

The Reproductive Biology of Steelhead (*Oncorhynchus mykiss*) in
the Bridge and Seton Rivers, As Determined by Radio Telemetry
1996/97 and 1998/99

Prepared for:

The Ministry of Environment, Lands & Parks
Fisheries Branch, Southern Interior Region
1259 Dalhousie Dr.
Kamloops, BC
V2C 5Z5

Prepared by:

Stacy Webb, Robert Bison, Al Caverly and Jim Renn

Abstract

The 1996/97 and 1998/99 studies of the spawning migrations of Bridge and Seton River steelhead were part of a larger study investigating the migration behaviour and stock composition of interior Fraser River steelhead. Steelhead were radio-tagged in the fall of 1996 and 1998 in the Lower Fraser River and in the winter/spring of 1997 and 1999 in the Middle Fraser River. Tagging effort was concentrated at the Seton/Fraser River confluence during the winter/spring captures, specifically to study Bridge and Seton River steelhead. A total of 15 steelhead were tracked during the 1997 spawning season and 18 steelhead were tracked during the 1999 spawning season in the Bridge and Seton watersheds. Immigration into the Seton and Bridge Rivers started around the middle of April and finished during the second week of May. Immigration into the Bridge and Seton Rivers in 1999 occurred primarily during the last two weeks of April. Spawning in the Bridge and Seton watersheds in 1997 started during the second week of May and ended around the middle of June. Spawning in the Bridge and Seton watersheds in 1999 occurred a little earlier, starting during the second week of April and finishing during the first week of June. Spawning in the Seton watershed occurred primarily in the Cayoosh Creek compensation channel. The lower reaches of the Bridge River were not well utilized by spawning radio-tagged steelhead in 1997 or 1999. In addition to studying the spring migration behaviours of Bridge River steelhead in 1999, escapement abundance was estimated using area-under-the-curve and maximum likelihood techniques. A 5.8 km long survey area in the Bridge River, upstream of the Bridge/Yalakom confluence was selected to count holding and spawning steelhead on a weekly basis. The parameters of observer efficiency, survey life, and proportion of spawners in the counting area relative to the entire watershed were estimated in the field. The 1999 escapement estimates ranged from 369 to 422 depending on the method used. The best estimate was considered to be 369. Precision estimates indicated that it was highly likely the population exceeded 200 spawners.

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1 Background

1.1 Study Objectives

The 1997 and 1999 studies of the spawning migrations of Bridge and Seton River steelhead were part of a larger study investigating the migration behaviour and stock composition of interior Fraser River steelhead.

The objectives of the 1997 and 1999 Bridge and Seton River telemetry studies were to understand the timing of spring migrations, to determine the geographic distribution of spawning, and to estimate spawning population abundance.

1.2 Study Area

The Fraser is the largest river system that is completely contained within the province of British Columbia. The basin is divisible into four subregions based on climate and topography. These subregions are the upper Fraser (from its source to Willow River near Prince George), the middle Fraser (from the Willow River to the Fraser Canyon), the Thompson system, and the lower Fraser (from the Fraser Canyon to the sea). The Fraser Canyon is a major barrier to fish and many of the anadromous fish species in the lower Fraser are absent above the canyon (McPhail and Carveth 1992). Where the Bridge and Seton rivers enter the middle Fraser River, it is classified as a 9th order river (Figure 1). The middle Fraser River flows through the warm and dry Ponderosa Pine biogeoclimatic zone and is the migration corridor and habitat of six anadromous fish species and 25 freshwater species (McPhail and Carveth 1992).

In its natural condition, the mainstem Bridge River is a 6th order tributary of the Fraser River. It joins the Fraser River 337 km upstream of the Fraser River mouth at an elevation of 220 m above sea level. The watershed is located in the Southern Interior Ecoprovince and drains the eastern slope of the Pacific Coast Mountains. The area of the watershed is 4735+ km² and includes five large subdrainages: the upper Bridge watershed itself, the Yalakom, Tyaughton, Gun and Hurley/Cadwallader subdrainages.

Two hydroelectric dams are located along the mainstem Bridge River. Terzaghi Dam, built in 1956, is the furthest downstream dam. It is located 40 km upstream of the Bridge/Fraser confluence. Except when periodic spills occur, Terzaghi Dam diverts the entire flow of the Bridge River. The upstream distribution of anadromous and adfluvial fish is limited to reaches downstream of the dam. The Bridge River channel is dry for a distance of about four kilometers downstream of the dam. The channel is recharged to a small degree by groundwater and some small tributaries until it joins the Yalakom River. From this point onward, there are no other large tributaries that contribute stream flow to the Bridge River, therefore almost all of the water that reaches the Fraser River now comes from 1 of the 5 large subdrainages (Yalakom) in the watershed. The other four drainages are diverted south, into the Seton watershed. The lower Bridge River presently drains an area of 1014 km² or 21% of the natural watershed area.

The seasonal hydrology of the Bridge watershed is snow-melt driven. Stream flows are at a maximum in the spring, usually peaking in June or July. Downstream of Terzaghi Dam, the Yalakom River has a mean maximum flow of 11.5 m³/s in June and a mean annual flow of 4.11 m³/s (eight years of WSC records from 1983 to 1990). This should closely resemble the hydrology of the Bridge River mainstem downstream of Terzaghi Dam although Water Survey Canada records are not available for this section of the Bridge River.

The Seton River is also a 6th order tributary of the Fraser River. It enters the Fraser River 329 km upstream of the Fraser River mouth at an elevation of 200 m. Two large oligotrophic lakes are located along the mainstem: Seton and Anderson lakes. The watershed area is 1915 km² and contains two major subdrainages: Cayoosh and Gates. There are 2 dams in the Seton watershed but unlike dams on the Bridge River, they do not disrupt the upstream migration of fish. A dam located at the outlet of the lower lake (Seton Lake) contains a fish ladder. A dam on Cayoosh Creek, which could block fish passage, is located at a waterfall that has always been a natural fish barrier. The flow of water downstream of both of these structures is diverted away from the natural channels for hydroelectric power generation, although some water is maintained in both Cayoosh Creek and Seton River. In Cayoosh, the power generation facility is a run-of-the-river type and therefore the flows in Cayoosh Creek typically follow a natural hydrograph when hydroelectric water licence quantities are exceeded.

The hydrology of the Seton watershed is also snowmelt driven. Peak flows typically occur in June. The Seton River, as measured at the hydrometric station near Lillooet, has a mean maximum flow of 46.3 m³/s in June and a mean annual flow of 23.2 m³/s. These flow measurements are not reflective of the natural condition of the watershed as they include the flow of water from the majority of the Bridge River watershed.

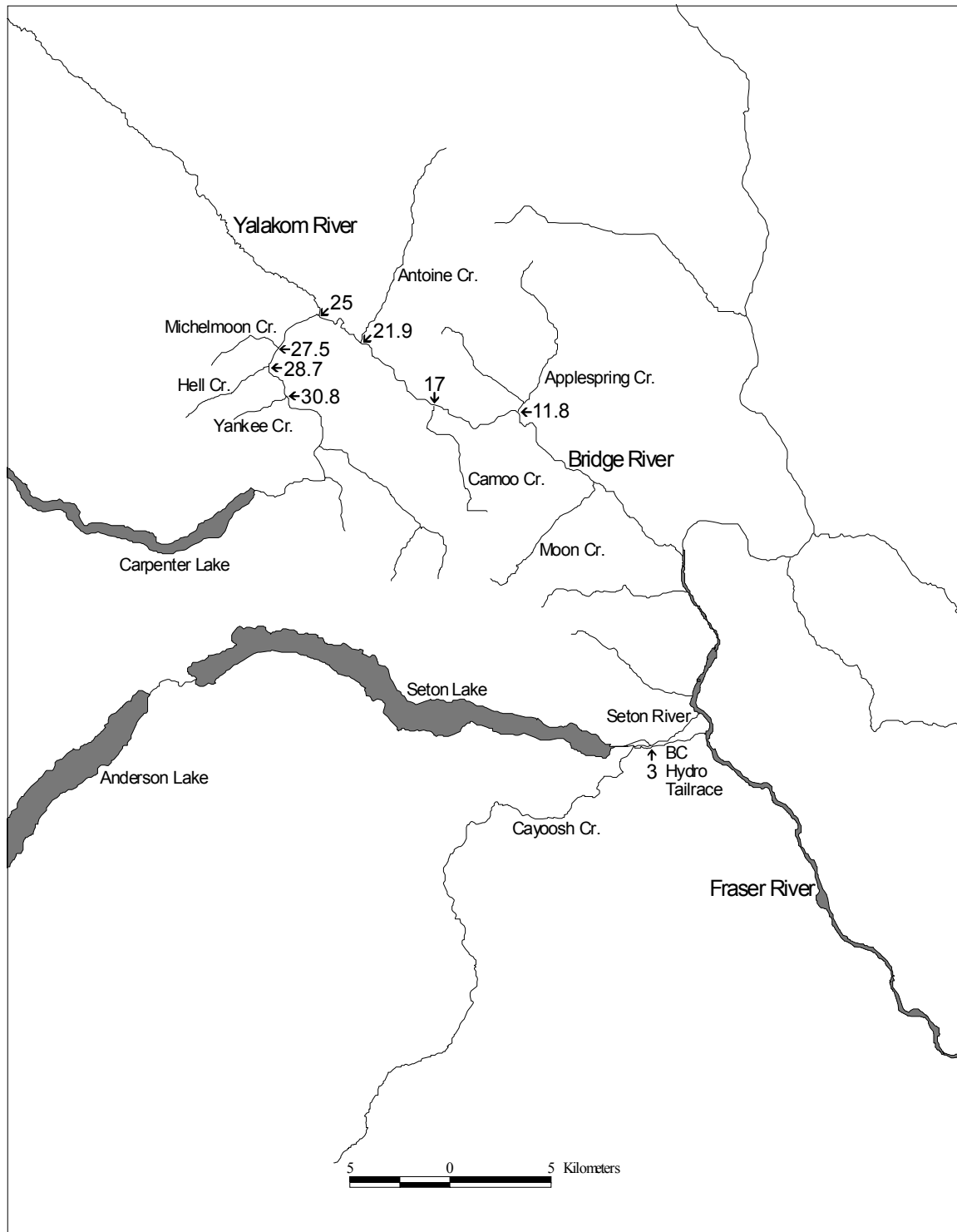


Figure 1. The Bridge and Seton River steelhead telemetry study area. Arrows point to reference kilometers upstream of the Fraser River, with zero occurring at the confluence of the Seton and Fraser River and the Bridge and Fraser River.

