

# **Habitat-Based Assessment of Steelhead Production and Escapement in Tributaries of the Mid-Fraser River**

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## Executive Summary

Fraser River steelhead are intercepted by a variety of commercial and aboriginal fisheries, are affected to various degrees by anthropogenic factors in freshwater, and have recently suffered reduced marine survival. These factors have resulted in reduced returns of steelhead and have generated concern about escapement needs for these stocks. This assessment summarizes existing information on habitat and stock characteristics for summer steelhead populations in the mid-Fraser River.

We assessed steelhead production in the mid-Fraser using map-based habitat area estimates as input to a juvenile production model (cf. Tautz et al. 1992) which estimates fry carrying capacity, potential smolt production, and potential adult returns. The analysis may be divided into five distinct parts: 1) the identification of stream reaches used by steelhead fry, 2) the estimation of usable habitat area for steelhead fry, 3) the estimation of steelhead fry carrying capacity, 4) the estimation of potential steelhead smolt yield and adult production based on fry capacity, and 5) the determination of minimum escapements required to fully seed useable habitat and maximum exploitation rates these stocks can sustain.

We estimated the usable habitat area for steelhead rearing in the study reaches to be approximately  $7 \times 10^6$  square meters (700 Ha; approximately 15 percent of the estimated total wetted surface area of  $46 \times 10^6 \text{ m}^2$ ), most of which was in the Thompson (38%) and Chilcotin (42%) systems. The total carrying capacity of the study reaches was estimated to be approximately  $7.2 \times 10^6$  fry; 35% were estimated to have been produced in the Thompson drainage and 44% in the Chilcotin drainage. Mean estimated fry-to-smolt survival was approximately 12% (range 1.8 - 23.9%), and we estimated the total steelhead smolt yield of the study area to be approximately 865,000 smolts. Under optimal conditions, we estimated that the mid-Fraser could produce a total adult run of approximately 104,000 steelhead. Potential sources of error and future directions for this production model are discussed.

Approximately 13,700 steelhead are estimated to be required to fully seed the available summer fry rearing habitat in mid-Fraser tributaries. Estimates of the maximum exploitation rate for individual stocks range from less than 0 to 96% and depend on stock productivity parameters. Accordingly, the minimum marine survival that still allows a sustainable harvest varies widely. Because marine survival rates are currently low, less productive steelhead stocks in the mid-Fraser study area may be in danger of collapse even at minimal harvest rates. Although this model provides a practical estimate of the required steelhead escapement for the mid-Fraser, we conclude that further research is required to determine an appropriate conservation limit for these stocks.

**Table of Contents**

**1. Introduction ..... 1**

**2. Methods ..... 1**

**2.1 Study area.....1**

**2.2 Habitat-based assessment of steelhead stocks.....1**

        2.2.1 *Identification of stream reaches used by steelhead fry.....2*

        2.2.2 *Usable habitat for steelhead.....2*

        2.2.3 *Steelhead fry carrying capacity.....4*

        2.2.4 *Potential steelhead smolt yield and adult production.....5*

        2.2.5 *Minimum escapements and maximum exploitation rates.....5*

**3. Results and Discussion..... 6**

**3.1 Distribution of steelhead.....6**

        3.1.1 *Nahatlatch River.....7*

        3.1.2 *Stein River.....7*

        3.1.3 *Seton River.....7*

        3.1.4 *Bridge River.....7*

        3.1.5 *Thompson River drainage.....7*

        3.1.6 *Chilcotin River drainage.....8*

**3.2 Total and usable habitat area.....8**

**3.3 Fry carrying capacity.....9**

**3.4 Potential smolt yield and adult production.....9**

**3.5 Minimum escapements and maximum exploitation rates.....10**

**4. References ..... 12**

**Appendix 1: Allen Plots for Mid-Fraser Tributaries ..... 31**

## List of Tables

Table 1. Water Survey of Canada stream gauges and hydrologic characteristics of associated stream reaches used in estimating stream width for mid-Fraser macroreaches.....	15
Table 2. Habitat-based estimates of steelhead production in mid-Fraser River and tributaries, excluding confined reaches.....	16
Table 3. Comparison of estimated usable areas and total fry, smolt and adult numbers for streams with and without inclusion.....	18

## List of Figures

Figure 1. Relationship between mean annual discharge (MAD) and total upstream stream length based on data from 15 Water Survey of Canada gauges in the Fraser and Thompson drainage systems. ....	19
Figure 2. Relationship between total upstream stream length and magnitude at the location of 15 Water Survey of Canada gauges in the Fraser and Thompson drainage systems. ....	20
Figure 3. Predicted and observed relationship between mean smolt age and age 1+ fork length for streams in the Thompson and Chilcotin River systems. ....	21
Figure 4. Model predictions of steelhead distribution (thick green lines) for the Bonaparte River and tributaries.....	22
Figure 5. Model predictions of steelhead distribution (thick green lines) for the Guichon River. WSC gauges are shown by black circles.....	23
Figure 6. Model predictions of steelhead distribution (thick green lines) for the Thompson River and minor tributaries.....	24
Figure 7. Model predictions of steelhead distribution (thick green lines) for the Deadman River and minor tributaries.....	25
Figure 8. Model predictions of steelhead distribution (thick green lines) for the Nicola River and tributaries.....	26
Figure 9. Model predictions of steelhead distribution (thick green lines) for the Fraser River and tributaries immediately downstream of Williams Lake.....	27
Figure 10. Model predictions of steelhead distribution (thick green lines) for the Fraser River and tributaries between Hope and Lytton. ....	28
Figure 11. Estimated maximum sustainable exploitation rates for three mid-Fraser steelhead stocks at marine survival rates ranging from 1 - 15 percent.....	29
Figure 12. Recent estimated escapements for the Deadman River and Criss Creek compared to the estimated number of adults required to fully seed the available habitat in these two streams (605, dark line).....	30

## 1. Introduction

Steelhead (*Oncorhynchus mykiss*) populations are found throughout the Fraser River basin as far inland as the Chilcotin River system. Coastal populations in the Fraser drainage may be summer- or winter-run, while virtually all interior populations are summer-run. Fraser River steelhead are intercepted by a variety of commercial and aboriginal fisheries, and have been affected to various degrees by other anthropogenic factors such as forest harvesting, hydropower generation, agriculture, and urban development. Moreover, reduced marine survival, as indexed by the Keogh River winter-run stock, has been observed in recent years (Ward 1996). These factors have resulted in reduced returns of adult steelhead to the Fraser River basin over the past decade, and have generated concern about escapement needs for these stocks.

An understanding of the production potential of the Fraser River and its tributaries is essential for the management of these steelhead stocks. The assessment presented in this report focuses on summer-run steelhead stocks that spawn in tributaries to the mid-Fraser River between the towns of Hope and Williams Lake. The purpose of the assessment is to summarize existing information on habitat and stock characteristics for summer-run steelhead populations in the mid-Fraser River, estimate freshwater carrying capacity, and to provide preliminary recommendations for escapement and harvest levels.

## 2. Methods

### 2.1 Study area

The Fraser River originates in the central plateau region of B.C.'s coastal mountain range and flows nearly 1600 km to the mouth near Vancouver. The study area for this project comprises the mainstem and tributaries of the Fraser River between the towns of Hope and Williams Lake, and includes three major watersheds consisting of the mainstem Fraser, Thompson, and Chilcotin River systems. These watersheds are represented by 16 watershed groups within the provincial 1:50,000 digital Watershed Atlas (FRCN, SETN, BBAR, DOGC, MFRA, SAJR, LNIR, GUIC, THOM, CONP, DEAD, BIGC, LCHR, TASR, CHIR, UCHR). The original intention for this project was to use the watershed atlas to estimate total and useable freshwater habitat for all streams as part of the modeling exercise. Coverages were not available for all of the major tributaries upstream of the Thompson River (i.e., Stein River, Seton River, Bridge River, Big Bar River, Dog Creek; watershed groups SETN, BBAR, DOGC, BIGC, SAJR) and for the entire Chilcotin basin (watershed groups LCHR, BIGC, TASR, CHIR, UCHR). We used different methods for streams where GIS coverages were not available.

