An exploratory investigation on possible approaches used to minimize terminal fishery impacts on the Skeena River steelhead population

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1. Introduction

Limiting commercial fishing impacts on summer run steelhead trout (*Oncorhynchus mykiss*) can be a complex task when they return to their natal stream during the same period as other salmon species. Large and productive salmon runs can sustain higher exploitation rates than some less abundant and less productive steelhead runs. Since 1998, the provincial government has implemented a non-retention policy which applies to steelhead using wild streams in British Columbia. It requires that recreational and commercial fishermen release all steelhead captured with minimal harm. Steelhead trout are often intercepted in commercial fisheries targeting large runs of co-migrating salmon stocks. Some steelhead are dead when brought on board, and others can die from stress and injuries shortly after capture or after release. Several investigations have indicated that incidental losses can be considerable in some cases, and are influenced by the location and time of capture, the gear used, the handling procedures and the release methods.

Using a combination of observer records, survey results and numerical simulation procedures, fishery scientists have attempted to determine the plausible impacts of fishery interceptions rates. Cox-Rogers (1994, 2007) describes the history and features of one model used to determine the incidental losses on Skeena River steelhead that might result from certain fishery management scenarios. Bison and Labelle (2007) describe an alternative model (based on that of Cave and Gazey 1994) used to determine incidental losses caused by some fisheries in southern BC and the Fraser River on the Thompson River steelhead. Unfortunately, due to the paucity of reliable figures on steelhead catches and escapements in both cases, these simulation models rely on many assumptions concerning migration patterns, gear selectivity, fishery catchability rates, and short-long term mortalities caused by certain gear types and handling methods.

An earlier version of the model used to determine fishery impacts on the Thompson River steelhead was examined by the Pacific Scientific Advice Review Committee (PSARC) during 2006, but was not endorsed at the time, in part because of insufficient data to support the various underlying hypotheses. And the model used to determine fishery impacts on Skeena River steelhead was also recently reviewed by a panel of experts, but was considered only useful for planning purposes, as it provided ‘unrealistically’ precise estimates that could not be compared to the actual interception rates (Walters et al., 2008, p. 5). These recent developments suggest that "data-poor" models cannot be singularly relied upon by fishery managers and scientists to formulate definitive pre-season fishery management plans, justify in-season fishery management action, and conduct a post-season assessment of the adequacy of fishing operations allowed.

Given this state of affairs, executives Fisheries & Oceans Canada (traditionally referred to as the Department of Fisheries & Oceans or DFO) and the BC Ministry of Environment (MoE) recently agreed to rely on a new approach to regulate impacts of terminal fisheries on steelhead populations. The 2008 DFO Integrated Fisheries Management Plan (IFMP) for southern BC salmon stocks (Anon. 2008, p. 27) describes it as follows;

> "The objective for Interior Fraser River Steelhead provided by the B.C. Ministry of the Environment is to protect 80% of the run with a 90% certainty in Fraser River commercial gill net fisheries. This objective does not apply to selective commercial fisheries (those using gear types other that gill nets) or fisheries conducted terminally on single stocks. In addition, other commercial South Coast fisheries are to release to the water with the least possible harm all steelhead caught incidentally in fisheries targeting other species".

The IFMP further stipulates that "There are ongoing discussions between DFO and the Province to develop a management framework for Interior Fraser Steelhead", that "the development of stop light criteria would govern opening fisheries in future years based on abundance indicators", and that "the management objectives of this approach are tied to the escapement targets of steelhead stocks. The size and timing of the fishery window may be varied in future years in accordance to the abundance of the constituent stocks".

The agreement is meant to provide some protection to Thompson River steelhead, but the wording can be subject to interpretation. Further clarifications were provided to the author in May 2009 by Mr. Al Martin, Executive Director of the Fish & Wildlife Branch of the MoE. Essentially, "80% of the run" does not refer to the run size, but rather to the run period. So if the temporal distribution of a run moving through a fishing area conforms to normal curve, and information is available on the mean and standard deviation of this distribution, one can compute the proportion (or percentage) of this distribution bounded by certain dates, and determine suitable fishery openings.

The fishery management objective as articulated in the Southern BC IFMP aims to offer protection to the Interior Fraser River steelhead. At the time of this writing, there were no such stipulations in the latest draft of the 2008 Northern BC IFMP[1] for Skeena River steelhead. Based on discussions with MoE executives, it was noted that for purposes of consistency, the MoE would require that the same criteria be used to regulate terminal fisheries in the Skeena River to protect its steelhead population.

The procedure used to ensure that "80% of the run is protected with 90% certainty" (termed in the following text as the 80/90 objective) has not yet been determined. Different approaches and data sources could possibly be used to achieve this goal. Fishery managers will likely require some input before and during the period when steelhead are moving through terminal gillnet fisheries to make decisions. The objective of the present investigation is to formulate an approach that could potentially be used for decision making purposes. Terminal gill-net fisheries take place downstream from the Tyee test-fishery which has provided data on escapement patterns for the past 50 years or so.

Since there is no certainty that DFO will use observers to monitor steelhead interception throughout the terminal gill-net fisheries in the future, or even that such data would be sufficient to accurately determine escapement patterns, efforts were made to develop a model that relies mainly on the Tyee test fishing records. The following sections provide descriptions of the data used, details on a procedure specifically designed to utilise historical and in-season observations to determine escapement patterns, and the approach used to determine the certainty of meeting the objectives stipulated.

[1] www-ops2.pac.dfo-mpo.gc.ca/xnet/content/consultations/salmon/ifmp/nc_ifmp_2009.pdf

2. Materials and Methods

2.1 Symbols and notation

The following symbols and notation are used for descriptive purposes in the following sections

d	subscript denoting a day number, with d=1 being June 15
d_y	variable denoting a day number, year y
$\bar{d}_y$	variable denoting the mean day of the run time distribution, year y
i	subscript denoting a 2 d interval (max. i = I = 54)
j	subscript denoting several specific dates, not separated by fixed intervals
g	gillnet mesh type (1 = old multi-filament, 2 = new mono-filament)
k	subscript denoting a set conducted during a calendar day (range 1-3, max.=K)
q_{yg}	catchability rate of the Tyee test fishing near, year y, mesh type g
y	subscript denoting a calendar year, with y=1 representing 1955. I=54 or 2008
C_{ydj}	reported catch of steelhead for year y, day d, and set j
$\hat{C}_{ydj}$	expected number of steelhead susceptible to capture, year y, day d, and set j
E_{ydj}	test fishing effort for year y, day d, for set j (in $m^2 \cdot h$)
L	likelihood of a hypothesized set of parameter values given the data
Log_e	natural logarithm (also denoted as Ln)
n	variable denoting the numbers of observations of a certain type
N_{yd}	number of fish passing Tyee during year y, day d (i.e. daily escapement)
N_y	number of fish passing Tyee during year y (i.e. total escapement)
s_y	scaling coefficient, year y
U_{ydj}	catch per unit effort (C/E) for year y, day d, and set j
$\bar{U}_{yd}$	arithmetic average of set-specific catch per unit effort, for year y, day d
$\bar{U}^c$	cumulative average catch per unit effort
$\mathbf{C_y}$	vector of test fishing catches by period, year y
$\boldsymbol{\theta_y}$	vector of hypothesized parameter values $\{\bar{d}_y, \sigma_y, s_y\}$, year y
ℓ	natural logarithm of the likelihood L
ρ_y	penalty value
ε	random error from a specified distribution
σ_y	standard deviation of the run timing distribution (in days), year y

2.2. Description of the Tyee test fishing datasets

Test fishing has been conducted annually in the lower Skeena River at Tyee during the summer and fall since the 1950s mainly to monitor sockeye and pink salmon escapements. These data were also used to generate escapement indices for other species, including those of anadromous steelhead trout. Until 2002, a 1200 feet gill-net was deployed 2-3 times a day during slack water tidal periods. It was laid out perpendicular to the flow, and usually left drifting for one hour before being retrieved slowly while the catch was removed. Net depth could reach 5-9 m depending upon the tide and the fishing location. Total fishing time per set is typically computed as half the deployment period, plus the drifting period, and half the retrieval period. Adjustments are made to account for snags, net breaks and other factors that affect catch rates. Test fishing effort is obtained by multiplying the total fishing time by the surface area of the net to provide an index expressed in terms of surface area per hour ($m^2 \cdot h$). Average daily catch-per-unit effort (CPUE or $\bar{U}_d$) indices and the cumulative indices over the season [for steelhead] are computed from the effort and catch figures;

[1] $$U_{ydk} = \frac{C_{ydk}}{E_{ydk}}$$

[2] $$\bar{U}_{yd} = \frac{\sum_{k=1}^{K_{yd}} U_{ydk}}{J_{yd}}$$ for K_{yd} = sets in year y, day d

[3] $$\bar{U}_y^c = \sum_{d=1}^{D_y} \bar{U}_{yd}$$ for D_y = total test-fishing days, year y

Total escapement can be computed using the total cumulative index and the gill-net catchability rate (q) such that $N_y = \bar{U}_y^c / q$. Based on the results of a short investigation by scientists from the University of Milan in the mid-1970s, plus accurate sockeye counts at the Babine River enumeration fence in recent years, and assumptions concerning the relative catchabilities of sockeye versus steelhead, it is generally assumed the test gill-net catchability (q) for steelhead is ≈0.41%. This implies that it intercepts (on average) about 1 out of about 244 steelhead passing by. So an expansion factor of 245 (i.e. $1/q$) is applied to the cumulative escapement index to determine total escapement. Cox-Rogers and Spilsted (2002) noted that sockeye escapement estimates based on the Tyee gill-net records differed from the actual escapements by as much as 24% during 1996-2001. This indicates that gill-net catchability rate can vary substantially, likely due to several factors such as debris build-up, water turbidity, discharge levels, luminosity, tidal conditions, water depth, gear saturation levels, and etc. Unfortunately, no comparable figures are given for steelhead because their spawning levels in various tributaries are not sufficiently well monitored (unlike Babine sockeye).

The above comments on catchability rates apply to the older multi-filament gill-net used for test fishing. In 2002, it was replaced by a mono-filament gill-net that could intercept salmon swimming deeper. Tests were conducted during 1996-2001 to provide a conversion factor so the two CPUE time series could be linked (see Cox-Rogers and Spilsted 2002). The authors reported the mono-filament net was (on average, across seasons) about 1.2 times more efficient at catching steelhead than the multi-filament net. However, the linear regression coefficient using both annual indices given in their Fig. 8 is actually 1.124 (not 1.2), and is substantially different than the coefficient obtained using daily indices (0.726). These relative catch efficiencies (1.20, 1.124 or 0.726) are used to determine the proper conversion factors (0.83, 0.89 and 1.38 respectively) to adjust the post-2001 series and generate a standard CPUE series and the escapement over 1956-2008.