1.3 Existing Information

Bridge and Seton River steelhead (*Oncorhynchus mykiss*) are part of a larger geographic and life history grouping referred to as interior Fraser summer steelhead. Their migration timing is similar to the better known Thompson River steelhead, another interior Fraser sub-group. Bridge and Seton River steelhead enter the Fraser River in the fall, overwinter in the Fraser mainstem, and begin ascent of their natal spawning tributaries in late April and early May (Renn *et al.* 2001, Hebden 1981).

Hebden (1981) described the abundance and distribution of Bridge River steelhead based on helicopter surveys, snorkel surveys and angling. He concluded that less than 200 steelhead spawn in the Bridge each year, with most spawning occurring in the section of the Bridge River that is upstream of the Yalakom River confluence.

Hebden (1981) reported that the capture of steelhead in Seton River near the Cayoosh Creek confluence indicated that both the Seton River and Cayoosh Creek were probable spawning habitats. Hebden also reported the presence of large rainbow trout in Gates and Portage Creeks, but concluded that these were adfluvial trout and not anadromous steelhead.

Steelhead migration into the Bridge and Seton rivers was first studied in 1996 (Baxter and Roome, unpublished data). Fourteen steelhead were radio-tagged at the confluence of the Fraser and Seton rivers and monitored for the duration of their spring migrations in and out of spawning tributaries. Two of the fish remained in the Seton watershed for a short period but later, entered the Bridge River to spawn. It is believed 10 of the fish spawned in the Bridge watershed in either the Bridge or Yalakom Rivers. Three fish migrated up the Fraser and spawned in the Chilcotin Watershed and one fish is believed to have died shortly after radio tagging (Baxter and Roome, unpublished data).

Steelhead spawning above the Seton dam has never been documented (McGregor, pers. com. 1999) although steelhead have passed through the fishway and have been captured in the power canal during trash-rack maintenance (Hebden, pers. com. 1999). Radio-tagged steelhead were not detected above the Seton dam in the 1996/97 or 1998/99 studies.

2 Methods

2.1 Fish Capture

Radio-tagged steelhead used as a part of the Bridge River steelhead telemetry study were initially captured in the lower Fraser River for the interior Fraser River steelhead telemetry study. In the fall of 1996, steelhead were captured for radio tagging using a tangle net, beach seine, angling and a 24-hour gill net fishery. In the fall of 1998, the same methods were employed to capture steelhead with a couple of exceptions: a gill net was not used to capture and radio tag steelhead and a fish wheel was added to the group

of “selective” fishing gear types. Steelhead assessed as being in vigorous condition were anaesthetised with clove oil and fitted with a LOTEK model MCFT-3A or 3B, 3-volt digitally encoded tag. All steelhead captured were also bio-sampled and marked with a florescent orange floy tag containing an identification number and a toll free telephone number to contact ministry personnel (Renn *et al.* 2001).

Radio tags applied in the late winter/early spring period were applied entirely by angling in several known overwintering locations. Due to cold water conditions at this time of year, no anaesthetic was used (Renn *et al.* 2001).

2.2 Telemetry

Tracking of radio-tagged steelhead was conducted using a combination of aerial, ground and fixed telemetry stations. In all cases a Lotek SRX 400 receiver using either a W5, W16, W17 or W30 E-prom in conjunction with a 2 or 4 element Yagi antenna was used. The fall movement of radio-tagged steelhead was monitored primarily through the use of fixed telemetry stations along the mainstem Fraser River. Overwintering locations were determined via aerial tracking. The upstream migration period, spawning distribution and residency times were determined using a combination of aerial and ground telemetry. The timing of immigration and emigration from the Bridge River in 1999 was determined by a fixed telemetry station at the confluence of the Bridge and Fraser Rivers. Emigration timing from the lower Fraser River was monitored by a fixed telemetry station at Hope. Details of fixed station telemetry operation, aerial telemetry and ground-tracking methodologies may be found in Renn *et al.* 2001.

2.3 Escapement Estimation

Estimation of abundance was based on periodic counts conducted while steelhead were in spawning areas (Hilborn *et al.* 1999). Spawners were counted in a 5.8 km section of the Bridge River from Yankee Creek to the confluence with the Yalakom River. This location was optimal for counting because of the extremely clear water conditions throughout the spawning season. Spawning and holding steelhead were counted during stream walks. Surveys were conducted at a frequency of about one per week in order to capture the shape of the escapement curve (Hill 1997). Survey life was defined as the total time that a fish spent in the survey area and was estimated using radio telemetry. Fish visibility (observer efficiency) was estimated as the proportion of radio-tagged to non radio-tagged steelhead observed during stream walk counts (radio-tagged steelhead were marked externally with spaghetti tags). Bridge River steelhead also spawn downstream of the counting area and in the Yalakom River, but the proportion of spawners that can be seen in these reaches is usually very low due to poor water clarity and higher flows. Therefore, the proportion of steelhead in the counting area relative to the entire watershed was estimated by the distribution of radio-tagged steelhead.

The trapezoidal approximation and four variations of a maximum likelihood method were used to calculate the escapement estimate (Hilborn *et al.* 1999). The trapezoidal and maximum likelihood methods were modified to incorporate an expansion factor to account for spawners outside the counting area. The trapezoidal method was modified as

$$\hat{E} = \left(\frac{AUC}{s} \right) v \left(\frac{R_w}{R_c} \right)$$

where E is the escapement in the entire watershed, AUC is the area under the curve, s is survey life, v is a correction for observer efficiency, and R_w/R_c is the ratio of the number of radio-tagged steelhead in the watershed relative the number of radio-tagged steelhead in the counting area.

Similarly for the maximum likelihood method, the arrival time model for fish entering the counting area was modified by including the correction for fish distribution as

$$A_t = E \left(\frac{R_c}{R_w} \right) \int_{i=0}^t \left[\frac{1}{\sigma_m \sqrt{2\pi}} \exp \left(-\frac{(i-m)^2}{2\sigma_d^2} \right) \right] di$$

where A_t is the cumulative number of arrivals, m is the mean date of arrival into the counting area, and σ_m is the standard deviation of date of arrival. The cumulative number of deaths (or emigrants as is the case with iteroparous steelhead) was similarly modified as

$$D_t = E \left(\frac{R_c}{R_w} \right) \int_{i=0}^t \left[\frac{1}{\sigma_m \sqrt{2\pi}} \exp \left(-\frac{(i-m)^2}{2\sigma_d^2} \right) \right] di$$

and the total number alive in the counting area is

$$N_t = A_t - D_t.$$

Survey life (s) is included in the arrival model to offset the timing of cumulative deaths relative to the timing of cumulative arrivals. The arrival and death model provide deterministic predictions about the number of fish in the counting area on any given day.

The predicted number of fish counted by an observer on a particular day t is assumed to be proportional to the number of fish alive in the counting area (N_t) scaled by observer efficiency (v):

$$C_t = vN_t.$$

As in Hilborn *et al.* (1999), we assumed deterministic dynamics in the process model and we assumed that all error was in the observation model. Three variations included normal arrival time models assuming observation error in fish counts was either normally distributed, lognormally distributed and distributed in a pseudo-Poisson manner. A fourth variation included an arrival time model based on the beta distribution with the assumption that observation error in fish counts was distributed in a pseudo-Poisson manner.

Methods for calculating likelihoods were as described by Hilborn *et al.* (1999) with an added likelihood component for uncertainty in fish distribution outside the counting area. Uncertainty in fish distribution was incorporated by including a likelihood component based on the binomial distribution as:

$$L\{R_c | R_w, p\} = \binom{R_w}{R_c} p^{R_c} (1-p)^{R_w-R_c}$$

where R_c is the number of radio-tagged steelhead in the counting area, R_w is the number of radio-tagged steelhead in the watershed including those in the counting area, and p is the sampled proportion in the counting area. The total likelihood was therefore

$$L_{total} = L(x | C)L(s | \bar{s}, \sigma_s)L(v | \bar{v}, \sigma_v)L(R_c | R_w, p).$$

Maximum likelihood estimates of escapements were computed for each of the arrival time model variations by searching over the two parameters of the arrival time model which are the mean day of arrival (m) and the standard deviation on mean day of arrival (σ_m) as well as the survey life (s), observer efficiency (v), and radio tags in counting area (R_c).

