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A daily simulation model of catch, mortality and escapement for Fraser-Thompson steelhead stocks

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ABSTRACT

A computer model was constructed to simulate the effects of alternative fishing patterns on catch, mortality and escapement of interior steelhead stocks from the Fraser-Thompson system, British Columbia. The model simulates the catch and mortality associated with various marine and in-river fisheries on a daily time step as fish migrate from the northern tip of Vancouver Island, through marine fishing areas, and up the Fraser River towards overwintering areas and spawning tributaries. Key inputs include the fishing schedule, migration speed, catch rates, and mortality rates of caught fish. As with similar models built for Fraser River sockeye stocks, the primary use of the model will be in the pre-season, in understanding the relative changes in catch, mortality and escapement expedcted with alternative fishing regimes. Testing of the model during the 1999 season led to some refinements and modifications as discussed in this paper, and in particular revealed limitations resulting from poor data for many parameters. The model is useful as a tool for exploring relative changes in catch rates expected for various fishing patterns, and for identifying critical data constraints. However, its value as a reliable predictive model is limited by the paucity of data available for steelhead and the need to use data for other species.

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INTRODUCTION

Background and Objectives

This report describes a computer model that will be used as a management tool for interior steelhead stocks from the Mid-Fraser and Thompson River systems. The objective of the model is to simulate catch, mortality and escapement of steelhead stocks associated with different fishing patterns in marine and in-river fisheries. The model's structure was based on similar models for commercial fisheries on Fraser River sockeye and pink stocks (Cave and Gazey 1994), fisheries on Skeena River salmon stocks (Cox-Rogers 1994), and in-river fisheries on Fraser River sockeye stocks (Hill et al, in prep).

The model was tested during the 1999 season and various modifications were made as discussed in this paper. In general, it should be emphasized that the quality of data that were used to support development of sockeye management models are not available for steelhead. Consequently, there are limitations to how the steelhead model should be used. Most importantly, absolute numbers in the model can be expected to be inaccurate. For example, for some fisheries we have assumed that steelhead would be caught at the same daily rate as sockeye. This assumption results in high estimates of overall catch in-river because steelhead migrate slowly and are therefore exposed to fishing for longer periods. We have attempted to account for some of these types of differences in spite of the lack of data, but we can still expect the model predictions to be somewhat unreliable. However, while absolute estimates of catch rates are uncertain, the model can still be used effectively to understand the relative changes in catch rates associated with changes to fishing schedules. As well, a major benefit of the model has proven to be identification of critical information gaps and data constraints.

Overview of Model

The model begins by simulating the arrival of three stock groups of steelhead to the northern tip of Vancouver Island in the late summer and fall. Information on run timing and abundance is used to break each of the stocks into daily migration blocks of fish that travel towards the Fraser River north through Johnstone Strait or south through Juan de Fuca Strait. Each daily migration block takes one or more days to travel through several different marine and freshwater fishing areas. If one or more fisheries are operating in an area on a date when the migration block is there, daily catch and mortality are calculated, and surviving fish from the migration block continue migrating upstream. Migration speeds are assumed to be constant in the ocean but are controlled by temperature in the river. After a specified date, all fish that have not made it to the spawning grounds are assumed to overwinter due to cold temperatures, and the following spring a portion of those fish successfully continue migrating to spawning tributaries.

The following sections describe the scope of the model, and the data and algorithms used in each component of the model. An attached User's Guide (Appendix A) discusses the user interface and system requirements and summarizes the key inputs and outputs of the model.

MODEL SCOPE

Spatial and Temporal Scale

The Fraser-Thompson steelhead model is limited to the analysis of catch and escapement of Fraser-Thompson steelhead stocks. Therefore, the spatial scope is limited to the area where they are most commonly intercepted by fisheries, from the northern tip of Vancouver Island to the spawning rivers and streams. The temporal scale is limited to the spawning migration period for steelhead (i.e., from the time they arrive at the first marine fisheries until overwintering). The time step in the model is one day.

Definition of Stock Groups

There are 3 steelhead stock groups from the mid-Fraser and Thompson River systems which are included in the model:

Group 1: Nicola River/ Bonaparte River
Group 2: Deadman River
Group 3: Chilcotin System (includes Chilcotin, Chilko and Taseko Rivers)

Other stocks from mid-Fraser tributaries such as the Nahatlatch River, the Stein River, Cayoosh Creek, the Seton system, or the Bridge River could also be included in the model with some minor modifications. However, these stocks have not been included to date because (1) inclusion of more stocks adds considerably to the time required to run the model, (2) we are currently more interested in the Thompson River stocks, and (3) these other stocks can be analyzed if necessary by changing the run timing of the Chilcotin stock group and setting a couple of fishery harvest rates in the model to zero. More information on the distribution of steelhead in interior rivers and streams is summarized in MELP and DFO (1998) and Riley et al (1998).

Definition of Fisheries

Interior steelhead stocks are exposed to many fisheries, including marine sockeye/pink and chum fisheries, U.S. fisheries, aboriginal and sport fisheries, and terminal fisheries. Most of these fisheries are aimed at other species but some are directed at steelhead. The fisheries to which interior steelhead are exposed (i.e., fishing areas and gears) are listed in Table 1 and shown in Figure 1.

MODEL COMPONENTS

This section describes details on how the model works and the data used to model each component.

Run Size

Pre-season run size estimates for steelhead are based on stock-recruitment analyses using historical escapement and catch data. Estimates can be updated in-season based on data from the Albion chum test fishery (i.e., historical correlation between Albion catches and escapement: Bison and Renn 1998). Absolute run size may be used in the model but are not necessary.

Run Timing

The run timing of each stock group is assumed to follow a normal distribution, which is represented in the model by a peak date and a standard deviation about that date. The model partitions each stock into daily migration blocks of fish that arrive at the northern tip of Vancouver Island. Run timing is estimated by first determining the peak from historical Albion test fishery catches, and then estimating the number of days required to migrate to Albion from the northern tip of Vancouver Island (see discussion of migration speeds in marine and freshwater).

Diversion Rate

The relative proportion of the interior steelhead runs that divert north through Johnstone Strait rather than south around Vancouver Island is variable for steelhead as it is for other Fraser River-bound salmonids (MELP and DFO 1998). Some information is available from Parkinson (1984) and catch data, but no formal assessment has been made. Currently the model assumes an 80% southern diversion.

Movement of Fish

Each migration block of fish travels through fishing areas en route to spawning tributaries. In total, there are 23 fishing areas (Table 1 and Figure 1), plus 3 areas in the marine environment where fish can be modeled to be between fisheries and therefore not exposed to fishing. These include (1) between marine areas 13 and 16, (2) between marine areas 16 and 29 (this option can be used if the area 29 fleet is assumed to be in-river only), and (3) between marine areas 6c and 7. The number of days required for a migration block of fish to pass through each area is a function of migration speed as described below.

Migration Speeds and Exposure Time to Fisheries

Migration speeds for steelhead in marine and in-river waters are uncertain. A radio-telemetry study by Ruggerone et al. (1990) estimated an average speed in the marine environment to be 17.2 km/day for fish returning to the Dean River. This value has been adopted for marine areas in the Fraser-Thompson steelhead model. Migration speed from the river mouth to Hope is estimated from radio-telemetry studies to average 9.77 km/day (Renn et al. 1999). Migration speed above Hope has been shown to depend on temperature. A relationship between migration speeds and temperature was derived based on radio-telemetry studies (Renn et al. 1999), and can be used in the model (speed(km/day) = 1.875*temp(degrees C) – 5.1358). Temperature itself can be modeled by the user as a function of date if desired, or temperatures can be simply entered manually. Unfortunately, the Renn et al. (1999) relationship was used during model testing on the 1999 season and the modeled migration speed up the river was so slow that very few fish reached the Thompson River by December 30th. Consequently, the temperature-independent value of 9.77 km/day is currently being used (modeled sport fishery catches are now in the range expected) until the temperature-migration speed relationship can be investigated further.

Migration speed is an important parameter because it determines how many days each migration block of fish will spend in each fishing area. The number of days spent in an area is equal to the length of the area in km divided by the average speed. The lengths of marine fishing areas were approximately from maps of known scale, and the lengths of in-river areas were taken from Macdonald (1992) but required slight map-based adaptations for differences in definitions of areas. The level of error in these estimates is expected to be insignificant because the daily time step of the model requires definition of areas in terms of the number of days required to migrate through them.

