Adult steelhead *(Oncorhynchus mykiss)* habitat use and population size in the Bridge River, springtime 2000.

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Prepared for BC Environment, Fisheries Branch, Kamloops

April 12, 2001

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Abstract

Flow release into a previously dewatered section of the Bridge River downstream of the Terzhagi Dam was initiated, following a negotiated settlement with Fisheries and Oceans Canada (DFO), by British Columbia Hydro and Power Authority (BC Hydro) on August 1, 2000. This report describes a radio telemetry investigation, which was a joint effort by the British Columbia Ministry of Environment, Lands, and Parks (MELP) and the BC Conservation Foundation, of adult steelhead habitat use and population status during the final year of pre-flow release conditions (springtime 2000). Eight radio tags were distributed to steelhead captured near the mouth of the Bridge River, and of these three (37.5%) spawned upstream of the Yalakom River confluence, one (12.5%) spawned in the Yalakom itself, and four (50%) spawned in the Bridge River downstream of the Yalakom. Mean proportions to these same areas were similar for the four years of radio telemetry data, and were 0.375 ± 0.035, 0.109 ± 0.017, and 0.517 ± 0.029, respectively. The size of the adult steelhead population was estimated using the area-under-the-curve (AUC) method to expand periodic counts in the relatively high-visibility reach upstream of the Yalakom confluence (Reach 3). Fifteen additional radio tags were deployed immediately downstream of this counting section, prior to the spawning period, to improve estimates of two parameters crucial to the AUC method: i) average time of residence (directly from telemetry data) and ii) observer efficiency (comparison of number of radio-tagged steelhead seen to that known to be present). After expansion to account for steelhead spawning outside the counting area the population estimate by the AUC method for the Bridge River overall was $N = 155 \pm 27.2$, suggesting that the population size in 2000 was at or below levels considered adequate for conservation.

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Introduction

Background

The construction of Mission Dam in 1948 and the Terzhagi upgrade in 1960 permanently blocked access by steelhead and other anadromous fish to most of British Columbia's Bridge River watershed, and greatly reduced flows in reaches downstream of the dam. As mitigation of dam impacts, continuous release of water at Terzhagi Dam into the Bridge River was initiated on August 1, 2000 by the British Columbia Hydro and Power Authority (BC Hydro), the operator of the dam, following a negotiated settlement with Fisheries and Oceans Canada (DFO). The primary purpose of this release was to increase the productive capacity of the Bridge River by re-watering a dry reach known as Reach 4 (dam downstream 4 km), and by augmenting flow in the partially dewatered but productive section extending from the end of Reach 4 downstream approximately 11 kilometers to the confluence with the Yalokom River (Reach 3).

Fisheries agencies and BC Hydro biologists need to understand the effect of this flow manipulation on the productive capacity of the Bridge River for steelhead (anadromous *Oncorhynchus mykiss*) and other species. BC Hydro has been annually monitoring (since 1996) juvenile steelhead production in the watershed, for comparison with production under alternate flow regimes. However, to assess the effect on productive capacity accurately biologists need to understand to what degree juvenile steelhead production in the system is limited by adult escapement. Typically, because of their low densities resulting from reduced egg deposition at low levels of adult escapement, juvenile salmonid populations are not limited by the carrying capacity of the environment. At higher escapement levels, however, density dependent processes related to total habitat capability will eventually limit the juvenile standing stock. Therefore, it is important that adult steelhead escapements be monitored in addition to juvenile production. Monitoring changes in adult steelhead habitat use and survival is also important in order to fully evaluate the effects of the flow release.

For the above reasons, adult steelhead studies in the Bridge River concurrent with the adaptive management flow regime experiment are deemed essential by the British Columbia Ministry of Environment, Lands, and Parks (MELP). In addition, MELP has other requirements for population monitoring in steelhead producing tributaries of the interior, Fraser River watershed. Current populations levels are thought to be low relative to historical indices. MELP is particularly concerned that fish entering fresh water in the fall (including Bridge River steelhead) face interception by commercial and aboriginal fisheries targeting salmon. Clearly, allocating steelhead to various fisheries while still managing for conservation goals requires that the effects of management actions on the dynamics of each population be monitored. The development of methods for estimating adult steelhead escapement is therefore a crucial step in the management of all stocks of interior, Fraser River steelhead. Population monitoring may be particularly important for the conservation of the smallest populations. Although the size of the steelhead population utilizing the Bridge River was not investigated directly prior to 1999, MELP believed that annual post-dam escapements ranged from 100-300 adults (Hebden 1981; I. A. McGregor, MELP Kamloops, pers. comm.). Both genetics and population dynamics-based models have suggested that populations of this size may be near the minimum that is viable over the longer term (reviews in Boyce 1992; Nunney and Campbell 1993). Population monitoring, therefore, alerts MELP of the need for stronger conservation measures under a scenario of small and declining adult stock sizes.

To address the joint requirements of both BC Hydro and MELP for pre-flow release habitat use information, BC Hydro in 1996 conducted an initial radio telemetry investigation of the adult steelhead population of the Bridge River (Baxter and Roome, in prep.). MELP also collected Bridge River steelhead habitat use information during spring, 1997 and spring, 1999, as part of an extensive radio telemetry study of all known summer steelhead populations of the interior, Fraser River watershed (Webb et al. 2000; Renn et al. 2001). The first time that an adult steelhead escapement estimate was attempted in the Bridge River was during spring, 1999 (Webb et al. 2000), when periodic counts in a relatively high-visibility index section (above the Yalokom confluence) were expanded using the area-under-the-curve method (Neilson and Geen 1981, Hill 1997).

The resulting population estimate of 356, however, was relatively imprecise (confidence interval as a proportion of mean = 0.67), primarily because of a small sample of observer efficiency observations (n=4). The springtime of 2000 provided the last opportunity to investigate adult steelhead habitat use and population size prior to the scheduled beginning of continuous flow release in August. This paper reports on the results of a joint MELP/BC Conservation Foundation radio telemetry study, which had as its stated goals the following:

1. To determine the distribution and habitat use of steelhead spawners within the Bridge River watershed during spring, 2000, and to determine the mean pre-flow release distribution of spawners based on the four years of available information.

2. To achieve greater precision in the adult steelhead population estimate for the Bridge River during springtime, 2000.

3. To estimate survival of Bridge River steelhead spawners, which will be combined with survival information from previous years for comparison with post-flow release survivals.

Study area

The Bridge River, in its natural condition, is a 6th order tributary of the Fraser River, and joins the Fraser near the town of Lillooet, 332 km upstream of the mouth of the Fraser and 220 m above sea level (Figure 1). Physical descriptions of the watershed are available in Higgins and Bradford (1996), Riley et al. (1998), and Webb (2000). The river channel is dry for approximately 6 km below Terzhagi Dam (Reach 4), at which point surface flow is maintained by groundwater flow and the inputs of several small tributaries (distances along channel presented in Figure 2). The Bridge river is a very small stream (mean annual total discharge approximately 0.6 m^3/s - Riley et al. 1998) in the reach extending approximately 9. 8 km downstream from the appearance of surface water to the Yalakom River confluence (Reach 3). The Yalakom River (mean annual discharge approximately 4.11 m^3/s - Riley et al. 1998) contributes the majority of the

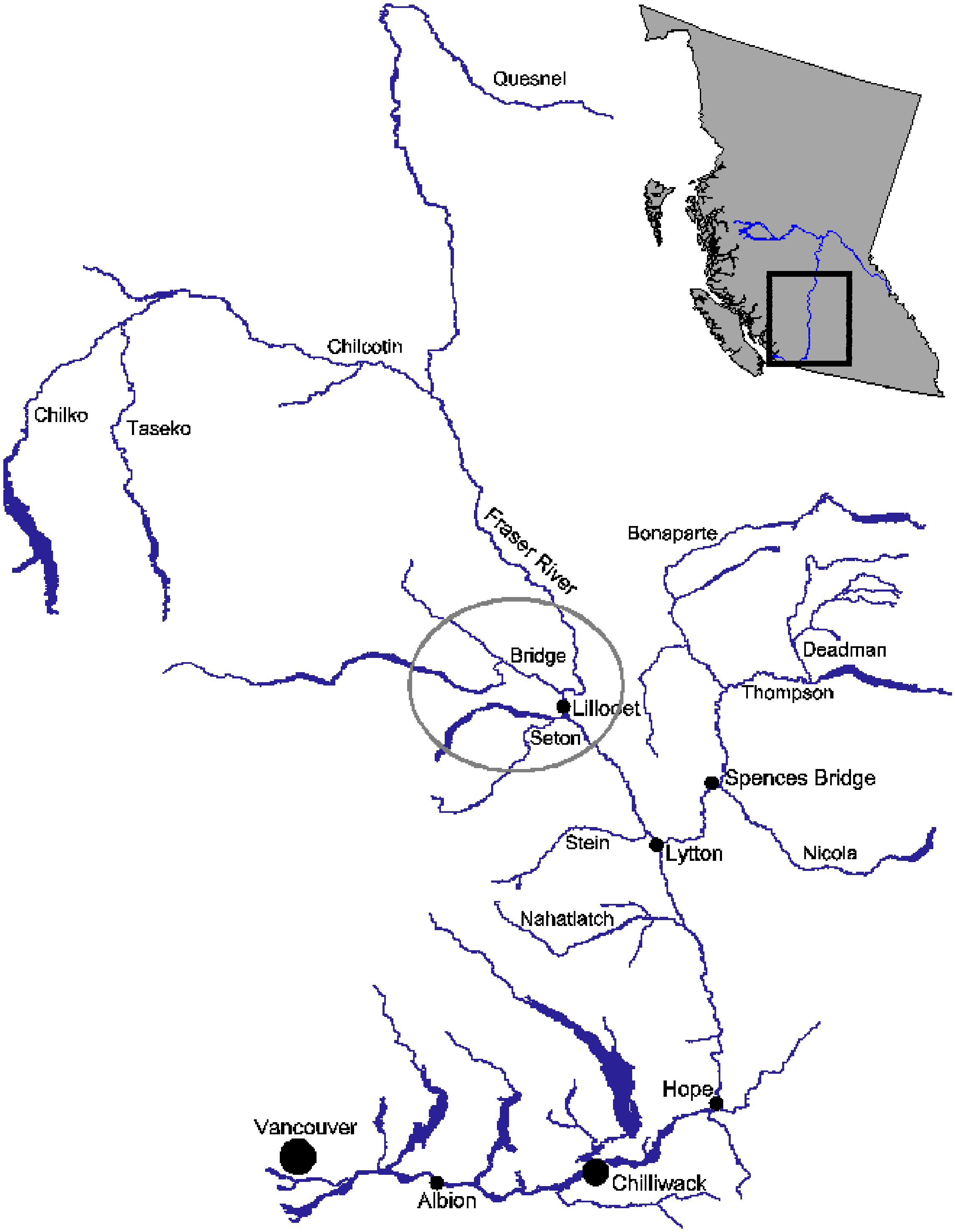

Figure 1. Location of the Bridge River study site within the interior, Fraser River watershed.