The regression plot in Cox-Rogers and Spilsted (2002) shows that the relation between the annual indices is not obviously linear, and in fact, a power function can provide a better fit. The regression does not pass through the origin. By specifying an intercept of 0.0, the slope would have less steep, or closer to that based on daily indices. Their regression plot based on daily indices includes many ‘zeros’ indicating the absence of fish, or are caused by insufficient sampling effort (fishing time) to monitor a species that is relatively rare (low densities). Their regression plots show more scatter in daily indices at larger catch levels (heterocedasticity). In such cases, a log-transformation of the data is usually recommended before fitting a linear regression (see Zar 1984, p. 287), which implies a non-linear relation between both indices. Based on such facts, and given the magnitude of the discrepancies between the regression coefficients (annual, daily), the data should be transformed to stabilize the variances, and re-analyzed to determine the most appropriate conversion factor.

To investigate this issue further, and compute indices using alternative procedures, a request was made to DFO to obtain the actual steelhead catches and corresponding fishing times for all individual test fishing sets conducted since 1955. A cursory examination of the data provided revealed that for the earlier periods (June 1955-1966) no steelhead were caught during June on most days, and even during the early part of July for some years. However, for the same periods, the average daily indices reported by the DFO are >0 on many days. Upon further inquiry, it was noted that many steelhead caught in June are kelts, so DFO staff eliminated these from the raw data set provided, using some general criteria when detailed records on steelhead condition were not available (largely before 1975). So in light of such facts, the raw data set was considered more suitable for the present investigation.

A second cursory examination of the 2005-2008 test fishing data set (which includes records on tidal conditions) revealed that catch rates during short periods (say 1 week) were consistently greater on one tidal phase (say high-high tide versus high-low tide) during some periods, but the pattern did not necessarily hold over different periods, perhaps because other conditions change (luminosity, discharge, etc.). The data provided by the DFO for earlier years do not specify the tidal phases for sets conducted since 1955, and do not provide information on various environmental factors that can also affect catch rates. To help cancel out some of the variation due to changes in conditions between sets, all daily test fishing catch records were pooled over successive 2 d periods to generate new sets of CPUE indices based on a larger number of sets covering more tidal phases and conditions. This ‘binning’ procedure yields a smaller data set for each season, but also helps reduce the number of zeros and very small CPUEs. A simple ratio estimator is used to determine the new CPUE figures by gear and 2 d intervals for each test fishing season. Let *i* denote 2 d intervals such that aggregated effort levels for successive periods are obtained from

[4] $$E_{yig} = \sum_{k=i}^{K_d} \left(E_{y(2i)gk} + E_{y((2i)-1)gk} \right) \quad \text{for } i = 1 \text{ to } 54$$

Examination of the two effort series revealed a wide range of fishing times by 2 d intervals when both mesh types were compared (1996-2001), with mean fishing times ranging from 5.1 to 6.3 h (Table 2.). To compensate for the large variation in fishing times, pooled catches were adjusted to reflect potential catches obtained for test fishing times of exactly 6 h.

[5] $$C_{yig} = \frac{6}{E_{yig}} \sum_{k=i}^{K_d} \left(C_{y(2i)gk} + C_{y((2i)-1)gk} \right) \quad \text{for } i = 1 \text{ to } 54$$

New CPUE series can be obtained by dividing the adjusted catches by 6 h, but since the effort is now constant, trends can be based on adjusted catches. A linear regression of the adjusted catches for the old gill-net against those of the new gill-net (Fig. 1) shows much less scatter about the regression line than that of Cox-Rogers and Spilsted (2002, Fig. 8). The scatter is still not uniform over the entire range of values, due mainly to a few values (perhaps errors or outliers). The coefficient of determination (r^2) associated with the new regression (0.72) is greater than that obtained by Cox-Rogers and Spilsted (2002) using average daily CPUE indices (0.66). However, the new regression coefficient is only slightly different that theirs (0.756 versus 0.726 respectively). The results suggest the new gill-net is on average, about 1.36 times more efficient than the old one, and the best conversion coefficient is 0.756. The following analysis is conducted using a single, adjusted CPUE (or catch) series as if the same mesh type (the old one; *g*=1) had been used since 1955. This is accomplished by setting

[6] $$C_{yig=1} = 0.756\, C_{yig=2}$$ *y*=48 to 54, for 2002-08

<u>2.3 Modeling of run and escapement patterns</u>

Irrespective of the uncertainties and gaps of the Tyee test fishing records, these still constitute an essential data set to describe the run and escapement patterns. An examination of the test fishing records for two seasons (1989, 2001) revealed additional data limitations that should be accounted for if these are to be used to estimate the escapement parameters. During 1989, test fishing started on June 21 and steelhead were caught (Table 1). Since 1990, steelhead catches before July 1 are usually not reported, partly because most (but not all) steelhead caught downstream of Tyee before statistical week 7-1 (Late June to early July) tend to be kelts. During 1989, test-fishing ceased in early September, but in 2001, it was conducted until the end of September with steelhead being caught up to the last test fishing week. It should be noted that inconsistent monitoring efforts can affect the cumulative index for the season and the corresponding total escapement if estimated using only test-fishing indices. Walters et al. (2008) recommended that Tyee test fishing should be extended to cover the entire steelhead run, and in recent years, the MoE has been providing extra funding to extend the test fishing operations so as to cover the tail end of the steelhead runs.

For some years, the daily test fishing indices can reflect the steelhead escapement pattern, but for other years, the indices may simply be too distorted by losses due to commercial fishing in approach waters to accurately reflect the escapement patterns. Patterns possibly ‘distorted’ by fishing should not be used in summaries, but these are not always easy to identify in the absence of detailed records of steelhead catches by fishery, which are not available for most seasons. In general, the Tyee test fishing catches of steelhead are typically low at the start of the run (mid-June), peak around mid-late August, and then decline until late September. It is often assumed that salmon runs conform to a normal distribution (Cave and Gazey 1994, Hilborn et al. 1999). The same is assumed here for Skeena steelhead runs. If a normal distribution can be fitted to the Tyee test fishing records, one can estimate the escapement distribution parameters of interest (mean and standard deviation), and the cumulative percentiles to bound periods covering ≤20% of the distribution. The expected numbers of steelhead passing Tyee each day is thus computed from

[7] $$N_{yd} = \frac{N_{oy}}{\sigma_y \sqrt{2\pi}} \exp\left[\frac{-(d_y - \bar{d}_y)^2}{2\sigma_y^2}\right]$$

In the above equation, total steelhead escapement for a given year (N_{oy}) is not known with certainty at the start of each season, but can be arbitrarily set to 1.0 when the main objective is to determine the escapement pattern (not the escapement level). The parameters are estimated by minimizing the differences between the expected and observed numbers of steelhead passing Tyee each day (the latter adjusted for sampling or catchability rates). The best fitting criterion to use is usually determined based on the data type (integers, real, interval, proportions, etc.), the mean:variance ratio of the data, the hypothesized observation error structure, and etc. In the present context, there are no replicate samples to determine the mean:variance ratio, since only a single set is made on a tidal phase each day. Sets made under different tidal conditions each day, or during the same tidal phase on adjacent days are not replicate samples, but amount to ‘pseudo-replicates’ (see Hurlbert 1984), and do not reflect the true mean:variance ratio. However, many fishery investigations have indicated that the variance of the catch (or CPUEs) often increases with the mean, with the mean often closer to the minimum than to the maximum value. Under such conditions, a non-normal, exponential error structure is implied, and the distribution of CPUEs is considered to be log-normally distributed. However, the daily CPUEs based on Eq. 2 are not for individual sets, but represent the arithmetic means of set-specific CPUEs for a given day. According to the central limit theorem, the means of samples from non-normal distributions tend towards normality with increasing sample sizes (see Zar 1984, p. 86), so one could assume that the mean daily CPUEs have a quasi-normal error structure.

An alternative fitting procedure involves using the adjusted pooled catch and effort records. The adjusted catch indices, rounded to the nearest integer, amount to pseudo-counts over a 2 d test fishing period of fixed duration. These are akin to rare observations since the gill-net catchability (i.e. sampling or capture probability) is a small fraction, and often, none or few steelhead are captured (by contrast to sockeye). A statistical distribution used to model the error structure in such a context is the Poisson distribution. It describes the probability of rare events, where a variance proportional to the mean. Unlike the log-normal, the Poisson distribution is suited for discrete counts that can include zeros. The Poisson probability of a sample of *Y* fish given there being X fish present is given by $P(Y) = X^Y/(e^X X!)$, with Y and X representing the observed and expected catches.

Expected catches can be obtained via the conventional equation; $\hat{C}_y=N_{oy}E_yq_y$. As noted earlier, N_{oy} is unknown before each season, and if arbitrarily set to a unit, yields a catch <1. To obtain expected catches comparable to observed (i.e. reported) catch, a scaling coefficient (s_y) is used such that $\hat{C}_y=N_{oy}s_yE_yq_y$. If the equivalency $N_y=N_{oy}s_y$ is used, then $\hat{C}_y=N_yE_yq_y$, and both N_y and q_y must be estimated from the data to solve the equation. However, the same catch can be obtained with a large N_y and small q_y, or a smaller N_y and a larger q_y. This causes a parameter confounding problem requiring an alternative transformation. Instead, let $s_y=E_yq_y$, and since the adjusted catches are computed using a fixed effort, E_y can be considered as being an arbitrary constant, which results in $\hat{C}_y \propto N_{oy}s_y$. Using notations for 2 d intervals, that relation becomes $\hat{C}_{yi} \propto N_{yi}s_y$. Expressed in this fashion, the scaling coefficient becomes an index of abundance, representing the relative numbers of steelhead susceptible to capture (at Tyee) each year. Expected catches are computed even for days with no test fishing based on a fixed effort level and a year-invariant run size. By contrast, the observed (or reported) catches by 2 d intervals (C_{yi}) are only available for the test fishing period. The latter are considered to be subject to an observation error, which is a Poisson distributed random variable (ε_i), such that $C_{yi} = \hat{C}_{yi}+\varepsilon_i$.