Currently the model does not allow migration through one area to exceed 18 days (with one exception discussed below). Setting an 18 day maximum under a constant migration speed assumption or an assumption of temperature-dependent migration is more than adequate. Using the temperature-dependent migration speed, (1) fish do not take 18 days to get through any of the areas until the water temperature drops below 4.6 degrees; (2) temperatures do not dip below 4.6 degrees until early November; and (3) temperatures between 4 and 5 degrees are observed in the first 2 weeks of November, but after mid-November temperatures drop below 2.8 degrees and migration stops. Since temperatures hover between 2.8 and 4.6 degrees only for about 2 weeks, setting a maximum of 18 days for fish to migrate through an area should have almost no effect on results - fish cannot even migrate through one entire fishing area during that short window.

Fish migrating through the Thompson system are assumed to stay in the mainstem Thompson and not migrate through the system to spawning tributaries. This is simulated currently in the model by making individual blocks of fish take 100 days to migrate through this area, to ensure that virtually all of the modeled fish (99%+) are still in the area once migration stops and overwintering starts due to cold temperatures. The use of 100 days is robust to significant variation in run timing and migration speeds. The assumption that fish do not migrate through the Thompson mainstem is consistent with the methods by which catch rates are estimated (described under Catch Rates – Sport Fisheries subsection below, and in Appendix E).

In recognition of the variation among individual fish in migration speeds, the model allows the user to define a "smoothing index" to allow the fish from different migration blocks to intermix. For example, a smoothing index of 0.8 means that the number of fish in migration block n on day t will be composed of 80% of block n after day t-1, plus 10% of block n-1 after day t-1 and 10% of block n+1 after day t-1. This smoothing of migration blocks is important because it is definitely noticeable in the Fraser River. After the area 29 gill net fishery harvests sockeye, a hole exists in the sockeye run that gradually disappears further upstream after several days.

Catch Rates

The catch from a block of fish within a fishery is modeled as abundance times daily catch rate. Specifically, migration blocks that are either entering or leaving a fishery on a given day are assumed to be partially exposed to fishing in that area and are caught at an elemental catch rate μ. Migration blocks that are somewhere in the middle of a fishing area and are therefore exposed to fishing for the entire day are caught at a rate $h = 2\mu - \mu^2$ (see Cave and Gazey 1994 for derivation).

The information available for estimating catch rates is different for different fisheries. Consequently, the model is flexible and allows the user to either (1) enter a point estimate of the elemental catch rate based on run reconstruction or less formal methods, (2) define catch rate as a function of date (e.g., if there is information suggesting that catchability of fish changes over the season), or (3) build a relationship between fleet size or some other variable(s) and catch rate for fisheries where that information exists.

Steelhead-specific data for catches are available (MELP and DFO 1998) but are very limited, and estimates of daily catch rates have not been made. Consequently, we have used catch rates for other species, especially sockeye, to approximate harvest rates for steelhead for many fisheries. Our assumption for most fisheries is that on any given day, an individual steelhead or sockeye in a particular area has equal probability of being caught. Differences in the average migration speed among species are generally assumed to not result in different daily catch rates (exceptions discussed below and in Appendix D), but ultimately result in different overall catch rates integrated over the entire season because slower species are exposed to fishing for longer periods (i.e., more days).

There are two potential sources of error in our assumption of similar daily catch rates among species. First, different species may have different migration behaviours (e.g., proximity to shoreline, average depth) and therefore have differential exposure to fishing gear. Fishers can be expected to optimize gear operation (e.g., depth, location, timing, mesh size) for sockeye and therefore harvest rates on sockeye may be higher than on species such as steelhead which are not targeted. We have not attempted to account for this potential error.

Second, it is possible that fish migrating at a faster rate (i.e., sockeye) have higher daily catch rates than fish migrating at a slower rate. This is especially true for fixed gear – if there are 50 nets in a river reach, a slow fish may swim past 25 nets in a day while a fast fish may swim past all 50 nets in one day. The probability of capture in the area might be the same, but it is spread over fewer days for a faster fish. During testing of the model in the 1999 season, it became apparent that modeled steelhead catch in set net and dip net fisheries was very high because of the combination of slow migration speeds in-river and the use of daily catch rates derived from sockeye. Consequently, as described below and in Appendix D, a function was introduced in the model to allow catch rate to vary with migration speed for set net and dip net fisheries (i.e., fixed gear). In future, it may be possible to better determine the relationship between migration speed and catch rate if we had quality data on daily harvest rates for several species in the same fisheries (e.g., we could regress daily harvest rate on migration speed for a particular fishing area). In the absence of that level of detailed data, however, the assumption of a relationship between daily catch rate and migration speed seems reasonable.

Table 2 shows the daily catch rates for various fisheries, each of which are discussed below.

Marine Fisheries

Steelhead are caught in marine commercial and US fisheries directed at sockeye/pink and chum. Estimates of catch rates for sockeye fisheries have been made by the Pacific Salmon Commission (PSC 1995) based on run reconstruction (Cave and Gazey 1994). For some of the fisheries, catch rates are estimated as a function of fleet size, but for others, a fixed rate is used. Current estimates of fleet size - catch rate relationships are based on linear regressions; other options are reviewed in Appendix B. Adjustments to fixed rates may be made by PSC staff if the fleet size changes significantly (J. Cave, Pacific Salmon Commission, Vancouver, BC, personal communication).

Annual exploitation rates have been estimated in the past for chum fisheries (e.g., Anderson and Beacham 1983) but there has been no derivation of daily catch rates for marine chum salmon fisheries. It may be possible to derive estimates of daily catch rates by assuming the stocks occur in the marine environment in proportion to escapements but the uncertainty in those estimates would be large (P. Ryall, Department of Fisheries and Oceans, South Coast Division, personal communication). Consequently, the daily catch rates estimated for sockeye were selected as the most appropriate for application in the steelhead model. As previously discussed, we are assuming that the daily elemental harvest rates are similar for sockeye and steelhead. Daily catch rates of steelhead are generally lower during chum fisheries because there are fewer boats. This is captured in the model because we have effort-catch rate relationships for most of these fisheries.

There are two marine fisheries to which interior steelhead are exposed but for which daily harvest rates have not been estimated. These are the area 14 gillnet fishery and the area 14 purse seine fishery. Both of these fisheries are insignificant in comparison to other marine fisheries (P. Ryall, Department of Fisheries and Oceans, South Coast Division, personal communication) and therefore have not been included in the steelhead model.

In-River Commercial Fisheries

Steelhead are also caught in in-river gillnet fisheries (i.e., area 29) directed at sockeye/pink and chum. Estimates of catch rates for sockeye fisheries have been made by the Pacific Salmon Commission (PSC 1995) and also to support the development of an in-river model (Hill et al., in prep.), both based on run reconstruction methods described by Cave and Gazey (1994). These estimates are fixed rates (i.e., no relationship to fleet size has been made), and may be too high because of recent reductions in the fleet size (J. Cave, Pacific Salmon Commission, Vancouver, BC, personal communication).

For in-river fisheries on chum salmon, data are available but have not been used to support the derivation of daily catch rates. Since the number of boats in area 29 gillnet fisheries is significantly lower during chum fisheries compared to sockeye fisheries, it is inappropriate to assume that the catch rates are as high in the chum fisheries. We derived an estimate of the effort-catch rate relationship for the area 29 chum fishery for use in this model (Appendix C).

It should be noted that the minimum mesh size for the chum gill net fisheries was increased in 1998 in order to minimize by-catch of steelhead and coho (MELP and DFO 1998). The effectiveness of this change on steelhead catch rates is unknown.

Aboriginal Drift Net, Set Net and Dip Net Fisheries

Catch rates of sockeye for aboriginal drift net and set net fisheries from the mouth of the Fraser River to Hope were estimated by run reconstruction for the 1995 season. The analysis was conducted to support development of the in-river sockeye management model (Hill et al. in prep) using the same methods used by the Pacific Salmon Commission (Cave and Gazey 1994). At the same time, catch rates for sockeye for set net and dip net fisheries above Hope were estimated roughly by simulating different catch rates until they matched available catch and escapement data (A. Macdonald, Department of Fisheries and Oceans, Fraser River Division, personal communication). Uncertainties in these catch rates are thought to be less important than in other fisheries because the total catch above Hope is relatively small.

