Fishing Mortality Trends for Thompson River Steelhead from 1991 to 2015

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1. Abstract

The Thompson steelhead sport fishery is one of the provinces' most highly-regarded sport fisheries. The steelhead stocks that support this fishery have been in a state of low abundance since the late 1980's and have been in a state of Conservation Concern since 2005. Consequently, the sport fishery is limited to catch and release or closed if in-season abundance estimates fail to exceed conservation abundance thresholds. Some southern BC and Washington State salmon fisheries are known to intercept Thompson steelhead. These fisheries are gillnet and purse seine fisheries that target salmon stocks which share migration routes and timing with Thompson River steelhead. This analysis serves to provide some insight into the level and trends in steelhead fishing mortality. A simulation model is used where input parameters, associated with migration timing, migration rate, and salmon fishing effort, are updated annually. The fisheries simulated include gillnet and purse seine fisheries in Johnstone Straits, gillnet fisheries along the west coast of Vancouver Island near Nitinat, US Juan de Fuca and north Puget Sound gillnet and purse seine fisheries, Fraser River gillnet fisheries, and the Thompson steelhead sport fishery. Results indicate that indices of fishing mortality and encounter rates are trending upward despite declining trend in steelhead abundance toward Extreme Conservation Concern levels. Simulation results suggest that fishing patterns like those in 2015, when only chum salmon are targeted, results in the encounter of about 3/8 fraction of the steelhead run with gillnet and purse seine fisheries and an annual reduction in abundance of about 1/5 of the run due to fishing mortality effects. By contrast, fishing patterns like in 2013 and 2014 when pink salmon or late-run Fraser sockeye are targeted in addition to chum salmon, such fishing patterns result in the encounter of about ½ of the steelhead run with gillnet and purse seine fisheries and an

annual reduction in abundance of about ¼ of the steelhead run due to fishing mortality effects. The recent increasing trend in steelhead fishing mortality is a result of increased fisheries targeting pink salmon in 2013 and increased fisheries targeting late-run Fraser sockeye in 2014, both of which affect the early part of the steelhead run. The increasing trend in steelhead fishing mortality is also the result of the removal of a steelhead conservation measure on the Fraser River commercial chum salmon fishery which affects the peak and latter part of the steelhead run.

2. Introduction

British Columbia provincial government policy for steelhead specifies the use of abundance reference points to describe the status of steelhead and to guide management decisions. In recent years, the abundance of Thompson River steelhead, which is population aggregate of 4 main individual spawning populations, has declined from thousands to as few as 430 spawners (file data, BC Ministry of Forests, Lands and Natural Resource Operations). In accordance with the classification system specified in the Provincial Steelhead Stream Classification Policy, this group of stocks is presently classified as "Conservation Concern" (Johnston 2013).

The Thompson steelhead sport fishery is one of the provinces' most highly-regarded sport fisheries. It is regulated by the provincial Ministry of Forests, Lands and Natural Resource Operations (FLNRO). The retention of steelhead is prohibited and the fishing opportunity is implemented in the form of a catch and release fishery. From 2004 to 2013, catch and release fishing remained closed until in-season forecasts of spawners abundance became available sometime during the month of October which is partway during the early part of the sport fishing season. If an in-season forecast of spawner abundance exceeded 850, the fishery opened. In 2014, this regulation approach was modified to where catch and release opportunity is open during the early season until October 31 and extension to the traditional season end date of December 31 occurs if forecast of spawner abundance exceeds 850.

Some southern BC and Washington State salmon fisheries are known to intercept Thompson steelhead (Anonymous 1998). These fisheries are gillnet and purse seine fisheries that target salmon stocks which co-migrate with Thompson River steelhead. These fisheries include those that target Fraser chum salmon stocks, but can also include fisheries that target pink salmon and late-run Fraser sockeye. The potential fishing mortality resulting from the combined effect of these fisheries can far exceed that which is administered by catch and release sport fishing (Anonymous 1998). In Canada, these fisheries are administered by the federal Department of Fisheries & Oceans (DFO). In Washington State, they are administered by the Washington Department of Fish & Wildlife and the Northwest Indian Fisheries Commission.

In recent years, fishery management objectives for Thompson steelhead have been included in annual management plans for southern BC salmon fisheries (Anonymous 2013). Presently, objectives for *Thompson* steelhead are accounted for as objectives for "Interior Fraser Steelhead" which is a grouping comprised of at least 10 populations grouped into 3 conservation units of which Thompson is one conservation unit containing 4 main populations (Parkinson et. al. 2005). Thompson and Chilcotin watersheds contain the larger population aggregates in comparison to populations that exist in the Bridge, Seton, Stein and Nahatlatch watersheds. Presently, the fishery management objective for Interior Fraser Steelhead is to minimize the impact of Canadian fisheries and to increase spawner abundance. In Canadian salmon fisheries, commercial fishers are required to release all steelhead caught even though mortality rate per release event is assumed to range from 20% for purse seine to 50% or 60% gillnet, depending on the fishery. The expected outcome of this objective is to ensure the combined escapement of Thompson and Chilcotin river steelhead exceeds 1250. Johnston (2013) has since estimated a conservation concern threshold abundance of about 2000 Thompson and Chilcotin steelhead spawners. Pre-fishery abundances are expected to be largely influenced by marine survival trends and variability. For both the Thompson and Chilcotin, favourable marine survival periods can produce many thousands of steelhead for each of these stock aggregates.

For Washington State, there are no explicit fishery objectives or plans that exist at this time that acknowledge or address Thompson steelhead or Interior Fraser steelhead other than the Pacific Salmon Treaty acknowledges that "in fulfilling their functions, the Panels and Commission shall take into account the conservation of steelhead" (Anonymous 2009). The reference to steelhead is general and applicable to all Pacific salmon fisheries subject to the Treaty.

It is noteworthy that not all fisheries are included in this analysis, particularly fisheries that are considered to be "selective", meaning that the mortality rate is considered to be immaterial and assumed to be zero. These include fisheries like beach seine fisheries, fishwheel fisheries, and troll fisheries. This analysis focuses on those fisheries that are known to intercept Thompson River steelhead and those that can potentially cause a material amount of fishing mortality, either on their own or cumulatively. As such, this analysis takes a single species approach from the perspective of the bycatch species. A complete analysis of the selectivity of the Fraser late-run Sockeye fishery and the Southern BC Pink and Southern BC Chum fisheries would include all fisheries including those in the times and places that these steelhead do not occur and in fisheries where the gear does not catch steelhead or does not cause mortalities. Such an analysis, from both the target species and steelhead perspective is required to provide a complete assessment of selectivity of the various salmon fisheries.

