methodology |
|---|---|
| 1965-1969 | $E(T)=\sum_i\sum_j C_{ij}$ <br> $\hat{V}[T]=0$ (24/7 whole hour counts) |
| 1970-1980 | $E(T)=\sum_i\left((1+\alpha)\cdot\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}\right)$ <br> $\hat{V}[T]=\hat{V}[\alpha]\left(\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}\right)^2$ $\hat{V}[\alpha]=\left(\frac{1}{4}\right)\sum_{y=1965}^{1969}\left(\frac{\sum_i\sum_{j=6}^{11}C_{yij}}{\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}C_{yij}}-\alpha\right)^2$ |
| 1981-1986 | $E(T)=\sum_i\left((1+E[\alpha])\cdot\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}\right)$ $E[\alpha]=\frac{\sum_i\sum_{j=6}^{11}C_{ij}}{\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}}$ <br> $\hat{V}[T]=\hat{V}[\alpha]\left(\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}\right)^2$ $\hat{V}[\alpha]=\left(\frac{1}{n_i-1}\right)\sum_i^{n_i}(\alpha_i-E[\alpha])^2$ |
| 1987-1993 | $E[T]=2\sum_i\left((1+E[\alpha])\cdot\sum_{j=0}^{5}\sum_{j=12}^{23}c_{ij}\right)$ $E[\alpha]=\frac{\sum_i\sum_{j=6}^{11}C_{ij}}{\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}C_{ij}}$ <br> $\hat{V}[T]=\sum_i\hat{V}[t_i]$ $\hat{V}[t_i]=\hat{V}'[t_i]+(E'[t_i])^2\hat{V}[\alpha]+(E[\alpha])^2\hat{V}'[t_i]-\hat{V}[\alpha]\hat{V}'[t_i]$ <br> $E'[t_i]=\left(\frac{N_i}{n_i}\right)\cdot\sum_{j=0}^{5}\sum_{j=12}^{23}c_{ij}$ $\hat{V}'[t_i]=N_i^2\left(\frac{N_i-n_i}{N_i}\right)\left(\frac{S^2}{n_i}\right)$ $S^2=\frac{\sum_{j=0}^{5}\sum_{j=6}^{23}c_{ij}^2-\frac{1}{n_i}\left(\sum_{j=0}^{5}\sum_{j=6}^{23}c_{ij}\right)^2}{n_i-1}$ <br> $\hat{V}[\alpha]=\left(\frac{1}{n_i-1}\right)\sum_i^{n_i}(\alpha_i-E[\alpha])^2$ |
| 1994-present | $E[T]=2\sum_i\left((1+E[\alpha])\cdot\sum_{j=0}^{5}\sum_{j=12}^{23}c_{ij}\right)$ $E[\alpha]=\frac{\sum_i\sum_{j=6}^{11}c_{ij}}{\sum_i\sum_{j=0}^{5}\sum_{j=12}^{23}c_{ij}}$ <br> $\hat{V}[T]=\sum_i\hat{V}[t_i]$ $\hat{V}[t_i]=\hat{V}'[t_i]+(E'[t_i])^2\hat{V}[\alpha]+(E[\alpha])^2\hat{V}'[t_i]-\hat{V}[\alpha]\hat{V}'[t_i]$ |

| | |
|---|---|
| | $E'[t_i] = \left(\frac{N_i}{n_i}\right) \cdot \sum_{j=0}^{5} \sum_{j=12}^{23} c_{ij}$ $\hat{V}'[t_i] = N_i^2 \left(\frac{N_i - n_i}{N_i}\right)\left(\frac{S^2}{n_i}\right)$ $S^2 = \frac{\sum_{j=0}^{5} \sum_{j=6}^{23} c_{ij}^2 - \frac{1}{n_i}\left(\sum_{j=0}^{5} \sum_{j=6}^{23} c_{ij}\right)^2}{n_i - 1}$<br>$\hat{V}[\alpha] = \left(\frac{1}{n_i - 1}\right) \sum_{i}^{n_i} (\alpha_i - E[\alpha])^2$ |

Table 4: Missing counts occuring outside of regular off-count hours and days.