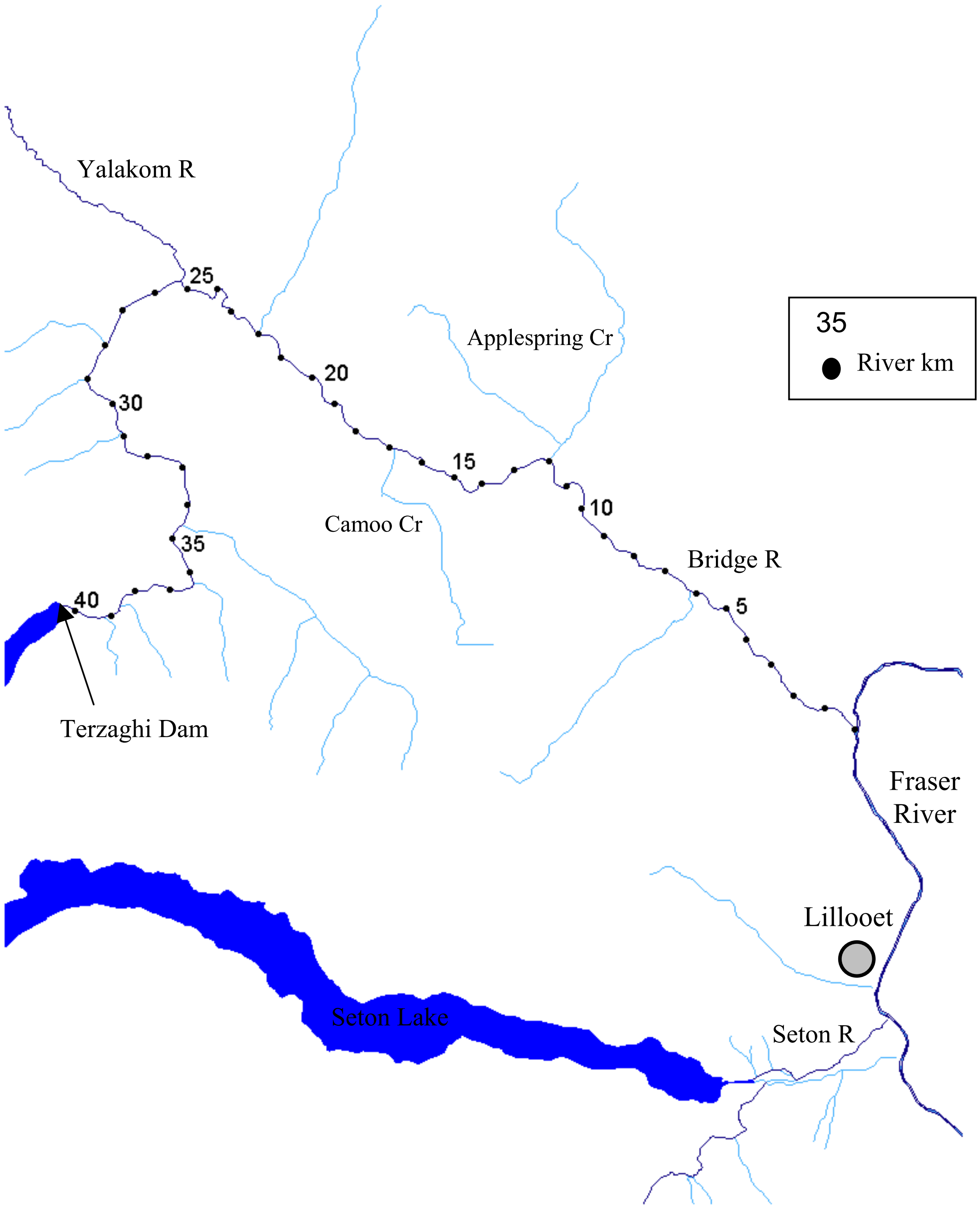

Figure 2. Distances along the Bridge River channel, measured upstream from the Fraser confluence.

flow to the remaining 25 km of the Bridge River. Dowstream of the Yalakom, the Bridge is divided into two reaches; one comprised of 5.6 km of stream length immediately below the Yalakom confluence (Reach 2), the other extending from that point to the Fraser River (Reach 1).

The accessible portion of the Bridge River supports populations of five species of anadromous salmonid: steelhead (*Oncorhynchus mykiss*), chinook salmon (*O. tsawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), and pink salmon (*O. gorbuscha*). Other fish species present in the river include resident rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*), mountain whitefish (*Prosopium williamsoni*), Pacific lamprey (*Lampetra tridentata*), and several species of suckers (*Catastomus spp.*) and sculpins (*Cottus spp.*) also (Riley et al. 1998).

Study Design

Each steelhead population of the Fraser River watershed is an exclusive group only in the springtime, when they enter their specific spawning tributaries during a relatively narrow time window. This then is the ideal time to estimate the size of any particular population. However, in the snowmelt-driven tributaries of the interior, Fraser watershed the springtime is a period of relatively variable turbidity, and therefore reliable population estimates from visual surveys are frequently not possible. MELP has addressed the visibility problem in two tributaries of the Thompson River (Deadman, Bonaparte) by installing a resistivity counter and a fishway equipped with a trap, but these structures are costly to install and/or operate, and are not suitable for larger systems. MELP has also developed a method that combines periodic visual counts with radio telemetry for the Nicola River. Periodic counts from an index reach can be turned into a population estimate for that reach using the area-under-the-curve (AUC) method (Ames 1984; Hilborn et al. 1999), whereby the estimate is the AUC divided by the average time of spawner residence in the index area (r) times the observer efficiency (ν), or:

$$N = AUC / (r * \nu)$$

The nature of the Bridge River with respect to water quality allows the application of this method, which occurred during springtime, 1999. Typically, water conditions downstream of the Yalakom River confluence do not allow visual counts of steelhead spawners during springtime. However, a sizeable portion of the population each year spawns in the reach upstream of the Yalakom confluence, and this reach typically does provide adequate visibility for periodic adult steelhead counts throughout the spawning period.

There were three principle challenges in designing a study that would allow a spawner abundance curve for Reach 3 of the Bridge River (index area) to be transformed into a population estimate for the entire watershed, which were: i) to estimate observer efficiency in the index area reliably; ii) to estimate residence time in the index area reliably, and iii) to devise a method for expanding the estimate in the index area to account for areas that could not be surveyed. During springtime, 1999 MELP took the innovative step of using radio tags in adult steelhead to estimate each of these parameters directly. Because each radio-tagged steelhead had also been outfitted with an orange plastic spaghetti tag, observer efficiency in the Reach 3 index area was estimated by comparing the number of spaghetti-tagged steelhead seen to the number known to be present from the telemetry record. The residence times of radio-tagged steelhead were the differences between times of entry and exit into the index area, which were estimated directly from the frequent tracking observations along the reach and averaged. Radio tags for fish that entered the Bridge River in 1999 were deployed either in the Fraser River or at the lower end of Reach 1, so the tagged fish were expected to distribute themselves throughout the watershed in an unbiased way. The relative distribution of fish to various portions of the watershed, therefore, which was important for determining pre-flow release habitat use, was estimated directly from the telemetry record.

The springtime, 2000 radio telemetry study design was modified substantially from that of 1999, primarily to improve precision in the observer efficiency and residence time estimates. First, all radio-tags were deployed within the Bridge River itself to reduce loss to other systems. This loss was substantial in 1997, when 11 of 25 fish radio-tagged in the Fraser River in the vicinity of the Bridge River did not enter the Bridge (Webb et al. 2000). Thirty radio tags were available for deployment during springtime, 2000. Fifteen of these were slated for deployment at the bottom of Reach 1 (a target that was not met), for the purpose of providing unbiased relative distribution information for the watershed. The other fifteen were to be deployed in holding water in the vicinity of the Yalokom confluence, with the assumption being that these fish had a higher likelihood of entering the index section and would increase the sample size for parameter estimation. The other substantial change in the study plan relative to 1999 was the increased number of ground surveys of the Reach 3-index section during the spawning period. This change, also, was made to improve the precision of the AUC and observer efficiency estimates, by increasing the number of observations.

We also mounted a concurrent effort to learn more about adult steelhead habitat use in the Seton River. However, the number of fish captured and tagged (n = 2) was insufficient to quantitatively address this goal. The results are reported on here nonetheless.