Methods for calculating confidence bounds were as described by Hilborn et al (1999) using the method of likelihood profile.

3 Results

3.1 1997 Results

3.1.1 Fall Deployment

Two of the 125 steelhead that were captured and radio-tagged in the lower Fraser River in the fall of 1996 were Bridge River steelhead. Both of the fish were captured by angling near Chilliwack (Appendix 1).

3.1.2 Overwintering

Results from helicopter surveys conducted on January 24th, 29th and March 10th were considered to represent the overwintering distribution of steelhead that were radio-tagged while migrating through the lower Fraser River in the fall. Both steelhead overwintered between Lytton and Lillooet. One steelhead was located approximately 12 kilometers upstream of the Stein River and the other was immediately downstream of Texas Creek (Figure 2).

3.1.3 Winter and Spring Deployment

Radio tags were deployed at the confluence of the Seton and Fraser Rivers during the spring and winter of 1997, specifically to study Bridge River steelhead. All winter and spring tagged fish were captured by angling. Twenty-one steelhead were tagged at the Seton/Fraser River confluence, one steelhead was tagged at the Seton hydro tailrace, three steelhead were tagged in the Bridge River, and four steelhead were tagged at the Thompson/Fraser confluence (Figure 2, Appendix 1). Eight of the 21 steelhead captured at the Seton/Fraser confluence did not spawn in the Seton or Bridge watersheds. One steelhead captured at the Seton/Fraser confluence was re-captured one week later, also at the Seton/Fraser River confluence (See Appendix 1).

3.1.4 Upstream Migrations

Fixed stations were not present at the mouth of the Bridge or Seton Rivers during the 1996/97 telemetry study. Mobile tracking occurred on April 9th and 23rd, but did not occur on a daily basis until May 7th. Due to these factors, the date of entry into the spawning tributaries was not detected for the majority of the radio-tagged steelhead. Average daily rates of movement were calculated from the total distance travelled in either upstream or downstream directions prior to the start of the spawning residency, divided by the total number of migration days.

The upstream migration start date was detected for one female and two male Bridge River steelhead. One male steelhead entered the Bridge River on May 7th and travelled an average rate of 3.12 km/day, while the other male entered the Bridge River on May 10th and travelled an average rate of 2.22 km/day. The female steelhead entered the Bridge River on May 11th and travelled an average rate of 1.45 km/day.

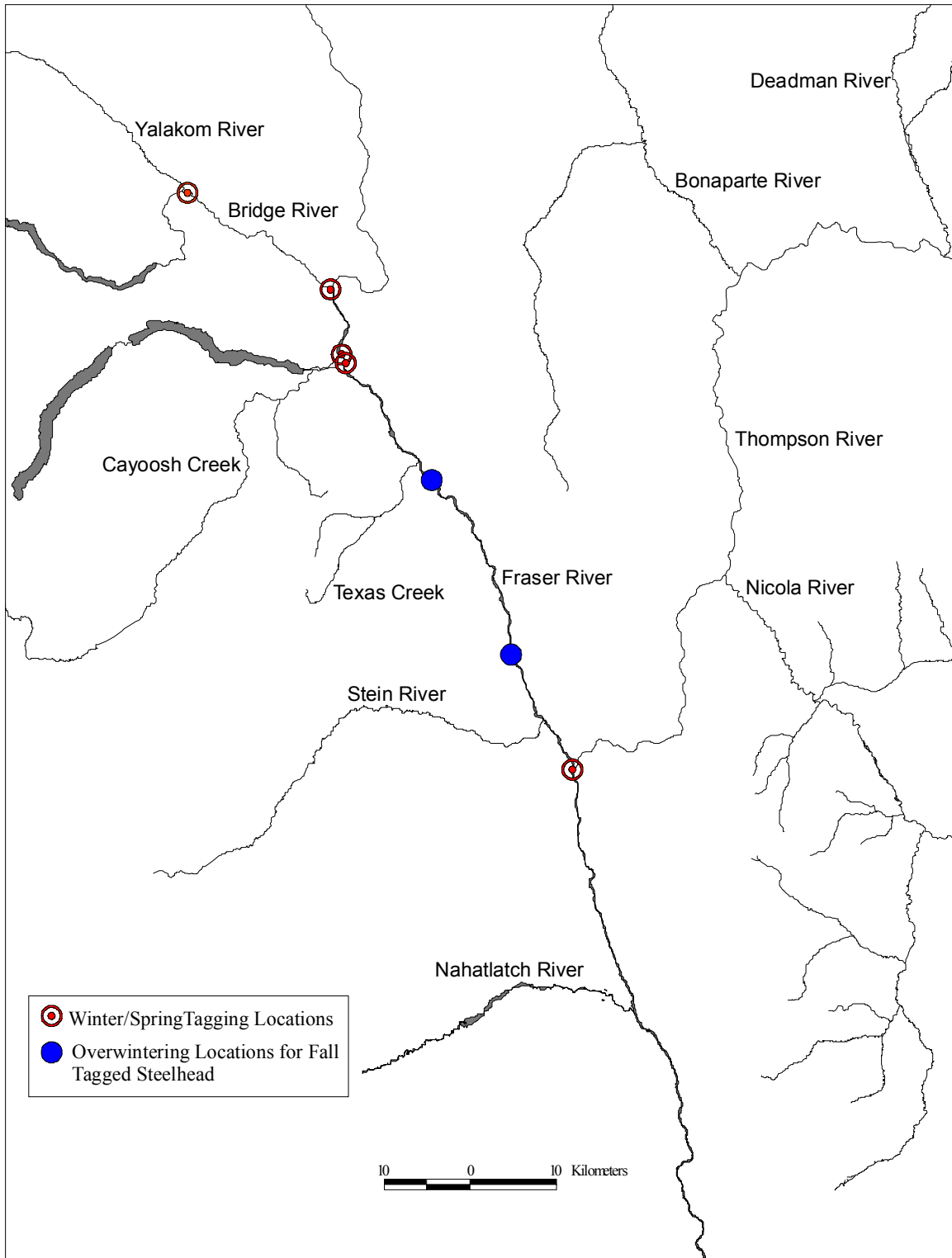


Figure 2. The overwintering locations for 1996 fall radio-tagged Bridge and Seton watershed steelhead and 1997 winter/spring radio-tagging locations.

The male steelhead that entered the Bridge River on May 7th was extremely mobile, travelling 90.5 km over 29 days before spawning in the Yalakom, 28.5 km upstream of the Bridge/Fraser River confluence. The other male entered and exited the Bridge River on May 9th before entering the river again on May 10th. At this time it was tracked moving steadily upstream over a period of 9 days to its spawning location 19 kilometers upstream of the Bridge/Fraser River confluence. The female steelhead moved upstream at a steady rate for a period of 20 days, with no recorded diversions or backtracking, before spawning in the Bridge River 29 km upstream of the Bridge/Fraser River confluence.

The Cayoosh Creek and Yalakom River steelhead entered the spawning tributaries after the first marked increase in discharge around the middle of May (Appendix 3). Both of the Yalakom spawning steelhead entered the Yalakom River on May 21st, before the second increase in water discharge. The movement of the Cayoosh spawning steelhead into Cayoosh Creek on May 27th coincided with the second major increase in water flow.

3.1.5 Spawning Distributions

In the spring of 1997, 31 radio-tagged steelhead were located during mobile tracking of the Bridge and Seton watersheds. Analysis of the telemetry data concluded that 13 steelhead spawned in the Bridge watershed and two steelhead spawned in the Seton watershed (Figure 3, Appendix 5). The spawning period and location were defined by a relatively stationary period at or near the upstream extent of movement, followed by a downstream movement out of the system or death. The 13 Bridge watershed steelhead likely spawned in the following locations: three downstream of the Bridge/Yalakom confluence, three near the Bridge/Yalakom confluence, five upstream of the Bridge/Yalakom confluence, and two in the Yalakom River. One Seton watershed steelhead is believed to have spawned in Seton River and the other in Cayoosh Creek. The likely spawning location and dates were determined for eight radio-tagged steelhead trout (Table 1). There was some uncertainty as to the exact spawning location or time for the remaining seven steelhead (Table 2). For steelhead in which there was uncertainty in the spawning residency, the range of locations and/or dates were given.

Table 1. The 1997 spawning locations and dates for 8 Bridge and Seton River steelhead.