3. Methods

The methodology follows that described in Bison (2007) and is referred to in this text as the "simulation model". Described simply, this is a box-car type model that simulates the migration of fish through space and time. The simulation model includes assumptions about uncertainty in model parameters as well as stochastic processes. Plausible ranges of the estimated fishing mortality, encounter and exposure rate indices are computed using Monte Carlo simulation. The model is not structured as an estimation model due to numerous steelhead specific data limitations, mainly with respect to fishery specific catchabilities but also with respect to migration diversion rate and fishery specific mortality rate parameters. In the absence of steelhead catchability parameters, catchability parameters based on salmon are used. However, it is noteworthy that catchability parameters for a given fishery can vary greatly between species. For example in the Fraser River, catchability of steelhead in a chum gillnet fishery appears to be about 3-fold higher for steelhead than what might otherwise be assumed if chum salmon catchabilities are used for steelhead (Bison 2007). Fraser River gillnet is the only location and gear type where catchability for Thompson and other interior Fraser River steelhead can be compared to other salmon species. Therefore given the large number of fisheries in which such comparisons are not possible, the fishing mortality indices generated by the simulation model only helps to provide a rough insight into the level of fishing mortality for a given season. Over time, the relative change in indices of fishing mortality, encounter or exposure rate is informative about whether fishing mortality is simply increasing or decreasing.

Bison (2007) reports that run timing parameters are the major factors influencing fishing mortality rate indices, given how the model is structured. The new input parameters specific to the 2015 simulation model include the mean date of arrival (denoted as $\bar{d}_{fk}$ in Bison 2007), the standard deviation of run timing (σ_{fk}), their respective distributions, as well as the effort data for Area 12 and 13 gillnet and purse seine fisheries, Area 21 gillnet fisheries, US Area 4b, 5 and 6c gillnet fisheries, US Area 7 and 7a gillnet and seine fisheries, Area 29 gillnet fisheries, and aboriginal drift gillnet and set gillnet fisheries in the lower Fraser River up to Sawmill Creek. Fraser River temperature data is also updated as a daily average time series for the 2015 fall migration season. In the model, temperature influences migration speed of steelhead in the Fraser River by way of an empirical regression (Renn *et al.* 2001).

All other parameter values and parameter distributions are as previously reported (Bison 2007; Table 10).

3.1. Model for Estimating Run Timing Parameters

A statistical model is used to estimate run timing parameters. The relative distribution of daily test fishery catch is predicted by assuming that the run is distributed according to a normal distribution function. The relative number of fish arriving by time t is:

(1)
$$N_t = \frac{1}{\sigma\sqrt{2\pi}}\exp\left(-\frac{(t-d)}{2\sigma^2}\right)$$

where d is the peak migration date akin to $\bar{d}_{fk}$ and σ is the spread of the run akin to σ_{fk} as reported in Bison (2007).

The predicted number of fish caught by the test fishery on a particular day *t* is assumed to be proportional to the relative number of fish present in the sampling area (N_t). However, the test fishery is scheduled to fish with "chinook" sized gillnet mesh on one day and with "chum" sized gillnet mesh on the alternating day up to around October 21st afterwhich the chum gillnet is fished on a daily basis. The mesh sizes are 8" for the chinook test fishery and 6.75" for the chum test fishery. Therefore, the predicted number of fish caught in the chinook test fishery on a particular day *t* is assumed to be proportional to the relative number of fish present in the sampling area (N_t) multiplied by a scaling coefficient (q') and the predicted number of fish caught in the chum test fishery on a particular day is assumed to be proportional to the relative number of fish present in the sampling area (N_t), multiplied by *different* scaling coefficient (q''), one that is specific to the chum net:

(2)
$$C_t' = q'N_t$$

(3)
$$C_t'' = q''N_t$$

By combining equations (1), (2) and (3), deterministic predictions are made about the number of fish caught in the each of the two test fisheries on any given day. These predictions are therefore a function of 4 parameters: mean day of arrival (d), standard deviation on the mean day of arrival (σ) and two catchability coefficients (q' and q'').

I assume deterministic dynamics as represented by the statistical model and I assume that all errors were in the respective observation models. Observation error is assumed to be Poisson distributed:

(4) $$x_t' = q'N_t + e_t$$

(5) $$x_t'' = q''N_t + e_t$$

where x_t' and x_t'' are the observed daily steelhead catch data in the chinook and chum test fisheries, respectively.

The likelihood of the daily number of fish caught (x_t' and x_t'') given the parameters is:

(6) $$L\left(x', x''\middle|d, \sigma, q', q''\right) = \prod \frac{e^{-C_t'} C_t'^{x_t}}{x_t'!} * \prod \frac{e^{-C_t''} C_t''^{x_t}}{x_t''!}$$

Simulation with known parameters indicates that this estimation model is unbiased with respect to the estimation of peak migration date (*d*), however it is positively biased with respect to the estimation of the spread of the run (σ). The amount of overestimation of σ is a function of abundance and catchabilities. Assuming the average catchability of the chum and chinook nets, overestimation of σ is inversely proportional to abundance for abundances greater than 500. Minimum abundances observed to date are about 500, therefore σ is expected to be overestimated by about 20% in such years. At abundances of 1000 and 2000, σ is expected to be overestimated by 16% and 12% respectively. The maximum likelihood estimate of σ as noted in equation 6 is therefore adjusted for estimation bias given the relationship between bias and abundance.

The historical test fishery records contain daily catch data for test fishing years 1983 to 2014. Maximum likelihood estimates (MLE's) of mean day of arrival (*d*) and standard deviation on mean day of arrival (σ) are derived from the test fishery time series for each year using the methods described above. The distribution of annual estimates of both *d* and σ are positively skewed and therefore the historical average of *d* and σ across years is computed from log-transformed values of *d* and σ .

To estimate run timing parameters for 2015, prior knowledge is incorporated in the form of uniform prior distributions for each run timing parameter (*d* and σ) within the range of the 1st and 99th percentiles of the respective lognormal distributions. The prior distribution for the catchability coefficients (q' and q'') is set as a uniform prior between the values of 1 and 100, implying no prior knowledge for these parameters.

To compute a description of the uncertainty for *d* and σ, Bayes posterior distributions are computed by simple Monte Carlo integration (Hilborn and Mangel, 1997; Gelman et al. 1995). Ten thousand simulations are used to estimate these parameter distributions which are then used as inputs in the simulation model.