Methods

Fish capture and tagging

Most steelhead captures during springtime, 2000 were made by angling in the Bridge River itself (n = 2 for the Seton River). Because of the cold water temperatures during the period of fish capture, no anaesthetic was used on individuals prior to handling. To facilitate handling and reduce stress on the fish, steelhead were held in zippered tubes made from black, rubberized fabric with flow-through ends. The fish, already quieted from the exhaustion of being captured, were relatively docile when held in this manner. Radio transmitters were inserted orally into the fish's stomach with the aid of a length of flexible, plastic tubing, and the antenna was left to protrude from the fish’s mouth.

Biological sampling for all fish captured was standardized. First, a small section of the adipose fin was removed and stored, along with a label, in a vial of 95% ethanol for future genetic analysis (Beacham et al. 1999). Following this a sample of at least 10 scales was removed for future aging analysis, and an orange spaghetti tag was then threaded and tied through a puncture across the fish's back, at the base of the dorsal fin. Sex, fork length, girth, spaghetti tag number, radio tag channel and code, genetic sample number, condition at time of release, and tagging location were recorded. Fish were released immediately after the completion of sampling.

Radio telemetry

Most of the telemetry information used for the study's analyses was collected by mobile tracking, either by pickup truck along the Lillooet-Goldbridge road or by helicopter. Tracking by truck along all reaches of the watershed that were being used by the radio-tagged steelhead took place once weekly during the migration period, from April 4th to April 30th. The frequency of mobile tracking was increased to three times weekly from May 2nd to the end of the spawning period on approximately June 5th. The index section above the Yalakom River (Reach 3) was typically tracked daily throughout the period that radio-tagged steelhead were using it, to enable reasonably exact estimates of the residence times and to calibrate the visual counts. A two-element directional antenna was utilized for reception, and was attached to a stand consisting of a tripod base, which sat in the box of the pickup, and a telescoping central pole which could be extended to a height of approximately 1.5 m above the truck's cab. Fish locations were recorded on 1:20,000 scale topographic mapping that had the river subdivided into 1 km sections.

Except for the index section in Reach 3, where the road runs directly along the channel margin, roads are not ideally situated for mobile tracking by vehicle in the Bridge watershed. The view of the river in Reaches 1 and 2, and along the Yalakom River, is frequently obstructed by broad terraces and the narrow rock gorge it is entrenched in. Hence, helicopter surveys of the portion of the watershed known to have radio-tagged steelhead present were conducted on April 20th, May 16th, and May 25th, in order to locate fish not detected during vehicle-based tracking. A four-element antenna was attached to the base of the helicopter's high frequency radio antenna, and was oriented with the elements perpendicular to the water surface. Positions were continuously logged by

Global Positioning System (GPS) equipment (Magellan model GPS Nav 5000 pro) synchronized in time with the two out-of-phase receivers that were being used, which enabled establishment of fish location based on time of observation.

Fixed telemetry stations were erected prior to the beginning of the spawning period at the Yalakom/Bridge and Seton/Fraser confluences. The receiver at the Bridge River improved the efficiency of mobile tracking by keeping record of when the first radio-tagged steelhead had entered Reach 3 and the Yalakom River, thereby informing us as to when regular surveys of these areas had to be initiated. The station was also important for estimating survival for steelhead spawners in the index section of Reach 3, by recording kelt exit dates. The solar-powered receiver at the fixed station monitored three, four-element directional antennae, one of which was directed up the Yalakom River, another upstream in Bridge River into Reach 3, and the other downstream in the mainstem in Reach 2. Receiver memory banks were downloaded to a portable computer at the site on an approximately weekly basis, or otherwise as needed.

Mobile telemetry along the Seton River and its tributary Cayoosh Creek took place approximately once weekly during April and three times weekly during the estimated spawning period of May 2nd to June 1st.

Surveys of index area

The index section of Reach 3 extended from the "swimming hole," a rare, deep section of holding water used extensively by steelhead prior to spawning (0.6 km upstream of the Yalokom River confluence), to the Mission Creek confluence located 8.8 km upstream. We assumed that no steelhead spawning took place upstream of Mission Creek because of the exceedingly low flow and coarse substrate. Two observers on foot, each taking a half of the distance, walked the index section three times weekly between May 2nd and June 5th. For each survey observers recorded the number of steelhead of each sex observed (if sex could be determined), and also whether or not the fish were spaghetti-tagged (signifying that they were also carrying a radio tag). Visibility was estimated and stream temperature recorded for each survey date also. Mobile tracking of the index section immediately followed these visual surveys, which enabled the observers to determine what proportion of the radio-tagged fish present they had actually seen.

Results and Discussion

Distribution of transmitters and biological sampling

Bridge River steelhead overwinter at various locations in the mainstem of the Fraser River between Hell's Gate and the Bridge River Rapids (Renn et al. 2001) and appear to enter the Bridge itself from approximately April 1st through May 14th. The majority leave the Fraser for the Bridge River during the final 2 weeks of April (Webb et al. 2000). Water temperatures at this time are gradually increasing from winter lows that are near 1°C in the Fraser and Bridge Rivers. During springtime, 2000, 9 steelhead were radio-tagged in the lower Bridge River between April 4th and May 4th, short of the 15 fish target for learning about spawner distribution. An additional 15 steelhead were radio-tagged in holding water below the Yalokom River confluence between April 19th and May 14th, to learn about residence and observer efficiency within the index section of Reach 3.

Capture information and body size data are presented in Appendix 1. Steelhead captured during springtime, 2000, had smaller body sizes on average than those reported for other tributaries of the interior, Fraser River watershed. Males averaged 833 mm fork length (S.E. = 28.9 mm; n = 10), which compares to male steelhead fork lengths of 930 mm (S.E. = 12.3 mm; n = 12), 895 mm (S.E. = 15.1 mm; n = 7), 857 mm (S.E. = 8.4 mm; n = 49) and 851 mm (n = 16) for the Nahatlatch, Stein, Bonaparte, and Chilcotin Rivers, respectively (Hagen 2000; Bison 1991; Spence 1981). Female Bridge River steelhead averaged 726 mm (S.E. = 18.0, n = 14), while averages for the Nahatlatch, Stein, Bonaparte, and Chilcotin River were respectively 829 mm (S.E. = 11.5; n = 22), 828 mm (S.E. = 8.7; n = 21), 797 mm (S.E. = 4.5 mm; n = 98), and 779 mm (n = 19). Scale aging has not yet been conducted for samples collected during recent radio telemetry investigations on the Bridge River, so it is no known to what degree the body size differences reflect differences in age composition relative to other stocks. In order to relate future Bridge River recruitment to spawner population sizes, such age-composition analysis is essential.

Genetic samples taken from Bridge River steelhead during previous years have received analysis, and the results, which include stock composition of the overall, interior Fraser River summer run population and genetic relationships between individual stocks, are reported in Beacham et al. (1999). In general, it appears that Bridge River steelhead are genetically unique from populations of the other Fraser River tributaries, but they form a sister population to steelhead from the Chilcotin River. These two populations, along with steelhead from other tributaries to the west side of the Fraser River (Nahatlatch, Stein Rivers), form a larger grouping of related stocks. This aggregate is sufficiently genetically distinct from aggregate of the populations of the Thompson River that even individual samples from a mixed stock situation can be consistently assigned to one or the other of these two groupings.

Fish movement

Although a total of 24 radio tags were distributed to Bridge River steelhead, only the 9 tags deployed at the lowermost reach of the watershed were expected to provide an unbiased estimate of fish movement and spawning distribution, as the others were deployed in holding water adjacent to known spawning areas. Of these 9 radio-tagged steelhead 8 were followed in the Bridge River through the expected pattern of upstream migration, residence at a spawning area, and emigration or death (Appendix 2 for the complete tracking record). The last of these transmitters was not detected again in the Bridge River but a tagged adult was later visually observed from the air during periodic steelhead enumeration surveys of the Chilcotin River (R.G. Bison, pers. comm). Because of relatively poor radio reception from the road in the lower Bridge River watershed, and the infrequent nature of helicopter-based tracking flights, the pre-spawning movements of the radio-tagged steelhead can only be described coarsely. Nonetheless, in general it appears that the upstream migration of radio-tagged, Bridge River steelhead was protracted and slow. Male Bridge River steelhead moved upstream from their tagging location at the bottom of Reach 1 to their eventual spawning location at an average rate of

1.3 km/day (n = 3; S.E. = 0.46 km/day), while females moved at a slightly slower rate, 0.91 km/day (n = 5; S.E. = 0.14 km/day). The combined average for the 8 fish was 1.0 km/day (S.E. = 0.18), comparable to the 1.39 km/day (n = 13; S.E. = 0.62) reported for Bridge River steelhead in Webb et al. (2000). Steelhead delayed all upstream migration upon reaching the low flow section in Reach 3. Under pre-flow release watershed conditions, therefore, the Yalakom confluence area contains critical habitats for holding steelhead prior to spawning. Only 3 of the 8 radio-tagged steelhead that had been tracked from the bottom of the watershed spawned in the index section upstream of the Yalakom confluence, but 6 of these 8 were tracked to the Yalakom confluence on at least one occasion.

The initiation of flow release from Terzhagi Dam has permanently altered springtime Bridge River conditions with respect to discharge and temperature. These changes may have an effect on steelhead immigration and movement within the Bridge River. Stream discharge and temperature in the accessible portion of the Bridge River watershed for springtime, 2000, are presented in Appendix 3.

Emigration of spawners from the Bridge River during springtime, 2000 was rapid for those steelhead known to have survived spawning, typical for steelhead spawning tributaries of the interior, Fraser River (Bison 1992; Maricle and McGregor 1993; Hagen 2000; Webb et al. 2000).