### 2.2 Habitat-based assessment of steelhead stocks

This assessment of steelhead production in the mid-Fraser estimates adult carrying capacity for individual stream reaches using map-based habitat area estimates as input to a freshwater juvenile production model and is similar to previous efforts for other watersheds (e.g., Tautz et al. 1992). The basic approach involves estimating the amount of habitat available for steelhead fry and uses a variety of models to estimate carrying capacity, potential smolt production, and potential adult returns. The analysis may be divided into five distinct parts: 1)

the identification of stream reaches used by steelhead fry for summer rearing, 2) the estimation of usable habitat area, 3) the estimation of fry carrying capacity, 4) the estimation of potential steelhead smolt yield and adult production, and 5) the determination of minimum escapements to fully seed useable fry rearing habitat and maximum sustainable exploitation rates. Each part of the analysis is described in detail below.

### 2.2.1 Identification of stream reaches used by steelhead fry

The identification of stream reaches used by steelhead fry in the mid-Fraser basin was based on an extensive review of available scientific literature, consultation with regional biologists, and information on the physical and hydrological characteristics of streams in the study area. For areas with available watershed atlas coverages, the streams were broken down into a series of macroreaches. Macroreaches consist of homogenous units where discharge, sediment delivery, and gradient are relatively constant, as determined from analysis of 1-50,000 maps. Information on barriers to migration and physical factors believed to limit steelhead distribution (e.g. presence of large lakes where rainbow trout residents rear) were used to restrict steelhead distribution to a subset of the total reaches available in the digital watershed atlas. Steelhead were restricted to reaches that:

- Were downstream of barriers to adult migration;
- Were downstream of any macroreaches with a gradient >20%;
- Were riverine (not in lakes);
- Had gradients <20%, Strahler order  $\geq 4$ , and Mean Annual Discharge (MAD) > 1 cms.

For drainages without watershed atlas coverages, the total stream length available to steelhead was determined from the literature. The spatial resolution for reaches without coverages was much coarser than those analyzed using the watershed atlas, and the results of these two analyses are therefore not strictly comparable.

There are a number of cases for which the distance to migration barriers do not reflect the actual distribution of steelhead based on observations by field personnel. For example, anadromous fish are able to migrate 276 km up the Chilcotin River (Tredger 1981), but radio telemetry indicates that few steelhead use the river above the Chilko confluence, 106 km from the confluence with the Fraser River (Spence 1981). In these cases we relied on professional judgement of regional fisheries biologists to dictate the limits to steelhead distribution in the study reaches.

### 2.2.2 Usable habitat for steelhead

The total area of habitat available for steelhead rearing in the study reaches was estimated by multiplying the mean wetted width by the length of each available reach. Empirical estimates of late summer wetted stream width were not available for the majority of streams in the study area, and it was therefore necessary to estimate width based on hydrologic information. Stream width during the minimum flow period was estimated as a function of mean annual discharge and the critical period mean monthly flow (CPMM, expressed as a percentage of MAD) following equation 1 of Tautz et al. (1992):

$$\text{WIDTH} = 5.42 * \text{MAD} ^ 0.523$$

We computed MAD and the critical period mean monthly flow from 33 Water Survey of Canada (WSC) gauges covering the mid-Fraser study region. Sixteen gauges were eliminated from this analysis because they were within watershed groups which were not available. The remaining seventeen gauges were spatially linked to the stream lines and macroreaches on the watershed atlas (Table 1). Total upstream length for each macroreach was computed using the network information inherent in the watershed atlas. The ratio of MAD to upstream length and MAD to stream magnitude was computed for each macroreach which contained a WSC gauge. When multiple gauges existed within a stream the ratios were averaged. Beginning at the bottom reach of each watershed group, our algorithm would 'crawl' up the stream network and compute MAD for each macroreach by multiplying the appropriate MAD-upstream length ratio by the actual upstream length for each reach. If a WSC gauge on a tributary was encountered, the MAD to upstream length ratio for that gauge would be used to compute MAD for all upstream reaches.

Upstream length is a good predictor of MAD (Fig. 1). As expected, MAD increases with upstream length and variability around this relationship can be explained by differences in water yield among drainages. The Nahatlach River gauge site (MAD=35 cms, outlier in Fig. 1) is well above the general relationship which is expected given its higher water yield relative to the other sites which are in dryer drainages to the east. The two Coldwater gauges and the Spius River gauge (cluster of 3 points with a MAD ranging from 5-10 cms and an upstream length < 1,000,000 m) also show slightly higher values which again is expected because these sites are within the wetter Cascade Hydrologic zone (M. Church et al., unpublished data), while the other Thompson drainage sites lie within the drier Thompson-Okanagan plateau.

An exception to our MAD calculation procedure was required for mainstem reaches of the FRCN and THOM watershed groups. These groups have mainstem streams which have an upstream component in other watershed groups which were not available, and upstream length for reaches in these streams could therefore not be computed. However, stream magnitude for these mainstem reaches (the total number of 1st order streams above the reach) was available and this statistic does account for all the streams in other upstream watershed groups. To compute MAD in mainstem reaches of THOM and FRCN, we therefore multiplied the magnitude of each reach by the MAD to magnitude ratio determined at the gauge location (Table 3) for all reaches in the mainstem of each group. This appears to be a reasonable procedure given the strong relationship between stream magnitude and upstream length (Fig. 2).

For streams without watershed atlas coverages, data from WSC stream gauges were used to estimate stream width for the Stein, Lower Chilcotin and Taseko Rivers and Cayoosh Creek using equation 1 in Tautz et al. (1992). For the remaining reaches in the Chilcotin basin and west side tributaries, stream width was estimated using field data (Seton River – Triton 1996; Bridge River – Triton 1992; Yalakom River – Griffith 1995b; Chilcotin River and Elkin Creek – Tredger 1981; Chilko River – Tredger 1984). In all cases, estimates of wetted stream width were multiplied by stream length available to steelhead to compute the total rearing area for each study reach.

The previous exercises produced estimates of the total area available to steelhead fry in the study reaches, and the next step was to adjust this to estimate usable area. The percentage of stream width that was usable (%UW) was estimated using a relationship developed by Tautz et al. (1992, equation 3) that is based on mean annual discharge and low-flow stage (CPMM as defined above) from WSC gauge records:

$$\%UW = 10^{(2.39 - 0.275 \cdot \log_{10}(MAD+1) - 0.4 \cdot \log_{10}(CPMM+1)) - 1}$$

This relationship will overestimate %UW in reaches of larger size streams which are rock controlled and highly confined (e.g. canyons). In these reaches, the banks are steep resulting in only minimal suitable depth-velocity conditions for fry rearing. The presence of mid-channel bars may offset this effect to some extent, but such features cannot be estimated off a map. Given the uncertainty in the amount of useable width in canyon-like reaches, basic production statistics computed in this exercise (number of fry, smolts, and adults) were based on estimates of useable width with and without the inclusion of canyon reaches, as determined by the channel type of macroreaches. For ungauged streams without watershed atlas coverages, we estimated the usable width using a relationship between stream width and percent usable width that was derived from streams where these data were available. The total usable area in each reach was then estimated as the product of reach length and usable width.

### 2.2.3 Steelhead fry carrying capacity

We used data on the size of steelhead fry and stream productivity (total alkalinity) to estimate the maximum density of fry that would be expected to occur in the study reaches. Estimates of the fork length of 1+ steelhead parr were available for all study streams in the Chilcotin basin and west side tributaries (Hebden 1981; Tredger 1981, 1982a, 1982b, 1986; Griffith 1995b; Lister and Benniston 1995; Triton 1996; P.S. Higgins, B.C. Hydro, unpublished data), with the exception of Elkin Creek and the Taseko River; we used estimates from the Chilko River for these reaches. In most cases, these estimates are based on small sample sizes and have low spatial resolution. Estimates of age 1+ fork length (or fry weight) were available for most tributaries to the Thompson system from the literature and from a provincial database (R. Ptolemy, unpublished data). In all cases, fork length estimates from the nearest downstream reach were used for those reaches where data were unavailable. Alkalinity data were obtained from the same reports plus several others (Newcombe 1977; Delany et al. 1982; MacKinlay 1984) and from a provincial water quality database. The weight of steelhead fry was estimated from 1+ fork length using an equation developed by MELP staff.