2.4 Estimation of escapement distribution parameters

Estimating of the best fitting parameters for each season is done using maximum likelihood procedures. Using a bold typeface to identify vectors, let $\boldsymbol{C_y}$ denote the set of observed, standardized catches in a season, by 2 d interval. Let $\boldsymbol{\theta_y}$ denote the set of hypothesized parameter values $\{\overline{d}_y,\sigma_y,s_y\}$ used to compute the expected catches. The probability of a set of parameter values given the observations is termed the likelihood of a hypothesis given the data (after Edwards 1992), and is denoted here by $L(\boldsymbol{\theta}_y|\boldsymbol{C}_y)$. Given a normally distributed run time, and a Poisson observation error, the likelihood of getting a sequence of catches in one season is given by

[8] $$L\{\boldsymbol{\theta}_{\boldsymbol{y}}|\boldsymbol{C}_{\boldsymbol{y}}\} = \prod_{i=1}^{I} \frac{\hat{C}_{yi}{}^{C_{yi}}}{\exp(\hat{C}_{yi})C_{yi}!}$$

Likelihoods can be very small numbers (i.e. probabilities), so fits are often expressed as the natural logarithms ($Log_e\ L$, denoted by ℓ) of the likelihoods. After some transformations (see Haddon 2001, p. 109), the previous equation reduces to

[9] $$\ell\{\boldsymbol{\theta}_{\boldsymbol{y}}|\boldsymbol{C}_{\boldsymbol{y}}\} = \sum_{i=1}^{I}\left\{Ln\left(\hat{C}_{yi}{}^{C_{yi}}\right) - Ln\left(exp\left(\hat{C}_{yi}\right)C_{yi}!\right)\right\}$$

Given that test fishing is not conducted each day, only records for $E_{yi}>0$ are used for parameter estimation. Given uncertainties about the type of steelhead caught during June (mainly), test fishing records for days prior to June 30th were not used for parameter estimation, although the expected numbers computing from the parameter estimates may indicate some steelhead present at Tyee before this date. Note that in cases when the test fishing catch series is short, contains gaps or distorted by fishery removals in approach waters, one can obtain ill-determined estimates that predict steelhead arriving before late June or after the end of September. To eliminate unrealistic trends, a penalty function (Bard 1974) is used to constrain the optimization. Let j=1 to 9, represent 2 d interval outside the monitoring period; namely June 16, 18, 20, 22, 24, and Oct, 2, 4, 6, 8. The function is

[10] $$\rho_y = \sum_{j=1}^{J}\left\{1 - \exp(2\hat{C}_{yj}^2)\right\} \quad \text{for } \hat{C}_{yj} > 1$$

The penalty simply increases exponentially with greater abundances outside the allowable period. The penalty function yields a negative number, as does the log-likelihood function. Both components are used to form a single objective function which yields smaller negative values when penalties <0.

[11] $$\ell\{\boldsymbol{\theta}_{\boldsymbol{y}}|\boldsymbol{C}_{\boldsymbol{y}}\} = \sum_{i=1}^{I}\left\{Ln\left(\hat{C}_{yi}{}^{C_{yi}}\right) - Ln\left(exp\left(\hat{C}_{yi}\right)C_{yi}!\right)\right\} + \rho_y$$

The best fitting parameter values are determined by maximizing the objective function value. All adjusted catches by period and gear type were compiled using a C++ application developed by the author for the present purposes. The outputs were inserted into an Excel spreadsheet, and all parameters values were estimated using the Excel add-in function minimization routines of the Premium Solver Platform (PSP Version 9.04) distributed by Frontline Systems Inc. The Generalized Reduced Gradient (GRG) routine was used with the automatic scaling option enabled, no maximum time or iteration limits, all parameter values >0, with precision and convergence levels set to 1E-6. Once the best fitting solution was found, the distributions of residuals and the position of the estimates within the allowable ranges were examined to detect convergence problems. After some trial and error, it was judged necessary to use an additional constraint to help improve convergence, at least for some cases. This involved requiring that the total expected catch for the season be within ±20% of the total reported catch. This range was chosen based on the comments of an expert review committee that noted the Tyee test fishery records provide "at best a noisy estimate of escapement" that is ±20% of the actual value (Walters et al., 2008, p. 6).

2.5 Approximation of escapement patterns

If steelhead escapement patterns in the near future are expected to be similar to one of the historical patterns, there is no need to use a function minimization procedure simply to determine the closest shape. The 1956-2008 estimates of the mean and standard deviations can be considered as a set of plausible values. Escapement patterns can be generated using all combinations of mean and standard deviation estimates (by 1d increments). Patterns with <1% of the steelhead arriving before June 26 or after September 28 can be eliminated, as they are likely caused by odd parameter combinations never obtained. The remaining set can be statistically compared to any future Tyee catch distribution to identify the closet corresponding escapement pattern. In past years, DFO staff used the cumulative CPUEs for monitoring and evaluation purposes. So the cumulative, adjusted catch series from Tyee test fishing were compared to the cumulative probabilities for each plausible parameter combination. Cumulative probabilities sum up to 1.0, but cumulative catches for each year do not. So the probability values (summed by 2 d intervals) for each set of plausible parameter combination were multiplied by the total annual Tyee catch for the year of comparison, with the values rounded to the nearest integers. This process yields two cumulative distributions in whole numbers and on the same scale. A Kolmogorov-Smirnov goodness of fit test (K-S test) was used to statistically compare each pair of distributions. This statistical testing procedure is suitable when comparing two sets of counts (observed and expected) by binned categories, which in this case are the successive 2 d intervals. Statistical comparisons were made using only the observed and expected catches over the test-fishing period for each season. The largest absolute discrepancy between the cumulative values over all 2 d periods (termed d_{max} in Zar, 1984, p. 54) is a measure of fit, with small values indicating better fits.

3. Results

3.1 Estimated escapement patterns

A summary of the best fitting parameter estimates (Table 3) shows considerable variation in the mean and standard deviation since 1956. On average, the expected speak escapement (mean day) occurs on the first week of August, but was as early as July 29, and and late as August 22. The spread of the escapement distribution (standard deviation) also varied substantially over the years, with estimates ranging from 10-24 d. If one considers the 1st and 99th percentiles of the cumulative distributions as representing the start and the end of the escapement periods, these started as early as June 27 (d=13), and as late as July 22 (d=38), and ended as early as Aug. 27 (d=74) and as late as Sept. 27 (d=105). Over 1956-2008, the average escapement period was 70 d, and ranged from 46-90 d.

A more detailed examination of the temporal trends in parameter values indicates that the peak period in recent years is later than in earlier years (Fig. 2, top). Several factors could be possibly induce this [apparent] shift, such as the loss of stocks arriving earlier due to overfishing or habitat degradations, long term changes in marine or fresh water conditions, or changes in test fishing and monitoring practices (longer test fishing periods, better accounting of kelts, etc.). With regards to the distribution spread, the trends suggest some cyclic pattern; a decline until the mid-1970s, then an increase until the mid-1990s, followed by another decline. However, for lack of time, no efforts were made to determine if this 'apparent' cycle was linked or correlated to some external factor. Changes in the scaling factors are more pronounced, but can be caused by a combination of factors, including inconsistent test fishing periods, long term changes in river conditions, using different gill-net, and variation in fishing impacts. Greater scaling values indicate more steelhead at Tyee, which a likely caused by relatively large runs coupled with low exploitation. Exploitation rates were relatively large during the early mid 1990s (24-39%, Anon. 2007) and the corresponding scaling factors are relatively low. By contrast, exploitation levels were severely curtailed in 1998-2000 (<5%) when scaling values reached their highest values.

The effects of fishing on the parameter estimates may not be negligible. As noted earlier, removals by commercial fisheries operating further downstream can influence the numbers of steelhead susceptible to capture at Tyee and the resulting catch pattern. For most years analyzed, the catch patterns are relatively well represented by a normal distribution, and show no signs of severe distortions from fishing impacts (Fig. 3, top). Various fisheries likely induced some steelhead losses during most seasons, but the impacts may have been spread randomly across the runs, causing no pronounced distortion at a particular time.

For a few years, the Tyee catch patterns were positively or negatively skewed (Fig. 3, middle). Assuming that fishing impacts for those years were not continuous over 3-4 weeks, skewed distributions could possibly be caused by unusual marine or fresh water conditions. And some test fishing catch patterns were seemingly bi-modal, with reported catches well below the expected catches between the two modes (Fig. 3, bottom). Overall exploitation on the 2001 run was only 9%, but was greatest on the early portion of the run (15%), possibly inducing the drop in catches at Tyee shortly after. Fits showing uneven residual distributions may indicate that fisheries distorted the escapement pattern detected at Tyee. But in spite of distortions in some years, most of run timing parameter estimates are considered plausible even if the distribution of residuals is not uniform; for instance in 2001, the mean and standard deviation estimates might not have changed even if fishing had not [supposedly] impacted the middle of the run.

<u>3.2 Approximations of escapement patterns</u>

One can determine the approximate escapement pattern directly from the cumulative catch distribution using the K-S testing procedure (Table 4). For most years, the mean and standard deviation estimates were similar to those of the closest corresponding pattern. Sometimes the parameter pairs (denoted as estimated and corresponding) were identical, but in some extreme cases differed by up to 7 d. On average, the differences were about 2 d for both the mean and standard deviations, which is considered relatively small given the data limitations, the effects of rounding and binning, and some non-normal catch patterns. The differences seemed to be inversely related to the number of days between the last test-fishing day and the peak run day (Fig. 5). When test fishing was conducted 25-40 d past the peak period, both figures matched. By contrast, greater discrepancies were detected when test-fishing ended <2 weeks from the mean escapement day. This issue is further investigated in the following section, but given the results obtained, the approximation procedure is not considered sufficiently accurate to determine the escapement pattern at Tyee each year with certainty.

3.3 Determining patterns in-season

When Tyee catch pattern is well represented by a normal distribution (like 1960, Fig. 3), the mean and standard deviations estimates based on part of the catch series (up to the mean escapement date) were close (±1d) to the estimates based on the entire series. However, when the Tyee catch pattern is not well represented by a normal distribution (as in 1977 in Fig. 4, a far-right point on Fig. 5), the estimates based on catch records that do not extend far beyond the mean date (< 1 week) could differ by up to 10 d from those based on the entire series. So determining the escapement pattern with certainty depends on how well the Tyee catch distribution pattern conforms to be normal, and if the catch series used extends beyond the mean date. There is no way of determining early in the season if the catch pattern will conform well to a normal distribution, so a reasonable course of action is to determine the run pattern after the [first] definite peak in Tyee test-fishing catches. The peak itself may be difficult to identify if the catch distribution is platykurtic, noisy or distorted by fishing impacts. For instance, the 2001 catch pattern (Fig. 3) shows high catches in late July and again in late August. So even if one uses the simple 'rule-of-thumb' proposed, the shape of the run needs to be re-assessed periodically after the first obvious peak is obtained. Walters et al. (2008) noted that even for the larger Skeena River sockeye runs, their shapes and sizes can usually be determined with some certainty after the runs have peaked, which supports the comments made above.