Spawning habitat use

Spawner distribution. Spawning locations and times for radio-tagged, Bridge River steelhead during springtime, 2000 could not be determined precisely, but were defined in the telemetry data by an extended and relatively stationary period at a possible spawning location, and subsequent, sustained downstream movement out of the system or death. Again, we expected only the sample of steelhead tagged at the bottom of Reach 1 to provide an unbiased estimate of relative spawner distribution. By the above definition spawning locations were identified for eight of these nine Bridge River steelhead (Table 1, Figure 3). Of the eight steelhead, three (37.5%) spawned upstream of the Yalokom

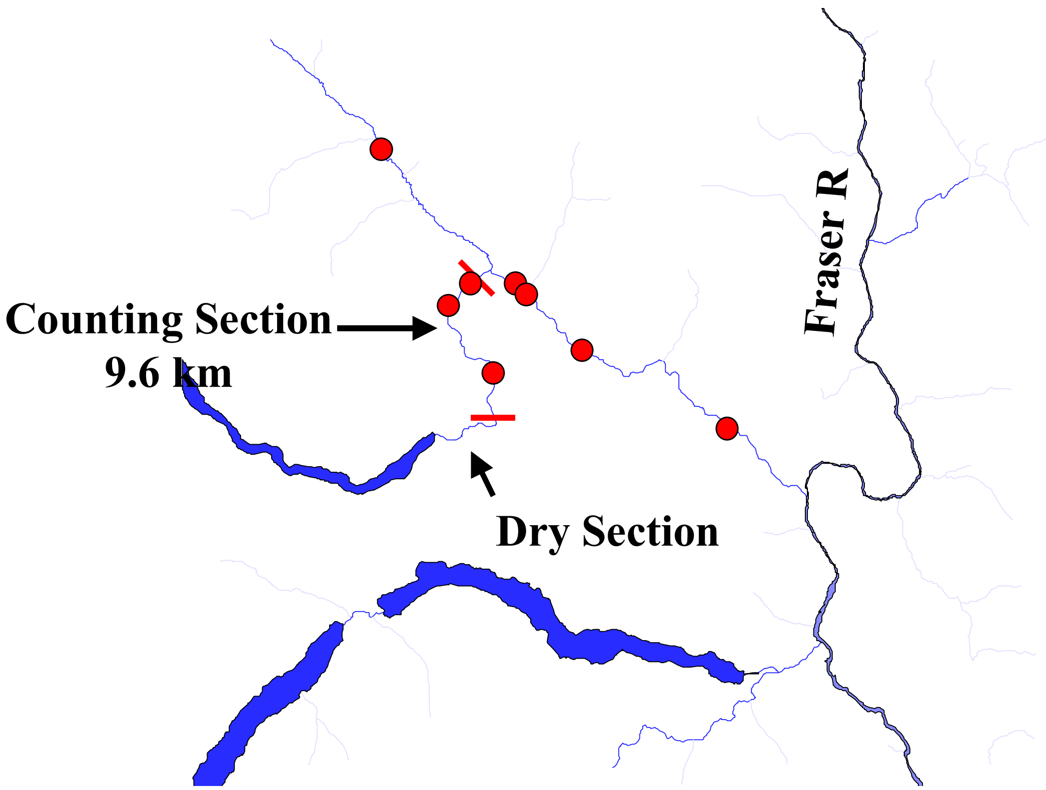

Figure 3. Suspected spawning locations of 8 radio-tagged, Bridge River steelhead that were captured near Fraser confluence and which were expected to represent relative distribution of spawners in an unbiased manner.

confluence (Figure 4), one (12.5%) spawned in the Yalokom River itself, and four (50%) spawned in the Bridge River downstream of the Yalokom. The avoidance of the lower 18 km of the channel by all but one of the fish is conspicuous, and suggests that spawning in the watershed is relatively concentrated in the sections upstream and downstream of the Yalakom.

Figure 4. Steelhead spawning in Reach 3 of the Bridge River, springtime 2000.

The comparison of pre- and post-flow release, relative spawner distributions may provide some insight, although indirect, into the effect of the flow release on the production capacity of the watershed for steelhead. Including the springtime, 2000 information, four years data exist with which to estimate the pre-flow release average relative distribution of spawners in the Bridge River watershed. As above, the proportions spawning in each of three stream sections are presented in Table 2 for the years 2000, 1999 (Webb et al. 2000), 1997 (Webb et al. 2000), and 1996 (Baxter and Roome, in prep.). The average proportions to each of these sections are 0.375 (S.E. = 0.035) to the Bridge River above the Yalakom confluence, 0.517 (S.E. = 0.029) to the rest of the Bridge below this confluence, and 0.109 (S.E. = 0.017) to the Yalakom River itself. These proportions are very close to those from the 2000 data. Because it has now become a substantially different environment after the beginning of flow augmentation in August, 2000, the section upstream of the Yalakom River is of particular interest for comparison with the future. The above estimate of 37.5% to this section is reasonably precise (confidence interval as a proportion of mean = 29%) and incorporates several years of information, so should therefore be considered reliable.

Both steelhead radio-tagged in the Seton River appeared to spawn approximately 2.0 km upstream in Cayoosh Creek. One of these fish was observed in the spawning channel at this location, suggesting that this structure may be effective.

Table 1. Spawning locations and times for radio-tagged, Bridge River and Seton River steelhead during springtime, 2000.

Radio tag no.	Sex	Spawning location (stream km)	Dates at spawning location	Comments
Radio tags deployed at bottom of Reach 1 (relative distribution estimation)				
565	m	22.8	13-May to 20-May	
566	f	1.6	02-May to 04-May	Redds seen at this location, time
1055	f	28.3	07-May to 12-May	Spawned in index area
1056	f	18.0	10-May to 15-May	
1065	m	11.0(Yal. R)	23-May to 24-May	Spawned in Yalokom R.
1608	f	23.0	02-May to 04-May	
1651	f	28.9	18-May to 21-May	Spawned in index area
1679	m	33.4	14-May to 29-May	
Radio tags deployed adjacent to index area (observer efficiency, residence time estimation)				
559	m	18.2	15-May to 19-May	
560	f	30.8	17-May to 19-May	
561	m	25.2	17-May to 22-May	
562	m	21.0	6-May to 20-May	Observed spawing on 7-May
563	f	28.2, 26.2	8-10 May, 15-16 May	Observed spawning at 2 locations
564	f	26.2	16-May to 17-May	Died or regurg. after spawning
570	f	30.3	17-May to 21-May	Died or regurg. at spawning location
573	f	28.0	2-May to 4-May	
584	f	24.5	10-May to 19-May	
588	f	28.9	17-May to 18-May	
1054	m	30.8	17-May to 25-May	Observed spawning on 23-May
1060	m	7.0(Yal. R)	17-May to 18-May	
1061	f	28.8	01-May to 05-May	
1062	m	33.3	8-May to 11-May	Eaten by eagle on 12-May
16100	m	28.3	8-May to 14-May	
Radio tags deployed in Seton River				
585	f	2.0 (Cay. C)	14-May to ?	Vicinity of compensation channel
589	f	2.0 (Cay. C)	16-May to 23-May	Observed at compensation channel

Table 2. Relative distribution of radio-tagged spawners within the Bridge River watershed - 1996, 1997, 1999, and 2000.

Year	Relative Distribution		
	above Yalokom	below Yalokom	in Yalokom
1996	0.300	0.600	0.100
1997	0.357	0.500	0.143
1999	0.467	0.467	0.067
2000	0.375	0.500	0.125

Spawning timing. Male steelhead are known to linger at spawning locations longer after the completion of spawning than do female steelhead (Hooton and Lirette 1986; Lirette and Hooton 1988; Hagen 2000), and therefore spawning timing for the stock is most reliably determined from the spawning activity of females. The period of spawning activity, determined in this manner, for radio-tagged, Bridge River steelhead during springtime, 2000 appeared to extend from May 1st to May 21st. The peak of spawning activity was estimated to be May 12th, and was derived by averaging the median dates for all of the estimated spawning periods for females. A second estimate of the spawning period comes from the observations of spawning activity during periodic surveys of the index area of Reach 3. Female steelhead were visually observed at spawning areas between the dates of May 2nd and May 26th, although the number of individuals observed on any one date were too low (maximum of 2) to detect the peak of activity. The spawning period for Bridge River steelhead is similar to those from other stocks with natal streams in the British Columbia interior. Radio telemetry studies from other Fraser tributaries and in the Skeena drainage have suggested spawning periods of late-April to late-May for the Bonaparte River (Bison 1992; Maricle and McGregor 1993), late-April to early-June for the Stein and Nahatlatch Rivers (Hagen 2000), and from the second week of May to mid-June for Skeena tributaries Zymoetz River, Kitwanga River, Kispiox River, Babine River, Suskwa River, and Morice River (Beere 1995, 1991; Lough 1983, 1980).

Only two radio-tagged steelhead spawned in the Seton River. It appears that they spawned between the dates of May 14th and May 23rd, within the range described for the Bridge River.

Spawner survival

MELP has been concerned about the survival and success of spawners utilizing Reach 3 of the Bridge River due to the low flows and clear water conditions (A. Caverly, MELP Kamloops, pers. comm.). From the springtime, 2000 data a comparison cannot be made between the survival of steelhead using Reach 3 and other areas of the watershed. A fixed station recorded emigration from Reach 3 of radio-tagged steelhead, but the only fixed station downstream of spawning areas in the lower Bridge River was at the Seton confluence. It is unknown what proportion of the steelhead migrating past this broad reach of the Fraser were detected (J. Renn, BCCF Kamloops, pers. comm.). One of the five radio-tagged male steelhead that used Reach 3 for spawning (20%) did not emigrate and was known to have died - the carcass was observed being eaten by an eagle. Two of the eight female steelhead that appeared to have used Reach 3 for spawning did not emigrate and were assumed to have died. In addition to the one radio-tagged male, four other steelhead mortalities were observed (Figure 5), one male and two females that had not spawned, and one other fish that was not examined (E. Braumandl, BCCF Kamloops, pers. comm.). The deaths may have been predator kills: the eagle was routinely observed adjacent to the river in Reach 3 during spawner surveys, and the unexamined fish was being eaten by a black bear. It seems highly likely that the post-flow release increase in discharge in Reach 3 will improve the pre- and post-spawning survival of adult steelhead.