3.2. Simulations of Encounter and Exposure Rates

As structured, the model is most sensitive to the run timing, migration rate and diversion rate parameters and much less sensitive to the large number of parameter and parameter distribution assumptions for catchability and release-mortality-rate parameters for each of the fisheries. Run timing and migration rate parameters are supported with steelhead data. Diversion rate is an unknown and the major data limitations are with respect to catchability and, to a lesser extent, release mortality parameters. Therefore, alternative indices of fishing pressure that are more in-keeping with the availability of steelhead data are the proportion of the run encountering gillnet and purse seines and the proportion of the run exposed to potential capture. While still not an "estimation model" per se, these measures (particularly exposure rate) are more in keeping with the available steelhead data and serves to inform as the extent to which the scheduling of fisheries is potentially limiting fishing mortality rather than relying on the extent by which effort, catchability or handling effects are limiting that mortality – all of which are model processes for which steelhead data remain largely unavailable.

For the simulations of encounter rate, mortality rate parameters are set to a value of 1. For simulations of exposure rate, catchability as well as mortality rate parameters are set to values of 1. Run timing parameter distributions are those estimated from the analysis of the test fishery catch data as described above. Diversion rate is assumed to be unknown and assigned a uniform distribution of 0 to 1. A diversion rate of 0 means all the fish migrate through Juan de Fuca Strait and a diversion rate of 1 means all the fish migrate through Johnstone Strait , and intermediate values is the proportion migrating through Johnstone Strait. All other parameters are set to their deterministic values as reported in Bison (2007).

4. Results

4.1. Run Timing

The average and median peak dates at Albion for the period from 1991 to 2014 are October 10. The average and median statistics for the spread of the run timing (measured as the standard deviation of the normal run timing model) are 15 and 14 days, respectively (Table 1). The standard deviations for each run timing parameter are 7.3 days and 4.5 days for d and σ, respectively. Based on these results, prior knowledge of run timing is incorporated into the estimation of run timing for 2015 as follows: for d, a uniform prior between September 22 and October 28 is assumed and for σ, a uniform prior between 2 and 25 days is assumed.

The estimated peak date of arrival in 2015 at Albion is October 16 which is 6 days later than the average for years 1991-2014. The 95% posterior interval for peak day is from October 2 to October 27. The estimated standard deviation in 2015 is 15 days and the 95% posterior interval for standard deviation is 9 to 27 days. However these estimates may be biased on account of Fraser River Licence Area E commercial gillnet fisheries that occurred in and about the test fishing site on October 23 and October 27. In order to account for potential bias in run timing estimation on account of the effects of these commercial fisheries, catch data from October 23 to November 3 are omitted and run timing parameters are re-estimated. Using these data, the estimated mean date of arrival in 2015 at Albion is October 17 which is 7 days later than the average for years 1991 to - 2014 (Figure 1). The 95% posterior interval for mean day is from October 5 to October 28 (Figure 2). The estimated standard deviation in 2015 is 13 days and the 95% posterior interval for standard deviation is 9 to 25 days. (Figure 3).

The run timing parameters for the simulation model are defined as the peak date of arrival at the northern tip of Vancouver Island rather than the peak date at Albion. To compute the peak date at the northern tip of Vancouver Island, the migration time between Albion and the northern tip of Vancouver Island is used according to the migration rate parameters in the deterministic version of the simulation model (Bison 2007). The mean date at the northern tip of Vancouver Island that corresponds to an October 17 peak date at Albion in 2015 is September 23. So for the simulation model input, the posterior distribution for mean date is advanced in time accordingly (95% posterior interval September 7 to October 3). The mean date at the northern tip of Vancouver Island that corresponds to the historical average peak date of October 10 is September 17.

4.2. Effort

In southern BC salmon fisheries, effort directed at co-migrating stocks like Fraser late-run sockeye, Fraser pink and Fraser chum generally corresponds to the period from August 15 to November 20 depending on the area. Table 2 lists effort in the various gillnet and purse seine fisheries and illustrates it in relation to the estimated Interior Fraser steelhead migration period (shaded cells). The dark shaded cell in the center of the range illustrates the estimated average peak-date derived from the Albion test fishery data for the monitoring time frame 1984 to 2014 and adjusted spatially according to steelhead migration rates (Renn et al. 2001). The lightly shaded cells illustrate the expected duration of 95% of the run. In 2015, fishing effort relative to steelhead migration time is distributed almost entirely on the latter part of the run. The 2015 season is a sub-dominant late-run Fraser sockeye cycle year and a high Fraser pink cycle year. However returns of both late-run Fraser sockeye were less than 20% of preseason forescast and returns of Fraser pink were about 40% preseason forecast. Consequently, there was very little salmon fishing early in the steelhead run.. Fishing during the peak and latter part of the run targets chum salmon. There are a total of 2600 vessel-days or net-days in 2015 that corresponds to the expected timing of 95% of the steelhead run. This compares to 3868 net-days in 2011, the prior sub-dominant cycle year for late-run Fraser. Chronologically, net days from 2012 to 2015 are 1968, 3006, 8756, and 2600, respectively. These correspond to the cyclical pink/sockeye sequences off year late-run sockeye/off year pink (2012), off year late-run sockeye/dominant pink (2013), dominant late-run sockeye/off year pink (2014), and of sub-dominant late-run sockeye/dominant pink (2015), respectively.

Of special note is the purse seine fishery in Area 29. In 2015, the fishery was directed at pink salmon in early September and at chum salmon on October 26 and 27. Purse seines were re-introduced into Area 29 in 2009 after many years of no fishing. Openings have occurred annually since then. Fisheries in 2009 and 2011 were directed to harvest Fraser pink and sockeye salmon while fisheries in 2010 were directed to harvest Fraser sockeye. Pink salmon fisheries were regulated under ITQ guidelines. 2012 was the first year since reintroduction of the fishery in which chum salmon were targeted. In 2013, the fishery was directed at pink salmon in early and mid-September and at chum salmon in a single opening on October 17. Catchability parameters for this fishery do not exist and consequently this fishery is not accounted for in the simulations.

The effort and fishing schedule directed at Fraser chum in 2015 is typical of chum fishing patterns over much of the past decade with a notable exception. A restriction on the timing and frequency of daily openings of the Area 29 commercial gillnet fishery targeting chum salmon was removed in 2014. The restriction is intended to conserve Interior Fraser steelhead however the change resulted in two commercial gillnet fishing opportunities for chum salmon in October and nearer to the peak of the steelhead run rather than a single opening in October or, alternatively, two openings in November as would have been prescribed in previous years. In 2015, Johnstone Strait chum fisheries commenced on October 2 with the first of three gillnet fisheries, each 3 days in duration.