Two modifications to these catch rates were made for use in the steelhead model. First, as discussed above, testing of the model during the 1999 season revealed the limitations of assuming that daily catch rates are the same for steelhead and sockeye even though steelhead can migrate much more slowly. Consequently, we have instead assumed that the overall catch by fixed gear (i.e., set nets and dip nets) in an area, if operating constantly and in the absence of other gears, should be the same regardless of migration speed. To accomplish this, we have modified the daily catch rates for set nets and dip nets in the model using the following equation (see Appendix D for derivation and explanation):

$$\mu_{st} = 1 - e \wedge [(Tsox/Tst)*\ln(1-\mu_{sox})]$$

where μ_{st} and μ_{sox} are the respective elemental daily catch rates for steelhead and sockeye, and Tst and Tsox are the number of days required to migrate through an area for steelhead and sockeye respectively. The number of days for sockeye to migrate through each river reach was taken directly from the Fraser River sockeye simulation model (A. Macdonald, Department of Fisheries and Oceans, New Westminster, B.C., Personal Communication). It should be noted that the user enters daily catch rates for sockeye for set net and dip net fisheries in the model, and that the adjustment for migration speed differences is made as the model runs.

Second, since steelhead reside in the Thompson River mainstem rather than migrate through to spawning tributaries, daily catch rate estimates for sockeye are inappropriate for that area. Currently, the catch rates for set net and dip net fisheries in the Thompson system are set at an arbitrarily low value. More rigorous analysis could be done to set the daily catch rates to match historical catch and escapement data.

Aboriginal Rod and Reel Fisheries

Aboriginal rod and reel fisheries occur in the Chilcotin and Thompson Rivers, but there are no catch data available (B. Ennevor, Department of Fisheries and Oceans, Fraser River Division, personal communication). It may be possible to use subjective estimates of effort provided by local Fishery Officers and assume a similar catch rate to sport fisheries. This has not been attempted to date and therefore catch rates for these two fisheries are currently a gap in the model. The relative influence of these fisheries on steelhead stocks is unknown.

Sport Fisheries

Sport fisheries other than the Thompson and Chilcotin are of negligible importance and therefore catch rates are assumed to be zero in the model. For the Thompson River sport fishery, we estimated an effort – catch rate relationship based on historical data, as described in Appendix E. Catch rates were an average daily rate for fish in the area, and therefore elemental daily rates were calculated in the model as $\mu = 1 - sqr(1-h)$. Chilcotin sport fishery data have not yet been gathered and analyzed. It may not be possible to estimate daily catch rates, so estimates of total catch rate over the season may need to be used. If this is the case, it may be useful to restructure the model to avoid the need to specify daily rates. We will assume same 5% catch and release mortality as for Thompson River fish explained in Appendix E.

Mortality Rates of Caught Fish

Mortality of caught fish results either because (1) the fish are kept instead of released, or (2) the fish are too stressed or injured to survive after being released. The user must define a mortality rate for fish caught in each fishery based on an understanding of the operation of the gear or other information. The mortality rate for caught fish is estimated by multiplying the catch by a mortality rate. The mortality rate in a fishery depends on what proportion of the caught fish are released and successfully continue migrating upstream.

For commercial fisheries, historical studies indicate that the majority of steelhead caught are not reported (MELP and DFO 1998). In spite of the relatively recent requirement to release all steelhead, it is still likely that a large proportion of steelhead caught will not be reported. Of those that are released, a portion can be expected to survive. In the absence of reliable data about the proportion of steelhead that are released and the proportion of released fish that survive, we have assumed a conservative default mortality rate of 100% for all commercial and U.S. fisheries.

For sport fisheries, a mortality rate for caught fish of 1.61% was estimated for Thompson River tributaries based on 436 fish over the period 1982 to 1995 (MELP and DFO 1998). Other systems also summarized by MELP and DFO (1998) showed a range of mortality rates up to about 5 percent. We have assumed a mortality rate of 5 percent for sport fisheries in the model. Although sport fishing mortality is known to vary significantly among streams, it is unlikely that the rate is higher for interior streams. First, interior fish are large and are generally caught in sport fisheries when the water is cold, therefore cumulative stress from angling and warm temperatures is likely to be less important than for other stocks. Second, in the case of the Thompson River sport fishery, an individual steelhead will be caught roughly once on average, therefore the cumulative stress from being caught multiple times is unlikely to be important.

In the absence of data, we assume that the mortality rate of steelhead caught in aboriginal fisheries is 100 percent. This is reasonable because First Nations capture fish for use as food.

Overwintering

Migration stops completely if temperatures are cold enough, and results in a portion of the steelhead runs overwintering in the mainstem Fraser, Chilcotin or Thompson Rivers. In the model, the user must specify the date at which overwintering begins, and must also specify a mortality rate for overwintering fish. Current estimates of these parameters are based on radio telemetry studies (Renn et al. 1999). Mortality of overwintering fish results from natural causes, aboriginal gill net fisheries targeting chinook, and aboriginal rod and reel fisheries. The user specifies the overall mortality rate resulting from these factors for fish overwintering below Lytton, above Lytton in the Fraser and Chilcotin, and in the Thompson. The model outputs include a summary of the number of overwintering fish from each stock and the overwintering mortality.

It is important to note that fish no longer migrate and are no longer available to fisheries after the overwintering date, even if fisheries continue to operate in the model.

Spatial Distribution of Fleets Within a Fishing Area

Specification of the spatial distribution of fleets within each fishery area has not been included as a generic option for all fisheries in the steelhead model for several reasons. Given the uncertainty already inherent in the model, there would be little benefit from attempting to incorporate fleet dynamics into the model. Appendix F describes how spatial fleet dynamics could be incorporated into the model and justifies its exclusion in this model.

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Table 1. Fishing areas and gears included in the model.

	Fishing Area	Comm Gillnet	Comm PSeine	Troll	Aboriginal Drift	Set Net	Dip Net	Aboriginal Rod & Reel	Sport
1	Area 11	x		x					
2	Area 12	x	x	x					
3	Area 13	x	x	x					
4	Area 16	x	x	x					
5	Area 25-27	x	x	x					
6	Area 22-24	x	x	x					
7	Area 21	x	x	x					
8	Area 20	x	x						
9	Areas 4b/5/6c	x	x						
10	Area 7	x	x						
11	Area 7a	x	x						
12	Area 29 to P Mann	x		x	x				x
13	A29 P Mann to Miss	x			x	x			x
14	Mission-Agassiz					x			x
15	Agassiz-Hope					x			x
16	Hope-Sawmill					x			x
17	Sawmill-Lytton					x	x		x
18	Lytton-Texas					x	x		x
19	Texas-Kelly					x	x		x
20	Kelly-Deadman						x		x
21	Deadman-Chilcotin						x		x
22	Chilcotin							x	x
23	Thompson					x	x	x	x

Table 2. Summary of elemental catch rates and associated methods and references for fisheries in the model.

Catch rates for most of the commercial fisheries are based on reconstructions using sockeye data from a recent version of the model developed by Cave and Gazey (1994) (J.Cave, Pacific Salmon Commission, Vancouver, personal communication). Harvest rates for aboriginal fisheries are based on sockeye data are from a recent version of the in-river sockeye model developed by Hill et al (in prep) (A. Macdonald, Department of Fisheries and Oceans, Fraser River Division, personal communication).