Figure 5. Dead steelhead found along Reach 3 of the Bridge River, springtime 2000.

Population estimate

The area-under-the-curve (AUC) method. Hilborn et al. (1999) were not aware of a satisfactory method for error analysis associated with published applications of the AUC method for population estimation. They presented a computationally demanding AUC model for population estimation based on theoretical run timing curves, whereby the estimate is computed via the technique of maximum likelihood and hence error analysis is completed simultaneously. The principal drawback of the Hilborn et al. (1999) model for application to the Bridge River watershed is that assumptions related to the shape of the run timing curve would, likely, decrease the accuracy of the estimate. Consistent, good viewing conditions during springtime, 2000 and frequent surveys of the index area should mean that the true shape of the spawner abundance curve is best described directly. Indeed, the bimodal appearance of the 2000 curve (Figure 6) may be related to a period of sustained cold temperatures and low flows that occurred in the middle of the spawning period. This would not be represented in any of the model's run timing curve options. The traditional method for population estimation by the AUC method is to measure the AUC directly from the observed spawner abundance curve (Ames, 1984), and then factor it together with the parameters residence time (r) and observer efficiency (ν) according to the equation:

$$N = AUC / (r * \nu)$$

Or, in the case of the Bridge River watershed, where a third parameter (dist - for distribution) must be incorporated to account for steelhead spawning outside of the counting area:

$$N = AUC / (r * \nu * dist)$$

The innovative method (radio tags) used by MELP in the Bridge River watershed allows error analysis to be done for each of the three parameter estimates r, ν, and dist (note: because observational error in the AUC is measured by ν, AUC is treated as a constant). By the delta method (Bevington 1969), then, the variance of the population estimate can be approximated by factoring together the variances for the parameter estimates according to how much each parameter contributes to the population estimate, or:

$$S_N^2/N^2 = S_r^2/r^2 + S_q^2/q^2 + S_{dist}^2/dist^2$$

The Bridge River population estimate presented here, therefore, is based on an empirical description of the spawner distribution curve and error analysis by the delta method.

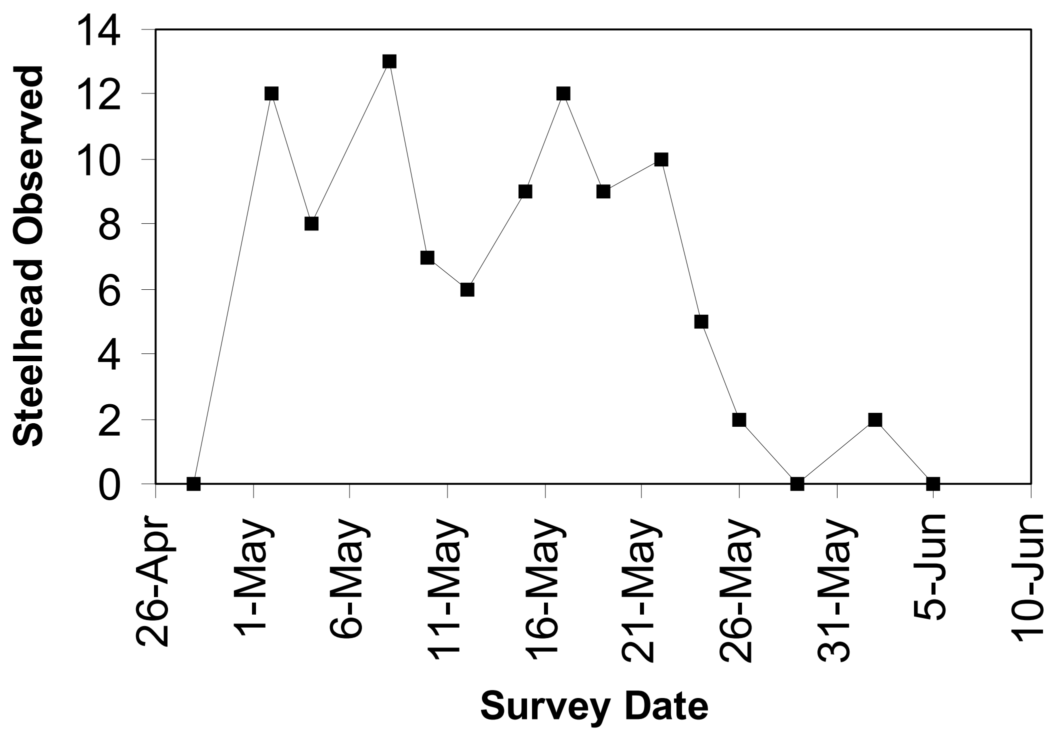

Figure 6. Spawner abundance during springtime, 2000 in the Reach 3 index section of the Bridge River.

AUC calculation. The area-under-the-curve itself was calculated by the trapezoidal method (Hilborn et al. 1999), where:

AUC (in fish*days) = ∑ (time period between survey dates * count on survey date)

Because fish were already present in the index section on the first survey date, the contribution of the period prior to this survey to the AUC was estimated as:

Fish*days (day 1) = (count on first survey date * r) / 2

where r is the average residence time in the survey area (Hilborn et al. 1999). By the above method, then, the AUC for the springtime, 2000 Bridge River spawner distribution curve, which was based on 14 surveys of the index area, was calculated to be 277.0 fish*days.

Parameter estimation. The estimates for each of the parameters r, ν, and dist were calculated from radio telemetry data. However, the variability of the estimate of the proportion of the 2000 total escapement that spawned in the index section (dist parameter) could not be determined from only the one year's information. Because of the small sample size (n = 8) and unknown sampling bias during springtime, 2000, the accuracy of this proportion was also a concern. The spawner distribution information from 1999 (Webb et al. 2000), 1997 (Webb et al. 2000), and 1996 (Baxter and Roome, in prep.), therefore, was also used in order to develop an estimate for which the variability could be assessed. The average proportion of the total Bridge River escapement, then, using the index section was 0.375 (n = 4; S.E. = 0.0346; 95% C.I. = ± 0.110). Choosing to use this distribution estimate over one based solely on the 2000 data had no effect on the best estimate of the population size, as they were identical.

Estimates of the average time of residence (r) used in the AUC method can be affected dramatically by sampling bias. In particular, male and female components of the spawning population can differ greatly. Male, radio-tagged Bridge River steelhead averaged 20.5 days (n = 3; S.E. = 3.19 days) residence in the index section, while females averaged 5.31 days (n = 8; S.E. = 0.718 days). Any sample of the population, therefore, that had a substantially different sex ratio than the true ratio would yield a highly biased estimate. Fortunately, sex ratios for steelhead populations of the interior Fraser watershed do not appear highly variable, and appear to fluctuate around a mean of approximately 2 females: 1 male (R.G. Bison, MELP Kamloops, pers. comm.). The estimated overall steelhead sex ratio for the entire, mixed stock aggregate homing to tributaries of the interior Fraser watershed is 2.02 females: 1 male (n = 181; Renn et al. 2001), which is probably the best available estimate for Bridge River steelhead population also. Male and female residence times, therefore, must be factored together according to this sex ratio to yield the composite residence time estimate for the AUC method calculations. Calculating the variance for the composite estimate is not straightforward. Residence times for each sex and the population sex ratio do not appear to be in themselves highly variable, which should yield a composite estimate in which we have confidence. However, if the variance is calculated for the combined sample it will be unrealistically large because of the great difference between male and female residence times. The composite residence time estimate for the index area and its variance were therefore computed by the method of stochastic simulation (Hilborn and Mangel 1997). Female and male residence times, simulated stochastically 10,000 times, were factored together according to the unvarying 2.02:1 sex ratio to yield an equally large distribution of composite residence times with mean 10.35 days and standard error 1.17 days (95% C.I. $\pm$ 2.31 days). These then were taken as the values for the parameter for use in calculating the population estimate. It should be noted that because the sex ratio was unvarying in the calculation of the parameter estimate, when in fact it does have a variance of unknown magnitude, the variance of the residence time estimate was likely underestimated.

Observer efficiency within the index area was estimated by regressing the number of tagged steelhead observed on 14 survey dates against the number of tagged steelhead known to be present from the telemetry detections (Figure 7). The observer efficiency (regression coefficient for the relationship) was calculated by this method to be 0.461 (n = 14; S.E. = 0.045; 95% C.I. $\pm$ 0.097), a surprisingly low figure considering the low flows and good visibility that prevailed during the springtime, 2000 spawning period.