We then estimated maximum fry density in study reaches using a model developed by Ptolemy (1993) that relates fry density (FPU, #/100 m<sup>2</sup>) to fish size at the end of the growing season (SIZEg) and total alkalinity (TALK):

$$FPU = 36.3 * (TALK^{0.5}) * SIZEg^{-1}$$

This model recognizes that salmonids are strongly territorial and that as fish grow larger the size of their territory increases. Fish density is therefore inversely related to size and increases in streams of higher productivity as indexed by total alkalinity. Within a stream where productivity

is relatively constant, the logarithm of density will decline with a slope of  $-1$  with the logarithm of size (Ptolemy, 1993). A graph of such a relationship is termed an Allen Plot, and it appears to apply very well when compared to density-size data for the streams analyzed in this exercise (Appendix 1). The potential maximum fry population for each reach was then estimated as the product of the estimated maximum density and usable area.

#### 2.2.4 Potential steelhead smolt yield and adult production

Mean smolt age (SMAGE) for steelhead in each reach was estimated as a function of 1+ parr fork length (FL1) based on the equation:

$$\text{SMAGE} = 587.203 * \text{FL1}^{-1.14116}$$

This equation provided an excellent fit ( $r^2 = 0.996$ ) using observed age 1+ fork lengths and estimated smolt ages for the Bonaparte, Thompson, Nicola, Little Chilcotin, Spius, Chilko, and Coldwater Rivers, and Nuaitch Creek (Fig. 3). Smolt ages were estimated based on the mean annual number of degree days  $> 7^\circ \text{C}$  for each system coupled with a requirement of 450 such days prior to smoltification.

Fry-to-smolt survival (FSURV) was then estimated as a function of smolt age using equations modified from those derived by Symons (1979):

$$\text{FSURV} = (10^{(-0.78-0.38*\text{SMAGE})})/0.09$$

A different equation was used for reaches with mean annual discharges less than 5 cms because juvenile steelhead survival is assumed to be lower in smaller streams which have limited rearing space for larger parr:

$$\text{FSURV} = (10^{(-1.01-0.5*\text{SMAGE})})/0.09$$

Total steelhead smolt production for each reach was then estimated as the product of the total estimated fry population and the fry-to-smolt survival rate.

Potential adult production was estimated by multiplying smolt yield by marine survival. Research from the Keogh River (Ward 1996) suggests that marine survival of steelhead has declined from approximately 12% to less than 4% in recent years. For selected stocks, we used several estimates of marine survival (ranging from 1 –15%) in order to provide a range of adult production estimates that could be interpreted in the light of recent unpredictable and highly variable marine survival rates.

#### 2.2.5 Minimum escapements and maximum exploitation rates

We estimated the number of adults required to fully seed all usable habitat (E) based on the equation:

$$E = (\text{FRYPOP} * \text{SR}) / (\text{FECUND} * \text{EFS})$$

where FRYPOP = total estimated fry population, SR = 1/proportion of adult females to total adults, FECUND = fecundity, and EFS = egg-to-fry survival. Estimates of fecundity for Thompson (12000) and Chilcotin (8400) stocks were obtained from MELP reports (Sebastian and Yaworski 1984; Tredger 1984; McGregor 1986; Sebastian 1989). Very little information was available to determine the mean fecundity of steelhead in west-side tributaries (Nahatlatch, Stein, Seton, Bridge); fecundities for all but the Bridge River were estimated at 4,000; Bridge River fecundity was conservatively estimated as 5000 based on limited data (B. Hebden, B.C. Hydro, Kamloops, personal communication). The sex ratios of Thompson and Chilcotin runs are skewed highly towards females (Spence 1978; Moore and Olmstead 1985; Bison 1992) and we used the observed female-to-male ratio of 62:38; we found no data on adult sex ratios for west-side tributaries, and sex ratios in these streams were assumed to be 1:1.

The maximum sustainable exploitation rate (MAXE) that populations can support was estimated as:

$$\text{MAXE} = (\text{ADULTS-E})/\text{ADULTS} \times 100$$

where ADULTS = the estimated potential maximum adult return based on freshwater capacity and the assumed marine survival rate.

### 3. Results and Discussion

#### 3.1 Distribution of steelhead

Steelhead ascend the Fraser River as far as the Chilcotin drainage basin; no steelhead populations are known to exist upstream of this system (J. Leggett, MELP, Williams Lake, personal communication). The majority of mid-Fraser steelhead are found in three areas: 1) the Thompson River system, 2) the Chilcotin River system, and 3) Fraser River west-side tributaries (Nahatlatch, Stein, Seton, and Bridge rivers). Although there are a large number of streams in the study area that could potentially support steelhead, it is generally believed that steelhead occur only in the above-mentioned systems. For example, there are no steelhead in Williams Lake River and San Jose River (J. Leggett, MELP, Williams Lake, personal communication) or in Texas Creek (Hebden 1981). Although juvenile *O. mykiss* have been found in a number of other Fraser River tributaries (e.g., Anderson, Ainsley, Stoyoma, and Kwoiek creeks), steelhead spawning has not been verified in these systems (I. MacGregor, MELP, personal communication). If any of these streams do support steelhead populations, it is unlikely that they represent a significant proportion of the total mid-Fraser run. Although steelhead are found in the Coquihalla River and Silverhope and Yola creeks, which are part of the FRCN coverage analyzed here, we did not consider these streams because they have been treated elsewhere (van Dishoeck et al. 1988).

Our model limited the distribution of mid-Fraser steelhead to macroreaches in the watershed Atlas based on the criteria specified in section 2.2.1 (Figs. 4-10). Note that the modelled distribution is used to estimate the amount of useable area for steelhead fry over the

growing season. Certain small tributaries where spawning occurs, but with limited fry rearing potential (which occurs in the mainstems of these tributaries), were therefore not included in the modelled distributions. The distribution of steelhead rearing areas within individual streams is described below.

#### 3.1.1 Nahatlatch River

A series of waterfalls and rapids located approximately 32.25 km upstream of the confluence with the Fraser River (Fig. 10) form a total barrier to migration of anadromous fish in the Nahatlatch River (Griffith 1995), although it has been suggested that most steelhead probably spawn below Frances Lake (Hebden 1981). Few juvenile rainbow trout were observed at a number of sites above Frances Lake (Griffith 1995). It has been suggested that this river may also support a winter-run steelhead population, although little evidence is available to support this contention (I. MacGregor, MELP, personal communication).

#### 3.1.2 Stein River

There is little information available about the steelhead stock of the Stein River. A barrier to anadromous fish migration exists approximately 42 km upstream of the confluence with the Fraser River (B.C. MOE 1975). Most tributaries to the Stein are very steep and many have impassable barriers near the mouth, although Cottonwood and Scudamore creeks may support steelhead (Eccles and Clark 1974; BCMOE 1975).

#### 3.1.3 Seton River

Steelhead ascend the Seton River as far as Seton Dam, 4.6 km upstream of the confluence with the Fraser River; although there is a fish ladder associated with the dam, steelhead spawning has not been verified upstream of the dam (B. Hebden, B.C. Hydro, Kamloops, personal communication). Steelhead are also found in the lower 3 km of the major tributary of the Seton, Cayoosh Creek.

#### 3.1.4 Bridge River

Approximately 37 km of stream habitat are available for steelhead in the Bridge River; the stream channel upstream of this point is dry up to Terzaghi Dam (Lister and Beniston 1995). The major tributary to the Bridge, Yalakom River, has a waterfall located 32 km upstream of the confluence that is thought to form a barrier to anadromous fish migration, although there are other potential barriers downstream and the distribution of steelhead spawning in the system is unknown (Griffith 1995b). No other tributaries to the lower Bridge River are suitable for steelhead.

#### 3.1.5 Thompson River drainage

Steelhead distribution in the Thompson River system is limited to the lower Thompson River below Kamloops Lake and its tributaries (Fig. 6). The majority of production occurs in the Thompson mainstem and the Nicola River system (Fig. 8). Within the Nicola River system, the

mainstem up to the Coldwater River confluence at Merritt, the lower reaches of the Coldwater River (to Juliet Creek), the Guichon River (Fig. 5), and the lower reaches of Spius Creek (to Maka Creek) are the most important for steelhead production. The Bonaparte River (Fig. 4) and the Deadman River (Fig. 7) are the other major tributaries to the lower Thompson that support steelhead. The Bonaparte River was largely inaccessible to anadromous fish (due to an impassable falls 2.6 km from the mouth) prior to 1988, but a fishway now allows access to over 100 km of suitable spawning and rearing habitat above the falls (Renn 1996; McGregor 1986). Several minor tributaries in the lower Thompson system that might otherwise support steelhead are inaccessible due to natural barriers. There are several minor tributaries to the Thompson River, Nicola River, Coldwater River, Spius Creek, Bonaparte River, and Deadman River systems that support steelhead spawning and rearing, but the majority of production occurs in mainstem areas.