Fishery	Elemental Daily Catch Rate	Methods, References and Discussion
Marine Fisheries		
Area 11 Gillnet	0.0003463 * bts + 0.00628	Estimated by run reconstruction on sockeye as in Cave and Gazey 1994 - current harvest rates derived by PSC.
Area 12 Gillnet	0.0002015 *bts + 0.014239	As above
Area 12 Purse Seine	0.0012*bts+0.2334	As above
Area 12 Troll	11.6% in area G (upper area), and 6.0% in area H (lower area)	Estimated by run reconstruction on sockeye as in Cave and Gazey 1994, using 1997 data. Conservative assumption for steelhead model is higher of the two harvest rates since the model does not differentiate the two sub-areas.
Area 13 Gillnet	Not estimated	Gillnets are counted as purse seine equivalents in the sockeye model (Cave and Gazey 1994)
Area 13 Purse seine	0.001*bts+0.2243	Estimated by run reconstruction as in Cave and Gazey 1994 – current harvest rates derived in PSC (1995).
Area 13 Troll	2.4%	Estimated by run reconstruction as in Cave and Gazey 1994, using 1997 data
Area 16 Gillnet	Fishery Insignificant	
Area 16 Purse seine	0.24	Estimated by run reconstruction in Cave and Gazey 1994 – current PSC model notes that this rate is quite variable
Area 25-27 Troll	0.12	Estimated by run reconstruction in Cave and Gazey 1994 – variable depending on fleet size
Area 22-24 Gillnet	Fishery Insignificant	
Area 22-24 Troll	0.12	Estimated by run reconstruction in Cave and Gazey 1994 – variable depending on fleet size
Area 21	Not specified	
Area 20 Gillnet	q = 0.05%	Applies to late in season. Estimated by run reconstruction as in Cave and Gazey 1994 - current PSC model notes this is out of date
Area 20 Purse seine	Variable	Estimated by run reconstruction in Cave and Gazey 1994 –PSC model currently recommends 85% if 75%+ of run using southern route, and 70% or less if a high Johnstone Straight diversion is expected.
Areas 4b/5/6c	q=0.2 on summer stocks, 0.1 on late	All gears are modeled together.

	stocks	
Area 7 Indian	0.09280 * ln(bts) - 0.18230	Estimated by run reconstruction as in Cave and Gazey 1994. All gears are modeled as purse seine equivalents where one seine equals 5 gill nets on summer run sockeye and 10 gill nets on late sockeye
Area 7 Non-Indian	0.00088 * bts + 0.04430	As above
Area 7a Indian	0.21200 * ln(bts) - 0.36020	As above
Area 7a Non-Indian	0.00378 * bts + 0.04050	As above
In-River Commercial and Aboriginal Fisheries		
Area 29 to P.Mann Gillnet - chum fisheries	(.000661*fleetsize)-.01648	Based on reconstruction of chum data for 1990-98, as detailed in this report.
Area 29 to P.Mann Aboriginal Drift	0.071	Estimated by run reconstruction on the 1995 data for use in the in-river sockeye management model.
Area 29 to P.Mann Troll	q=0.02	Speculative
P.Mann to Mission Gillnet – chum fisheries	0.31	Based on reconstruction of chum data for 1990-98, as detailed in this report.
P.Mann to Mission Aboriginal Drift	0.15	Estimated by run reconstruction on the 1995 data for use in the in-river sockeye management model.
P.Mann to Mission Set Net	0.01	Estimated by run reconstruction on the 1995 data for use in the in-river sockeye management model.
Area 29 to Mission Gillnet - chum fisheries	h = 0.000615 * bts + 0.0184	Based on reconstruction of 1990 to 1995 data as shown in Appendix C - average rate for all of area 29
Mission to Agassiz Set Net	0.06	Estimated by run reconstruction on the 1995 data for use in the in-river sockeye management model. Modified for steelhead as model runs to account for differences in migration speed.
Agassiz to Hope Set Net	0.05	Estimated by run reconstruction on the 1995 data for use in the in-river sockeye management model. Modified for steelhead as model runs to account for differences in migration speed.
Hope to Sawmill Set Net	0.20	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Sawmill to Lytton Set Net	0.008	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Sawmill to Lytton Dip Net	0.002	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Lytton to Texas Set Net	0.009	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Lytton to Texas Dip Net	0.0035	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Texas to Kelly Set Net	0.009	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.

Texas to Kelly Dip Net	0.0015	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Kelly to Deadman Dip Net	0.003	Rough fit to historical data using in-river forward model
Deadman to Chilcotin Dip Net	0.0006	Rough fit to historical data using in-river forward model. Modified for steelhead as model runs to account for differences in migration speed.
Chilcotin Rod and Reel		No data
Lytton to Kamloops Set Net	0.001	Not yet formally estimated but likely to be very low
Lytton to Kamloops Dip Net	0.001	Not yet formally estimated but likely to be very low
Lytton to Kamloops Rod and Reel		No data.
Sport Fisheries		
Area 29 to P.Mann	Insignificant	
P.Mann to Mission	Insignificant	
Mission to Agassiz	Insignificant	
Agassiz to Hope	Insignificant	
Hope to Sawmill	Insignificant	
Sawmill to Lytton	Insignificant	
Lytton to Texas	Insignificant	
Texas to Kelly	Insignificant	
Kelly to Deadman	Insignificant	
Deadman to Chilcotin	Insignificant	
Chilcotin	No data yet	
Lytton to Kamloops	h = 0.0086* ln (rod-hours) - 0.0376	Based on reconstruction of 1998 run in Appendix D

APPENDIX A. USER'S GUIDE

Following are instructions for use of the Fraser-Thompson steelhead model.

User Interface and System Requirements

The user interface for the steelhead model is Microsoft Excel 5.0 with Visual Basic modules. The inputs and outputs are located in Excel sheets, and all calculations are conducted in Visual Basic. This combination allows the user to work with inputs and outputs in a familiar environment, while coding calculations in VB increases the speed of the model and decreases the size of the Excel file. With 23 fishing areas, 8 gear types, 3 stock groups, 2 migration routes, and a time period of over 150 days, the model would be too cumbersome in a standard spreadsheet.

Due to the large number of fishing areas, gears, stocks, and the daily time step of the model, it was necessary to define arrays in the model with many dimensions. The total amount of memory needed to dimensionalize all variables in the model is significant, so machines with 64 MB of RAM are recommended. The model takes about 1 minute to run on a Pentium 466 with 64 MB of RAM, and may be several times slower with less RAM.

Model Inputs and Outputs

The following tables give a brief description of each of the inputs and outputs of the steelhead model and where they are found. Details of the algorithms for particular inputs and outputs are discussed in detail in later sections. General instructions, a list of all fisheries and gears in the model, and the button which runs the model are all found in the 'Start' sheet. The code used to run the model is hidden in Visual Basic modules. All cells in which the user must define inputs in the model are colored yellow.

Inputs:

Input	**User Control**
Run size and timing	In the 'stocks' sheet, the user must define the run size for each stock, the peak date of arrival, and the standard deviation (in days) describing the spread of the arrival timing.
Diversion rate	In the 'stocks' sheet, the user must define the proportion of each stock that will be diverted south around Vancouver Island and through Juan de Fuca Strait.
Smoothing index	In the 'stocks' sheet, the user must define the degree to which fish vary in their migration speed, and therefore the degree to which daily migration blocks of fish intermix.
Overwintering date	In the 'stocks' sheet, the user must define the date after which all fish are assumed to stop migrating and find suitable to overwinter.
Overwintering mortality rates	In the 'stocks' sheet, the user must define the overwintering mortality rate (due to natural causes, aboriginal gill net fisheries targeting chinook, and aboriginal rod and reel fisheries) for fish that overwinter below Lytton, above Lytton in the Fraser and Chilcotin, and in the Thompson.
Migration speeds	In the 'stocks' sheet, the user must define the migration speed in the ocean, which remains constant over time, and the migration speeds in-river (above and below Hope), which are a function of temperature and/or date. Migration speeds determine how many days fish spend in each fishing area. Currently the time required to migrate through any one area cannot exceed 18 days.
Sockeye Migration Speed	In the 'Stocks' sheet, the user must enter the number of days required for sockeye to migrate through each in-river area, either directly or as a function of migration speed and length of river reach. This information is used in the model to adjust daily catch rates in set net and dip net fisheries to account for differences in migration speeds between sockeye and steelhead.
Date and days of week	In the 'Schedule' sheet, the user must define the first date in which the first few fish start to arrive at the northern tip of Vancouver Island - it is important to specify the year. The user must also set the days of the week to correspond to the date for the current year.
Fishing schedule	In the 'Schedule' sheet, the user must indicate which fisheries are open on which dates (i.e., gear by area).
Catch and mortality rates	In the 'Hrates' sheet, the user must define the elemental daily catch rate for each fishery by date. There are extra columns to allow the user to define catch rates as a function of fleet size or date or other variables. The user must also define the mortality rate for each fishery, which is the portion of the catch that does not survive being caught. Note that elemental catch rates defined for set and dip net fisheries should be rates estimated for sockeye – these are modified as the model runs to account for differences in migration speed between sockeye and steelhead.