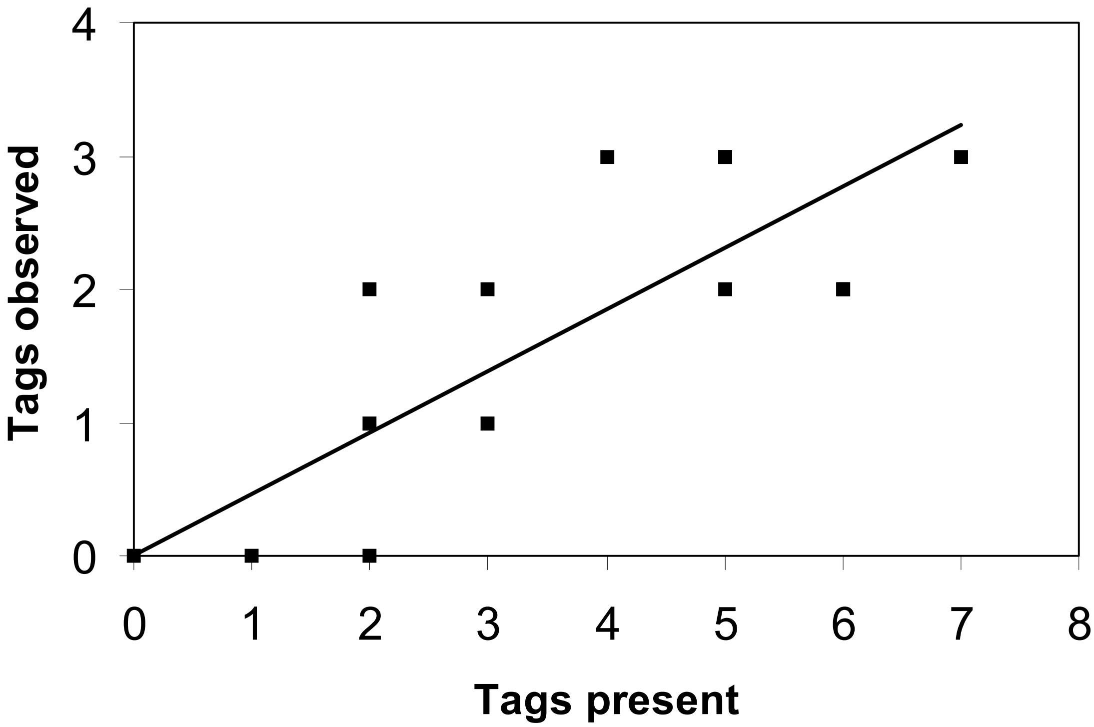

Figure 7. Counts of visually-identified, radio-tagged steelhead in the Reach 3 index area relative to the number known to be present.

Population estimates and error analysis. Dividing the AUC by the above parameters observer efficiency, residence time, and relative distribution yielded an adult steelhead population estimate for the Bridge River watershed of N = 155, with S.E. calculated by the delta method of 27.2. Under the assumption that the appropriate *t*-statistic was 1.96, given that the variance for each parameter had already been adjusted for sample size (variance of parameter estimate = $S.E.^2$), the 95% confidence interval for the estimate was calculated to be 155 $\pm$ 53.3, implying a relative precision (C.I. as a proportion of the mean) for the estimate of 0.34.

Two assumptions of the error analysis method were deemed worthy of direct investigation by the method of stochastic simulation (Hilborn and Mangel, 1997). The first, as mentioned, was that the appropriate *t*-statistic for the 95% confidence interval was 1.96. A distribution of 10,000 population sizes with mean = 155 and S.E. = 27.2 was generated on the computer, and the resulting confidence interval, 155 ± 52.8, confirmed that the *t*-statistic was in fact appropriate. The second assumption of interest was that the delta method approximates the true variance of the estimate reasonably well. Investigating this assumption required simulating each parameter 10,000 times, then factoring together the stochastically generated values into an equal number of population sizes. The mean population estimate generated in this manner was 159, with S.E. and 95% C.I. of 29.2 and 159 ± 56.4 (relative precision = 0.35), respectively. The means and levels of relative precision of the two estimates were thus comparable, suggesting that the delta method for approximating variance was indeed appropriately applied. It should be noted that, given the computing power and convenience of modern spreadsheet programs, the method of stochastic simulation itself provides an intuitively understandable, reasonable alternative process for population estimation and error analysis by the AUC method.

Management implications

The conservation of wild fish populations is the first management priority for the BC Fisheries Program. Predicting the persistence or extinction of small populations has been a primary focus of the growing academic discipline of conservation biology. Because there are many potential causes of extinction (those with some theoretical support include demographic stochasticity, environmental stochasticity, severe inbreeding, and long-term genetic losses - Nunney and Campbell 1993), predicting the extinction of a particular population is very difficult. Speculation about the minimum population sizes necessary to reduce extinction risks to acceptable levels (MVP - minimum viable population size) has been primarily from two perspectives, one based on genetic processes and the other on stochastic population dynamics. In the genetics-based approach the conservation minimum is generally set by i) the risk of fixation of deleterious alleles (genetic drift), and/or ii) the requirement for some minimum amount of genetic variation that allows the population to evolve, which from this perspective is an essential buffer against environmental change. Conversely, from the perspective of the population dynamics-based approach, the conservation minimum is determined according to the extinction probabilities set by stochastic demographic processes.

Genetics and population dynamics-based models of extinction tend to reach similar conclusions about minimum viable population sizes, which is perhaps surprising, given that the mechanisms of extinction are fundamentally different. The importance of genetic drift in fixing deleterious alleles in a population is related to N_e, the effective population size, which is a measure of how many individuals are contributing their genes to the next generation (Nunney and Campbell, 1993). Franklin (1981, as cited in Nunney and Campbell, 1993) argued that N_e must remain > 50 for a population to avoid suffering inbreeding depression, and probably greater still to maintain the genetic diversity required for adaptation to a changing environment. Turning this N_e into N (number of adults in the population) is not straightforward, because N will increase relative to N_e with increases in the magnitude of population fluctuations. A recommended minimum adult population size of at least five times N_e (N = 250) therefore, has been suggested if populations fluctuate significantly (Nunney and Campbell 1993), although it should be noted that the importance of genetics in extinction may not be sufficient to allow specific management predictions (Boyce 1992). Models of extinction due to demographic stochasticity alone (reviewed in Boyce 1992; Nunney and Campbell 1993) support a lower limit to the MVP of approximately N = 100, although the MVP can increase by up to an order of magnitude if populations have a relatively high degree of environmental stochasticity. The MVP's in these cases are typically described in terms of carrying capacity, so corresponding mean population sizes will be lower. Neither genetics nor population dynamics-based models of minimum viable population size are uncontroversial. However, empirical evidence does suggest that the above guidelines may be of the appropriate magnitude. Studies of extinction in mammals and birds have generally suggested that N < 50 is clearly insufficient for a population's long-term persistence, populations of 50 < N < 200 are marginally secure, and those of N > 200 are secure at least over time frames as limited as those used in the studies (reviewed in Boyce 1992).

The estimate of the Bridge River adult steelhead population size for springtime, 2000 was 155 ± 27.2, which according to the above criteria implies that the current population size is at or below levels considered adequate for conservation. Two additional factors warrant a conservative interpretation of the MVP criteria. The first is the apparent moderate-to-high level of environmental or demographic stochasticity in the population dynamics of interior Fraser watershed steelhead, which is indicated by a poor adult-to-adult stock-recruitment relationship for monitored populations (R.G. Bison, MELP Kamloops, pers. comm.). The second is the apparent recent decline in productivity of southern British Columbia steelhead stocks likely due to declining ocean survival (Ward 2000). The steelhead population of the Bridge River, therefore, should be considered a conservation concern. Management actions to ensure the population's future survival, therefore, appear justified. Clearly, first among these should be continued population monitoring. If the population's status appears to be deteriorating other measures, such as altering the patterns of aboriginal and/or commercial fisheries in which steelhead are intercepted or further restricting the recreational fishery (winter closure to replace non-retention), can be considered. Efforts to increase steelhead habitat capability in the Bridge River watershed by flow augmentation may be important, as extinction risk declines relatively rapidly with increases in carrying capacity (Nunney and Campbell 1993 for review). Monitoring the effects of this manipulation is therefore essential. Four years' data with respect to pre-flow release population sizes will exist for both juvenile and adult life phases, which can be compared in future to the post-flow release populations. Continuous monitoring of juvenile standing stock sizes by BC Hydro has taken place since 1996, and adult population estimates from 1999 to 2002 can all be attributed to pre-flow release environmental conditions (although scale analysis has yet to be conducted, body sizes of adult, Bridge River steelhead suggest that the majority have an ocean age of .2+). Of the estimates for the two life stages, juvenile standing stock will likely be the most precise measure of carrying capacity (smolt-adult survival may be highly variable) provided that the estimate is accurate and also that the stock size is being limited by the juvenile rearing capacity and not escapement. The relationship between Bridge River juvenile steelhead population sizes and the carrying capacity is currently unknown, but it is possible that it can be determined empirically for post-flow release conditions by relating juvenile stock sizes to the parental adult population estimates. Ideally, over time the carrying capacity estimate will emerge as the adult population size beyond which further increases in spawner abundance no longer result in increased juvenile production (the asymptote of the stock-recruitment relationship). A pre-flow release carrying capacity estimate cannot be determined in this manner, as the parental escapements corresponding to the juvenile stock estimates are unknown. An indirect method is possible if the four years of pre-flow release escapements (1999-2002) correlate well with the Albion test fishery index of the aggregate, interior Fraser steelhead stock size. In this scenario the pre-flow release juvenile standing stock sizes could be related to the Albion index for the parental year(s), although it is important to realize that the relationship is likely to be far too variable to allow a meaningful carrying capacity estimate with such a small sample (n = 4 years).

Conclusions

This study completes the pre-flow release investigation of habitat use and adult population size in the Bridge River, British Columbia. Habitat use by radio-tagged steelhead in the watershed, in terms of spawner distribution, has been relatively consistent, with 37.5% of the spawners on average utilizing the largely dewatered section of the Bridge River upstream of the Yalakom confluence. This distribution pattern has been established for the purposes of comparison with spawner habitat use post-flow augmentation, which can only be determined by future radio telemetry investigations. The recognition that the Bridge River steelhead population size may be at or near the minimum considered adequate for conservation is an important result of this study, and suggests that close monitoring of the future population status is required.