It should also be noted that when test fishing does not extend well past the mean date, the cumulative average catch indices (multiplied by 245) may underestimate the total escapement for the season since monitoring does not cover the entire steelhead escapement period. In such cases, the expected Tyee catches (from the fitted distribution), adjusted by some alternative coefficient (not 245 since catches by set are pooled) should be added to the cumulative index, at a minimum, for a period of several days after the last terminal fishery, so as to obtain a more representative (but crude) estimate of total escapement.

3.4 Implementation of the 80/90 objective

Some of the MoE officials contacted thought that the procedures used to meet the 80/90 objective could be based on past run timing data, which explains why efforts were made to estimate the 1956-2008 run timing parameters. The proportions of the steelhead escapement passing Tyee by day/year can be computed from the parameter estimates. The predicted proportions are not as accurate as those that could potentially be obtained if actual fishery losses could be quantified, but are considered sufficient for the following descriptions.

From the predicted proportions, the 5^{th}, 50^{th}, and 90^{th} percentile of the distribution of proportions across years can be computed. An example using the 2000-2009 figures (Table 5) indicates that on July 15, the median (50^{th} percentile) is 0.15%, and the upper bound (90^{th} percentile) is 0.48%. The 10^{th}, 50^{th}, and 90^{th} percentiles computed for each day over 1956-2006 (Fig. 6) indicate that on August 1^{st}, the 50^{th} and 90^{th} percentiles were 2.0% and 2.8% respectively. Some interpret these figures as implying that, given historical trends, there is a 10% chance that 2.8% of the run would escape past Tyee on that date in the future. Assuming it takes 2 days for steelhead to move from the River/Gap/Slew region (where most Area 4 GN fishing is done) to the Tyee test fishing site, this implies there is 90% certainty that a fishery opening in the River/Gap/Slew on July 30 (2 d earlier) would impact ≤ 2.8% of the run. Consequently, it has been hypothesized that this single fishery opening would protect 97.2% of the run with 90% certainty.

Unfortunately, the logic is flawed, and the approach may not ensure that a portion of the run is protected “with 90% certainty”. Historical escapement patterns do not necessarily reflect future patterns, even if only the most recent records are used to forecast these. And as noted previously, the predicted historical trends based on run timing parameter estimates may not accurately reflect the actual patterns that might have been observed if all fishing impacts were accounted for. And perhaps more important, the 90^{th} percentile value is definitely not a measure of risk or “certainty” *per se*, but a crude yardstick to determine what the upper time limit might be under similar combination of conditions (run patterns, fishery openings, effort levels) comparable to those observed previously.

The only effective way to ensure "certainty" is to rely on updated in-season observations. Unfortunately, in the absence of empirically based estimates of terminal GN fishery impacts on past runs, one cannot predict with certainty the impact of complex combinations of fishery openings during the steelhead run. In fact, one cannot even use in-season Tyee escapement records to determine what the likely shape of the escapement pattern is before well way into the season; no statistically significant Spearman rank correlations coefficients (P>0.05) were found between the 1956-2008 steelhead escapement estimates reported by the DFO and the initial slope of the test fishing catch curve, the first day steelhead catches are obtained, the peak steelhead test fishing catch date, and the spread of the escapement pattern based on test fishing catch records. The only weak trend observed is between the start of the steelhead catch period at Tyee and total escapement, with the largest escapements [reported] arriving at Tyee during the first week of July.

In light of the above, it would appear that the best way to ensure that a certain portion of the steelhead run period (and abundance) is protected from GN fishing impacts with a given level of certainty is to use an extremely simplistic 'rule of thumb' that does not rely heavily on past observations or predicted impacts. Simply allow 1 d of gill-net fishing in approach waters on every 5th d once the steelhead run is clearly underway. Terminal GN fishing would impact at most 1/5th or 20% of the steelhead run throughout the run period, thus protecting 80% of it and with close to 100% certainty, given there would be no opening until the run is already underway. An even more risk adverse approach would be to allow only a 1 d opening per week, thus affecting 1/7th (or 14%) of the run, thus protecting 86% of it with >90% certainty. This 'sliding rule' works for both short runs and longer ones; 46 d (≤9 d openings), or 90 d (≤18 d openings).

Terminal GN fishery openings in the DFO Statistical Area 4 are not always at the upstream boundary of Area 4-15 (few km downstream from Tyee), but can extend up to the edge of Portland Inlet about 100 km north of Tyee. So there can be a time lag between the effects of terminal fishery impacts and the Tyee test fishing catches. Steelhead have been reported to travel about 17 $km \cdot d^{-1}$ in marine waters (Ruggerone et al. 1990), and 9.8 $km \cdot d^{-1}$ in fresh water (Renn et al. 2001). Comparable rates were determined from the Skeena River steelhead tagging operations (Lough 1981, Spence 1989, Koski et al. 1995). If future gill-net fisheries are concentrated on traditional sites (Brown Passage, Connis Rocks, Edye Pass, River/Gap/Slough), the potential impacts would occur 10-70 km from Tyee, with incidental mortalities affecting Tyee catch patterns some 1-5 d later (if no holding in the river mouth). So having fishery openings at 5 d intervals or more should allow the Tyee test fishing patterns to more accurately reflect the impacts of prior GN fishery openings, even distant ones. Furthermore, by not concentrating fishing effort in several adjacent days, only small distortions of Tyee catch patterns could occur periodically, and make it easier to determine the escapement pattern and level with greater certainty.

The ‘sliding rule’ proposed could also help ensure the 1994 DFO/MOE agreement on maximum allowable exploitation rate (21%) on steelhead is met. As noted by Labelle and Beere (2007), a precautionary approach recommended by some DFO scientists noted there should be <10% probability of exceeding the maximum allowable exploitation rate. Consequently, the upper 90% confidence interval of the exploitation rate (i.e., incidental losses) should not exceed the 21% level set in 1994, so efforts should be made to ensure that the estimated fishery impacts are lower than this level to account for substantial uncertainties in incidental mortality rates. A ‘sliding rule’ with openings every 5^{th} day would likely limit the exploitation rate to <20%, and a one opening per week would likely translate into even lower exploitation rates.

3.5 Limitations of approach used to meet the 80/90 objective

In principle, the ‘sliding rule’ allows the runs to be protection to be protected with substantial certainty without any pre-season forecast and with little information on run pattern. However, as currently formulated, it does not guarantee this without further stipulations. Protecting 80% of a standard 70 d run could potentially allow GN fishery impacts of 20%, that translate into ≤14 d of fishing. The 80/90 objective as currently described does not specify when the impact can take place. Openings could be allowed at the start of the run. Walters et al. (2008) emphasized the need to protect the early components of the steelhead runs that historically were subject to excessive exploitation. If this objective is to be met, there should be no GN fishery openings until the Tyee test fishing records indicate the steelhead run is well underway (say after 1+ week of non-zero catches in July). This would protect the early part of the run, reduce the impacts on kelts, and the Tyee test fishing catch pattern would more clearly reflect the initial escapement build-up in the absence of distortions caused by early openings.

Even in the absence of early openings, a 14 d GN fishery could be allowed in the middle of the steelhead run, potentially causing excessive incidental mortality rates (>21%), and make it difficult (if not impossible) to determine the actual escapement pattern based on test fishing records in the absence of observed reports, and uncertainties about movement patterns and incidental mortality rates. This observation highlights the need to spread the GN fishing impacts over the entire period, ideally using intervals of 5 days or more.

Another major issue of concern is how meet the 80/90 objective if monitoring activities indicate that minimum conservation requirements might not be met. These were estimated at ≈23,000 spawners per year (Tautz et al. 1992). Cumulative Tyee test fishing indices indicated that target escapements were not reached in 1997 and 2005 when test fishing ended in late August (Fig. 4), with total escapements of 12,848 and 17,363 respectively (Anon. 2007). At the time of this writing, no information on this issue had been provided to the author by MoE/DFO officials, but ideally, in-season monitoring should clearly indicate that escapement trends are large enough to justify even the first GN fishery openings. The most risk-adverse policy is to delay openings until the escapement target is reached, and allow openings periodically afterwards using the sliding rule to meet the 80/90 objective. A potential scenario is no openings during the first 3 weeks of the run, then allow openings every 3rd or 4th day afterwards until the end of the escapement period (instead of 5-7) to compensate for the initial delay.

If escapement increases slowly as the season progresses, fishery managers may be pressured to allow terminal fishery openings before the steelhead escapement target is met, at a minimum to harvest surplus sockeye escapement. Even in the sliding rule is used, each opening increases the risk of not meeting the steelhead escapement target. The risk is a complex function of the frequency and timing of terminal fishery openings, the level and distribution of fishing effort, the steelhead run size, the escapement level attained by a certain date, and etc. At the time of this writing, no information on this issue had been provided to the author from MoE/DFO officials, and what procedure would be used to ensure minimum conservations requirements will be met. In the following section, some approaches are proposed to deal with this issue.

4. Discussion

This investigation revealed that historical trends in average daily Tyee test fishing indices provided by DFO for steelhead possibly included kelts. These were removed from the raw data set provided recently. For purposes of consistency, identical data sets should be used to compute trends irrespective of the equation used. Average daily CPUE indices of steelhead escapement for 1956-2008 should be recomputed without kelts to ensure the statistics reported do not suggest greater steelhead returns than detected early in the season.

The present investigation also proposed a slightly different conversion coefficient than used by DFO to link CPUEs of both test-fishing gears. The method used to compute the [alternative] coefficient should be examined by MoE/DFO staff to determine if it is mutually acceptable. And in past seasons when test fishing ended early, the cumulative test fishing indices may not reflect the total steelhead escapement. No information was provided to the author on adjustments made by DFO or MoE staff to deal with this shortcoming, but this issue needs to be addressed.

The results of this investigation suggest that a given escapement pattern (and level) may be difficult to determine before a peak has been detected. And by then, there are no assurances the peak is real or that the distribution is normal and symmetrical. For lack of sufficient time and resources, no further investigations were conducted to determine why some escapement patterns appear to be non-normal. It is possible that the skewed distributions may be common, in which case, efforts should be made to model the escapement distribution patterns using alternative models (Beta, etc.), and determine if non-symmetrical escapement patterns are caused by certain environmental conditions.