Two derby style purse seine fisheries were also conducted in Johnstone Strait on October 5 and October 19, respectively,. Effort directed at Fraser River chum in US Areas 7 and 7a started on October 6. Chum directed effort in the lower Fraser drift gillnet fisheries commenced on October 10. Accounting for differences in peak steelhead migration time in the various fishing areas and the later than average run timing estimated in 2015, non-selective fisheries targeting Fraser chum in marine area fisheries generally commenced after the estimated peak of the Interior Fraser Steelhead run and non-selective fisheries in Area 7a and in the Fraser River commenced on the estimated peak of the run.

With regard to salmon fisheries in Area 21 targeting hatchery enhanced chum salmon, gillnet fisheries commenced one day after the estimated peak of the steelhead run in Area 21 in 2015. Gillnet opportunities in Area 21 were available until latter October near the end of the steelhead run in that area, but no effort ensued during the final opening, reportedly on account of gillnet opportunity for chum salmon in the Fraser River when and where a higher proportion of the steelhead were at risk to capture. Purse seine opportunities in Area 21 commenced on October 17 and during the latter part of the steelhead run.

The Thompson River steelhead sport fishery was open until October 31. The season was not extended to the normal end date of December 31 because an in-season estimate of abundance indicated that the estimated probability of exceeding the reference point abundance of 850 spawners was 20%. Inseason abundance estimates through mid and latter October consistently indicated that the abundance classification if either “Conservation Concern” or “Extreme Conservation Concern”. The inseason forecast of spawner abundance at the end of the test fishing season (November 20) was 470 Thompson River steelhead.

Table 2 lists effort data used in the 2015 simulations.

4.3. Simulation Results

Using the estimated 2015 run timing parameters (*d* and σ) and their estimated distributions, the median fishing mortality rate index in 2015 is 15% and 95% of the distribution of fishing mortality rate indices is within 9-26% (Table 3a). Using average run timing parameters and their estimated distributions produce similar results as follows: the median fishing mortality rate index is 16% and 95% of the distribution of fishing mortality rate indices for all fisheries combined is within 7-27% (Table 3b).

Sensitivity analysis indicates that migration parameters are the dominant factors influencing estimation of overall mortality rate in 2015 (Figure 4). This result is generally consistent with previous years. Diversion rate, defined as the proportion migrating through Johnstone Straits, is modestly positively correlated with fishing mortality indicating that fishing mortality was greater for fish migrating through Johnstone Strait as opposed to Juan de Fuca Strait. Peak date is weakly negatively correlated using 2015 run timing parameters, but modestly positively correlated using historical average run timing pararmeters. This result can be explained by the later-than-average run timing estimated for 2015 which places the start of many fisheries in the Fraser River prior to the estimated peak of the run whereas had the timing been average, the peak of the run would have passed most fisheries before they started. Spread of run is modestly negatively correlated. Correlations of fishing mortality rate with all other parameters and variables were very weak.

Diversion rate for steelhead is not known, however extremely high fractions of Fraser sockeye and Fraser pink migrated via the Johnstone Strait route in 2015 with estimates of 99% and 91%, respectively. If Fraser steelhead migrated similarly, the median fishing mortality rate index is 20% (2.5 and 97.5 percentiles are 13% and 31% respectively assuming 95% diversion and 2015 run timing parameters; Table 4a). Assuming average run timing parameters, median fishing mortality rate index is 19% (2.5 and 97.5 percentiles are 7% and 30%, respectively; Table 4b).

It is noteworthy at this point that the following fisheries are not accounted for by the simulation model: Nitinat purse seine, Johnstone Strait purse seine daily effort less than 10 vessels, Area 20 purse seine, Area 29 purse seine, all non-gillnet and non-purse-seine fisheries, and any illegal fishing effects. Breakdown by fishery and geography

Fishing mortality rate indices for specific fisheries are listed in Table 3 for the 2015-run-timing and average-run-timing simulations, respectively and in Table 4 assuming a high rate of diversion through Johnstone Straits. Fishing mortality from salmon fishing accounts for majority of the total fishing mortality (88-94% of the total depending on run timing and diversion rate assumptions). The majority of the total fishing mortality in 2015 comes from 3 fisheries, those being the Area 12/13 purse seine fisheries, the Area 29 Aboriginal Driftnet Fishery and the Area 29 commercial gillnet fishery. Fishing mortality from the US fishery is of similar magnitude only if diversion rate is assumed to be unknown or low.

Fishing mortality rate indices summarized by geographic area indicate that about one-third to one-half (32-49%) of the 2015 fishing mortality occurs in the various fisheries within the lower Fraser River, the range conditional on run timing and diversion rate assumptions. All of these fisheries are gillnet fisheries whether they be commercial gillnet, aboriginal drift gillnet or aboriginal set net. The remaining proportion of the mortality (51-68%) occurs in the marine approach areas through either the northern or southern migration route around Vancouver Island, range conditional on run timing and diversion rate assumptions.

Assuming average run timing parameters and the 2015 fishing schedule, the simulation suggests that the proportion of the run that encounters gillnets and purse seines is 28% (median; 2.5 and 97.5 percentiles are 10% and 56%, respectively), meaning that 72% of the run does not encounter gillnets or purse seines (not accounting for Area 29 chum purse seine fishery). Using the same assumptions, the proportion of the run exposed to gillnet and purse seine fishing times is 75% (median; 2.5 and 97.5 percentiles are 31% and 96%, respectively), meaning that the "window" with which steelhead can pass without potentially being caught in a non-selective salmon fishery is about 25% of the run.

Assuming average run timing parameters and the 2015 fishing schedule, and assuming that 95% of the steelhead migrates through Johnstone Straits, the simulation suggests that the proportion of the run that encounters gillnets and purse seines is 37% (median; 2.5 and 97.5 percentiles are 20% and 60%, respectively), meaning that 63% of the run does not encounter gillnets or purse seines (not accounting for Area 29 chum purse seine fishery). Using the same assumptions, the simulation suggests that the proportion of the run exposed to gillnet and purse seine fishing times is 65% (median; 2.5 and 97.5 percentiles are 19% and 93%, respectively), meaning that the "window" with which steelhead can pass without potentially being caught in a non-selective salmon fishery is about 35% of the run.