Estimating the size of adult steelhead populations of interior, British Columbia rivers is challenging because of water quality conditions at the time of spawning, which are frequently too poor for effective visual surveys. In this study, the use of radio telemetry in combination with periodic visual counts has been proven to be an effective method in the Bridge River watershed. Importantly, the relative precision of the population estimate can be investigated with this method. Both the confidence intervals for the estimate and the total effort expended to acquire it were reasonable given the importance of the information. It is important to note that the costs of acquiring a population estimate of this precision will decline in future, when parameters required for calculating the estimate in the post-flow release watershed have been estimated from 3 or 4 years of telemetry information, and the technique is no longer required in the estimation procedure.

The habitat use and population size information for adult, Bridge River steelhead will improve the ability to monitor the effects of flow augmentation into the Bridge River downstream of Terzhagi dam. Spawning habitat conditions upstream of the Yalakom confluence are assumed to have been improved for adult steelhead, and future telemetry investigations can investigate and validate this assumption. Accurate adult escapements can be related to subsequent juvenile steelhead standing stock sizes, indicating the importance of escapement relative to habitat capacity on the stock size and therefore addressing an important source of error in the habitat capability estimation procedure. The conservation of Bridge River steelhead and steelhead habitat is a principal goal of the British Columbia Fisheries Program with respect to this population. Improving the habitat capability of the watershed and closely monitoring population sizes are important steps towards ensuring that this goal is achieved.

Acknowledgements

This project was managed by Alan Caverly, Fisheries Branch, MELP, Kamloops. Funding for this work was provided primarily through BC Hydro's Bridge Coastal Compensation (now restoration) Program. BC Hydro and MELP provided the radio telemetry and sampling equipment. Alan Caverly, BC Conservation Foundation (BCCF) biologists Mike Chamberlain, John Hagen, and Jim Renn, BCCF technician Eric Breumandl, and contracting technician Rob Basok assisted with radio-tagging and sampling of Bridge and Seton River steelhead during springtime, 2000. BCCF technicians Bonnie Adolph and Eric Braumandl assisted with truck-based mobile telemetry and also the surveys on foot of the counting area. The author thanks the Bridge River Band of the Stat'li'mix Nation (contact Bradley Jack) for granting access to reserve lands for tagging and tracking.

Jim Renn, Alan Caverly and Eric Braumandl assisted with downloading fixed telemetry receivers and with helicopter-based aerial telemetry, while Jim Renn processed the radio telemetry data prior to report preparation. Gary Watson of MELP's GIS section generated maps for the field study and report. MELP biologist Robert Bison assisted with the design of the study, and MELP biologist Eric Parkinson and consulting biologists Joe DeGisi and Josh Korman provided highly valuable commentary during the population estimate analysis. Editorial comments by reviewers Alan Caverly and Robert Bison improved the quality of the final report.

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Appendices

Appendix 1. Steelhead capture data for the Bridge River, springtime 2000

Sp Tag	Radio Tag	Sub Location	Easting	Northing	Km	Capture Date	Genetic Sample	Sex	Length	Girth
430	585	Seton - near Cay. confl.	573390	5613519	3.0	06-May-00	REB-176	F	750	320
428	589	Seton - near Cay. confl.	573390	5613519	3.0	06-May-00	REB-177	F	680	310
322	565	Lower Bridge	574682	5623124	1.0	03-May-00	JHBR-18/00	M	855	420
281	566	Lower Bridge	574682	5623124	1.0	01-May-00	JHBR-17/00	F	660	310
344	1055	Lower Bridge	574682	5623124	1.0	07-Apr-00	JHBR-03/00	F	720	370
279	1056	Lower Bridge	574682	5623124	1.0	28-Apr-00	JHBR-13/00	F	820	395
346	1065	Lower Bridge	574682	5623124	1.0	04-Apr-00	JHBR-01/00	M	890	410
350	1608	Lower Bridge	574682	5623124	1.0	04-Apr-00	JHBR-02/00	F	810	380
345	1651	Lower Bridge	574682	5623124	1.0	14-Apr-00	JHBR-06/00	F	625	300
342	1679	Lower Bridge	574682	5623124	1.0	07-Apr-00	JHBR-04/00	M	620	310
328	564	Bridge u/s Yalakom	558107	5634941	25.7	06-May-00	JHBR-19/00	F	810	360
NA	559	Bridge d/s Yalakom	558348	5634826	24.7	29-Apr-00	JHBR-14/00	M	810	390
324	560	Bridge d/s Yalakom	558348	5634826	24.7	09-May-00	JHBR-21/00	F	620	320
NA	561	Bridge d/s Yalakom	558348	5634826	24.7	29-Apr-00	JHBR-15/00	M	870	420
286	562	Bridge d/s Yalakom	558348	5634826	24.7	30-Apr-00	JHBR-16/00	M	850	440
280	563	Bridge d/s Yalakom	558348	5634826	24.7	28-Apr-00	JHBR-11/00	F	670	320
358	570	Bridge d/s Yalakom	558348	5634826	24.7	11-May-00	BR00358	F	770	340
351	584	Bridge d/s Yalakom	558348	5634826	24.7	11-May-00	BR00351	F	800	340
319	588	Bridge d/s Yalakom	558348	5634826	24.7	06-May-00	JHBR-20/00	F	660	330
283	1054	Bridge d/s Yalakom	558348	5634826	24.7	27-Apr-00	JHBR-09/00	M	770	390
321	1060	Bridge d/s Yalakom	558348	5634826	24.7	14-May-00	JHBR-23/00	M	960	465
348	1061	Bridge d/s Yalakom	558348	5634826	24.7	28-Apr-00	JHBR-10/00	F	730	350
288	1062	Bridge d/s Yalakom	558348	5634826	24.7	28-Apr-00	JHBR-12/00	M	810	395
424	573	Bridge Camoo	562577	5630974	18.3	19-Apr-00	JHBR-08/00	F	770	
282	16100	Bridge Camoo	562577	5630974	18.3	19-Apr-00	JHBR-07/00	M	890	410

Appendix 2. Locations (stream kilometers from mouth) of radio-tagged Bridge River steelhead, springtime 2000.

Tag no.	04-Apr-00	05-Apr-00	06-Apr-00	07-Apr-00	08-Apr-00	09-Apr-00	10-Apr-00	11-Apr-00	12-Apr-00	13-Apr-00	14-Apr-00	15-Apr-00	16-Apr-00	17-Apr-00	18-Apr-00	19-Apr-00	20-Apr-00	21-Apr-00	22-Apr-00	23-Apr-00	24-Apr-00	25-Apr-00	26-Apr-00	27-Apr-00	28-Apr-00	29-Apr-00	30-Apr-00
559																										23.4	
560																											
561																										24.6	25.2
562																											24.7
563																									24.7	25.2	
564																											
565																											
566																											
570																											
573															18.3	18.8										21.3	
584																											
585*																											
588																											
589																											
1054																								24.7			
1055				1.0							0.0			0.0			0.0										
1056																									1		
1060																											
1061																									24.7	25.2	
1062																									24.7	25.2	
1064										1						7											
1065	1																1.6										
1608	1																15										25.2
1651											1			0			0										
1679				1																							
16100															18.3	19.3		25.2								25.8	

Appendix 2. Locations (stream kilometers from mouth) of radio-tagged Bridge River steelhead, springtime 2000 cont'd.

Tag no.	01-May-00	02-May-00	03-May-00	04-May-00	05-May-00	06-May-00	07-May-00	08-May-00	09-May-00	10-May-00	11-May-00	12-May-00	13-May-00	14-May-00	15-May-00	16-May-00	17-May-00	18-May-00	19-May-00	20-May-00	21-May-00	22-May-00	23-May-00	24-May-00	25-May-00	26-May-00	27-May-00
559				18.5	18.5		17.0		16.7		16.1			17.0		18.2		18.2		0.0							
560									24.7		24.5	25.4		28.2	31.0	33.0	31.8	31.0	30.8	25.2				0.0			
561		25.8	25.8	25.2	25.8		25.8	26.8	25.2		24.5			25.2	25.8	25.8	25.2						12.0	1.50			
562				25.2	25.8				18.0		18.7			21.0		19.5		21.0					18.2		11.5		
563		25.8	25.8	25.8		21.0	25.8		28.1	28.3	27.7	28.7		27.0	26.2		25.2			0.0							
564						25.7	24.7	26.0	25.8	25.8	25.8			25.8	25.8		26.2	25.8	25.8			25.8	25.8	25.8			
565			1.0	1.5	0.0		0.0		4.3		13.8			22.5		22.9		22.8					25.2	25.2	25.2		
566	1.0			1.6	0.0		0.0																				
570											24.7				25.2	28.0	30.3	30.5	30.4			30.3	30.3	30.3	30.3	30.3	
573		25.2	28.0	25.2	1.5		0.0																				
584											24.7					24.5							10.5		5	0	
585*						3.0S					0S			2.0C													
588						24.7			23.2		24.5		25.2	25.5	25.5	25.2	30.8	28.9	26.3		25.2		1.0		0		
589						3.0S			3.0S							2.0C											
1054			24.7	25.8	25.8			28.3	27.9	28.6	28.6	27.8		28.8	29.0		30.8	32.0	31.3			32.0	30.8	31.3	30.8	33.1	
1055			15.0	21.0	23.3	25.2	28.0	28.3	28.4	28.6	28.3		25.2			1.9		0.0									
1056					1.5				10.5		18.3			18.3						0							
1060														24.7		25.2		7.0Y	25.2				24.0		15.7		
1061		28.0	28.1	28.5	28.8	25.2		0.0																			
1062		30.9	31.1	30.6	30.4		30.5	33	33.3	33.3	33.3																
1064			0.5	0.5	0																						
1065			25.2														7.5Y					9.5Y		11Y	8.5Y		25.2
1608	25.2		22	23.2	1.8		0																				
1651							2				10.8			15.8		24	25.2	28.9	28.8			26.2	25.8	25.8	8.5		
1679					15.8			24.7	25.3		28.7	31		33.7	33.3	32	32	34	34			33	33.3	33.4		33.1	
16100		25.8	25.8	27.4	26.5		26	28.3	28.3	28.3	28	28		28.2	29	27.9	27.9	25.2					18.3		18.4		