### 3.1.6 Chilcotin River drainage

The Chilcotin River is accessible to anadromous fish for approximately 276 km (Tredger 1981), although few steelhead are found upstream of the Chilko confluence (Spence 1981), and steelhead are not thought to occur upstream of Chilcotin Lake, 162 km upstream of the Fraser (J. Leggett, MELP Williams Lake, personal communication). The vast majority of steelhead in the Chilcotin River drainage spawn in the Chilko River, a major tributary of the Chilcotin (Spence 1981). Steelhead are thought to ascend the Chilko River as far as Chilko Lake, 84 km upstream of the confluence with the Chilcotin (Tredger 1982). The Taseko River, a major tributary of the Chilko, is accessible for 99 km from the Chilko, but few steelhead are found in this river (Tredger 1982). Elkin Creek, a tributary of the Taseko, has a barrier to anadromous fish migration located 12 km from its mouth (Tredger 1981). Other tributaries to the Chilcotin system, including Big Creek, apparently do not support steelhead populations (J. Leggett, MELP Williams Lake, personal communication).

## 3.2 Total and usable habitat area

We estimated the usable habitat area for steelhead fry rearing in unconfined study reaches to be approximately  $7 \times 10^6 \text{ m}^2$  (700 Ha), most of which was in the Thompson (38%) and Chilcotin (42%) systems (Table 2); the mainstem Fraser River reaches were excluded from this estimate because of high turbidity that reduces the quality of habitat for steelhead fry rearing. This is approximately 15 percent of the estimated total wetted surface area of  $46 \times 10^6 \text{ m}^2$  (4,600 Ha). Tautz et al. (1992) found that approximately 10 percent of the total wetted area of habitat in the Skeena watershed was usable by juvenile steelhead, but they included the mainstem Skeena in their estimates. It is important to note that estimates of usable area for reaches without watershed atlas coverages are provisional.

We estimated useable area with and without rock-controlled (canyon) reaches because these reaches provide a small yet uncertain amount of habitat for steelhead fry (Section 2.2.2). When rock canyon reaches were included in the analysis, the total usable area in the study reaches (excluding the mainstem Fraser) was estimated to be  $7.9 \times 10^6 \text{ m}^2$  (Table 3).

### 3.3 Fry carrying capacity

The total carrying capacity of the study reaches in the mid-Fraser was estimated to be approximately  $7.2 \times 10^6$  fry ( $7.9 \times 10^6$  if confined reaches are included); 35% were estimated to have been produced in the Thompson drainage and 44% in the Chilcotin drainage (Table 2). The overall mean density of fry in the study reaches was approximately 1.0 fry/ m<sup>2</sup> of usable habitat.

We estimated the fry carrying capacity of the Thompson drainage (excluding confined reaches) to be approximately  $2.5 \times 10^6$  fry, which is similar to an estimate produced by a previous exercise of this type ( $2.1 \times 10^6$  fry; Sebastian 1989). If canyon reaches are included in the analysis, the estimated fry carrying capacity is increased to  $3.2 \times 10^6$  fry. Thus, the exclusion of these reaches, the majority of which were in the mainstem Thompson (Fig. 6) and Deadman (Fig. 7) Rivers, had a significant effect on the results. This exclusion may be appropriate for the Thompson mainstem, but not for the Deadman River where the confinement is not extensive enough to limit fry useable area. This highlights the difficulty of using map-based estimates of confinement to predict the effect on useable habitat. Field studies or a comparison of field survey data with map-based estimates of useable width should be conducted to determine the proportion of habitat in these reaches that is suitable for steelhead rearing.

### 3.4 Potential smolt yield and adult production

We estimated the total steelhead smolt yield of the mid-Fraser study area (excluding canyon reaches) to be approximately 865,000 smolts. Mean estimated fry-to-smolt survival, which we estimated as a function of smolt age modified by stream size, was approximately 12% (range 1.8 - 23.9%). Under optimal conditions, we estimated that the mid-Fraser could produce a total adult run of approximately 104,000 steelhead. Smolt and adult estimates for the Thompson River and major tributaries (ca. 334,000 and 40,000, respectively) are higher than those of Sebastian (1989; 260,000 smolts and 31,000 adults).

Uncertainties in our estimates of smolt and adult carrying capacity based on map-derived habitat estimates can be classified into the following categories: 1) error in estimating the spatial extent of summer rearing habitat using the watershed atlas and our steelhead distribution rule; 2) error in estimating the amount of total and useable habitat (which is estimated by projecting MAD across reaches and computing total stream width and useable width); 3) error in our estimate of fry potential (which is computed by multiplying the maximum FPU estimated from the FPU-fish size/alkalinity model [see Appendix 1] by the amount of useable habitat); and 4) error in estimates of parameters effecting the intrinsic growth rate of each stock which include egg-fry, fry-smolt, and marine survival rates, and fecundity and sex ratio.

The most challenging uncertainties in this analysis are associated with items 3 and 4. The spatial extent of steelhead rearing habitat has been confirmed within allowable constraints by comparing predicted distributions with actual distributions, which are well established for many of the stocks we examined. Errors in the amount of total and useable habitat can be assessed by comparing map-based projections with field-derived estimates; this has not been done in this exercise due to time constraints but should be done for streams where field data are available. Fry production can potentially be overestimated by applying maximum fry densities

to all reaches does not account for variability in habitat quality due to natural or anthropogenic factors. Application of map-based relative habitat quality models using variables such as gradient and channel type is highly recommended, but will require validation against field-derived estimates of habitat quality and fry production across large reaches.

There are few data available from mid-Fraser steelhead stocks to allow the validation of parameters which effect intrinsic population growth rates. Data on the fecundity and sex ratio of adult steelhead are available for only a few well-studied stocks. An assumed egg-to-fry survival rate of 9% was used in the calculation of smolt production. This value may represent a relatively high estimate for interior streams where suspended sediment concentrations can reduce incubation survival. Fry-to-smolt survival rates used in this analysis were similar to those used in Tautz et al. (1992). Long smolt migrations of interior steelhead stocks may result in higher smolt-migration mortality compared to coastal stocks. Therefore, in general, we believe our production and sustainable harvest rate estimates be overly optimistic. It is important that appropriate field data be collected to allow these critical model assumptions to be tested and revised.

### 3.5 Minimum escapements and maximum exploitation rates

Approximately 13,700 steelhead are estimated to be required to fully seed the available habitat (excluding confined reaches) in mid-Fraser tributaries. When habitat is fully seeded, we estimate that over 103,000 adults are produced which implies an aggregate sustainable incidental harvest rate of approximately 86% under an assumed marine survival rate of 12%. Estimates of the maximum exploitation rate for individual stocks range from less than 0 (Riske Creek, Yalakom River, Bridge River) to 96% (Thompson and Nicola Rivers). Depending on stock characteristics, the minimum marine survival that still allows a sustainable harvest varies widely. The highly productive Nicola River stock can withstand harvest even at very low marine survival rates, while stocks from the Deadman River and Maka Creek can withstand minimal harvest only above marine survival rates of approximately 5 and 12 percent, respectively (Fig. 11). Because marine survival rates are currently thought to be very low (<4%; Ward 1996), less productive steelhead stocks in the mid-Fraser study area (e.g. Deadman) may be in danger of collapse even at minimal harvest rates. Recent escapement estimates for the Deadman River (including Criss Creek; Bison and Renn 1997) suggest that the minimum number of adults required to fully seed the available habitat in this system has been exceeded only once since 1980, although escapements have exceeded 90% of the required number four times (Fig. 12).