| Year | Operation Dates | |
|---|---|---|
| 1965 | 6/18-7/19 | |
| 1966 | 6/19-7/28 | 6/19 0-16, 7/12 11-23, 7/13 0-23, 7/14 0-7, 7/15 23-24, 7/16 0,22,23, 7/18 0, 7/19 23,24, 7/20 0,22,23, 7/21 0, 7/22 0, 7/22 22,23, 7/23 0, 7/26 0 |
| 1967 | 6/25-7/22 | 6/25 0-7, 6/26 0-7, 7/15 12-23, 7/16 0-23, 7/17 0-9, 7/18 0-8, 7/19 0-8 |
| 1968 | 6/25-7/25 | 6/25 0-9, 7/25 12-23 |
| 1969 | 6/26-7/26 | 6/25 0-16 |
| 1970 | 6/25-7/29 | 7/29 12-23 |
| 1971 | 6/26-7/29 | |
| 1972 | 6/26-7/27 | |
| 1973 | 6/25-7/25 | |
| 1974 | 6/18-7/26 | |
| 1975 | 7/4-7/26 | |
| 1976 | 6/28-8/1 | 7/3 12-23, 7/29 3-17 |
| 1977 | 6/26-7/25 | |
| 1978 | 7/4-7/22 | 7/16 18-23, 7/22 18-23 |
| 1979 | 6/27-7/25 | 6/27 12-18, 6/27 22,23, 6/28 0-5,15,19, 21-23, 6/29 0-5,12-16,22,23, 6/30 0-5,12,13,15,17,18,22,23, 7/1 0-5,12-16,22,23, 7/2 0-5,12-19,7/3 0-5,12-14,20-23, 7/4 0-5,12,13,22,23, 7/6 0-5,23, 7/7 0-5, 7/24 3-5,12-14,16,17-23, 7/25 0-5,20-23 |
| 1980 | 6/22-7/28 | 6/22 19-23, 6/23 0-5, 7/23 2,3, 7/26 18-23, 7/27 0-5 |
| 1981 | 6/19-8/2 | 7/28 12-23, 7/29 0-5, 7/31 23, 8/1 0-7,23, 8/2 23 |
| 1982 | 6/21-7/26 | 6/21 12-17, 6/22 0-5, 7/1 17, 7/8 18, 7/9 2-5, 7/26 23 |
| 1983 | 6/19-7/27 | 6/19 21-23, 6/20 0-5,12-14, 6/21 0-5, |
| 1984 | 6/19-7/25 | 6/19 12-15 |
| 1985 | 6/26-7/28 | 6/26 12-14, 6/29 18,19, 6/30 3-5, 7/1 14, 7/28 5,12-23 |
| 1986 | 6/19-7/26 | 7/6 0 |
| 1987 | 6/25-7/23 | 6/25 14,19-21, 7/6 0, 7/23 16-23 |
| 1988 | 6/19-7/27 | 7/27 18-23 |
| 1989 | 6/27-7/27 | 6/30 16-23, 7/1 0-5,12-20, 7/2 0-5,12-14 7/27 18-23 |
| 1990 | 6/21-7/25 | |
| 1991 | 6/22-7/27 | 6/25 12,13 |
| 1992 | 6/29-7/28 | |
| 1993 | 6/24-7/27 | |
| 1994 | 6/23-8/9 | 7/28 0-23, 8/1 11,12, 8/2 0-23, 8/5 0-23 |
| 1995 | 6/21-7/26 | 6/12 12-15, [6/12 16-23, 6/13 0-5: "Count adjusted at 1100 hours 6/22 by aerial survey. Previous counts omitted in totals." (Rob 1996) Further detail information is missing.] |
| 1996 | 6/20-7/25 | 6/20 0-5, Above tower aerial survey on 6/22 (Rob 1997) |
| 1997 | 6/18-7/27 | |
| 1998 | 6/18-7/27 | 7/4 2-5 |
| 1999 | 6/25-7/28 | 6/25 12-15, 7/21 14-20 |
| 2000 | 6/22-7/27 | 7/15 12-23, 7/16 0-23 |

Table 5: Revised total escapement estimate and coefficient of variation.