Outputs:

Output	Details
General summary by stock	Table 1 in the ‘output’ sheet gives run size, fishing mortality by sector, terminal harvests, overall fishing mortality rate, fall escapement, number of overwintering fish, number of overwintering survivors, total escapement, and total natural and fishing mortality rate.
Catch by gear and area	Table 2 in the ‘output’ sheet gives catch for each of the fishing areas and gear types. Terminal harvests are not included.
Catch by gear, area, and stock	Table 3 in the ‘output’ sheet is a large table summarizing catch by stock for each fishery and gear type.
Overwintering	Table 4 summarizes where fish from each stock group overwinter
Weekly catch for key fisheries	The 14 tables in the ‘DetailedOutput’ sheet summarize catch by week-ending date for each stock, for key fishing areas/gears/sectors.

APPENDIX B. OPTIONS FOR MODELING CATCH RATES IN RELATION TO FLEET SIZE

The Fraser-Thompson steelhead model uses catch rates that are derived mostly from sockeye fisheries. Currently, fleet size - catch rate relationships for those fisheries are based on linear regressions of the number of catch rate on the number of boats. This appendix reviews other alternatives that have been used or suggested, that could also be used in the steelhead model.

The Skeena model (Cox-Rogers 1994) uses an algorithm from Hilborn and Walters (1992) of the form $h = 1 - e^{-qE}$ where *h* is the daily harvest rate, *q* is the catchability coefficient, and *E* is effort. Cave and Gazey (1994) present (but did not use in their model for commercial fisheries on Fraser River sockeye) an alternative algorithm $\mu = a + b\ln(F)$ where μ is the elemental daily harvest rate, *a* and *b* are constants specific to each fishery, and *F* is the fleet size. In either case, these models require historical data relating fleet size to harvest rate for each fishery.

Since there is a lack of data for historical fleet size for many of the Fraser River fisheries, fleet size is modeled in the in-river Fraser sockeye model (Hill et al., in prep) on a relative scale. The base fishing power (*p*) is equal to 1.0 for all fisheries, and the user can increase or decrease the relative fishing power to account for changes in fleet size over time relative to the base year. The elemental harvest rate is modified according to the relationship $\mu' = 1 - (1 - \mu)^p$. This method of modeling changes in fleet size gives the same result as the algorithms above, but may be more practical in cases where historical data relating fleet size to harvest rate are limited. Currently in the in-river Fraser sockeye model, all fishing powers are set to zero, partly because of the difficulty and time required to determine fleet sizes and harvest rates relative to the base year of 1995.

APPENDIX C. ESTIMATION OF DAILY CATCH RATE FOR THE AREA 29 CHUM GILLNET FISHERY

Introduction

This appendix describes the derivation of an effort - catch rate relationship for chum salmon in the area 29 gillnet fishery based on data from previous years. This relationship is currently used in the model for openings in area 29 after October 1st. The number of area 29 gillnet openings on chum are few each year. Openings during the months of October and November (the only months when a significant number of chum might be caught) for past years can be summarized as follows: no openings in 1996 or 1997; one opening each in 1992, 1993, and 1995; two openings in 1990; and three openings each in 1991, 1994, and 1998. We used all of the data from this period (only one of the three openings for 1998 was used because the other two occurred in the same statistical week and could not be distinguished due to data limitations).

Methods

In order to estimate daily catch rates, we need to have estimates of both catch and the number of fish available to be caught in area 29 on a given day. All necessary data were supplied by the Department of Fisheries and Oceans (P. Ryall, South Coast Division, Nanaimo, BC; A. Macdonald, Fraser River Division, New Westminster, BC), and consisted of total catch in area 29 by week, a summary of fishery openings for the area 29 gillnet fishery, Albion test fishery data (catch, effort, and catch per unit effort by date), and fleet size information.

In estimating catch by date, it should be noted that available data from DFO does not distinguish among gears for catch data. However, the gillnet fishery takes almost all of the catch on days when it is open, so we assumed that after subtracting the Albion test fishery data from the catch, the remainder of the catch could be entirely attributed to the gillnet fishery on the days when it was open. Over the period analyzed, there is never more than one opening per week, therefore commercial gillnet catch on the date of opening was estimated as total weekly catch minus the Albion test fishery catch for the week.

Estimation of the number of fish available to be caught in area 29 on a given day was relatively straight-forward. We assumed that the catch per unit effort (catch per time fished in minutes) in the Albion test fishery was proportional to the abundance of fish in the river. Consequently, we scaled the daily cpue in the test fishery to the total returns (area 29 catch plus escapement) to the river to generate an estimate of the daily number of fish passing Albion. For days where the test fishery did not operate, we assumed the cpue would have been the average of the day before and the day after (very few days so this approximation has little effect).

Since chum migrate at a rate of about 10 km/day as they approach the river (Anderson and Beacham 1983), if we assume the same or a slightly slower rate of movement once they enter the river, they will take about 7 days to travel from the mouth of the river to Mission, and they would pass Albion on about day 5. This information was used to calculate the total number of fish available during a fishery, because we assume that 7 daily migration blocks of chum are present between Steveston and Mission at any one time. Thus the number of fish available for a one day chum fishery in area 29 is equal to the number of fish that we estimated to pass Albion on that day, plus the number estimated to pass on the 2 previous days and the following 4 days (total = 7 days).

Results and Discussion

Our estimates of the proportion of chum in area 29 that are caught during a day fishery for the 12 openings from 1990 to 1998 ranged from 0.002 to 0.54, and showed a relationship with effort (Figure C-1; $p=0.014$). The relationship is reasonable and is consistent with general expectation (i.e., substantial catch rate, but lower than during sockeye fisheries due to smaller fleet size). It is likely that the catch rate is higher between the mouth and the Port Mann and lower between the Port Mann and Mission due to higher density of vessels, but this level of detail cannot be estimated without more specific information on the distribution of the fleet. We have selected the average rather than a higher, more conservative percentile because steelhead catch rates can be expected to be lower than chum catch rates due to net mesh size specifications and other factors. As discussed above, this estimate is the percentage of fish between the mouth of the river and Mission that are harvested during a daily opening of the chum gillnet fishery. In other words, this is the average catch rate for fish already present in the area, represented by h. The elemental catch rate for fish entering or leaving this section of the river on the day of an opening is therefore $u = 1 - sqr(1-h)$ (Cave and Gazey 1994).

During testing of the model on the 1999 season, the data point for 1998 was not yet available, and it was noted that the effort in 1999 was expected to be outside the range of historical effort since 1990. The ability of the data to predict a catch rate for 1999 was considered to be very unreliable. However, now that the relationship has been updated with 1998 data, reliability for predicting catch rates in years of small fleet size (e.g., 1999 openings) has presumably increased. The relationship in Figure C-1 should be updated each year to increase its reliability.

It may be possible to analyze data for chum and sockeye fisheries simultaneously to estimate a single effort - catch rate relationship for area 29. As well, consistent with the division of spatial areas in both the sockeye and steelhead models, it should be possible to develop individual relationships for different areas (e.g., Steveston to Port Mann and Port Mann to Mission) if fleet distribution data are available.