Radio-tag	Sex	Spawning Location (Stream km)	Dates at Spawning Location	Description
209	female	25.5 - 27.7	May 11 - 13	Bridge - 0.5 - 2.7 km u/s Br/Yal confl
251	male	28.5	June 5 - 12	Yalakom - 3.5 km u/s Br/Yal confl
430	male	30 - 30.6	May 19 - 28	Bridge - 5 - 5.6 km u/s of Br/Yal confl
706	female	25.5 - 26	June 11 - 15	Bridge - 0.5 - 1 km u/s of Br/Yal confl
719	male	4.0 - 5.0	May 31 - June 6	Cayoosh - 1 - 2 km u/s Cay/Set confl
831	female	29	May 31 - June 1	Bridge - 4 km u/s of Br/Yal confl
1317	female	22.8 - 23	June 5 - 7	Bridge - 22.8 - 23 km u/s Br/Frsr confl
1319	female	10.5	May 12-14	Bridge - 10.5 km u/s Br/Frsr confl

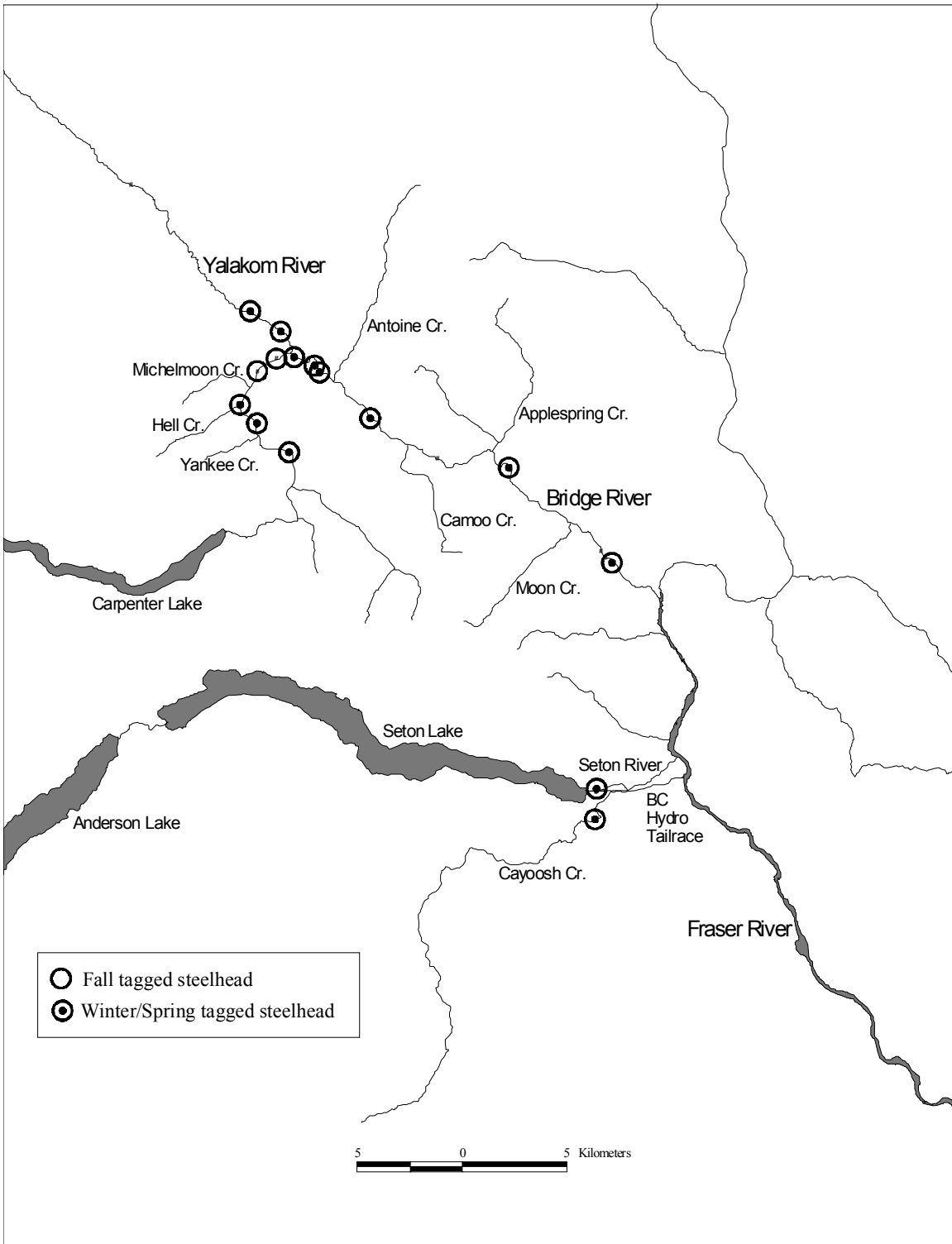


Figure 3. The steelhead spawning distribution in the Bridge and Seton watersheds based on 1997 telemetry data. Circles represent individual spawning locations.

Table 2. The 1997 spawning locations and dates for Bridge and Seton steelhead in which there is uncertainty in location and/or dates.

Radio-tag	Sex	Spawning Location (Stream km)	Dates at Spawning Location	Description
204	male	19 - 19.2	May 19 - June 18	Bridge - 19 - 19.2 km u/s Br/Frsr confl
214	female	31 - 33.1	May 23 - June 18	Bridge - 6 - 8.1 km u/s Br/Yal confl
217	male	23 - 26	May 14 - June 16	Bridge - near Br/Yal confl
408	female	0.5 - 3	June 1 - 9	Bridge - 0.5 - 3 km u/s Br/Frsr confl
1316	male	26 - 27.7	May 21 - June 1	Yalakom - 1 - 2.7 km u/s Br/Yal confl
1331	female	3 - 3.5	May 19 - 23	Seton - 3 - 3.5 km u/s Set/Frsr confl
1380	male	25	May 7 - 14	Bridge - Br/Yal confl

One steelhead was tagged in the Bridge River on May 8th downstream of the Bridge/Yalakom River confluence. This fish appears to have reacted badly to radio-tagging and was only tracked on a few occasions moving downstream in the Bridge River (Appendix 5).

The remaining fifteen radio-tagged steelhead that were tracked via mobile telemetry do not appear to have spawned in the Bridge or Seton watersheds. Nine are considered to have spawned in a Fraser River tributary upstream of the Nahatlatch River, possibly at the Bridge/Fraser confluence. Five fish were tracked on only one or a few occasions before disappearing (two immediately after tagging at the Seton/Fraser confluence and three in the Bridge River between the Bridge River mouth and Camoo Creek) and one steelhead may have died or regurgitated its tag.

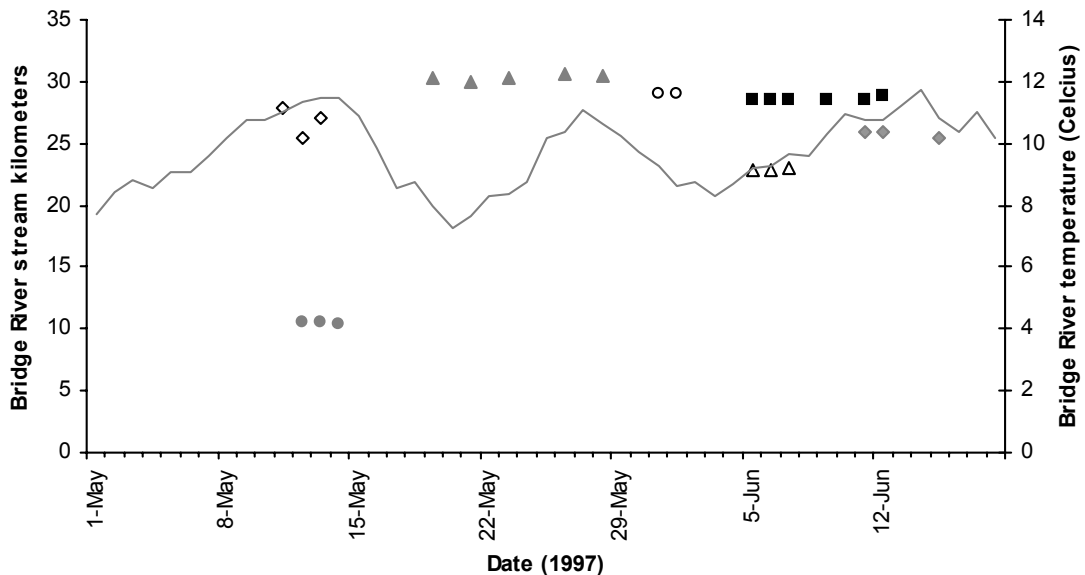


Figure 4. The 1997 spawning locations of radio-tagged Bridge River steelhead and Bridge River mean daily water temperatures (at 26.4 km). Only Bridge River steelhead listed in Table 1 are in the figure. Spawning locations were determined from mobile telemetry data.

The telemetry data suggests spawning in the Bridge and Seton watersheds started around May 7th and ended as late as June 15th. The mean spawning date in the Bridge watershed, based on the seven Bridge steelhead for which both a defined spawning location and date was determined, was May 28th (n = 7, SE = 4.83). During this time, the mean daily water temperature in the Bridge River was greater than 9°C (Figure 4).

The average spawning residency in the Bridge and Seton watersheds in 1997, based on the eight steelhead for which there was some certainty to the spawning location and time, was 5.13 days (SE = 1.03). Spawning residencies ranged from 2 to 10 days.

3.1.6 Downstream Migration

At the completion of spawning, some steelhead began a rapid downstream migration out of their spawning tributaries, eventually returning to the ocean. Kelting fish move rapidly and were difficult to detect with mobile telemetry. Downstream migration rates were calculated by dividing the kilometers travelled downstream in the Bridge or Seton watershed by the number of travel days. The date radio-tagged steelhead exited the Bridge or Seton watersheds was determined for only 2 Bridge River steelhead. Their downstream migration rates were 7.25 and 11.5 km/day.