| Year | Operation Dates | Chum | | Pink | | Coho | | Chinook | |
|---|---|---|---|---|---|---|---|---|---|
| 1965 | 6/18-7/19 | 32,860 | 0 | 8,643 | 0 | | | 19 | 0 |
| 1966 | 6/19-7/28 | 34,751 | 0 | 10,933 | 0 | | | 7 | |
| 1967 | 6/25-7/22 | 26,436 | 0 | 3,615 | 0 | | | 13 | |
| 1968 | 6/25-7/25 | 18,993 | 0 | 129,150 | 0 | | | 26 | |
| 1969 | 6/26-7/26 | 19,800 | 0 | 57,509 | 0 | | | 12 | |
| 1970 | 6/25-7/29 | 68,527 | 0.01 | 235,371 | 0.01 | | | | |
| 1971 | 6/26-7/29 | 39,206 | 0.01 | 16,599 | 0.01 | | | | |
| 1972 | 6/26-7/27 | 30,922 | 0.01 | 62,526 | 0.01 | | | | |
| 1973 | 6/25-7/25 | 28,837 | 0.01 | 38,466 | 0.01 | | | | |
| 1974 | 6/18-7/26 | 36,183 | 0.01 | 40,858 | 0.01 | | | | |
| 1975 | 7/4-7/26 | 14,454 | 0.01 | 57,318 | 0.01 | | | | |
| 1976 | 6/28-8/1 | 6,914 | 0.01 | 27,735 | 0.01 | | | | |
| 1977 | 6/26-7/25 | 22,890 | 0.01 | 46,156 | 0.01 | | | | |
| 1978 | 7/4-7/22 | 11,298 | 0.01 | 73,727 | 0.01 | | | | |
| 1979 | 6/27-7/25 | 12,189 | 0.01 | 168,732 | 0.01 | | | | |
| 1980 | 6/22-7/28 | 19,538 | 0.01 | 325,905 | 0.01 | | | | |
| 1981 | 6/19-8/2 | 34,309 | 0.02 | 555,723 | 0.02 | | | | |
| 1982 | 6/21-7/26 | 42,023 | 0.02 | 455,366 | 0.02 | | | | |
| 1983 | 6/19-7/27 | 52,914 | 0.03 | 166,197 | 0.02 | | | | |
| 1984 | 6/19-7/25 | 53,195 | 0.03 | 720,226 | 0.05 | | | | |
| 1985 | 6/26-7/28 | 9,859 | 0.02 | 18,087 | 0.2 | | | 959 | 0.18 |
| 1986 | 6/19-7/26 | 85,908 | 0.04 | 831,031 | 0.06 | | | 2390 | 0.08 |
| 1987 | 6/25-7/23 | 16,306 | 0.02 | 5,665 | 0.04 | | | 266 | 0.03 |
| 1988 | 6/19-7/27 | 13,313 | 0.06 | 193,482 | 0.03 | | | 318 | 0.29 |
| 1989 | 6/27-7/27 | 9,758 | 0.02 | 28,796 | 0.01 | 54 | 0.07 | 245 | 0.06 |
| 1990 | 6/21-7/25 | 14,052 | 0.02 | 774,586 | 0.001 | | | 940 | 0.1 |
| 1991 | 6/22-7/27 | 19,731 | 0.03 | 53,541 | 0.02 | | | 578 | 0.09 |
| 1992 | 6/29-7/28 | 23,228 | 0.11 | 1,186,630 | 0.15 | | | 455 | 0.04 |
| 1993 | 6/24-7/27 | 15,888 | 0.02 | 43,341 | 0.02 | | | 683 | 0.09 |
| 1994 | 6/23-8/9 | 31,495 | 0.02 | 2,264,050 | 0.03 | 2,917 | 0.02 | 578 | 0.05 |
| 1995 | 6/21-7/26 | 34,828 | 0.02 | 17,148 | 0.11 | 114 | 0.04 | 462 | 0.03 |
| 1996 | 6/20-7/25 | 27,556 | 0.03 | 946,677 | 0.03 | 458 | 0.03 | 588 | 0.08 |
| 1997 | 6/18-7/27 | 20,420 | 0.02 | 9,805 | 0.04 | | | 1,005 | 0.04 |
| 1998 | 6/18-7/27 | 18,963 | 0.25 | 693,660 | 0.04 | | | 330 | 0.05 |
| 1999 | 6/25-7/28 | 8,662 | 0.03 | 562 | 0.33 | | | 121 | 0.06 |
| 2000 | 6/22-7/27 | 13,764 | 0.04 | 803,801 | 0.08 | | | 147 | 0.04 |
| Median | | | 0.02 | | 0.015 | | 0.035 | | 0.06 |