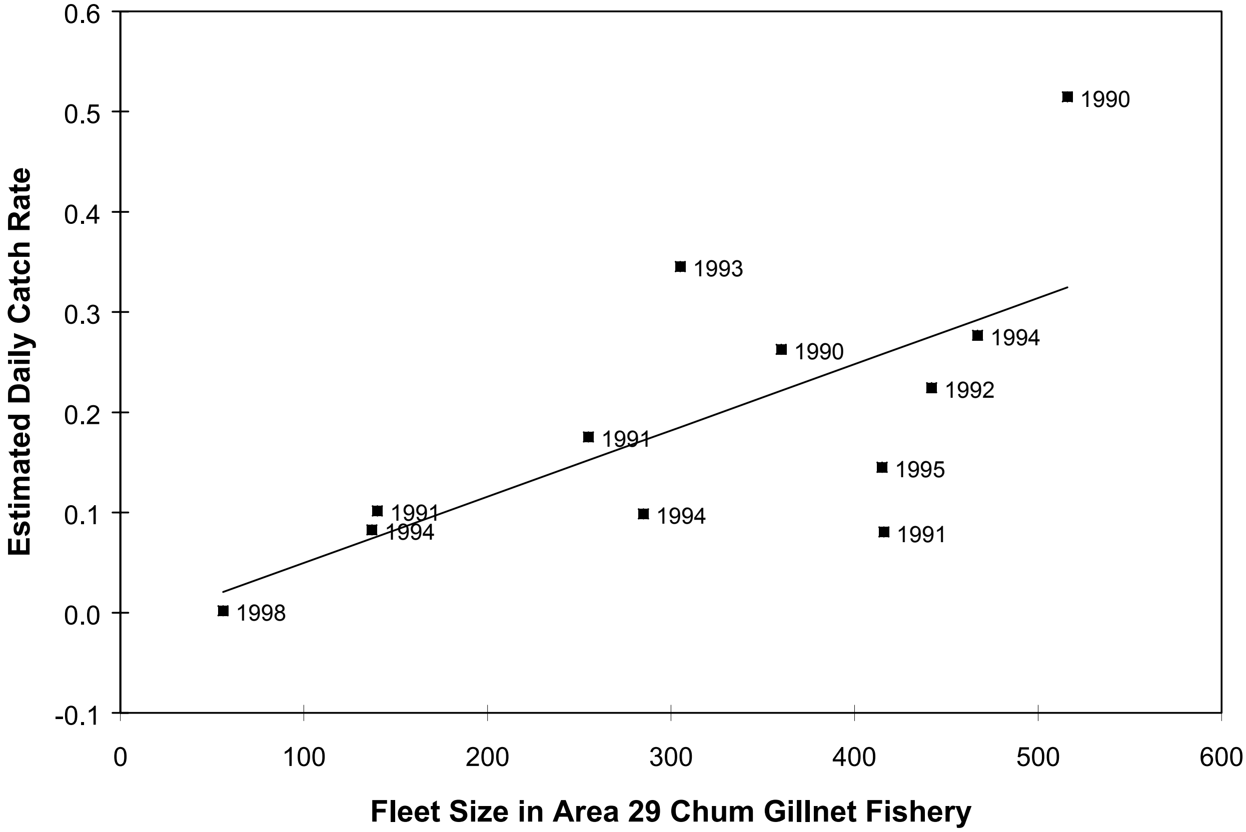

Figure C-1. Daily catch rate of chum in the area 29 gillnet fishery (catch rate = (0.000661*fleet size) – 0.01648). Data points are most openings in months of October and November between 1990 and 1998.

APPENDIX D. MIGRATION-SPEED ADJUSTMENTS TO DAILY CATCH RATES IN SET NET AND DIP NET FISHERIES TO ALLOW USE OF SOCKEYE DATA FOR STEELHEAD

Since daily catch rates for many fisheries in steelhead model are based on sockeye data, it is important to consider differences among sockeye and steelhead that may affect our ability to use the sockeye data. One important difference between the 2 species is migration speed. We have assumed for commercial fisheries that daily catch rates are the same regardless of migration speed. This can be justified in part because these fisheries tend to be very efficient and also mobile, so that they can catch fish at a high rate regardless of whether fish are moving quickly or not (i.e., a fish moving slowly is almost as likely to be intercepted during an opening as one that is moving quickly because the fishers actively search for and find fish).

In contrast, some in-river fisheries such as set nets and dip nets are fixed in place and are passive – that is, they stay in place a wait for fish to run into the net. In this situation, it is easy to imagine that daily catch rates should be lower for slower fish. For example, if an area has three set nets, a slow fish may only pass one of them on a given day while a fast fish may pass all three. The fast fish has a higher chance of capture that day, even though the overall chance of capture may be the same for both fish since they pass the same nets. Using this logic, we have made the assumption in the steelhead model that the overall catch rate for set and dip nets for a given reach in the river is the same for both steelhead and sockeye. Since the model uses daily catch rates, however, it is necessary to adjust daily catch rates to make the overall catch rate in a river reach the same for steelhead as for sockeye. The derivation follows:

If a block of fish takes one day to migrate through an area, the overall catch rate on the block, assuming continuous fishing, is defined as $h=\mu^2-2\mu$ (Cave and Gazey 1994). This is derived by assuming that a block of fish can be harvested at the elemental rate μ twice in succession for each full day required to migrate through an area (this allows us to distinguish catch rates for blocks of fish entering or leaving an area versus blocks of fish in a fishing area for an entire day). If a block of 100 fish enters an area and $\mu = 0.2$, then there will be 20 fish caught as the block enters the area and another 16 fish (80*0.2) caught as the block leaves the area. The number of fish remaining is 64, which is calculated as $100 * (1-\mu)^2$. If the fish are exposed to fishing for 2 days rather than one, the number of remaining fish would be $100 * (1-\mu)^4 = 41$. The following equations are based on this understanding.

For sockeye: $N_L = N_e * (1-\mu_{sox})^{(2*Tsox)}$

where

N_L = number of sockeye that leave an area

N_e = number of sockeye that entered an area

μ_{sox}= elemental daily harvest rate on sockeye

Tsox = # of days for sockeye to migrate through the area

Similarly, for steelhead: $N_L = N_e * (1-\mu_{st})^{(2*Tst)}$

where

N_L = number of steelhead that leave the area

N_e = number of steelhead that entered the area

μ_{st}= elemental daily harvest rate on steelhead

Tst = # of days for steelhead to migrate through the area

If we want to make N_L and N_e are the same for both species (i.e., if we want to assume that the overall catch rate in the area is the same for steelhead as for sockeye), we can use the following derivation to determine the daily catch rate for steelhead:

For sockeye: $N_L/N_e = (1-\mu_{sox})^{(2*Tsox)}$ For steelhead: $N_L/N_e = (1-\mu_{st})^{(2*Tst)}$

Therefore: $(1-\mu_{sox})^{(2*Tsox)} = (1-\mu_{st})^{(2*Tst)}$

Therefore: $Tsox*\ln(1\mu_{sox}) = Tst*\ln(1\mu_{st})$

Solving for μ_{st} we get: $\mu_{st} = 1 - e \wedge [(Tsox/Tst)*\ln(1-\mu_{sox})]$

This equation is contained in the model, and allows us to determine the elemental daily catch rate for steelhead by knowing the elemental daily catch rate for sockeye (μ_{sox}) and the ratio of the relative speed of sockeye and steelhead (Tsox/Tst). In the equation as shown, Tsox and Tst are the number of days required to migrate through an area. Currently the model user must enter the number of days for sockeye to migrate through the in-river areas to use the equation. It would also be possible to use the migration speeds of steelhead and sockeye directly with the following adjustment, although the model is not currently based on this approach:

$$\mu_{st} = 1 - e \wedge [(Vst/Vsox)*\ln(1-\mu_{sox})]$$

where Vst and Vsox are the velocity of steelhead and sockeye respectively in equivalent units.

APPENDIX E. ESTIMATION OF DAILY CATCH RATE FOR THE THOMPSON STEELHEAD SPORT FISHERY

Methods

Estimates of average daily catch rates in the Thompson River steelhead sport fishery were derived from estimates of the number of steelhead available in the Thomspon River sport fishery and the number caught and landed on a given day. The number of steelhead available to Thompson River sport anglers on a given day was estimated by scaling the run timing of steelhead entering the Thompson with the estimated steelhead run size. Run timing was estimated by monitoring the arrival of radio tagged steelhead into the Thompson River. Run size was estimated by adding the post season spawner escapements plus the estimated number of mortalities in the catch and release sport fishery. Mortalities subsequent to the closure of the sport fishery (December 31), whether natural or by illegal sport fishing or by First Nation fishing, is not known, but considered to be low. For the purpose of this exercise, we assumed this mortality to be zero. Steelhead mortality in the sport fishery was estimated by roving angler survey as described in Webb and Bennett 2000. Briefly, the survey did not sample every day of the sport fishery, so total catch and release mortality for the entire season was estimated by extrapolating the daily sampled catch estimates by week and by weekend/weekday strata. The mortality rate for the catch and release fishery was assumed to be 5% per capture (Webb and Bennett 2000, Anonymous 1998).

It was assumed that fish are available to the fishery on the day that they arrive to the area and on all subsequent days. By treating the entire area as one box we do not need to understand the fate of specific groups of fish. Differences in catch rates for the 3 stocks in the Thompson system due to different catch rates in the sport fishery are assumed to be insignificant since most fish are caught below the Nicola River confluence. No data are available for estimating specific catch rates for each stock in the sport fishery.