Even if the normal distribution turns out to be the best model of escapement patterns, the mean, standard deviation and scaling factor values presented so far are point estimates, and lack corresponding variance estimates. The later could be generated from test fishing catches using bootstrap methods (Efron 1981), but that might be be too late for in-season management purposes, and the results would still not account for incidental losses caused by terminal GN fisheries. Numerical simulations could be conducted using a combination of past escapement patterns, information on fishing plans, gear configurations and handling practices (weed lines, short sets, revival boxes) to provide insight on what could be expected under some conditions, and provide crude measures of the risks of not meeting the escapement target under given scenarios. As noted in the introduction, numerical simulations were conducted in the past for similar purposes (Cox-Rogers 1994), but the results were not considered sufficiently reliable for management and assessment purposes (Walters et al., 2008). An innovative multi-year tagging program recently proposed by Labelle (2009) could provide valuable information to improve the reliability of the simulation results, but the tagging program has yet to be implemented, and the results would only be available after 5+ years of tagging. In light of such facts, trying to quantify the risks of not meeting escapement targets if fishery openings are allowed before the target is met is problematic, and the results might not be acceptable to some.

It should be emphasized that DFO/MoE officials can still agree on mutually acceptable levels of risks that are not based on the results of extensive simulations. The risks can be expressed using simple criteria other than point estimates and their associated confidence intervals. These would mount to simple rules-of-thumb. For instance, do not apply the sliding rule if the cumulative expanded test fishing index is ≤50% of the steelhead escapement target by late August (i.e. minimum conservation goal likely not met). Alternatively, no terminal fishery openings until the cumulative expanded test fishing index reaches 30% of the escapement target by a certain date, then one opening after each additional 15% increment, with maximum GN effort set to have 'negligible' impacts on steelhead (say ≤5% or the abundance detected at Tyee that week), and once the escapement target is reached, allow more openings using the sliding rule to meet the 80/90 objective.

Determining the threshold values for peculiar situations, amounts to agreeing on a level of risk that both agencies (and perhaps stakeholders) are willing to accept when the run size is uncertain, and is an essential step in establishing "stop-light criteria to govern opening fisheries in future years based on abundance indicators" (Anon. 2008). The decision making algorithm used to justify terminal fishery openings when faced with uncertainty should be clearly articulated even before more detailed analyses or simulations are conducted.

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TABLES

Table 1. Daily and cumulative test fishing indices for steelhead during 1989 and 2001. Daily indices are average daily catch rates estimated by means of Eq. 2 (see text for details).

Date	Daily Index 1989	Daily Index 2001	Date	Daily Index 1989	Daily Index 2001	Date	Cumul. Index 1989	Cumul. Index 2001	Date	Cumul. Index 1989	Cumul. Index 2001
21-Jun	0.00		10-Aug	0.29	1.13	21-Jun	0.00	0.00	10-Aug	34.68	47.30
22-Jun	0.87		11-Aug	0.00	0.83	22-Jun	0.87	0.00	11-Aug	34.68	48.13
23-Jun	2.24		12-Aug	1.62	2.31	23-Jun	3.11	0.00	12-Aug	36.30	50.44
24-Jun	1.20		13-Aug	2.19	1.73	24-Jun	4.31	0.00	13-Aug	38.49	52.17
25-Jun	0.31		14-Aug	2.49	2.49	25-Jun	4.62	0.00	14-Aug	40.98	54.66
26-Jun	0.00		15-Aug	1.58	2.24	26-Jun	4.62	0.00	15-Aug	42.56	56.90
27-Jun	0.62		16-Aug	2.63	1.72	27-Jun	5.24	0.00	16-Aug	45.19	58.62
28-Jun	0.90		17-Aug	3.22	3.58	28-Jun	6.14	0.00	17-Aug	48.41	62.20
29-Jun	0.85		18-Aug	2.95	1.73	29-Jun	6.99	0.00	18-Aug	51.36	63.93
30-Jun	0.31	0.00	19-Aug	4.67	1.67	30-Jun	7.30	0.00	19-Aug	56.03	65.60
01-Jul	0.61	0.00	20-Aug	1.77	2.58	01-Jul	7.91	0.00	20-Aug	57.80	68.18
02-Jul	0.00	0.00	21-Aug	0.92	3.99	02-Jul	7.91	0.00	21-Aug	58.72	72.17
03-Jul	0.59	0.00	22-Aug	2.03	2.12	03-Jul	8.50	0.00	22-Aug	60.75	74.29
04-Jul	0.00	0.00	23-Aug	2.22	1.53	04-Jul	8.50	0.00	23-Aug	62.97	75.82
05-Jul	0.00	0.00	24-Aug	2.00	5.69	05-Jul	8.50	0.00	24-Aug	64.97	81.51
06-Jul	0.00	0.00	25-Aug	1.13	3.76	06-Jul	8.50	0.00	25-Aug	66.10	85.27
07-Jul	0.00	0.00	26-Aug	1.67	3.40	07-Jul	8.50	0.00	26-Aug	67.77	88.67
08-Jul	0.00	0.00	27-Aug	3.80	3.59	08-Jul	8.50	0.00	27-Aug	71.57	92.26
09-Jul	0.26	0.00	28-Aug	2.08	1.26	09-Jul	8.76	0.00	28-Aug	73.65	93.52
10-Jul	0.00	0.00	29-Aug	1.89	1.18	10-Jul	8.76	0.00	29-Aug	75.54	94.70
11-Jul	0.00	0.28	30-Aug	1.41	3.53	11-Jul	8.76	0.28	30-Aug	76.95	98.23
12-Jul	0.00	0.00	31-Aug	1.36	1.98	12-Jul	8.76	0.28	31-Aug	78.31	100.21
13-Jul	0.43	0.00	01-Sep	1.35	2.12	13-Jul	9.19	0.28	01-Sep	79.66	102.33
14-Jul	0.43	0.22	02-Sep	0.94	2.30	14-Jul	9.62	0.50	02-Sep	80.60	104.63
15-Jul	0.54	0.40	03-Sep	1.86	2.09	15-Jul	10.16	0.90	03-Sep	82.46	106.72
16-Jul	0.81	0.83	04-Sep	1.41	1.26	16-Jul	10.97	1.73	04-Sep	83.87	107.98
17-Jul	0.00	1.28	05-Sep	0.95	0.44	17-Jul	10.97	3.01	05-Sep	84.82	108.42
18-Jul	0.00	0.59	06-Sep	0.50	1.27	18-Jul	10.97	3.60	06-Sep	85.32	109.69
19-Jul	0.29	0.66	07-Sep	0.63	2.98	19-Jul	11.26	4.26	07-Sep	85.95	112.67
20-Jul	0.00	1.52	08-Sep	0.32	0.45	20-Jul	11.26	5.78	08-Sep	86.27	113.12
21-Jul	0.00	2.01	09-Sep		0.93	21-Jul	11.26	7.79	09-Sep	86.27	114.05
22-Jul	0.41	1.12	10-Sep		1.53	22-Jul	11.67	8.91	10-Sep	86.27	115.58
23-Jul	0.55	1.65	11-Sep		2.79	23-Jul	12.22	10.56	11-Sep	86.27	118.37
24-Jul	0.51	3.02	12-Sep		0.44	24-Jul	12.73	13.58	12-Sep	86.27	118.81
25-Jul	0.52	4.59	13-Sep		0.31	25-Jul	13.25	18.17	13-Sep	86.27	119.12
26-Jul	0.80	3.46	14-Sep		0.63	26-Jul	14.05	21.63	14-Sep	86.27	119.75
27-Jul	0.52	2.46	15-Sep		0.00	27-Jul	14.57	24.09	15-Sep	86.27	119.75
28-Jul	0.83	1.91	16-Sep		0.95	28-Jul	15.40	26.00	16-Sep	86.27	120.70
29-Jul	0.57	3.51	17-Sep		0.97	29-Jul	15.97	29.51	17-Sep	86.27	121.67
30-Jul	2.45	2.01	18-Sep		0.46	30-Jul	18.42	31.52	18-Sep	86.27	122.13
31-Jul	1.84	3.35	19-Sep		3.86	31-Jul	20.26	34.87	19-Sep	86.27	125.99
01-Aug	1.93	0.79	20-Sep		0.95	01-Aug	22.19	35.66	20-Sep	86.27	126.94
02-Aug	1.54	0.80	21-Sep		0.95	02-Aug	23.73	36.46	21-Sep	86.27	127.89
03-Aug	2.32	0.43	22-Sep		0.42	03-Aug	26.05	36.89	22-Sep	86.27	128.31
04-Aug	2.31	3.55	23-Sep		0.00	04-Aug	28.36	40.44	23-Sep	86.27	128.31
05-Aug	0.40	0.69	24-Sep		0.90	05-Aug	28.76	41.13	24-Sep	86.27	129.21
06-Aug	1.37	2.23	25-Sep		0.00	06-Aug	30.13	43.36	25-Sep	86.27	129.21
07-Aug	1.93	2.26	26-Sep		0.00	07-Aug	32.06	45.62	26-Sep	86.27	129.21
08-Aug	1.48	0.00	27-Sep		0.00	08-Aug	33.54	45.62	27-Sep	86.27	129.21
09-Aug	0.85	0.55	28-Sep		1.15	09-Aug	34.39	46.17	28-Sep	86.27	130.36

Table 2. Summary statistics for comparative Tyee test fishing operations, 1996-2001. Gear code 10 is the the multi-filament net used during 1956-2001, while gear code 11 is the mono-filament net used since 2002. The figures under `Number Sets` label are the total sets conducted during 2 d periods each season when both nets were deployed. The Mean, minimum, maximum, and standard deviations (S.D.) of fishing times (F_time) are summary statistics based on 2 d fishing periods when both nets were deployed. Test fishing records provided by Shawn Davies (DFO, Prince Rupert office).