The maximum sustainable harvest rates shown in Figure 11 were estimated based on the difference between the number of adults required to fully seed the available habitat and the number of returning adults produced from fully seeded habitat (adult production potential). The number of adults required per unit habitat area is a function of adult sex ratios, fecundity, and the egg-to-fry survival rate. Adult production per unit area is a function of fry-to-smolt and marine survival rates. It is important to realize that harvest rates are not dependent on the amount of usable or total habitat. Harvest rate is solely a function of parameters controlling the intrinsic population growth rate (survival in various life history stages and fecundity), while target escapements, the approach adopted by BC Ministry of Fisheries, are a function of both these parameters and the adult carrying capacity of the river system. Although many of the steelhead

populations we examined are capable of sustaining moderate to high exploitation rates, given the current poor status of many of these stocks, it would be difficult to justify any exploitation rate at all. Harvest rates associated with interception in commercial and aboriginal fisheries and hooking mortality in recreational fisheries should be minimized to allow stock rebuilding.

There are four types of reference levels which can be used in fisheries management decisions: 1) the stock size which achieves carrying capacity, that is, the number of adults required to fully seed all available habitat ( $S_{cap}$ ); 2) the stock size which generates the maximum sustainable yield ( $S_{msy}$ ); 3) the stock size where recruitment overfishing occurs (the stock size where the steep initial slope of the recruitment curve begins,  $S_{overfish}$ ); and 4) the minimum stock size ( $S_{min}$ ) required to: a) maintain sufficient variation so future generations can adapt to changing environmental conditions; and b) to withstand stochastic environmental disturbances (e.g. debris flows, large floods).

In the case of interior steelhead, there is trade-off between maximizing the by-catch ( $S=S_{msy}$ ) and minimizing the risk of stock collapse (minimizing the probability of  $S < S_{min}$ ). The management target stock size should be a value which reflects a balance between these opposing measures. The target should take into account basic population parameters as defined by a stock-recruitment curve (fecundity, egg-to-smolt survival, adult sex-ratios, marine survival), the amount of useable habitat, variability around this relationship (process error principally driven by variable marine survival rates), and uncertainty in inseason management and stock size estimation. A decision theoretic approach using a Monte Carlo simulation of these components is required to derive the target stock size which meets allowable by-catch and conservation objectives.

The current provincial approach to steelhead stock assessment is to use the total number of adults required to fully seed summer fry rearing habitat as the conservation limit ( $S_{cap}=S_{min}$ ). This is an extremely conservative approach, but is currently the most practical because there is insufficient information for most stocks to estimate  $S_{msy}$  and  $S_{overfish}$ , and current understanding of genetics and the behaviour of populations at low stock sizes is inadequate to define  $S_{min}$ . The only somewhat defensible number that can be estimated is  $S_{cap}$ . Because the initial slope of stock-recruitment relationships for steelhead may be very steep (e.g. Ward and Slaney 1993), however,  $S_{cap}$  may be only slightly higher than  $S_{overfish}$ , and a certain high proportion of  $S_{cap}$  might be suitable as a conservation limit. Estimates of  $S_{cap}$  also provide a useful target for stock rebuilding and watershed restoration activities.

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**Table 1.** Water Survey of Canada stream gauges and hydrologic characteristics of associated stream reaches used in estimating stream width for mid-Fraser macroreaches.

<b>Water-shed Group</b>	<b>Gauge Location</b>	<b>Watershed Code</b>	<b>Distance of Gauge above Confluence (m)</b>	<b>Upstream Length above Gauge</b>	<b>Stream Magnitude</b>	<b>Mean Annual Discharge (m<sup>3</sup>/sec)</b>	<b>Critical Period Mean Monthly Flow (% of MAD)</b>
THOM	Thompson River at Spences Bridge	120	27789	-	15088	775	58.58
FRCN	Fraser River at Hope	100	13427	-	58281	2720	88.24
FRCN	Natatlatch River below Tachewana Creek	100170100	33539	393885	98	35.5	65.99
BONP	Bonaparte River below Cache Creek	1205068	11152	2429882	1306	5.87	58.95
BONP	Bonapte River near Bridge Lake	1205068	134768	370446	133	2.90	60
BONP	Hat Creek near Cache Creek	120506800148	2201	634599	256	0.710	47.46
DEAD	Deadman River above Criss Creek	1207146	26760	565825	187	1.65	44.79
DEAD	Criss Creek near Savona	120714600204	1281	275999	94	1.73	26.11
GUIC	Guichon Creek near Lower Nicola	120246600296	3579	1065068	354	1.04	8.89
GUIC	Guichon Creek above Tunkwa Lake diversion	120246600296	68948	46906	18	0.130	44.66
LNIC	Nicola River near Spences Bridge	1202466	16765	5023443	1988	26.5	24.01
LNIC	Nicola River near Merritt	1202466	63228	2777678	1669	13.7	28.51
LNIC	Spilus Creek near Canford	120246600234	1863	488156	136	10.28	14
LNIC	Coldwater River at Merritt	120246600337	1710	672814	194	8.42	11
LNIC	Coldwater River near Brookmere	120246600337	46308	237903	70	6.79	14.87
NICL	Nicola River above Nicola Lake	1202466	7419	2058833	540	3.87	21
NICL	Spahomin Creek near mouth	120246600649	2250	162140	61	0.631	37.88

**Table 2.** Habitat-based estimates of steelhead production in mid-Fraser River and tributaries. Length and total area are computed based on all accessible reaches meeting steelhead fry criteria. Useable area estimates and production values exclude confined reaches.