Only seven of the 15 steelhead (47%) that were tracked in the Bridge and Seton watersheds appear to have survived spawning and emigrated out of their tributary systems in 1997. Six of the eight females (75%) that were tracked spawning in the Bridge and Seton watersheds exited their natal streams. However, only one of the seven males (14.3 %) survived spawning and emigrated out of the Bridge River. It is assumed the remaining six male and two female steelhead died in the Bridge and Seton watersheds.

3.2 1999 Results

3.2.1 Fall Deployment

Eight of the 105 steelhead that were captured and radio-tagged while migrating through the lower Fraser River in the fall of 1998 were Bridge or Seton watershed fish: four of the steelhead were captured by angling, two were captured in a fishwheel, and one was captured in a tangle net (Appendix 2).

3.2.2 Overwintering

Fall radio-tagged steelhead that eventually entered the Bridge or Seton Rivers overwintered in the Fraser River upstream of the Nahatlatch/Fraser River confluence (Figure 5). Four of the fall radio-tagged steelhead overwintered near Texas Creek, two overwintered near Lytton, one overwintered downstream of the Seton/Fraser confluence, and one overwintered between the Lillooet bridges.

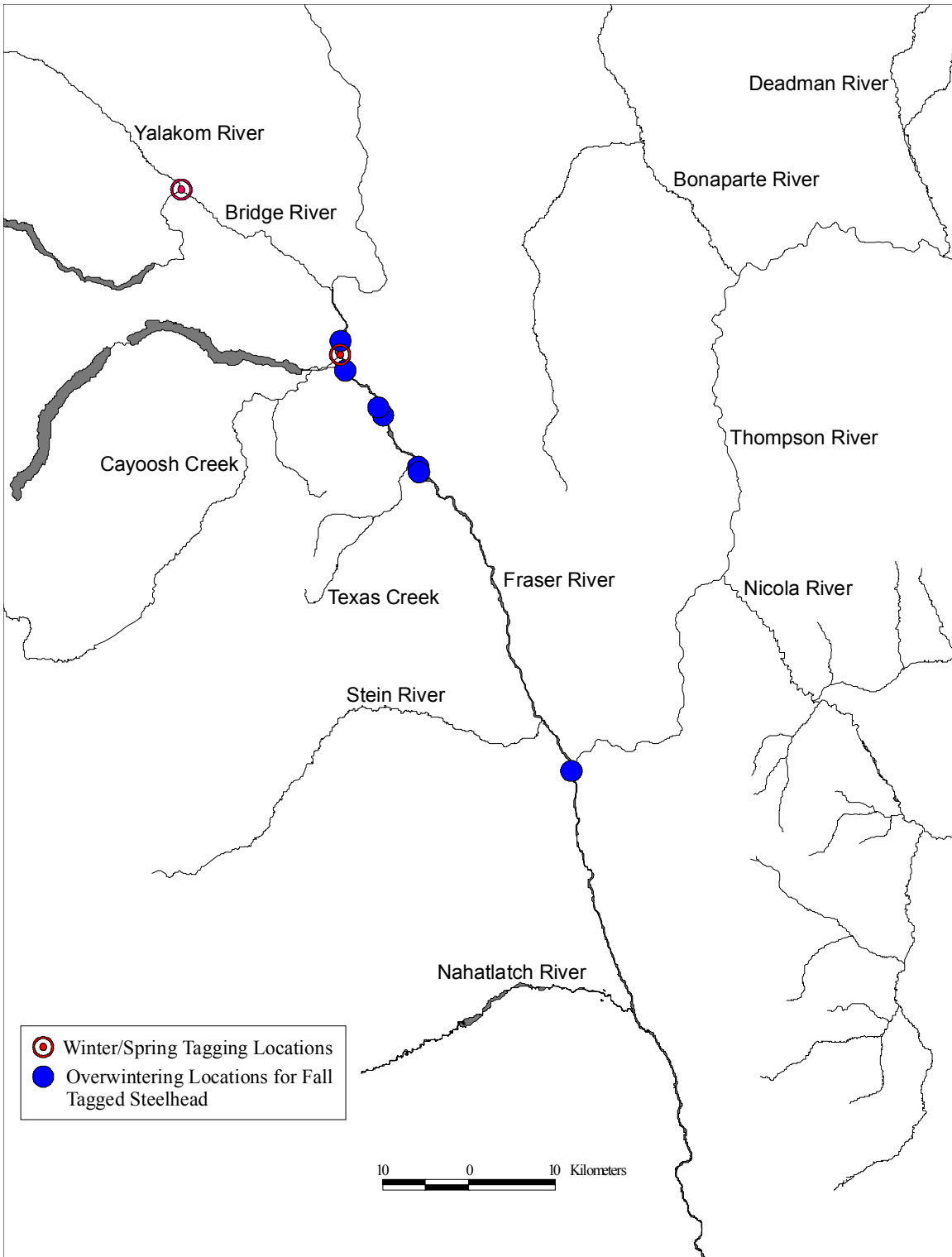


Figure 5. The overwintering locations for fall 1998 radio-tagged Bridge and Seton watershed steelhead and 1999 winter/spring tagging locations.

3.2.3 Winter and Spring Deployment

Radio tags were deployed at the confluence of the Seton and Fraser Rivers during the spring and winter of 1999, specifically to study Bridge River steelhead. All spring radio-tagged fish were captured by angling. Thirteen steelhead were captured and radio-tagged in the winter/spring at the Seton/Fraser confluence and two steelhead were tagged in the spring at the confluence of the Bridge and Yalakom Rivers (Figure 5, Appendix 2). Four of the 13 steelhead captured at the Seton/Fraser River confluence did not spawn in the Seton or Bridge watersheds. The capture location and date of one steelhead is unknown, but is thought to be a spring radio-tagged fish.

3.2.4 Upstream Migrations

The fixed station at the Bridge/Fraser River confluence recorded 13 radio-tagged steelhead entering the Bridge River. Two more steelhead were radio-tagged in the Bridge River during their upstream migrations.

Steelhead started entering the Bridge River on April 1st, continuing until May 14th. The majority of steelhead moved into the Bridge River during the two-week period from April 14th to April 26th (mean = April 20th, SE = 2.86) (Figure 6).

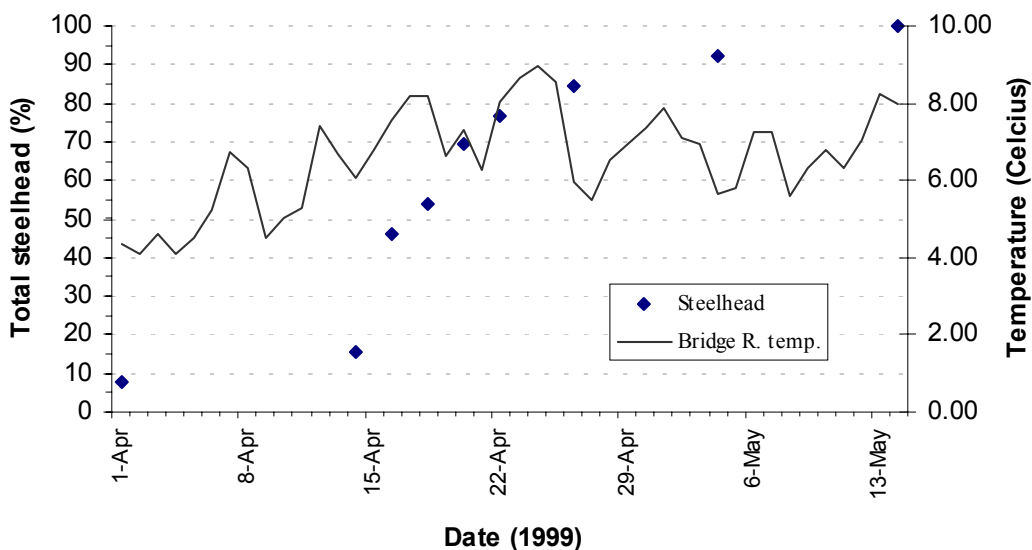


Figure 6. The cumulative number of radio-tagged steelhead (percent) entering the Bridge River in the spring of 1999 and the mean daily water temperature of the Bridge River taken 20 km upstream of the Bridge/Fraser River confluence (downstream of the Bridge/Yalakom confluence).

On April 15th the mean daily water temperatures in the Bridge River rose above 7°C. This coincides with the start of the peak immigration period. Temperatures in the Seton River remained between 6°C and 7°C for most of the spring immigration period.

In general, steelhead migrate slowly upstream to their spawning locations. Average daily rates of movement were determined for the 13 Bridge River steelhead in which there was confidence in both the date ascent of the Bridge River began and the date spawning began. The average daily rates of movement were calculated from the total distance travelled in either upstream or downstream directions prior to the start of the spawning residency, divided by the total number of migration days. The average rate of upstream movement by steelhead in the Bridge watershed in 1999 was 1.39 km/day (n = 13, SE = 0.17). Upstream migration rates ranged from 0.48 to 2.78 km/day.