Survey Year	Gear Code	Number Sets	Mean F_Time	Min. F_Time	Max. F_Time	S.D. F_Time
1996	10	47	5.45	1.05	7.80	1.50
	11	47	5.07	1.07	7.84	1.85
1997	10	36	5.78	3.31	8.01	1.30
	11	36	5.25	1.11	8.28	1.87
1998	10	52	5.34	3.41	7.00	1.09
	11	52	5.29	1.09	7.35	1.30
1999	10	33	5.83	2.32	7.99	1.41
	11	33	5.54	1.40	8.09	1.62
2000	10	37	6.32	2.69	10.11	1.63
	11	37	6.26	2.44	10.37	1.61
2001	10	37	6.24	3.92	8.20	1.17
	11	37	6.22	3.94	7.80	1.17

Table 3. Summary of run timing parameter estimates and associated statistics by season for 1956-2008. Day 1 is June 15. Days 40, 50, 60, 70, 80, 90 and 100 respectively represent July 24, Aug. 3, Aug. 13, Aug. 23, Sept. 2, Sept. 12 and Sept 22.

	Mean	St.Dev		Percentiles			
Year	**day_n**	**day_N**	**Scaler**	**1%**	**10%**	**90%**	**99%**
1956	55	18	284	16	32	77	95
1957	62	16	106	25	41	81	97
1958	64	20	293	20	38	88	104
1959	55	16	115	18	33	76	93
1960	53	14	220	21	35	70	84
1961	57	19	194	16	32	82	100
1962	51	15	307	17	31	69	85
1963	46	14	265	15	28	63	78
1964	54	16	191	19	34	74	90
1965	49	14	244	18	31	66	81
1966	46	14	445	15	28	65	80
1967	61	12	334	27	37	76	89
1968	51	13	235	20	33	68	82
1969	62	12	334	33	46	77	90
1970	50	12	354	22	35	64	77
1971	59	14	274	27	41	77	91
1972	55	15	209	21	35	74	90
1973	60	11	196	34	45	74	85
1974	62	16	197	25	42	82	98
1975	63	13	194	32	46	80	93
1976	61	10	342	38	48	73	84
1977	61	19	289	18	35	85	102
1978	55	15	286	22	36	73	88
1979	62	14	174	29	43	79	94
1980	55	13	310	24	38	72	85
1981	47	13	288	21	32	62	74
1982	53	18	433	15	31	76	94
1983	55	18	164	15	31	78	97
1984	52	17	580	17	29	73	91
1985	52	18	406	15	30	74	92
1986	54	15	542	19	33	73	89
1987	69	19	231	25	44	91	105
1988	65	17	587	25	43	86	102
1989	63	16	270	27	43	83	99
1990	54	19	309	14	30	78	96
1991	68	22	161	19	39	92	105
1992	62	24	203	15	33	89	105
1993	59	15	183	24	39	78	93
1994	50	18	292	13	28	72	90
1995	61	13	256	31	44	78	91
1996	54	13	308	24	37	70	84
1997	64	11	205	38	49	78	89
1998	54	18	740	17	33	77	97
1999	66	16	596	28	44	85	101
2000	58	19	628	17	34	82	100
2001	60	16	305	24	39	79	95
2002	60	16	680	24	40	80	96
2003	65	17	365	26	43	86	101
2004	52	14	361	20	34	69	83
2005	54	15	245	20	35	72	87
2006	69	16	442	30	47	89	103
2007	65	14	259	33	47	82	96
2008	62	19	541	20	38	85	101
min.	46	10	106	13	28	62	74
max.	69	24	740	38	49	92	105
mean	58	16	320	22	37	77	92

Table 4. Run time parameter estimates versus corresponding values determined by K-S tests. Figures under the Diff. labels are differences between both estimates. The 'Last day' label denotes the last test-fishing day that year. Difference (in days) between the last test-fishing day and the estimated mean date are given in the last column.

Year	Est. Mean	Est. SD	Corresp. Mean	Corresp. SD	Diff. Mean	Diff. SD	Last day	Diff. Est. Mean
1956	55	18	55	18	0	0	100	45
1957	62	16	60	13	2	3	80	18
1958	64	20	61	17	3	3	90	26
1959	55	16	52	15	3	1	82	27
1960	53	14	52	13	1	1	86	33
1961	57	19	55	18	2	1	84	27
1962	51	15	49	14	2	1	82	31
1963	46	14	45	10	1	4	84	38
1964	54	16	53	16	1	0	82	28
1965	49	14	48	13	1	1	76	27
1966	46	14	45	16	1	-2	76	30
1967	61	12	60	10	1	2	78	17
1968	51	13	50	12	1	1	72	21
1969	62	12	61	10	1	2	78	16
1970	50	12	49	10	1	2	74	24
1971	59	14	56	12	3	2	74	15
1972	55	15	52	14	3	1	72	17
1973	60	11	59	10	1	1	76	16
1974	62	16	59	11	3	5	76	14
1975	63	13	60	10	3	3	74	11
1976	61	10	60	10	1	0	74	13
1977	61	19	55	14	6	5	74	13
1978	55	15	54	12	1	3	76	21
1979	62	14	58	11	4	3	76	14
1980	55	13	53	12	2	1	76	21
1981	47	13	47	11	0	2	74	27
1982	53	18	50	16	3	2	74	21
1983	55	18	52	15	3	3	76	21
1984	52	17	49	17	3	0	74	22
1985	52	18	50	17	2	1	78	26
1986	54	15	51	14	3	1	72	18
1987	69	19	68	14	1	5	84	15
1988	65	17	62	15	3	2	88	23
1989	63	16	62	14	1	2	86	23
1990	54	19	53	17	1	2	88	34
1991	68	22	61	15	7	7	82	14
1992	62	24	60	21	2	3	88	26
1993	59	15	58	14	1	1	98	39
1994	50	18	49	17	1	1	76	26
1995	61	13	60	11	1	2	80	19
1996	54	13	54	13	0	0	92	38
1997	64	11	61	10	3	1	72	8
1998	54	18	51	17	3	1	108	54
1999	66	16	64	17	2	-1	108	42
2000	58	19	56	18	2	1	108	50
2001	60	16	54	13	6	3	72	12
2002	60	16	58	13	2	3	78	18
2003	65	17	64	17	1	0	104	39
2004	52	14	50	12	2	2	72	20
2005	54	15	51	13	3	2	72	18
2006	69	16	67	15	2	1	92	23
2007	65	14	61	10	4	4	72	7
2008	62	19	62	19	0	0	106	44
Mean					2.1	1.8		

Table 5. Example of calculations to determine the proportions of the runs that escaped each day passed Tyee during 2000-2008, based on figures generated using the run timing parameter estimates for each season. The terms 90, 5, and 50 percentiles of the distribution of daily proportions are given in the 3 rightmost columns. These values are multiplied by 100 to represent percentages on the run.