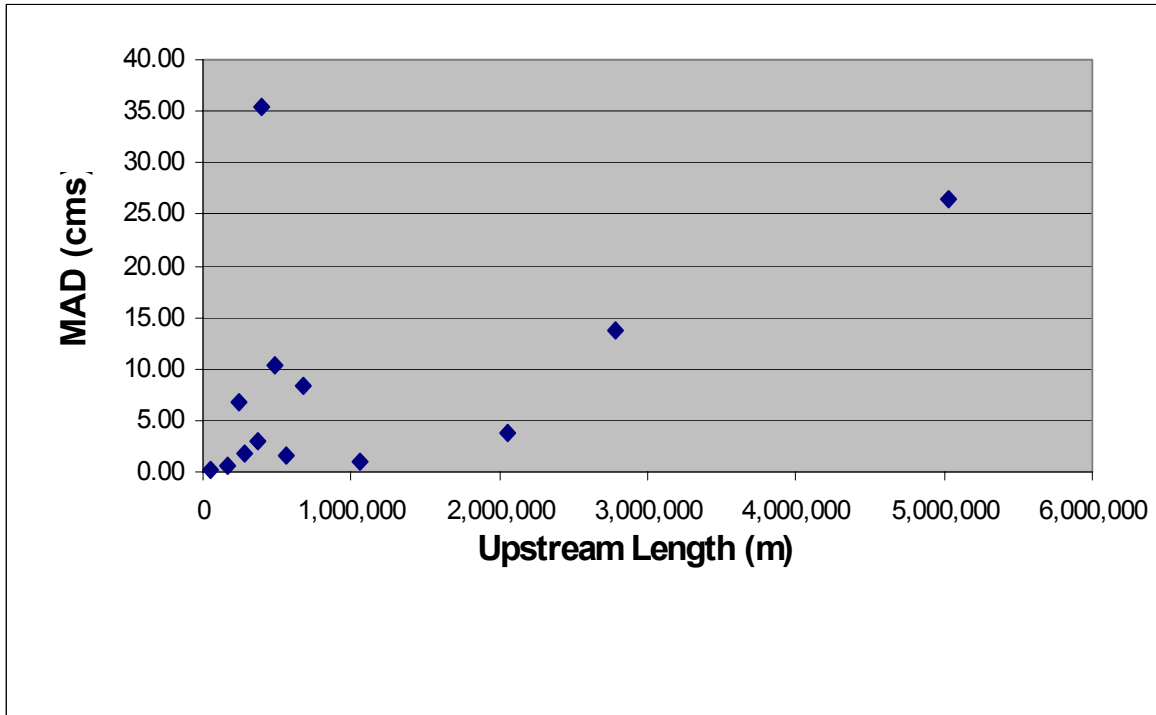
Watershed Group	Stream Name	Order	Length (km)	Total Area (m <sup>2</sup> )	Useable Area (m <sup>2</sup> )	Age 1+ Length (mm)	Total Alkalinity (mg/l)	Fry	Smolts	Adults	Fecundity	Required Escapement	Maximum Percent Exploitation
FRCN	FRASER RIVER	9	127.1	42763016	494468	96.1	57	684763	76278	9153	5000	1707	81
FRCN	SPUZZUM CREEK	4	17.4	300655	28774	96.1	57	39848	3690	443	5000	109	75
FRCN	SCUZZY CREEK	4	5.7	110773	21392	96.1	57	29624	3300	396	5000	74	81
FRCN	NAHATLATCH RIVER	4	35.7	1369271	207241	97.3	15	139768	16196	1944	5000	348	82
FRCN	MOWHOKAM CREEK	4	12.8	158060	24056	96.1	57	33314	1453	174	5000	113	35
<b>FRCN</b>	<b>TOTAL</b>		<b>198.7</b>	<b>44701775</b>	<b>775931</b>			<b>927316</b>	<b>100917</b>	<b>12110</b>	<b>5000</b>	<b>2351</b>	<b>81</b>
<b>FRCN</b>	<b>TOTAL WITHOUT FRASER</b>		<b>71.6</b>	<b>1938759</b>	<b>281462</b>			<b>242554</b>	<b>24639</b>	<b>2957</b>	<b>5000</b>	<b>644</b>	<b>78</b>
<b>THOM</b>	<b>THOMPSON RIVER</b>	<b>7</b>	<b>118.4</b>	<b>19327881</b>	<b>718483</b>	<b>122.7</b>	<b>31</b>	<b>344294</b>	<b>75881</b>	<b>9106</b>	<b>12000</b>	<b>358</b>	<b>96</b>
LNIC	NICOLA RIVER	6	99.0	2368483	735766	126.9	78	503970	120308	14437	12000	523	96
LNIC	SKUHUN CREEK	4	18.9	135952	71808	99.3	78	105259	3252	390	12000	158	60
LNIC	SPIUS CREEK	4	30.3	455060	99005	101.8	61	118755	13673	1641	12000	133	92
LNIC	MAKA CREEK	4	14.6	133459	64941	97.7	37	68780	1995	239	12000	103	57
LNIC	COLDWATER RIVER	4	63.1	1016907	381051	93.3	34	444229	34715	4166	12000	522	87
LNIC	JULIET CREEK	4	0.9	6107	3314	103.0	34	2842	102	12	12000	4	65
LNIC	CLAPPERTON CREEK	4	2.3	19282	9663	93.3	78	17163	409	49	12000	26	47
<b>LNIC</b>	<b>TOTAL</b>		<b>229.0</b>	<b>4135250</b>	<b>1365548</b>			<b>1260998</b>	<b>174452</b>	<b>20934</b>	<b>12000</b>	<b>1470</b>	<b>93</b>
<b>GUIC</b>	<b>GUICHON CREEK</b>	<b>5</b>	<b>32.7</b>	<b>238458</b>	<b>114630</b>	<b>130.8</b>	<b>191</b>	<b>111880</b>	<b>9034</b>	<b>1084</b>	<b>12000</b>	<b>168</b>	<b>85</b>
BONP	BONAPARTE RIVER	6	135.3	1705945	406774	119.6	169	492247	68887	8266	12000	616	93
BONP	LOON CREEK	5	5.2	29480	11189	104.3	169	20679	778	93	12000	31	67
<b>BONP</b>	<b>TOTAL</b>		<b>140.6</b>	<b>1735425</b>	<b>417963</b>			<b>512926</b>	<b>69666</b>	<b>8360</b>	<b>12000</b>	<b>647</b>	<b>92</b>
DEAD	DEADMAN RIVER	5	44.1	339913	69035	88.1	164	212312	3906	469	12000	451	4
DEAD	CRISS CREEK	4	4.9	35156	17150	77.1	135	72355	1331	160	12000	154	4
<b>DEAD</b>	<b>TOTAL</b>		<b>49.0</b>	<b>375069</b>	<b>86185</b>			<b>284667</b>	<b>5237</b>	<b>628</b>	<b>12000</b>	<b>605</b>	<b>4</b>
MFRA	FRASER RIVER	9	62.3	16076177	190640	96.1	57	264007	29409	3529	5000	658	81
MFRA	RISKE CREEK	4	9.7	54844	11011	96.1	57	15249	412	49	5000	55	-11
<b>MFRA</b>	<b>TOTAL</b>		<b>71.9</b>	<b>16131022</b>	<b>201651</b>			<b>279256</b>	<b>29821</b>	<b>3579</b>	<b>5000</b>	<b>713</b>	<b>80</b>

Table 2. (continued).

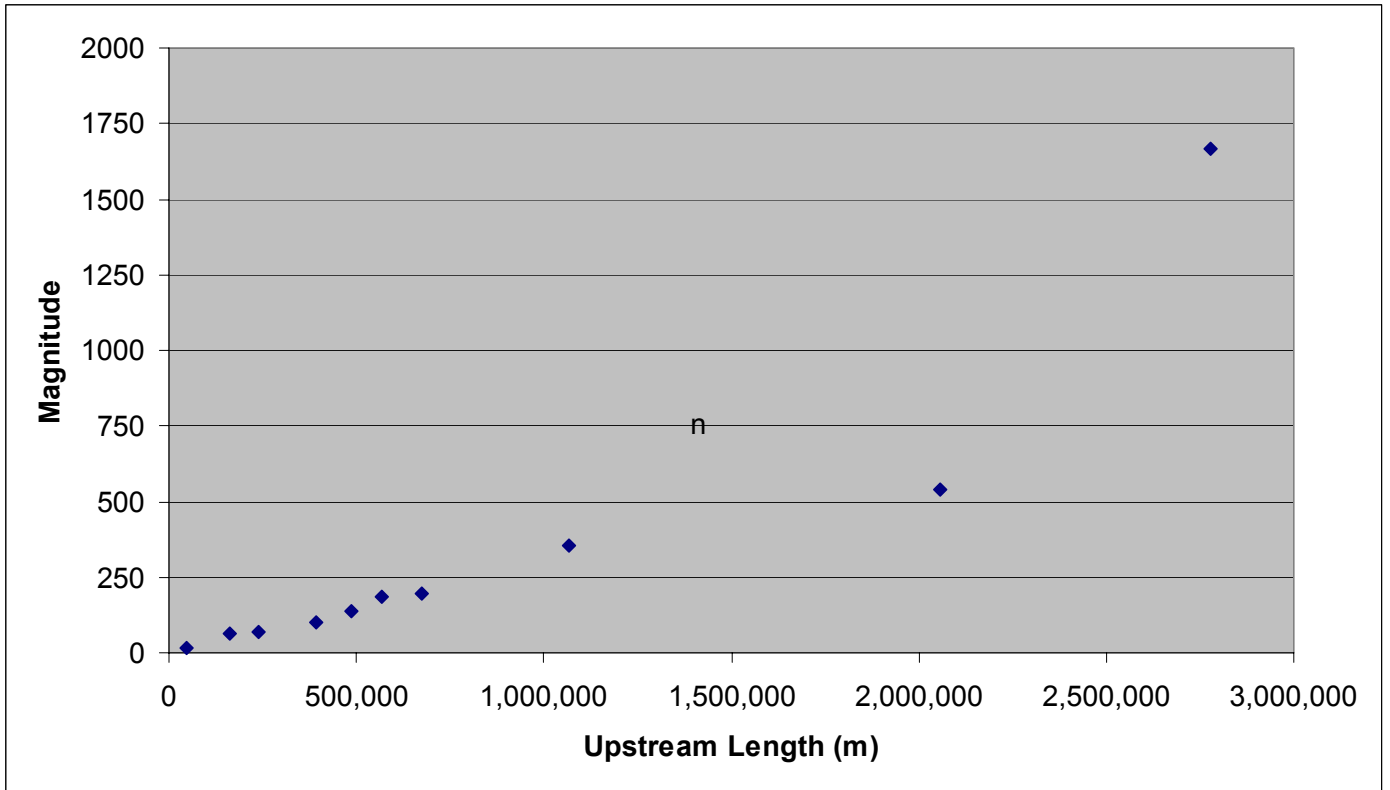
Watershed Group	Stream Name	Order	Length (km)	Total Area (m <sup>2</sup> )	Useable Area (m <sup>2</sup> )	Age 1+ Length (mm)	Total Alkalinity (mg/l)	Fry	Smolts	Adults	Fecundity	Required Escapement	Maximum Percent Exploitation
SETN	STEIN RIVER		42.0	1268072	384825	93.7	28	406852	41745	5009	4000	1565	69
SETN	SETON RIVER		3.3	86988	23390	111.8	32	15253	2652	318	4000	59	82
SETN	SETON RIVER		1.3	29380	7900	111.8	32	5152	896	107	4000	20	82
SETN	CAYOOSH CREEK		3.0	72919	30832	111.8	32	20106	3495	419	4000	77	82
SETN	BRIDGE RIVER		20.0	300000	219139	101.8	50	237735	31661	3799	5000	731	81
SETN	BRIDGE RIVER		4.3	51000	37225	101.8	50	40384	5378	645	5000	124	81
SETN	BRIDGE RIVER		9.5	76000	50658	101.8	150	95189	3255	391	5000	423	-8
SETN	YALAKOM RIVER		15.3	191250	157097	109.0	80	174421	7732	928	5000	775	16
SETN	YALAKOM RIVER		16.4	219760	180516	96.2	75	285831	7762	931	5000	1270	-36
<b>SETN</b>	<b>TOTAL</b>		<b>115.1</b>	<b>2295368</b>	<b>1091581</b>			<b>1280923</b>	<b>104576</b>	<b>12549</b>		<b>5045</b>	<b>60</b>
<b>LCHR</b>	<b>CHILCOTIN RIVER</b>		<b>106.0</b>	<b>6468837</b>	<b>564935</b>	<b>91.2</b>	<b>28</b>	<b>644598</b>	<b>60446</b>	<b>7254</b>	<b>8400</b>	<b>956</b>	<b>21</b>
UCHR	CHILCOTIN RIVER		68.8	1279680	123251	122.5	92	102159	22444	2693	8400	152	94
UCHR	CHILCOTIN RIVER		97.9	1302070	774454	122.5	92	641916	141028	16923	8400	952	94
<b>UCHR</b>	<b>TOTAL</b>		<b>166.7</b>	<b>2581750</b>	<b>897705</b>			<b>744075</b>	<b>163472</b>	<b>19617</b>	<b>8400</b>	<b>1104</b>	<b>94</b>
CHIR	CHILKO RIVER		20.0	940000	130116	92.8	24	130251	12949	1554	8400	193	88
CHIR	CHILKO RIVER		39.5	1185000	436832	92.8	24	437288	43473	5217	8400	649	88
CHIR	CHILKO RIVER		24.5	1237250	189473	92.8	24	189671	18856	2263	8400	281	88
<b>CHIR</b>	<b>TOTAL</b>		<b>84.0</b>	<b>3362250</b>	<b>756422</b>			<b>757210</b>	<b>75277</b>	<b>9033</b>	<b>8400</b>	<b>1123</b>	<b>88</b>
TASR	TASEKO RIVER		99.0	3408736	634623	92.8	24	635284	63156	7579	8400	942	88
TASR	ELKIN CREEK		21.8	152250	103545	92.8	340	390137	38785	4654	8400	579	88
<b>TASR</b>	<b>TOTAL</b>		<b>120.8</b>	<b>3560986</b>	<b>738168</b>			<b>1025421</b>	<b>101941</b>	<b>12233</b>	<b>8400</b>	<b>1521</b>	<b>88</b>
	<b>GRAND TOTAL</b>		<b>1243.3</b>	<b>46074877</b>	<b>7044093</b>			<b>7224794</b>	<b>865033</b>	<b>103804</b>		<b>13696</b>	<b>87</b>