The first marked increase in discharge in Cayoosh Creek and the Yalakom River did not occur until the last week of May in 1999. As a result, both the Yalakom and Cayoosh spawning steelhead entered the spawning tributaries prior to the onset of freshet (Appendix 4).

3.2.5 Spawning Distributions

Analysis of the telemetry data concludes that 18 (fourteen females, four males) of the 28 radio-tagged steelhead that held near the mouths of the Seton and Bridge Rivers in the spring of 1999 spawned in those watersheds. The spawning period and location were defined by a relatively stationary period at or near the upstream extent of movement, followed by a downstream movement out of the system or death. Fifteen steelhead spawned in the Bridge watershed and three steelhead spawned in the Seton watershed (Figure 7, Appendix 6). The 15 Bridge watershed steelhead are believed to have spawned in the following locations: one in the Yalakom River, seven in the Bridge River above the Bridge/Yalakom confluence, and seven in the Bridge River downstream of the Bridge/Yalakom confluence. All three Seton watershed steelhead spawned in the Cayoosh Creek compensation channel (near the West Kootenay Power powerhouse site). The spawning locations and dates were determined for 12 radio-tagged steelhead trout (Table 3). There was some uncertainty as to the exact spawning locations or dates for six radio-tagged fish (Table 4). For steelhead where there was uncertainty in the spawning residency, the range of locations and/or dates is shown.

The remaining ten steelhead that were tracked near the Bridge/Fraser and Seton/Fraser confluence's during the spring of 1999 did not spawn in those watersheds. The fixed telemetry station at the Bridge/Fraser confluence recorded five steelhead that held near the mouth of the Bridge River for a period of time during the spawning period. Two of these steelhead were recorded moving upstream of the Chilcotin River in the Fraser, two were recorded entering the Chilcotin River, and the other steelhead was last detected in the Fraser River upstream of the Bridge/Fraser confluence. Two other fish held at the Bridge/Fraser confluence throughout the spring (April 2nd – May 9th and April 2nd – June 19th) and are believed to have spawned in or near the mouth of the Bridge River. The last steelhead captured and radio-tagged at the Seton/Fraser confluence was detected for the

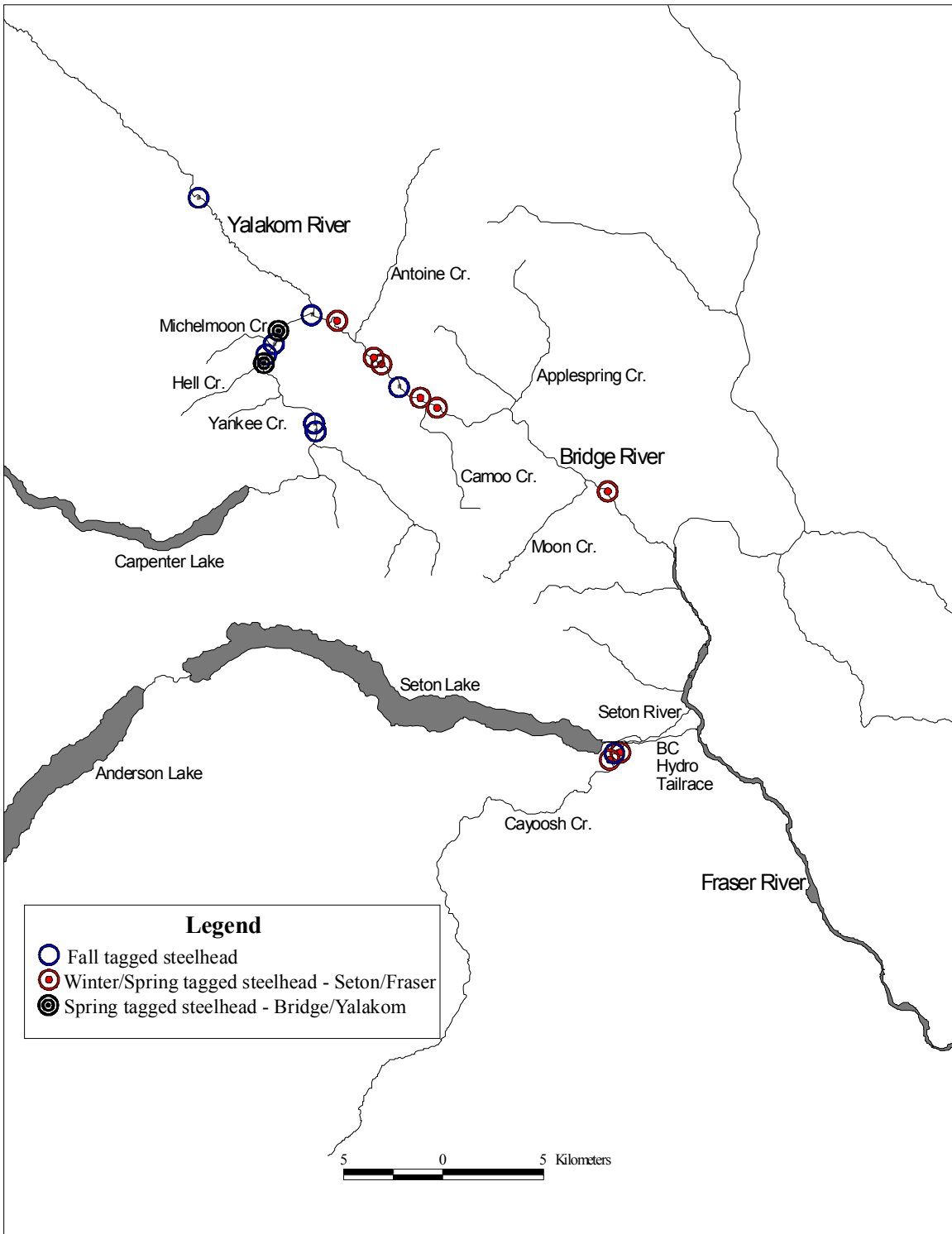


Figure 7. The spawning distribution of Bridge and Seton River steelhead in 1999. Circles represent individual spawning locations.

final time, on an April 30th flight, in the Fraser River downstream of Lillooet. One steelhead was detected on April 7th at the Seton/Cayoosh confluence and was not detected in the Seton or Bridge Rivers again. The radio tagging location of one steelhead was unknown, but it was detected only once at the Bridge/Yalakom confluence.

Table 3. The spawning locations and dates for Bridge and Seton steelhead in 1999.

Radio-tag	Sex	Spawning Location (Stream km)	Dates at Spawning Location	Description
1251	Female	28.4 – 28.9	May 26 – May 31	Bridge – 3.4-3.9 km u/s Br/Yal confl.
1254	Female	25.2	May 4 – May 11	Bridge – 0.2 km u/s Br/Yal confl.
1543	Female	34.5	May 26 – May 28	Bridge – 9.5 km u/s Br/Yal confl.
1589	Female	34	May 16 – May 19	Yalakom – 9 km u/s Br/Yal confl.
1880	Female	27.2	May 19 – May 28	Bridge – 2.2 km u/s Br/Yal confl.
1892	Female	16.3	May 16 – May 18	Bridge – 0.7 km below Camoo Crk.
1893	Female	23.6	May 29 – June 2	Bridge – 1.4 km d/s Br/Yal confl.
1894	Female	5.0	May 13 – May 16	Cayoosh – 2 km u/s Cay/Set confl.
1896	Female	20	April 12 – 14	Bridge – 5 km d/s Br/Yal confl.
1897	Male	20.5	May 16 – May 18	Bridge – 4.5 km d/s Br/Yal confl.
1899	Female	4.8 – 5	May 14 – May 20	Bridge – 4.8-5 km u/s Br/Frasr confl.
2061	Female	4.7	May 25 – June 4	Cayoosh – compensation channel

Table 4. 1999 Spawning locations and times for Bridge and Seton steelhead in which there is uncertainty in the location and/or time.

Radio-tag	Sex	Spawning Location (Stream km)	Dates at Spawning Location	Description
1274	Male	25 – 29.3	April 25 – June 11	Bridge – 0-4.3 km u/s Br/Yal confl.
1592	Female	34.5 – 35	May 20 – May 21	Bridge – 9.5-10 km u/s Br/Yal confl.
1895	Male	4.7	May 2 – June 11	Cayoosh – compensation channel
1898	Male	14.5 – 20.5	May 14 - 29	Bridge – 14.5–20.5 km u/s Br/Frasr confl
2059	Female	15.5 – 19.5	April 26 – May 2	Bridge – 15.5-19.5 u/s Br/Frasr confl
2084	Female	33 – 34	May 9 – June 11	Bridge – 8-9 km u/s Br/Yal confl.

Spawning in the Bridge and Seton watersheds appears to have started as early as April 12th and ended as late as June 4th. Most of the spawning activity in the Bridge watershed, based on the 10 Bridge steelhead for which both a defined spawning location and date was determined, occurred during the last two weeks of May (mean = May 16th, SE = 4.37). This coincides with a two week period in the Bridge River in which mean daily water temperatures were 8°C or warmer (Figure 8).