5. Conclusions

Fishing mortality has been on an increasing trend since 2009 despite record low abundances of steelhead in the 2008 to 2010 fishing seasons and a return to record low abundance in 2015. Simulation results suggest that fishing patterns like those in 2015, when only chum salmon are targeted, results in the encounter of about ¼ to 1/3 of the steelhead run and an annual reduction in abundance of about 1/6 of the steelhead run due to fishing mortality effects. If diversion rate for steelhead is high and similar to sockeye and pink salmon, the simulations suggest that fishing patterns like those in 2015 results in the encounter of about a 3/8 fraction of the steelhead run with gillnet and purse seine fisheries, and an annual reduction in abundance of about 1/5 of the steelhead run due to fishing mortality effects. Fishing patterns like those in 2013 and 2014, when pink salmon (2013) or late-run sockeye (2014) are targeted in addition to chum salmon, results in the encounter of about ½ of the steelhead run with gillnet and purse seine fisheries and an annual reduction in abundance of about ¼ of the steelhead run due to fishing mortality effects. The recent increasing trend in fishing mortality is mainly a result of increased fisheries during the early part of the run due to fisheries targeting pink salmon in 2013 and fisheries targeting late run-sockeye in 2014. Also, a restriction on commercial chum fishing in the Fraser River was removed in 2014 resulting in two non-aboriginal commercial gillnet fisheries in October as opposed to options prior to the removal of this restriction of either a single fishery in October or the option of two fisheries in early November. Indices of fishing mortality and encounter rate are trending upward despite a declining trend in Thompson steelhead abundance to near Extreme Conservation Concern levels (Johnston 2013; Figure 5).

The majority of the fishing mortality in 2015 appears to be the result of Area 12/13 purse seine and gillnet fisheries, the Fraser drift gillnet and the Area 29 commercial gillnet fisheries. Fishing mortality in US gillnet and seine fisheries is only of similar magnitude to each of the lower Fraser fisheries if diversion rate through the southern migration route is high. Fishing mortality effects of other fisheries appear to be relatively insignificant.

The estimated run timing of steelhead in 2015 is later than recent average run timing, peaking on October 18 in comparison of the average peak date of October 10. The later than average run timing for steelhead in 2015 is similar run timing of Fraser coho and chum. According to test fishery catches and using the same methods described in section 3.1. Fraser coho were later in 2015 with a mean date of October 14 which is 9 days later than the average since 2001. Fraser chum salmon were on time in 2015. Chum salmon mean date in 2015 was October 18 identical to the average mean date of October 18 and identical to the estimated timing of steelhead. The degree to which these stocks co-vary in their migration timing has not been examined to date.

Migration parameters usually rank among the dominant factors in previous years and results for 2015 are consistent in that regard. The manner in which migration parameters influence fishing mortality rate in 2015 is consistent with the timing and intensity of the lower Fraser gillnet fisheries and the Area 12/13 purse seine and gillnet fisheries which collectively operated on or around the estimated peak and latter part of the steelhead in 2015.

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8. Tables

Table 1. Estimates of steelhead run timing parameters based on Albion test fishery catches from 1984 to 2015. The mean date corresponds to the number of days after August 31. Standard deviations expressed in number of days. Figures that are not-available are represented by blank cells.

Test Fishing Year	Mean Date	Standard Deviation
1984	39	21
1985	41	17
1986	45	12
1987	55	18
1988		
1989		
1990		
1991		16
1992	29	30
1993		
1994	44	11
1995	45	14
1996	47	18
1997	57	11
1998	36	20
1999	36	16
2000	32	10
2001	34	15
2002	37	18
2003		
2004		
2005	33	11
2006		
2007	34	13
2008		
2009	40	13
2010	35	12
2011	43	14
2012	48	16
2013	34	10
2014	41	12
n	22	23
Min	29	10
Max	57	30
Mean	40	15
Median	39	14
Standard deviation	7.3	4.5

**Note for mean date, day 1 corresponds to September 1.*

Table 2. Reported effort. Data are number of fishing vessels, set nets or drift nets. GN=gillnet vessels. SN=purse seine vessels. Shaded cells illustrate historical average run timing of steelhead. Darker shaded cells illustrate historical average peak run timing dates for the various areas. In 2015, peak run timing was estimated to be 6 days later than average.

	Area 12		Area 13		Area 21		Area 4b/5/6c Indian		Area 7 Indian		Area 7a Indian		Area 7 Non Indian		Area 7a Non Indian		Area 29 Commercial	Area 29 Commercial	Fraser River First Nations: Steveston to PM		PM to Miss		Miss to Harr		Harr to Hope		Hope to SMC	
Date	(GN)	(PS)	(GN)	(PS)	(GN)	(PS)	(GN)	(PS)	1(GN)	2(PS)	1(GN)	2(PS)	1(GN)	2(PS)	1(GN)	2(PS)	(SN)	(GN)	drift net	set net	drift net	set net	drift net	set net	drift net	set net	drift net	set net
15-Aug-10																												
16-Aug-10																												
17-Aug-10											1																	
18-Aug-10																												
19-Aug-10																									1			
20-Aug-10																												
21-Aug-10																												
22-Aug-10																			28		35		6	1	14	6	1	25
23-Aug-10																			23		34		3	4	15	7		25
24-Aug-10																												
25-Aug-10														3		1												
26-Aug-10													1	5	1	5												
27-Aug-10										5									2									
28-Aug-10										10		3																1
29-Aug-10										4									8		31		5	3	13	15	1	29
30-Aug-10										1				14	1	3			28		21		5	2	13	15	2	29
31-Aug-10										8									8									
01-Sep-10										4			1	2		8												
02-Sep-10																												
03-Sep-10																												
04-Sep-10																												
05-Sep-10																			23		24		5	2	15	5	2	22
06-Sep-10																			19		23		7	1	16	3	2	12
07-Sep-10																			2		24		6	4	11	5	1	17
08-Sep-10																												
09-Sep-10																	2											
10-Sep-10																												11
11-Sep-10																												11
12-Sep-10																												
13-Sep-10																												
14-Sep-10																												
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25-Sep-10							1																					
26-Sep-10																												
27-Sep-10																												
28-Sep-10					19																							
29-Sep-10					18																							
30-Sep-10																												
01-Oct-10																												
02-Oct-10	109		37																									
03-Oct-10	114		34																									
04-Oct-10	83		37																									
05-Oct-10		65		20	66		1																					
06-Oct-10					67						1																	
07-Oct-10							1																					
08-Oct-10							1																					
09-Oct-10																												
10-Oct-10										1									26	1	20							
11-Oct-10										7	1								27	1	15							
12-Oct-10										3	1		3		12				20	1								
13-Oct-10					74		3			4	2		2	17	20	7												
14-Oct-10							5			5	5																	
15-Oct-10											5		2	1	16	5												
16-Oct-10	115		53				2			8	6	1												7		9		
17-Oct-10	108		60			14	1		1	3	5								10		18		13	7	5	9		
18-Oct-10	81		48			10				6									35		19		7	7	1	9		
19-Oct-10		27		46			2				7		2		5	1			24									
20-Oct-10						9	2			3	7		3	2	3													
21-Oct-10						9			2	3	3		5	6	3	1												
22-Oct-10							2		2	5	4	1	3	8	5	3			48									
23-Oct-10							3		2	11	3	1						207		1				13		8		
24-Oct-10					0	6	2				2	1							1	1	21		6	13	3	8		
25-Oct-10	57		55		0	0	1												38	1	28		12	13	1	3		
26-Oct-10	44		51				3				1																	
27-Oct-10	20						1				2						14	200										
28-Oct-10							1										2											
29-Oct-10							3																					
30-Oct-10																								9		8		
31-Oct-10																					13		8	9	4	8		
01-Nov-10																					17		4	9	2	8		
02-Nov-10																												
03-Nov-10							1																					
04-Nov-10							1																					
05-Nov-10							1																					
06-Nov-10																				1								
07-Nov-10																				1								
08-Nov-10																			2	1	1		1	4		1		1
09-Nov-10																							1					
10-Nov-10																												
11-Nov-10																												
12-Nov-10																												
13-Nov-10																												
14-Nov-10																							1					
15-Nov-10																			2		1		1	2		1		
16-Nov-10																												
17-Nov-10																												
18-Nov-10																												
19-Nov-10																												
20-Nov-10																												