**Table 3.** Comparison of estimated usable areas and total fry, smolt and adult numbers for streams with and without inclusion of confined reaches.

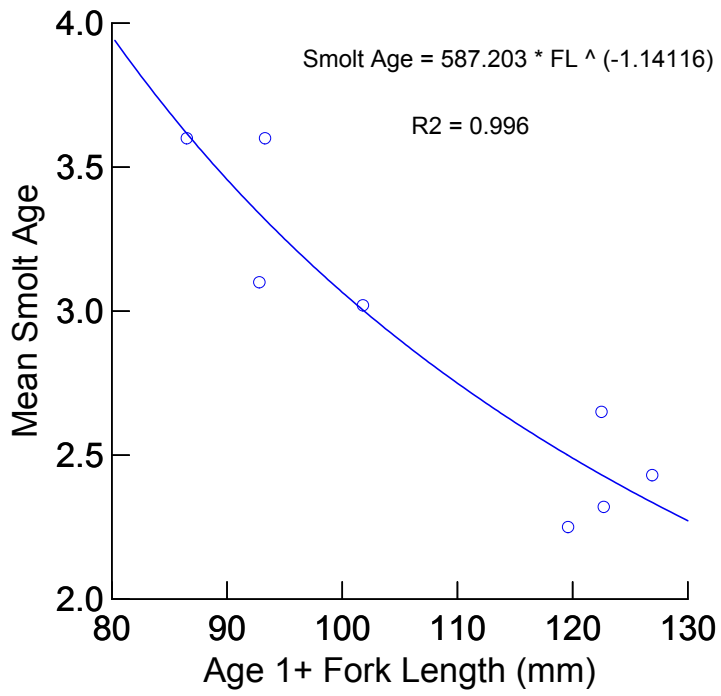
STREAM	Without Confined Reaches (comparable with Table 2)				With Confined Reaches			
	USABLE AREA (m <sup>2</sup> )	TOTAL FRY	SMOLTS	ADULTS	USABLE AREA (m <sup>2</sup> )	TOTAL FRY	SMOLTS	ADULTS
FRASER RIVER	494468	684763	76278	9153	1558810	2158711	240467	28856
MOWHOKAM CR.	24056	33314	1453	174	37976	52591	3423	411
SPIUS CREEK	99005	118755	13673	1641	176126	211260	25980	3118
THOMPSON R.	718483	344294	75881	9106	1345059	646462	142477	17097
BONAPARTE R.	406774	492247	68887	8266	466200	564115	78726	9447
DEADMAN RIVER	69035	212312	3906	469	129791	399160	7343	881
RISKE CREEK	11011	15249	412	49	17675	24478	662	79



**Figure 1.** Relationship between mean annual discharge (MAD) and total upstream stream length based on data from 15 Water Survey of Canada gauges in the Fraser and Thompson drainage systems.



**Figure 2.** Relationship between total upstream stream length and magnitude at the location of 15 Water Survey of Canada gauges in the Fraser and Thompson drainage systems.



**Figure 3.** Predicted and observed relationship between mean smolt age and age 1+ fork length for streams in the Thompson and Chilcotin River systems.

**Figure 4.** Model predictions of steelhead distribution (thick green lines) for the Bonaparte River and tributaries. Stream reaches with steelhead present and a white border denote confined (canyon) areas that provide a limited but unknown contribution to steelhead fry capacity. WSC gauges are shown by black circles.

**Figure 5.** Model predictions of steelhead distribution (thick green lines) for the Guichon River. WSC gauges are shown by black circles.