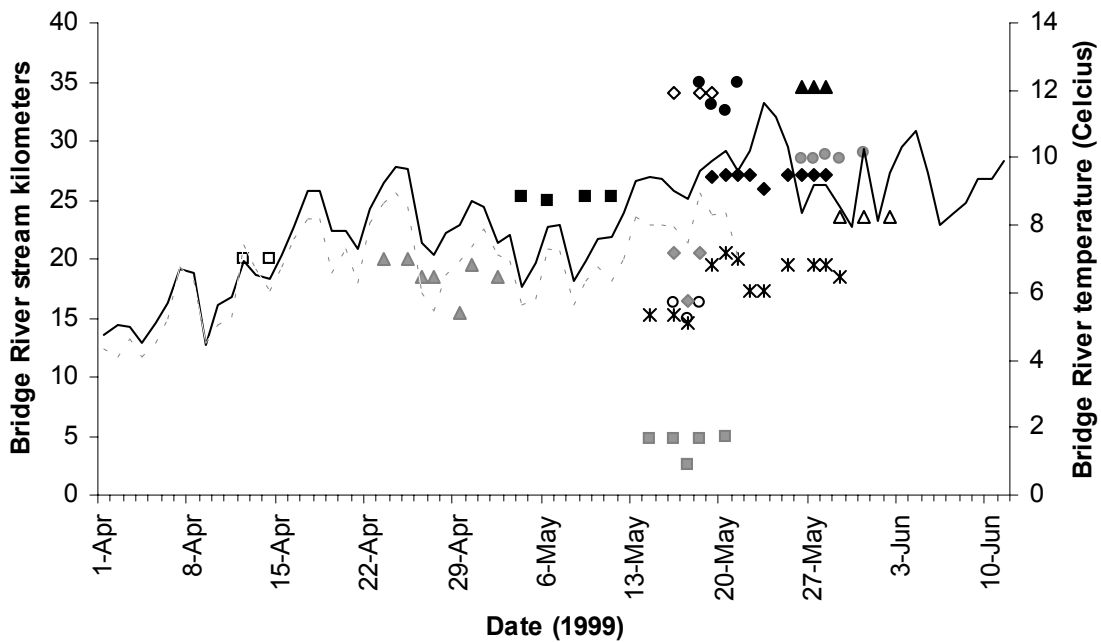


Figure 8. The spawning locations of radio-tagged Bridge River steelhead in 1999 and the mean daily water temperature of the Bridge River. The solid line represents the mean daily water temperature of the Bridge River taken at 26.4 km (upstream of the Bridge/Yalakom confluence) and the slashed line represents the mean daily water temperature of the Bridge River taken at 20 km (downstream of the Bridge/Yalakom confluence).

The average spawning residency in the Bridge and Seton watersheds in 1999, based on the 12 steelhead in the study in which there was some certainty to the spawning location and time, was 5.58 days (SE = 0.82). Spawning residencies ranged from 3 to 11 days. Visual observations of untagged fish between the Bridge/Yalakom River confluence and Yankee Creek suggest a residency on individual redds of only one to two days. However, if steelhead are selecting two or three redds in close proximity, the average total spawning residency is similar. The spawning activity in the Bridge River upstream of the Bridge/Yalakom confluence may also be largely nocturnal due to the extremely low and clear water conditions.

3.2.6 Downstream Migration

At the completion of spawning, some steelhead began a rapid downstream migration out of their spawning tributaries, eventually returning to the ocean. Downstream migration rates were calculated by dividing the downstream kilometers travelled in the Bridge and Seton watersheds by the number of travel days. The fixed station at the mouth of the Bridge River recorded the departure of radio-tagged steelhead from the Bridge River into the Fraser River. The average downstream migration rate in the Bridge watershed was 10.66 km/day (SE = 1.44, n = 11). The furthest distance a Seton watershed radio-tagged steelhead had to emigrate to reach the Fraser River was five kilometers.

Thirteen of the 18 radio-tagged steelhead (72%) appear to have survived spawning and emigrated out of the Bridge and Seton Rivers into the Fraser River. This is very similar to the 71% of tracked steelhead that emigrated out of the Nicola watershed in 1999 (Webb *et al.* 2000). Only four male steelhead were tracked in the Bridge and Seton watersheds, but two (50%) of them did not enter the Fraser River and are presumed to have died in the watersheds. Of the 14 female steelhead that were tracked in the Bridge and Seton watersheds, three (21.4%) did not enter the Fraser River and are presumed to have died in the watersheds. All four of the Bridge River steelhead that died within the watershed did so in the Bridge River upstream of the Bridge/Yalakom confluence.

3.2.7 Escapement Estimation

Five fish counts within the section of the Bridge River from the Bridge/Yalakom confluence upstream to Yankee Creek were completed between April 27th and May 21, 1999. The shape of the escapement curves (or trapezoid) was consistent with previous observations of steelhead spawning timing in 1997 and as reported previously by Baxter and Roome (1996) and Hebden (1981). The fish count data also corroborated with the timing and movement patterns of radio-tagged steelhead in the 1999 study. The fish count data did not include zero or near zero counts on either extreme of the run timing which introduces uncertainty in the computed AUC by the trapezoid method. Points on either extreme were estimated by linear extrapolation in order to complete the trapezoid (Fig. 9). In such cases, estimation of the run timing curve using an arrival time model is preferred (Hilborn *et al.* 1999).

Maximum likelihood escapement estimates (MLE) for steelhead in the Bridge watershed ranging from 369 to 420 spawners. These estimates were lower but similar to the estimate of 422 based on the trapezoidal method. The normal arrival model assuming pseudo-Poisson observation error was considered the best of the maximum likelihood methods by Hilborn *et al.* (1999). The MLE from this model was 369 spawners (Table 5).

The field estimates of observer efficiency (v), survey life (R_t) and proportion of spawners in the counting area (R_c/R_w) were based on few data. Observer efficiency was estimated to be 0.40 (SE=0.13) based on 4 observations. Survey life was estimated to be 9.6 days (SE=1.2 days) based on 5 radio-tagged steelhead. The proportion of spawners in the counting area was 7/15 (0.47) based on radio tag distribution (Table 6).

Uncertainty in the various MLE's were generally similar (Fig. 10). The lower 95% confidence limit ranged from 205 to 230 depending on the method used. The upper 95% confidence limit was more varied ranging from 530 to 700. Expressed as a percentage of the MLE, the lower 95% confidence limits ranged from out 42-49% of the MLE. The upper 95% confidence limits were more varied ranging from 31-67% of the MLE.

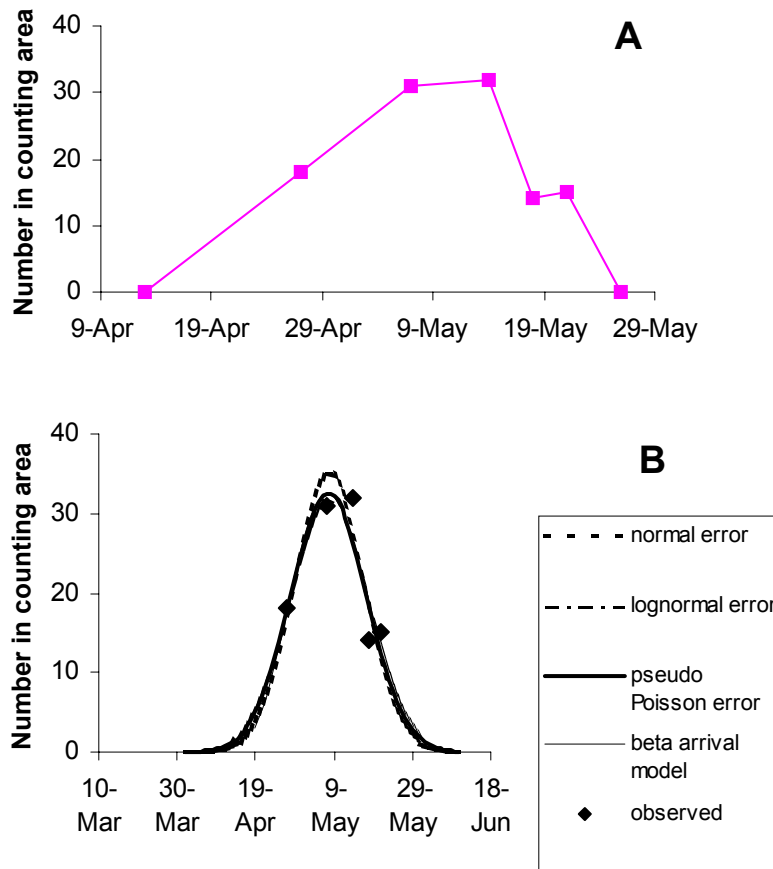


Figure 9. Profiles of instantaneous counts using the trapezoidal approximation (a), 3 variations of the normal arrival time model and the beta arrival time model (b). The 3 variations of the normal arrival time model are those in which the observation error is assumed to have a normal, lognormal and pseudo-Poisson distributions. Observation error in the beta model is assumed to have a pseudo-Poisson distribution.