Bison, Robert
FLNR:EX:
Open but zero effort

Bison, Robert
FLNR:EX:
Open but zero effort

Bison, Robert
FLNR:EX:
Open but zero effort

Table 3a. Monte Carlo sampling distributions of fishing mortality rate indices by fishery assuming 2015 run timing parameter distributions.

Fishery	Exploitation Rate Index (%)		
	2.5 Percentile	Median	97.5 Percentile
Area 12/13 GN	0.1	1.2	3.1
Area 12/13 SN	0.3	5.0	13.0
Area 21 GN	0.0	0.1	0.3
US (all)	0.1	1.6	4.3
Area 29 GN	1.6	2.9	5.6
Fraser to Mission Drift Net	1.5	3.0	5.5
Mission to Sawmill Creek Set Net	0.2	0.3	0.7
Thompson Sport	0.4	0.8	1.2
All Fisheries	8.7	15.3	25.8

Table 3b. Monte Carlo sampling distributions of fishing mortality rate indices by fishery assuming average run timing parameter distributions.

Fishery	Exploitation Rate Index (%)		
	2.5 Percentile	Median	97.5 Percentile
Area 12/13 GN	0.1	0.7	2.5
Area 12/13 SN	0.3	3.5	12.3
Area 21 GN	0.0	0.1	0.4
US (all)	0.1	2.0	5.4
Area 29 GN	1.0	3.3	6.4
Fraser to Mission Drift Net	2.2	4.1	6.5
Mission to Sawmill Creek Set Net	0.2	0.4	0.8
Thompson Sport	0.4	0.8	1.2
All Fisheries	7.3	16.0	27.0

Table 4a. Monte Carlo sampling distributions of fishing mortality rate indices by fishery assuming 2015 run timing parameter distributions and 95% diversion through Johnstone Straits.

Fishery	Exploitation Rate Index (%)		
	2.5 Percentile	Median	97.5 Percentile
Area 12/13 GN	1.0	2.3	3.8
Area 12/13 SN	5.1	9.8	17.0
Area 21 GN	0.0	0.0	0.0
US (all)	0.1	0.2	0.3
Area 29 GN	1.7	2.9	5.7
Fraser to Mission Drift Net	1.8	3.1	5.7
Mission to Sawmill Creek Set Net	0.2	0.3	0.7
Thompson Sport	0.4	0.8	1.1
All Fisheries	12.8	19.6	30.7

Table 4b. Monte Carlo sampling distributions of fishing mortality rate indices by fishery assuming average run timing parameter distributions and 95% diversion through Johnstone Straits.

Fishery	Exploitation Rate Index (%)		
	2.5 Percentile	Median	97.5 Percentile
Area 12/13 GN	0.4	1.6	3.2
Area 12/13 SN	2.0	8.1	15.1
Area 21 GN	0.0	0.0	0.0
US (all)	0.1	0.2	0.4
Area 29 GN	0.8	3.1	6.0
Fraser to Mission Drift Net	2.0	4.0	6.3
Mission to Sawmill Creek Set Net	0.2	0.4	0.8
Thompson Sport	0.4	0.8	1.2
All Fisheries	6.8	18.9	30.0

9. Figures

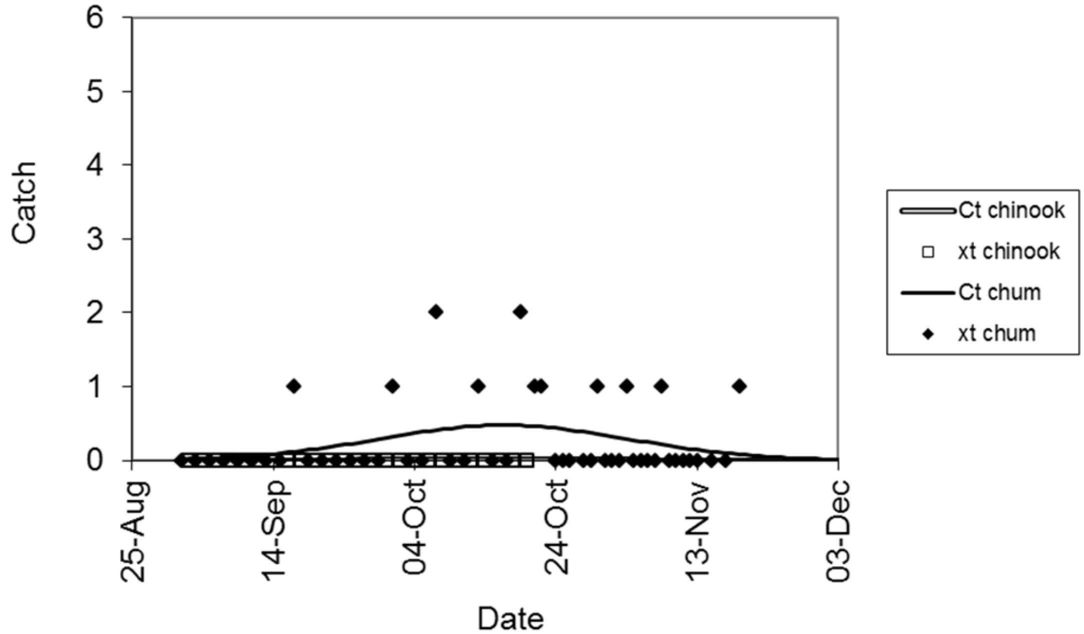


Figure 1. Predicted (C_t) and observed (x_t) catches of Interior Fraser Steelhead in the Albion chum and chinook test fisheries in 2015.