It was also assumed that all Thompson stocks successfully migrated into the Thompson River during the fall migration period rather than overwintering in the Fraser River. The temperature of the Fraser River was sufficiently warm in 1998 to facilitate upstream migration through the entire fall migration period. The migration pattern and fate of radio tagged steelhead supported this assumption.

The estimated number of steelhead landed on a particular sampled day was estimated by a roving angler survey as described in Webb and Bennett 2000. Data on steelhead landed per rod-hour as well as start-of-fishing and end-of-fishing times were collected by interviewing anglers. For each day in which the survey was conducted, daily fishing activity profiles were constructed by compiling the fishing times for each angler interviewed. Surveyors also conducted instantaneous angler counts usually around 1000 hrs. Total daily effort (in rod-hours) was estimated by extrapolating the activity profiles by the instantaneous rod counts. Total daily number of steelhead landed was estimated by multiplying the number of steelhead landed per rod-hour by the total estimated rod hours.

The daily landing rate for each day in which angler surveys were conducted was calculated as the estimated total number of steelhead landed divided by the estimated number of steelhead in the Thompson River on that day. The relationship between daily landing rate and effort (rod-hours) was estimated by regression analysis.

Results

The escapement estimate of Thompson River steelhead in the spring of 1999 was 2420 (MELP file data). The estimated number of steelhead mortalities in the corresponding 1998 sport fishery was 21-70 depending on the assumption of mortality rate (Webb and Bennett 2000). We assumed a mortality rate of 5% per capture for the purpose of this analysis, therefore the corresponding estimate of mortality due to sport fishing was 70 steelhead.

During the course of the 1998 fall migration, 38 steelhead radio tagged in the lower Fraser River migrated into the Thompson River. The distribution of radio tagged steelhead in the lower Fraser River followed a daily deployment schedule which was based on the steelhead run timing reflected in Albion chum test fishery for the years 1989 to 1997. Since timing as reflected in the 1998 test fishery results was similar to previous years, it was assumed that radio tags were distributed in proportion to abundance and that all run timing components were represented equally. It was therefore assumed that the arrival of radio tagged steelhead to the Thompson River was an accurate representation of timing.

Estimates of effort and number of steelhead landed varied considerably over the days surveyed (Table E-1). The number of steelhead landed roughly varied with the amount of effort. Estimated effort ranged from a high of 958 rod hours on November 12 (the Thursday of the Remembrance Day week) to 162 rod hours on December 11 (a Friday). These estimates reflect a range in the respective instantaneous rod counts of 82 (at 0900 hr. on November 12) and 18 (at 1000 hr. on December 11). The most steelhead landed over the dates surveyed was 46 on November 12, the day that had the most effort. The least number of steelhead landed over the dates surveyed was 4 on December 11 and December 13.

The estimated number of steelhead available to sport anglers on the dates for which the angler survey was conducted ranged from 1634 on the first date sampled (November 12) to 2159 on the last date sampled (December 13). As illustrated in Figure E-1, the majority of steelhead arrived to the Thompson River by mid November. The relationship between effort and the proportion of steelhead available that were landed was represented by a regression equation. Natural log transformation of effort resulted in an r^2 value 0.39 for the landing rate relationship (Figure E-2).

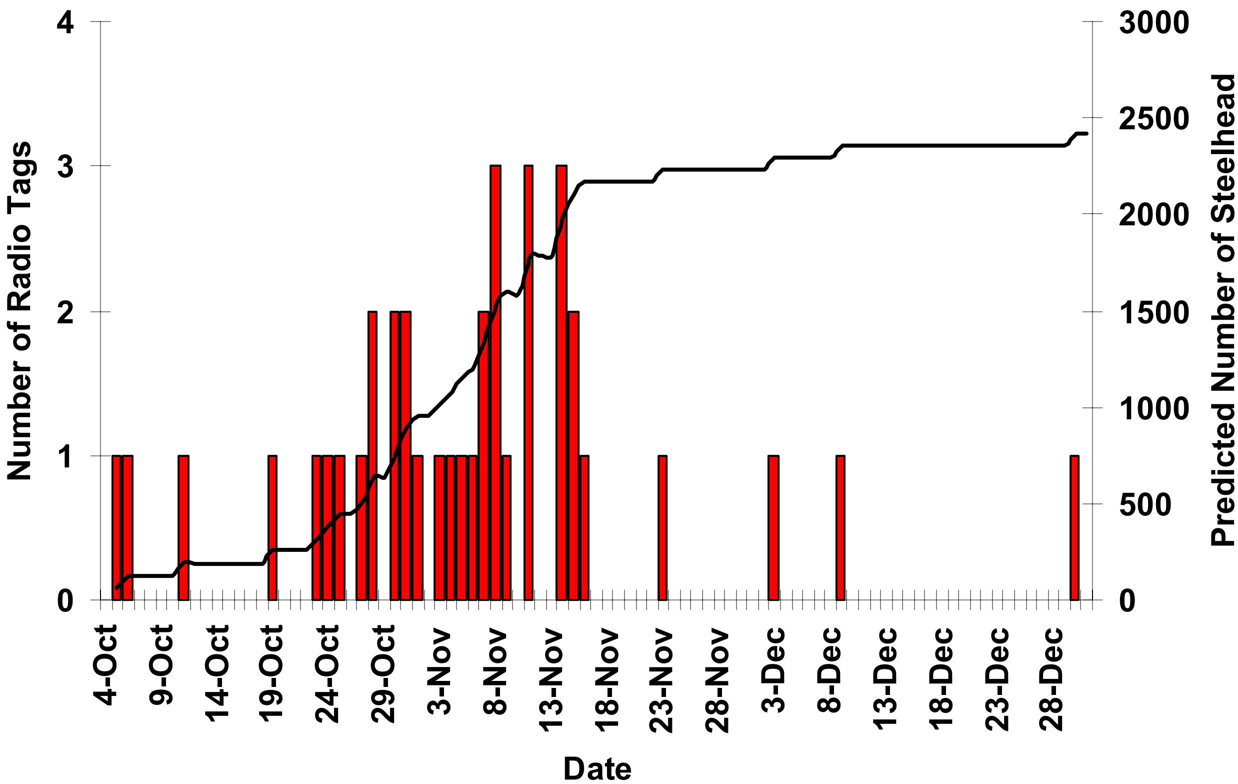

Figure E-1. The timing of radio tagged steelhead arriving to the Thompson River in 1998 and the estimated abundance of steelhead available to the sport fishery.

Table E-1. Estimation of average daily landing rates.

	CPUE				Total Daily Effort		Average Daily Rate		
Date	Anglers Interviewed	Actual Hours	Steelhead Landed	Steelhead/ Rod Hour	Instantaneous Rod Counts	Estimated Rod Hours	Total SH Landed	Steelhead Available	Average Daily Landing Rate
12-Nov	72	243	12	0.048	82	958	46	1634	0.028
15-Nov	64	270	6	0.021	78	659	14	1931	0.007
17-Nov	39	165	16	0.098	51	477	47	1984	0.024
18-Nov	38	176	22	0.124	47	413	51	1984	0.026
19-Nov	37	162	13	0.079	46	417	33	1984	0.017
21-Nov	41	195	12	0.056	70	558	31	1984	0.016
24-Nov	30	121	10	0.078	33	315	25	2042	0.012
25-Nov	15	38.5	5	0.120	21	179	21	2042	0.010
26-Nov	32	140	12	0.084	43	365	31	2042	0.015
28-Nov	46	187	12	0.065	80	654	42	2042	0.021
3-Dec	37	141	16	0.097	35	397	39	2103	0.018
11-Dec	14	45	4	0.068	18	162	11	2159	0.005
12-Dec	30	149	8	0.054	54	471	25	2159	0.012
13-Dec	27	100	4	0.040	33	264	11	2159	0.005