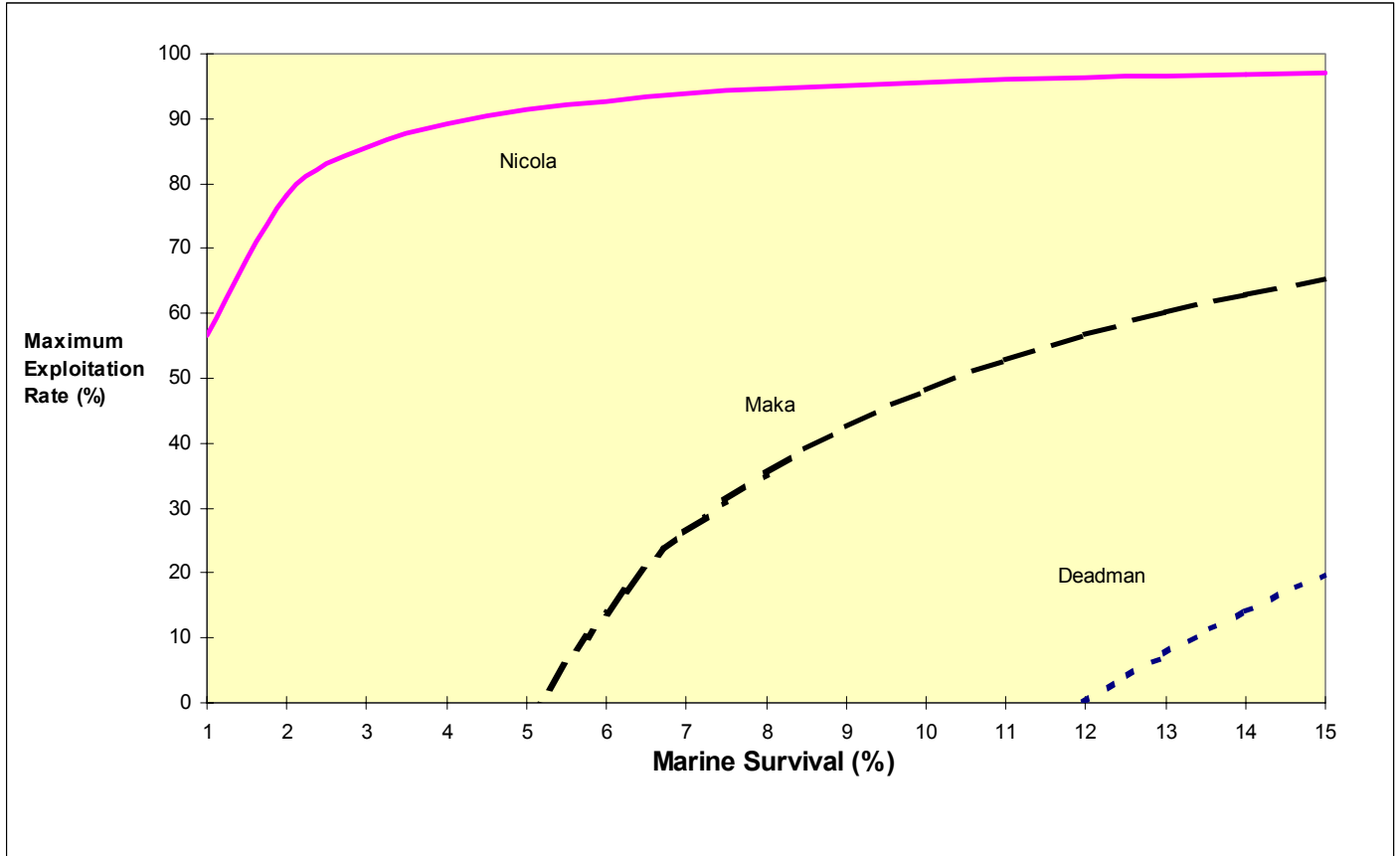
**Figure 6.** Model predictions of steelhead distribution (thick green lines) for the Thompson River and minor tributaries. Stream reaches with steelhead present and a white border denote confined (canyon) areas that provide a limited but unknown contribution to steelhead fry capacity. WSC gauges are shown by black circles.

**Figure 7.** Model predictions of steelhead distribution (thick green lines) for the Deadman River and minor tributaries. Stream reaches with steelhead present and a white border denote confined (canyon) areas that provide a limited but unknown contribution to steelhead fry capacity. WSC gauges are shown by black circles.

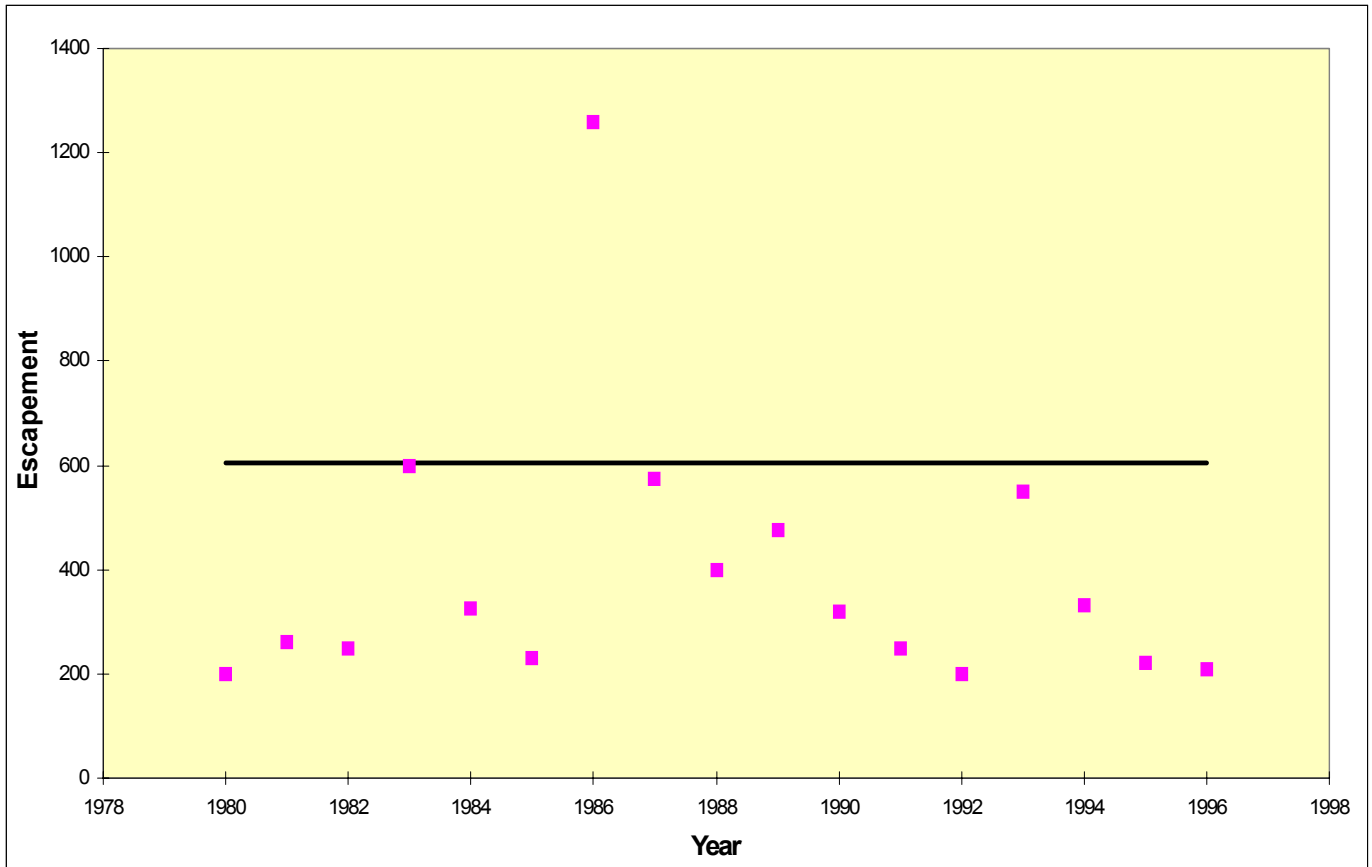
**Figure 8.** Model predictions of steelhead distribution (thick green lines) for the Nicola River and tributaries. Predicted distributions show potential historic steelhead distribution above Nicola Lake prior to construction of the dam at the lake outlet but this habitat was not included in carrying capacity estimates summarized in this report. Stream reaches with steelhead present and a white border denote confined (canyon) areas that provide a limited but unknown contribution to steelhead fry capacity. WSC gauges are shown by black circles.

**Figure 9.** Model predictions of steelhead distribution (thick green lines) for the Fraser River and tributaries immediately downstream of Williams Lake. Stream reaches with steelhead present and a white border denote confined (canyon) areas that provide a limited but unknown contribution to steelhead fry capacity. WSC gauges are shown by black circles.

**Figure 10.** Model predictions of steelhead distribution (thick green lines) for the Fraser River and tributaries between Hope and Lytton. Predicted steelhead distribution in the Coquihalla and Silverhope-Yola Rivers and the mainstem Fraser River (thick green lines in lower right part of Fraser drainage) are shown but were not included in estimates of capability for this watershed group. See Fig. 9 caption for additional details.



**Figure 11.** Estimated maximum sustainable exploitation rates for three mid-Fraser steelhead stocks at marine survival rates ranging from 1 - 15 percent.



**Figure 12.** Recent estimated escapements for the Deadman River and Criss Creek compared to the estimated number of adults required to fully seed the available habitat in these two streams (605, dark line).

**Appendix 1:**

**Allen Plots for Mid-Fraser Tributaries**