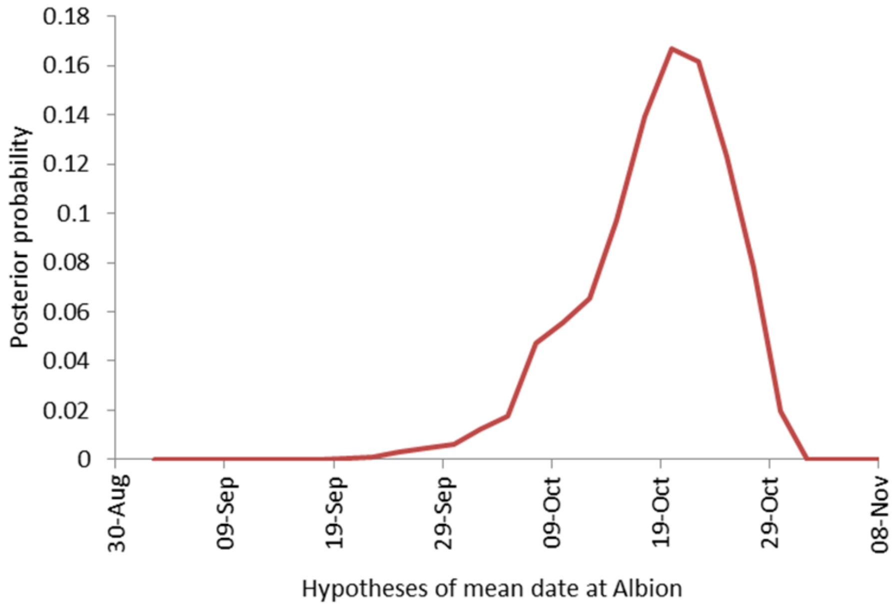


Figure 2. Bayes posterior distribution for mean date (d) in 2015.

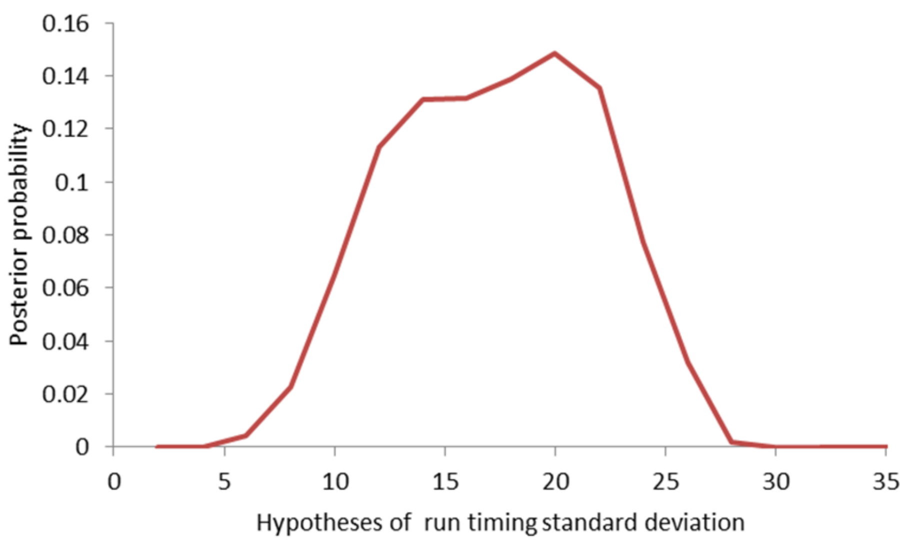


Figure 3. Bayes posterior distribution for standard deviation (σ).

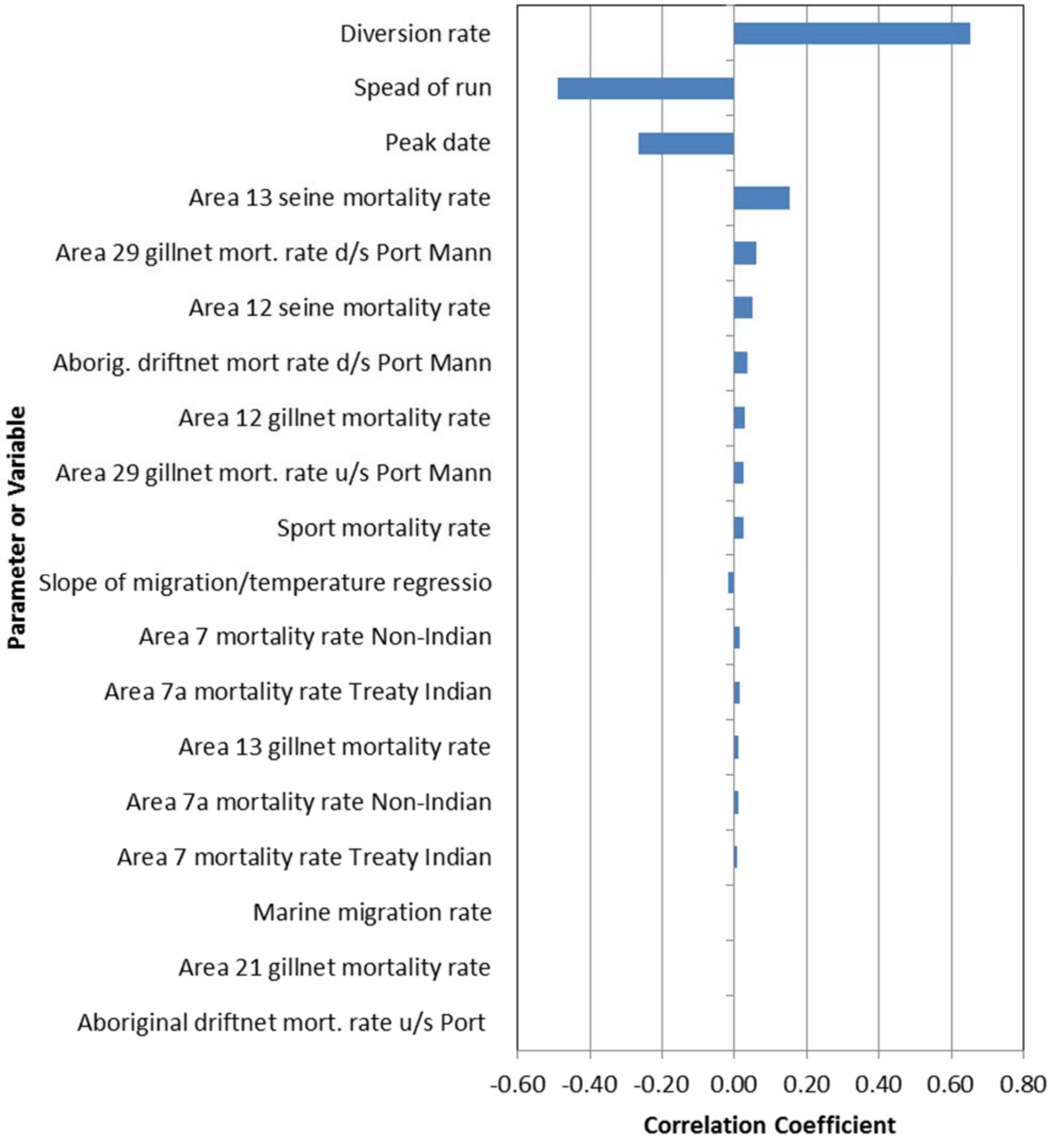
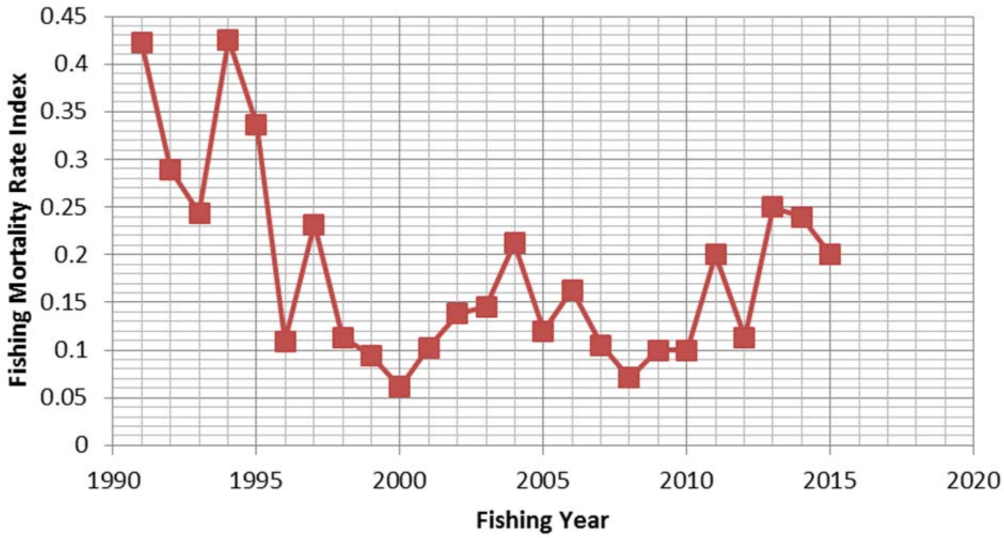