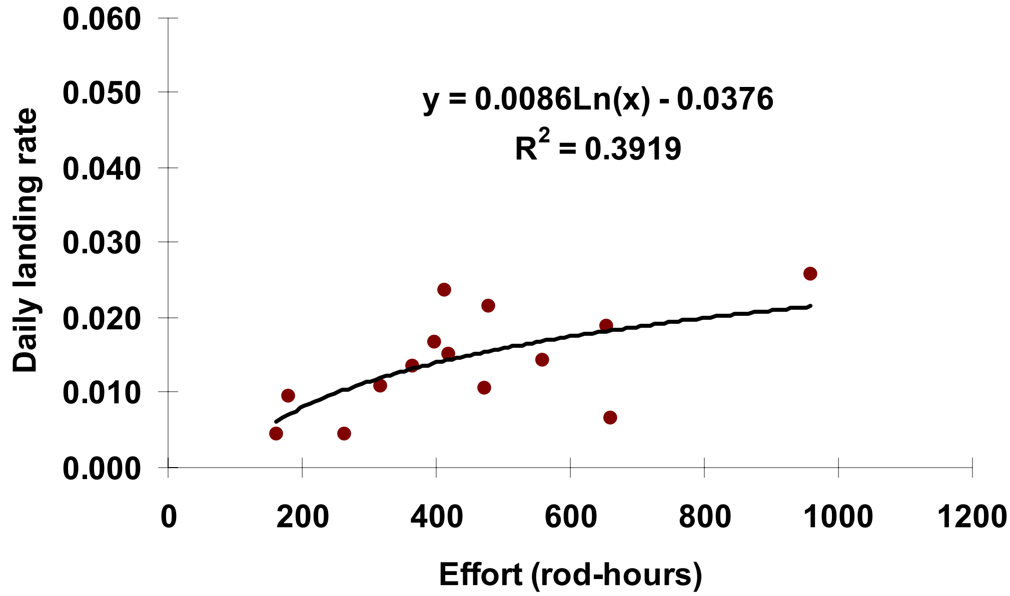

Figure E-2. The relationship between effort and daily landing.

Appendix F. Incorporation of fleet dynamics

This section explains how the spatial distribution of fleets would be incorporated in a forward simulation model and justifies why it is not incorporated here. To begin, it is important to understand that incorporation of the spatial distribution of a fleet means modifying the harvest rates on different migration blocks of fish within a fishery area based on changes in fishing effort. The goal is to modify the harvest rate μ so that it can be higher on daily migration blocks where the fleet is concentrated and lower on blocks where the fleet is less concentrated. In order to do this, we need to first either have a relationship between μ and fleet size F or assume that the relationship is linear, and second have some way of modifying F to account for changes in fleet dynamics (it should be pointed out that Cave and Gazey suggest that fleet dynamics can be incorporated by modifying μ directly with a weighting factor - this assumes that the relationship between μ and F is linear).

In order to understand how the spatial distribution of fleets could be incorporated into the model, it is necessary to review how harvest rates are reconstructed. First, daily harvest rates μ are reconstructed from past data for fisheries. Thus, in the forward simulation model, we define μ for each date for each fishery. This μ is applied to all of the daily migration blocks of fish present in a fishery on that date. If it takes fish 4 days to migrate through a fishery, we can say that there are 4 'sections' of the fishery and that the daily migration block will be exposed to an elemental harvest rate of μ (depending on whether the migration block is entering or leaving the area or somewhere in the middle, the true harvest rate will be either $h=\mu$ or $h=2\mu-\mu^2$. If the harvest rate is calculated as a function of fleet size (e.g., $\mu=a+b*\ln(F)$), then the fleet size is the fleet size for the entire fishery, not for individual sections. *It is important to recognize that if F is the fleet size for the entire area, and we calculate and apply μ to all 4 sections of the area, we are implicitly assuming that the fleet is evenly distributed among the 4 sections of the area (i.e., that the fleet size in any one section of the area is actually 1/4 of F.*

Therefore, the only way to account for the spatial distribution of a fleet *within* an area is to modify μ for each section separately by modifying the F in the μ versus F relationship. For example, if our hypothetical fishery has a relationship $\mu=0.01+0.12\ln(F)$, and the fleet size is 50 boats, then $\mu=0.48$. This value of $\mu=0.48$ is applied to the 4 migration blocks of fish in the 4 'sections' of the fishery area. The implicit assumption is that there are 12.5 boats in each of the 4 sections. If the fleet now moves so that half the boats are in section 1 and half are in section 2 (none in sections 3 or 4), the fleet size has doubled for those sections, so we can modify μ for those sections as $\mu=0.01+0.12\ln(2*F)$. The new value for μ is 0.56 (it has only increased slightly in spite of a doubling of fleet size because the fishery is almost saturated). Thus we have defined a new generic algorithm for μ in a specific section of the fishery area in which F is replaced by w*F where w is a weight defining relative change in fleet size *in that section* of the fishery area. A value for w of 2.0 is used for a doubling of fleet size, a value of 1.0 is no change, a value of 0.5 is a 50% reduction in fleet size, etc.

Unfortunately, in the case of the steelhead model, incorporation of such weights is difficult because we have included considerable flexibility in the model for definition of μ for each fishery. There is a column for μ for each fishery by date. For some fisheries, the user may enter the fleet size in the preceding column and use a formula to calculate μ. For other fisheries, the user may enter the date in the preceding column and allow μ to be modified by date. For other fisheries, data used for run reconstruction may be insufficient to specify a relationship between μ and F, so the reconstructed μ may be entered directly without any formulas to relate it to other variables. In order to allow the user to have this flexibility, the relationships between μ and F are defined in the excel spreadsheet rather than in code. Unfortunately, because these relationships are in the spreadsheet, it would be difficult to modify F for each section of a fishery and stock and date. Each column of μ by date for a particular fishery would have to be modified for each section of the fishery.

Based on this limitation, and the belief that errors caused by ignoring fleet dynamics are small in comparison to errors caused by uncertainty in harvest rates and fish migration speeds, it is my suggestion that a generic option to define the spatial distribution of fleets within areas not be included in the steelhead model. Instead, if there are specific fisheries in which the spatial distribution of the fleet obviously affects harvest rates within a fishery (other than area 29 which is already incorporated in the model using a particular algorithm described below), those can be addressed individually. It is expected that fleet dynamics are unimportant for most of the fisheries. In addition, for those areas in which a fleet clearly concentrates in particular section(s) of the area, it is likely that the reconstructed harvest rates do not or will not account for the spatial distribution. In that case, μ will be biased low unless the relationship between μ and F is linear across the historical range of F. Therefore, if a fleet was not uniformly distributed in an area for reconstructed years and it remains the same now, we are better off ignoring the current spatial distribution or we will end up underestimating true harvest rates for that area.

The fleet dynamics and nature of the commercial fishery between Steveston and the Port Mann bridge (part of area 29) have been incorporated into the model as in the in-river sockeye model. Due to the extremely high harvest rate in this area, if the fishery is open for two consecutive days, the fleet will not behave the same on the second day. On the first day, the fleet will move down from the bridge to the mouth of the river and thereby harvest the block leaving the area and the block entering the area with equal intensity. However, on the second day, the fleet will not start near the bridge because that block of fish that is now leaving the area was almost completely harvested the day before when it entered the area at the river mouth. Instead, the fleet will fish only at the lower end of the area, and therefore the harvest rate on the block leaving the area is assumed to be zero. A second complication with this area is related to tides and the degree to which the fleet leaves the river and accesses fish not yet migrating upstream. If there are 3 tides rather than 2 on a particular day, *or* if the fleet is assumed to move out of the river late on the day of an opening, boats may have access to the block of fish that won't actually enter the river until the next day. There is an option in the model (in the 'Schedule' sheet) to allow the commercial gillnetters to harvest that next block of fish with a harvest rate equal to 50% of the usual elemental harvest rate.

Additional Info

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- Paul says gives exploitation rates only. Suggests should be relatively easy to take the chum test fishing info (where is test fishing done?), scale to a daily abundance migrating through the river, and calculate a harvest rate.
- this report also has migration speeds - slower than sockeye at 25 km/h through JS, 16 from lower JS to Texada, and 10 from Texada to Fraser River.

Lough, M.J. 1981. Commercial interceptions of steelhead trout in the Skeena River: radio telemetry studies of stock identification and rates of migration. British Columbia Fish and Wildlife Branch. Skeena fisheries report 80-03. 33p.
- probably limited usefulness

Horton, H.F., and R. Wilson-Jacobs. 1985. A review of hooking mortality rate of coho (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Oregon State University, Department of Fisheries and Wildlife. 34 p.

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