DATE	CD	2000	2001	2002	2003	2004	2005	2006	2007	2008	DATE	90 Perc.	5 Perc.	50 Perc.
15-Jun	1	0.00023	0.00003	0.00003	0.00002	0.00004	0.00005	0.00000	0.00000	0.00012	15-Jun	0.01437	0.00017	0.00278
16-Jun	2	0.00027	0.00003	0.00003	0.00002	0.00005	0.00007	0.00000	0.00000	0.00014	16-Jun	0.01693	0.00022	0.00349
17-Jun	3	0.00032	0.00004	0.00004	0.00003	0.00006	0.00008	0.00001	0.00000	0.00017	17-Jun	0.01989	0.00030	0.00437
18-Jun	4	0.00037	0.00005	0.00005	0.00004	0.00008	0.00010	0.00001	0.00000	0.00020	18-Jun	0.02331	0.00039	0.00545
19-Jun	5	0.00043	0.00007	0.00007	0.00005	0.00010	0.00013	0.00001	0.00000	0.00023	19-Jun	0.02724	0.00051	0.00677
20-Jun	6	0.00050	0.00008	0.00008	0.00006	0.00013	0.00016	0.00001	0.00000	0.00027	20-Jun	0.03175	0.00067	0.00838
21-Jun	7	0.00057	0.00010	0.00010	0.00007	0.00016	0.00020	0.00001	0.00001	0.00032	21-Jun	0.03689	0.00087	0.01033
22-Jun	8	0.00066	0.00013	0.00013	0.00008	0.00020	0.00024	0.00002	0.00001	0.00037	22-Jun	0.04276	0.00113	0.01268
23-Jun	9	0.00075	0.00016	0.00016	0.00010	0.00025	0.00030	0.00002	0.00001	0.00043	23-Jun	0.04942	0.00146	0.01551
24-Jun	10	0.00086	0.00019	0.00019	0.00013	0.00032	0.00036	0.00003	0.00001	0.00050	24-Jun	0.05697	0.00187	0.01889
25-Jun	11	0.00098	0.00023	0.00023	0.00015	0.00039	0.00044	0.00003	0.00002	0.00057	25-Jun	0.06548	0.00240	0.02292
26-Jun	12	0.00112	0.00028	0.00028	0.00018	0.00048	0.00053	0.00004	0.00002	0.00066	26-Jun	0.07506	0.00307	0.02770
27-Jun	13	0.00127	0.00033	0.00033	0.00022	0.00059	0.00063	0.00005	0.00003	0.00075	27-Jun	0.08581	0.00391	0.03335
28-Jun	14	0.00144	0.00040	0.00040	0.00026	0.00072	0.00076	0.00007	0.00004	0.00086	28-Jun	0.09783	0.00496	0.03999
29-Jun	15	0.00162	0.00048	0.00048	0.00031	0.00087	0.00091	0.00008	0.00005	0.00098	29-Jun	0.11123	0.00626	0.04777
30-Jun	16	0.00182	0.00057	0.00057	0.00037	0.00104	0.00107	0.00010	0.00006	0.00112	30-Jun	0.12611	0.00787	0.05683
01-Jul	17	0.00205	0.00067	0.00067	0.00044	0.00125	0.00127	0.00013	0.00008	0.00127	01-Jul	0.14260	0.00986	0.06736
02-Jul	18	0.00229	0.00080	0.00080	0.00051	0.00149	0.00149	0.00016	0.00010	0.00144	02-Jul	0.16523	0.01231	0.07953
03-Jul	19	0.00255	0.00094	0.00094	0.00060	0.00177	0.00175	0.00019	0.00013	0.00162	03-Jul	0.19279	0.01529	0.09352
04-Jul	20	0.00284	0.00110	0.00110	0.00071	0.00209	0.00204	0.00023	0.00016	0.00182	04-Jul	0.22409	0.01893	0.10955
05-Jul	21	0.00315	0.00128	0.00128	0.00082	0.00246	0.00236	0.00028	0.00020	0.00205	05-Jul	0.25947	0.02333	0.12783
06-Jul	22	0.00349	0.00149	0.00149	0.00096	0.00287	0.00273	0.00033	0.00025	0.00229	06-Jul	0.29925	0.02863	0.14857
07-Jul	23	0.00385	0.00172	0.00172	0.00111	0.00333	0.00314	0.00040	0.00032	0.00255	07-Jul	0.34374	0.03499	0.17201
08-Jul	24	0.00423	0.00198	0.00198	0.00128	0.00386	0.00360	0.00048	0.00039	0.00284	08-Jul	0.39321	0.04258	0.19837
09-Jul	25	0.00465	0.00228	0.00228	0.00147	0.00444	0.00410	0.00057	0.00048	0.00315	09-Jul	0.44792	0.05159	0.22788
10-Jul	26	0.00508	0.00261	0.00261	0.00169	0.00508	0.00466	0.00067	0.00059	0.00349	10-Jul	0.50806	0.06225	0.26076
11-Jul	27	0.00555	0.00297	0.00297	0.00193	0.00579	0.00526	0.00080	0.00072	0.00385	11-Jul	0.55951	0.07478	0.29721
12-Jul	28	0.00604	0.00337	0.00337	0.00220	0.00656	0.00592	0.00094	0.00087	0.00423	12-Jul	0.61405	0.08944	0.33744
13-Jul	29	0.00655	0.00382	0.00382	0.00249	0.00739	0.00663	0.00110	0.00104	0.00465	13-Jul	0.67837	0.10650	0.38163
14-Jul	30	0.00709	0.00430	0.00430	0.00282	0.00829	0.00739	0.00128	0.00125	0.00508	14-Jul	0.75738	0.12625	0.42991
15-Jul	31	0.00765	0.00482	0.00482	0.00318	0.00925	0.00821	0.00149	0.00149	0.00555	15-Jul	0.84173	0.14886	0.48242
16-Jul	32	0.00823	0.00539	0.00539	0.00357	0.01027	0.00907	0.00172	0.00177	0.00604	16-Jul	0.93120	0.17406	0.53923
17-Jul	33	0.00884	0.00600	0.00600	0.00399	0.01135	0.00998	0.00198	0.00209	0.00655	17-Jul	1.02546	0.20265	0.60038
18-Jul	34	0.00946	0.00666	0.00666	0.00445	0.01247	0.01093	0.00228	0.00246	0.00709	18-Jul	1.12410	0.23494	0.66586
19-Jul	35	0.01009	0.00736	0.00736	0.00495	0.01363	0.01192	0.00261	0.00287	0.00765	19-Jul	1.22658	0.27120	0.73561
20-Jul	36	0.01074	0.00809	0.00809	0.00548	0.01483	0.01295	0.00297	0.00333	0.00823	20-Jul	1.33227	0.31171	0.80948
21-Jul	37	0.01140	0.00887	0.00887	0.00604	0.01605	0.01399	0.00337	0.00386	0.00884	21-Jul	1.44045	0.35673	0.88731
22-Jul	38	0.01207	0.00969	0.00969	0.00665	0.01728	0.01506	0.00382	0.00444	0.00946	22-Jul	1.55027	0.40647	0.96883
23-Jul	39	0.01274	0.01054	0.01054	0.00729	0.01852	0.01613	0.00430	0.00508	0.01009	23-Jul	1.66083	0.46114	1.05371
24-Jul	40	0.01340	0.01142	0.01142	0.00796	0.01974	0.01721	0.00482	0.00579	0.01074	24-Jul	1.77112	0.52088	1.14156
25-Jul	41	0.01407	0.01232	0.01232	0.00866	0.02093	0.01827	0.00539	0.00656	0.01140	25-Jul	1.88009	0.58578	1.23191
26-Jul	42	0.01473	0.01324	0.01324	0.00940	0.02208	0.01931	0.00600	0.00739	0.01207	26-Jul	1.98662	0.65587	1.32423
27-Jul	43	0.01538	0.01418	0.01418	0.01016	0.02318	0.02033	0.00666	0.00829	0.01274	27-Jul	2.08957	0.73112	1.41792
28-Jul	44	0.01601	0.01512	0.01512	0.01094	0.02420	0.02130	0.00736	0.00925	0.01340	28-Jul	2.18779	0.81141	1.51232
29-Jul	45	0.01661	0.01607	0.01607	0.01175	0.02515	0.02221	0.00809	0.01027	0.01407	29-Jul	2.28015	0.89654	1.60671
30-Jul	46	0.01720	0.01700	0.01700	0.01257	0.02600	0.02307	0.00887	0.01135	0.01473	30-Jul	2.36553	0.98622	1.70034
31-Jul	47	0.01776	0.01792	0.01792	0.01340	0.02674	0.02385	0.00969	0.01247	0.01538	31-Jul	2.44288	1.08005	1.77571

FIGURES

Figure 1. Relation between two Tyee test fishing abundance indices based on the 1996-2001 catches records for two different nets (multifilament=old, monofilament=new). The indices are the total number of steelhead caught (in pieces) over a two day test-fishing period, divided by the total test fishing time, and adjusted for a 6 h fishing period (see text for details).

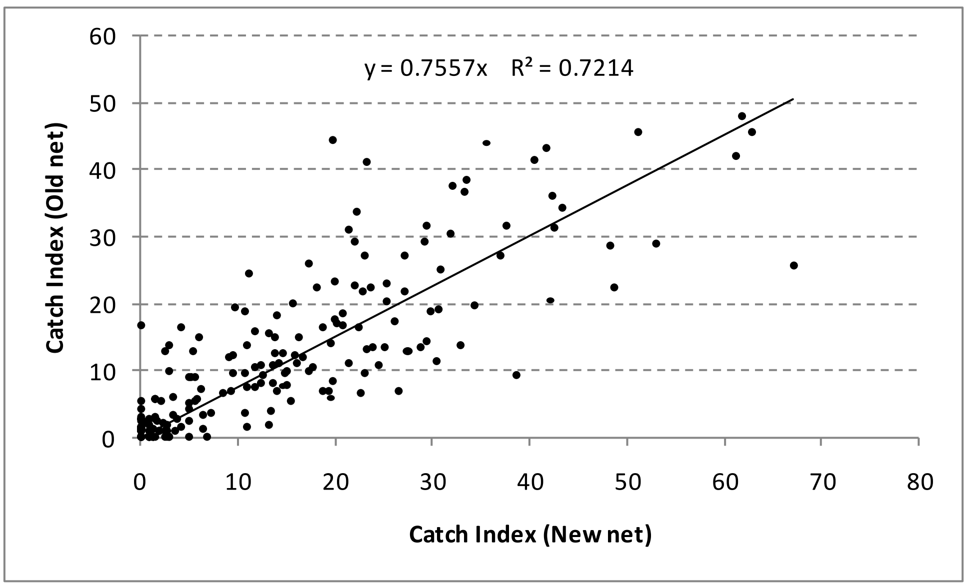

Figure 2. Temporal changes in the estimated parameter values, 1956-2008. Regression lines given for visualization purposes only, and do not imply a linear relation between sequential periods and the parameter values.

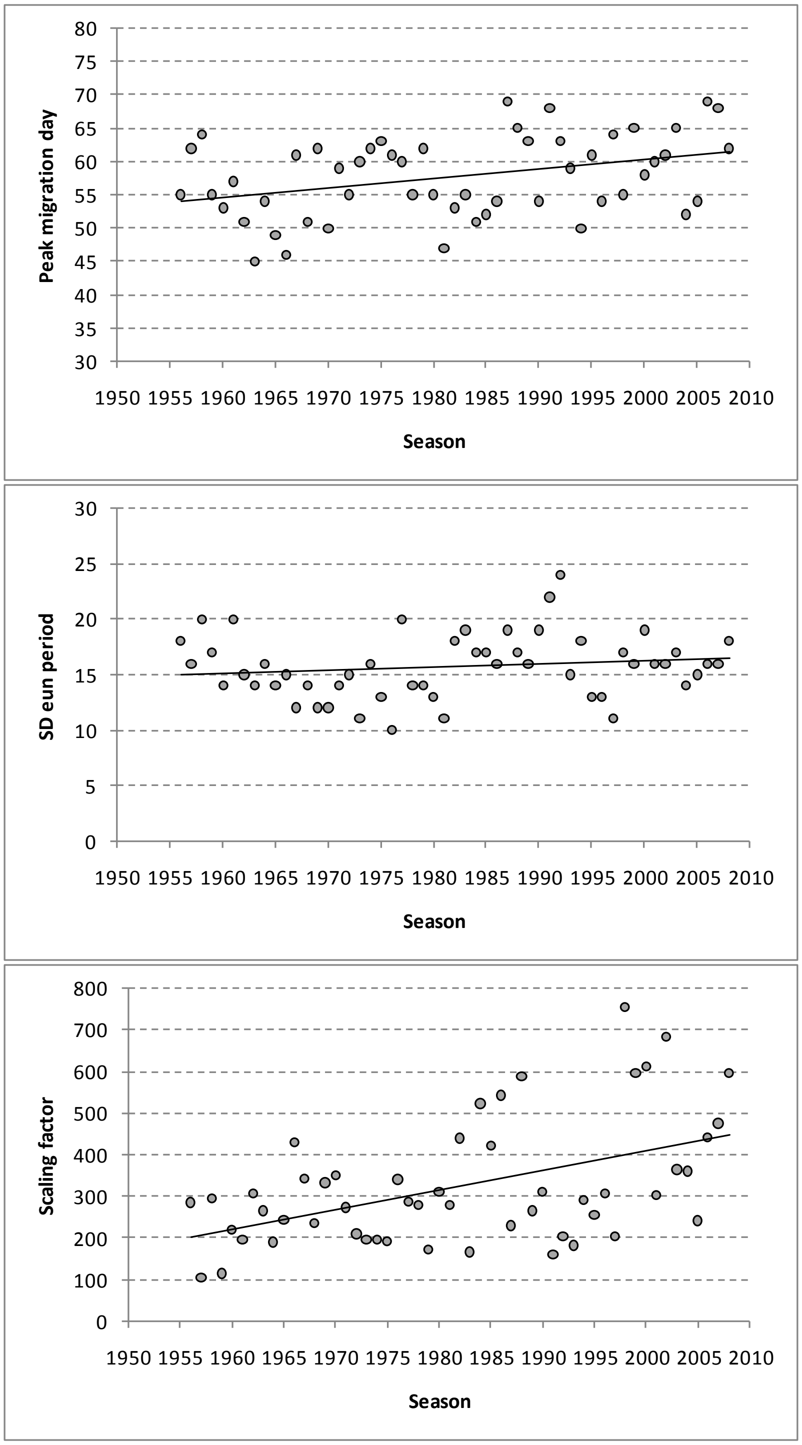

Figure 3. Examples of a typical Tyee test fishing catch patterns for a reasonably well represented by a normal distribution (top), and less common patterns that are seemingly skewed or bimodal (middle, lower). All catches are adjusted figures for fixed 6 h test fishing period over 2 successive days.