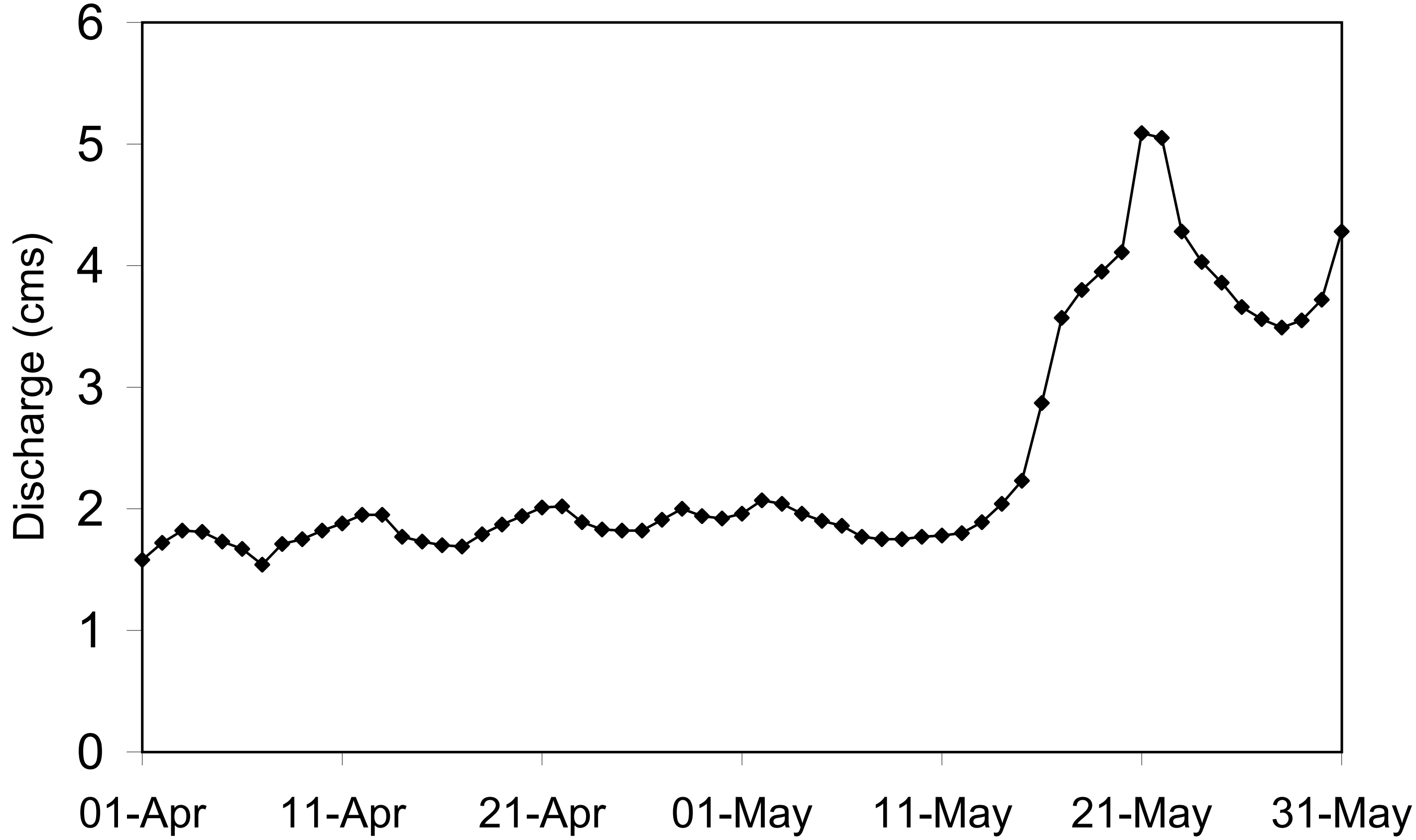
Appendix 2. Locations (stream kilometers from mouth) of radio-tagged Bridge River steelhead, springtime 2000 cont'd.

Tag no.	28-May-00	29-May-00	30-May-00	31-May-00	01-Jun-00	02-Jun-00	03-Jun-00	04-Jun-00	05-Jun-00	Comments
559										kelt 20-May
560										kelted 24-May
561										kelt?
562		12.0			12.0				12.0	died or regurg?
563										Obs. Spawning at 28.3, May 10 and at 26.2, May 15
564										died or regurg in swimming hole?
565					21.5					
566										kelted 05-May, D/S Fraser
570		30.3							30.3	Died/regurg at 30.3
573										kelted 07-May, recaptured in Fraser near Siska
584										kelted 26-May
585*										Seton fish spawning in vicinity of compensation channel, Cayoosh C.
588										kelted 25-May
589		0								Seton fish visually observed in compensation spawing channel, Cayoosh C.
1054		29.7	25.2		12.0				12.0	Visually observed spawning at 30.8, May 23 and 33.1, May 26
1055										kelted 18-May
1056										kelted after 14-May, recaptured in lower Fraser 20-May
1060		8.3			8.3				8.3	died/regurg at 8.3
1061										kelted 08-May
1062										eaten by eagle May 12, visually observed spawning at 33.3, 10-May
1064										suspected to have left Bridge River and later spawned in Chilcotin River
1065					23				23	died/regurg at 23?
1608										Kelted 07-May
1651							0			kelted 03-June
1679		33.1		31.6		31.4	25.2		0	kelted-05-June
16100		18.6			18.6				18.6	died/regurg 05-June

Appendix 3. Temperature (MELP data on file) and discharge (WSC data on file for Yalakom R.) data for the Bridge River watershed, springtime 2000

March			April			May			June		
Date	flow (cms)	Temp (^{0}C)	Date	flow (cms)	Temp (^{0}C)	Date	flow (cms)	Temp (^{0}C)	Date	flow (cms)	Temp (^{0}C)
-	-	-	01-Apr	1.6	8.2	01-May	2.0	10.0	01-Jun	4.5	11.0
-	-	-	02-Apr	1.7	9.3	02-May	2.1	10.5	02-Jun	4.6	11.3
-	-	-	03-Apr	1.8	9.1	03-May	2.0	10.8	03-Jun	4.9	12.5
-	-	-	04-Apr	1.8	8.1	04-May	2.0	9.5	04-Jun	5.8	13.2
-	-	-	05-Apr	1.7	6.3	05-May	1.9	9.4	05-Jun	8.4	11.5
-	-	-	06-Apr	1.7	6.6	06-May	1.9	9.5	06-Jun	9.5	10.1
-	-	-	07-Apr	1.5	5.8	07-May	1.8	10.4	07-Jun	8.6	11.0
-	-	-	08-Apr	1.7	7.4	08-May	1.8	9.6	08-Jun	8.7	11.4
-	-	-	09-Apr	1.8	9.2	09-May	1.8	9.4	09-Jun	8.2	11.1
-	-	-	10-Apr	1.8	9.9	10-May	1.8	9.0	10-Jun	7.4	10.7
-	-	-	11-Apr	1.9	9.8	11-May	1.8	8.9	11-Jun	6.8	10.3
-	-	-	12-Apr	2.0	9.4	12-May	1.8	10.6	12-Jun	6.7	10.4
-	-	-	13-Apr	2.0	8.3	13-May	1.9	11.8	13-Jun	6.5	10.8
-	-	-	14-Apr	1.8	5.4	14-May	2.0	12.6	14-Jun	7.0	10.6
-	-	-	15-Apr	1.7	5.1	15-May	2.2	12.7	15-Jun	7.3	10.9
-	-	-	16-Apr	1.7	7.0	16-May	2.9	13.2			
-	-	-	17-Apr	1.7	8.2	17-May	3.6	12.8			
18-Mar	1.6	4.6	18-Apr	1.8	8.8	18-May	3.8	12.2			
19-Mar	1.6	4.7	19-Apr	1.9	10.6	19-May	4.0	12.5			
20-Mar	1.6	4.1	20-Apr	1.9	11.2	20-May	4.1	11.5			
21-Mar	1.6	5.0	21-Apr	2.0	10.6	21-May	5.1	11.9			
22-Mar	1.6	6.1	22-Apr	2.0	10.2	22-May	5.1	11.1			
23-Mar	1.5	5.8	23-Apr	1.9	9.3	23-May	4.3	10.5			
24-Mar	1.5	5.4	24-Apr	1.8	9.0	24-May	4.0	10.9			
25-Mar	1.5	6.2	25-Apr	1.8	8.5	25-May	3.9	10.9			
26-Mar	1.4	5.8	26-Apr	1.8	9.2	26-May	3.7	10.4			
27-Mar	1.5	6.3	27-Apr	1.9	9.7	27-May	3.6	10.0			
28-Mar	1.4	5.9	28-Apr	2.0	8.8	28-May	3.5	11.6			
29-Mar	1.4	6.0	29-Apr	1.9	9.0	29-May	3.6	12.0			
30-Mar	1.4	6.0	30-Apr	1.9	9.4	30-May	3.7	11.6			
31-Mar	1.5	6.7				31-May	4.3	11.8			

Appendix 3, Figure 1. Discharge in the Yalakom River, 01-Mar-00 to 31-May-00



Appendix 3, Figure 2. Bridge River mean daily temperatures, springtime 2000