Figure 4. Coefficients of the rank correlation between each variable and the fishing mortality rate index for all fisheries combined, <u>assuming the estimated 2015 run timing parameter distributions</u>. Diversion rate is defined as the proportion of the run migrating through Johnstone Strait.



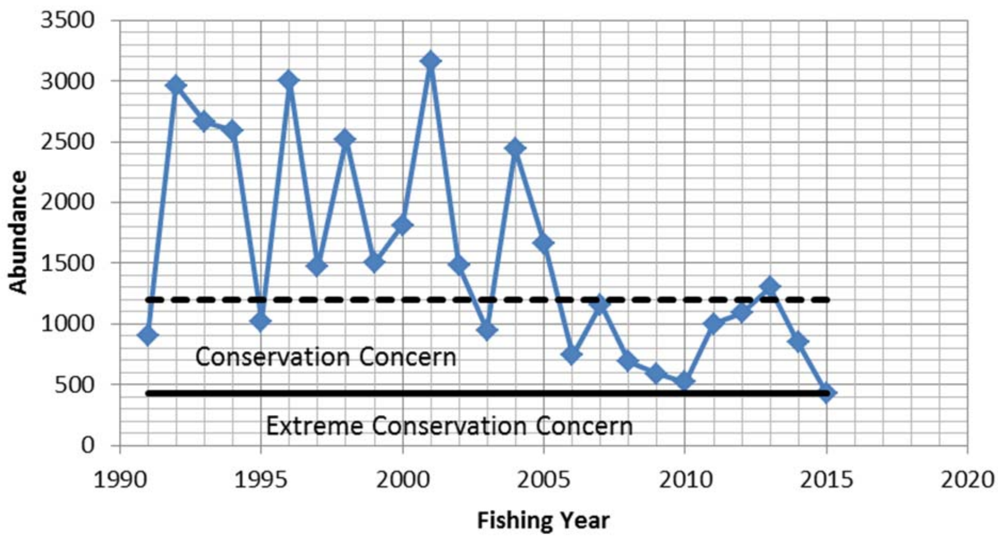
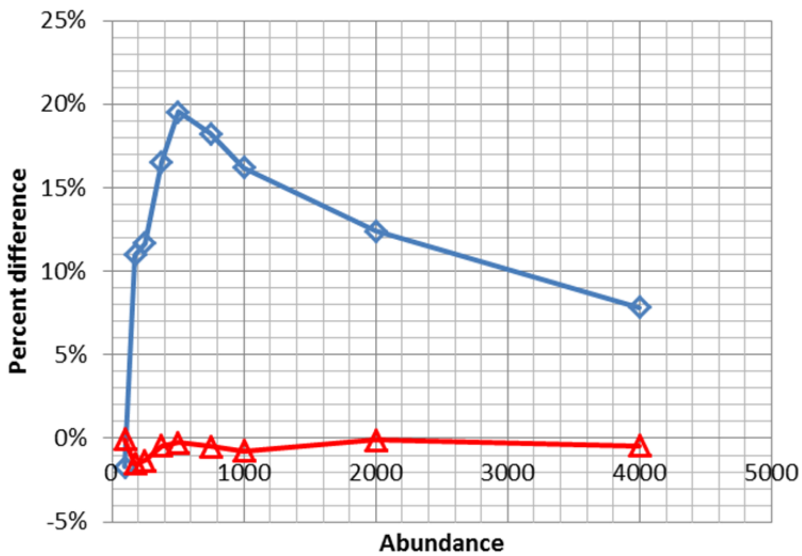


Figure 5. Updated fishing mortality trend (upper chart) and spawner abundance trend (lower chart) for Thompson steelhead. Fishing Year denotes the fishing season which is one calendar year prior to the spawning year. Dash line represents the Conservation Concern Threshold. Solid line represents the abundance below which the stock is classed as Extreme Conservation Concern.

10. Technical Notes



Note I. Percent differences between estimated and true values of peak date (triangles) and spread of run (diamonds) using the estimation model described in 3.1. Estimation of peak date is unbiased while estimation of spread of run is positively biased.

Note II. Average MD and average SD is simulated assuming lognormal distribution.