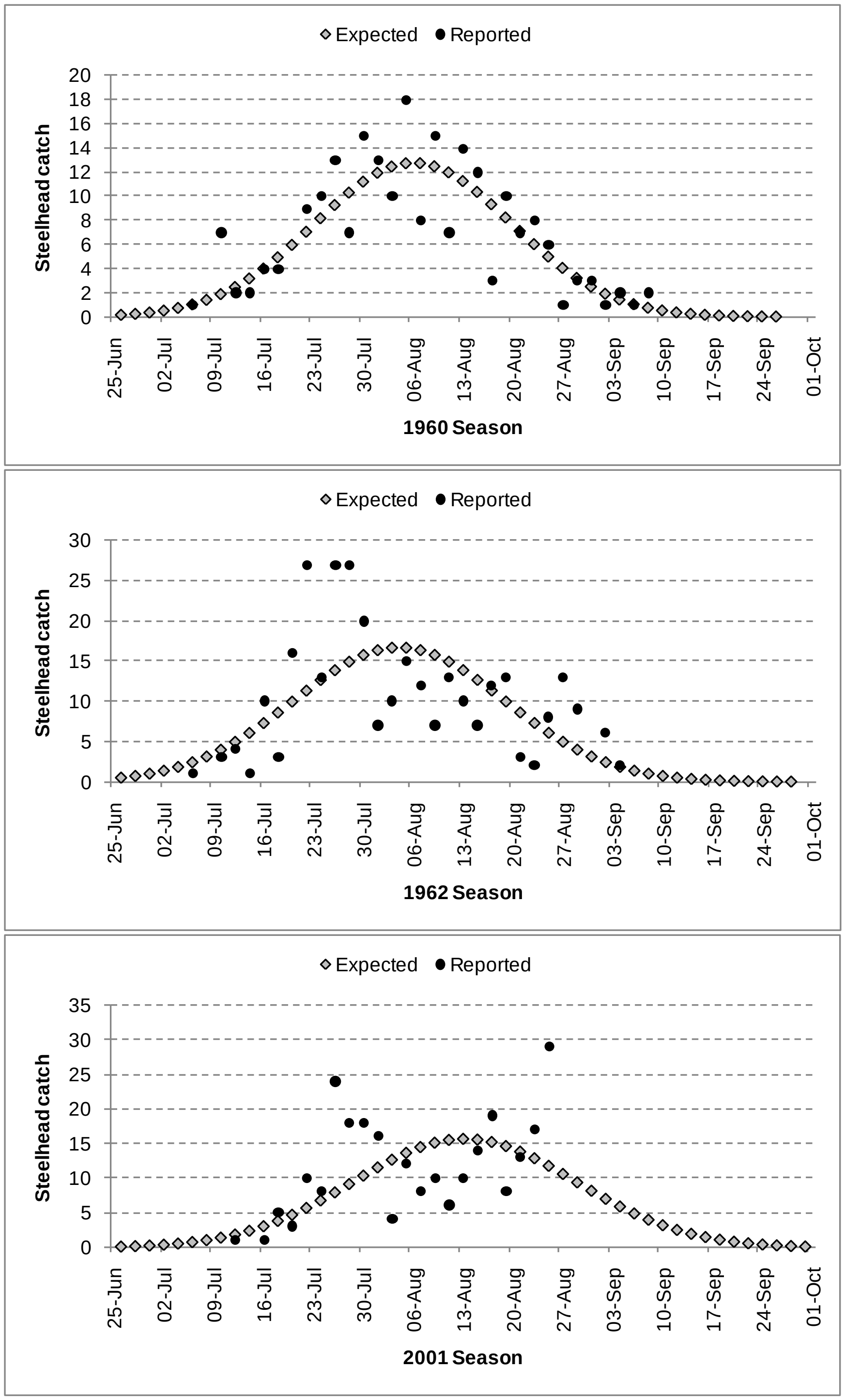

Figure 4. Observed and expected Tyee test fishing catch patterns for selected seasons referred to in the text. All catches are adjusted figures for fixed 6 h test fishing period over 2 successive days.

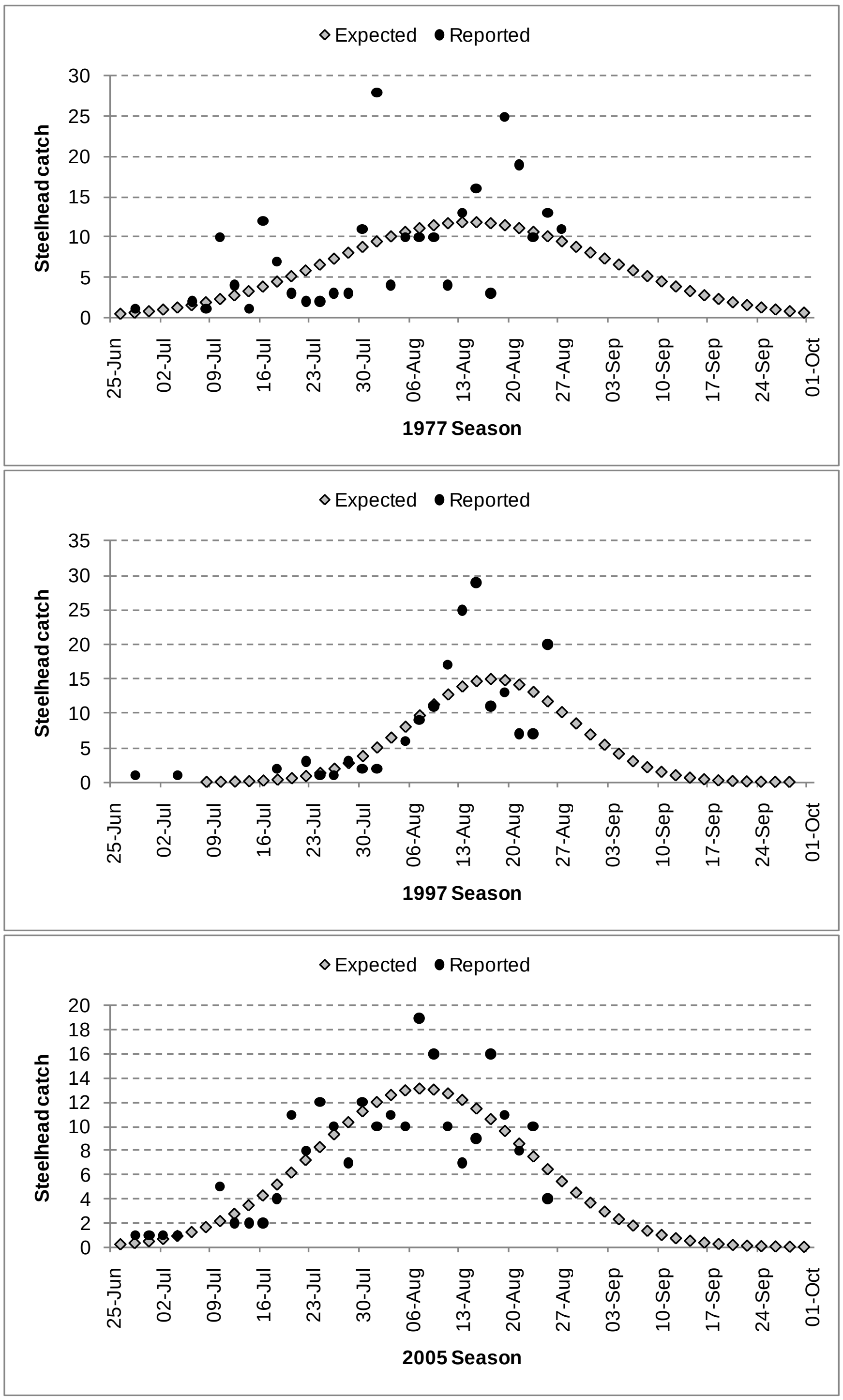

Figure 5. Differences between peak (mean) run time estimates, and the corresponding figures based on a statistical comparison of the actual and plausible cumulative Tyee catch distributions. The ordinate represents the difference between the last test-fishing period and that of peak run timing (in days). The abscissa represents the difference between the estimated peak run period (mean date) and that of the closest plausible catch distribution (in days, each point is one year).

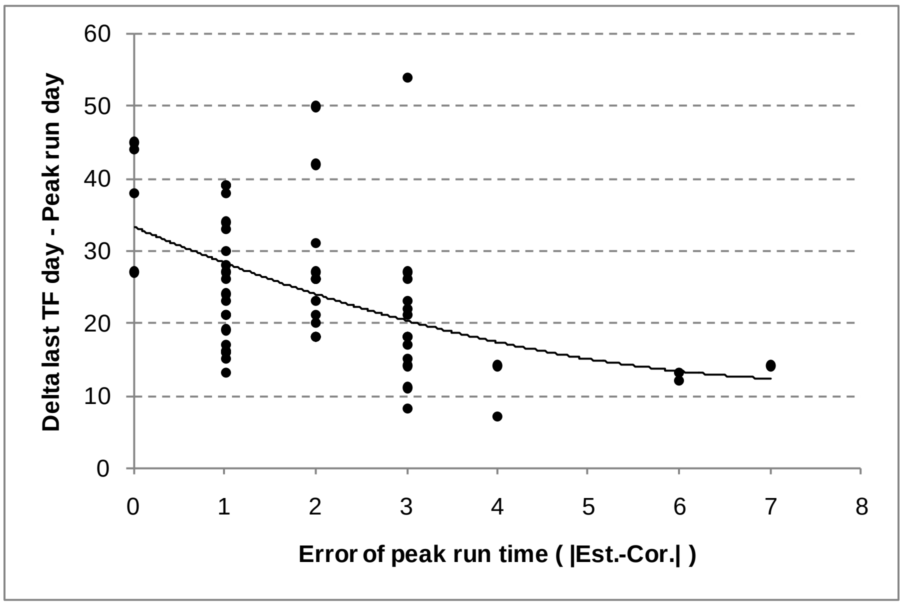

Figure 6. Proportions of the runs that escaped each day passed Tyee during 1956-2008, based on figures generated using the run timing parameter estimates for each season. The bars represent the 10th and 90th percentiles of the distribution of daily proportions, and the mid-point represents the median (50th percentile). All proportions multiplied by 100 to represent percentages on the run.