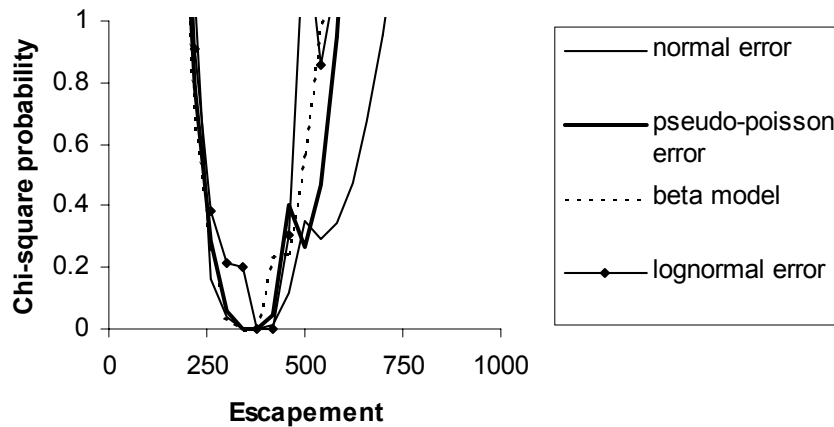


Figure 10. Chi-square probability graphs for total escapement using the normal arrival time model under three observation error assumptions and the beta arrival time model. Confidence bounds can be found by drawing a horizontal line at the desired probability level on the y-axis and finding the two points that intersect the probability graph.

Table 5. Escapement estimates and confidence limits.

Method	Escapement estimate	Lower 95% confidence limit	Upper 95% confidence limit
Trapezoidal	422	n/a	n/a
Normal entry and normally distributed error	420	230	700
Normal entry and lognormally distributed error	377	220	550
Normal entry and pseudo-poisson error	369	210	580
Beta entry and pseudo-poisson error	406	205	530

Table 6. Parameter estimates based on direct field estimates and parameter search routines (MLE methods).

Method	Mean day of arrival (alpha)	Standard deviation on mean day of arrival (beta)	Residency time (Rt)	Observer efficiency (v)	Number of radio tags in counting area (Rc) given Rwa=15 and p=0.47.
Trapezoidal	-	-	9.6 ^a	0.40 ^a	7
Normal entry and normally distributed error	49.7	8.4	9.6	0.40	7.0
Normal entry and lognormally distributed error	49.7	9.5	9.6	0.43	7.3
Normal entry and pseudo-poisson error	49.6	9.2	9.6	0.43	7.4
Beta entry and pseudo-poisson error	4.7 ^b	6.4 ^b	9.6	0.43	6.5

^aDirect field estimates

^bParameters of the beta distribution, not comparable to parameters of the normal entry models.

4 Discussion

4.1 Overwintering Distribution

On a large geographic scale, Bridge and Seton River steelhead congregate for the winter in the middle Fraser River, showing a general affinity for their spawning tributaries. However, within the middle Fraser River, the distribution of radio tags suggests these steelhead are quite dispersed. They don't show an attraction to clear water confluences and they aren't particularly concentrated near the Seton River mouth where there is a mix of both Seton and Bridge River water. None of the 1996 or 1998 fall radio-tagged steelhead were recorded overwintering at the Seton/Fraser River confluence.

Based on results from the winter and spring tagging at the Seton/Fraser River confluence, it appears a number of Chilcotin steelhead overwinter in the middle Fraser River. The Bridge River rapids, located just upstream of the Bridge/Fraser River confluence, may have been impassable for these fish at the time of upstream migration, forcing them to overwinter near Lillooet until water levels and temperatures rose in the spring.

4.2 Upstream Movement Patterns

In the spring of 1997, frequent mobile tracking did not occur until after May 7th and fixed stations were not present at the mouth of the Bridge or Seton Rivers. Therefore, the immigration date was missed for the majority of the radio-tagged steelhead. Six of the 15 radio-tagged steelhead entered the Bridge or Seton Rivers during the second week of May. The other nine radio-tagged steelhead are believed to have entered the Bridge and Seton Rivers during the last two weeks of April.

In the spring of 1999, the majority of the radio-tagged steelhead entered the Bridge and Seton Rivers during the last two weeks of April. April 15th, 1999, was the date that the average daily water temperatures in the Bridge River rose above 7°C. This coincides with the start of the peak immigration period. Average daily temperatures in the Seton River remained between 6°C and 7°C for most of the spring immigration period. Water flow data for the Bridge River is not available from Water Survey Canada, therefore, no observations can be made on a possible correlation between immigration and freshet.

The first major increase in water discharge in the Yalakom River and Cayoosh Creek occurred around the middle of May in 1997. Cayoosh and Yalakom steelhead entered the spawning tributaries shortly after the initial increase in flows (Appendix 3). In the spring of 1999, freshet did not begin in the Yalakom River or Cayoosh Creek until the final week of May. The Yalakom spawning steelhead entered the Yalakom River at the start of May and kelted as the water discharge began to increase. Two Cayoosh spawning steelhead entered Cayoosh Creek before the major freshet event. The movement of the third Cayoosh spawning steelhead into Cayoosh Creek coincides with the first major increase in water discharge (Appendix 4).

During both the 1997 and 1999 spawning migrations, mobile telemetry data shows that radio-tagged steelhead held at the Bridge/Yalakom confluence before moving upstream in the Bridge River. Steelhead may have hesitated before moving into the Bridge River upstream of the Bridge/Yalakom confluence due to the low, clear water conditions. Radio-tagged steelhead were not detected holding at the confluence's of larger spawning tributaries in the Nicola River telemetry study. Steelhead in the Nicola telemetry study however were observed, holding near the confluence's of small tributaries until adequate water levels were achieved during freshet (Webb *et al.* 2000).

4.3 Spawning Distribution

Of the 15 radio-tagged steelhead that were tracked during the 1997 Bridge and Seton River telemetry study, two (13%) spawned in the Seton watershed and 13 (87%) steelhead spawned in the Bridge watershed. Analysis of the tracking data suggests one Seton watershed steelhead spawned in the Seton River mainstem and the other steelhead spawned in Cayoosh Creek. The tracking data shows that some Bridge watershed steelhead spawned in the lower reaches of the Bridge River, but the majority of the 13 Bridge watershed steelhead spawned within five kilometers of the Bridge/Yalakom confluence.

In the 1999 telemetry study of the Bridge and Seton watersheds, three (17%) of the 18 radio-tagged steelhead spawned in the Seton watershed and 15 (83%) radio-tagged steelhead spawned in the Bridge watershed. All three Seton watershed steelhead spawned in Cayoosh Creek: either in or upstream of the compensation channel. Only one out of 15 radio-tagged Bridge watershed steelhead spawned in the Yalakom River. Seven steelhead spawned in the Bridge mainstem above the Yalakom confluence and the remaining seven steelhead spawned below the Yalakom River. Spawning activity was not as clumped around the Bridge/Yalakom confluence in 1999 as in 1997, however the lower reaches of the Bridge River were still not well utilized.

There appears to be a relationship between capture location, timing of entrance into a natal stream and spawning location. Both of the 1996 fall tagged steelhead that spawned in the Bridge River did so above the Bridge/Yalakom River confluence (Figure 3). Six of the seven 1998 fall tagged steelhead that spawned in the Bridge watershed did so above the Bridge/Yalakom confluence (Figure 7). During the 1997 spawning season, almost all of the Bridge watershed steelhead that were captured at the Seton/Fraser confluence in March and April spawned above the Bridge/Yalakom confluence. All of the steelhead that were captured in February 1997 at the Seton/Fraser confluence or the Thompson/Fraser confluence spawned in the Bridge River below the Bridge/Yalakom confluence. During the 1999 spawning season, spring radio-tagged steelhead that were captured at the Seton/Fraser River confluence spawned only below the Bridge/Yalakom confluence in the Bridge River (Figure 7).

All of the radio-tagged steelhead in the 1996 BC Hydro telemetry study were tagged at the Seton/Fraser confluence in March and April. The telemetry data suggested that radio-tagged Bridge River steelhead spawned both above and below the Bridge/Yalakom River confluence (Baxter and Roome, unpublished data).

The reason for the apparent relationship between capture and spawning location in the 1996/97 and 1998/99 Bridge River studies is unknown. It has not been observed in other interior Fraser steelhead rivers. One possible explanation why fall radio-tagged fish appear to spawn further up in the Bridge River than winter tagged fish may be due to a correlation between angling susceptibility and reduced fitness from angling recaptures.

During the 1996/97 and 1998/99 studies, fall tagged fish overwintered in the Fraser River, but none were recorded overwintering near the Seton/Fraser confluence (Figures 2 and 6). The majority of the winter/spring tagged steelhead were caught at the mouth of the Seton River from February through to April, and there is a high probability they overwintered there. Unlike most streams in Region 3, the Fraser River upstream of Lytton is exempt from the January 1st to June 30th spring angling closure. Steelhead that overwintered at the Seton/Fraser confluence would have been susceptible to angling recaptures throughout the winter, possibly causing a reduction in fitness that resulted in shorter upstream migrations in the Bridge River.

In early March of 1999, when a lot of the spring radio tagging took place, some of the fall radio-tagged steelhead were detected at the Seton/Fraser confluence. In the early spring, steelhead may hold at the mouth of the Seton River for a few days as they migrate upstream in the Fraser River towards spawning tributary streams. Steelhead captured at the Seton/Fraser River confluence in March and April may not have overwintered at the mouth of the Seton River, but were migrating up the Fraser River when they were radio-tagged. This may explain why steelhead captured in March and April 1997 at the Seton/Fraser confluence spawned further upstream in the Bridge River than steelhead captured in February. It is also possible that a small proportion of the Bridge run will hold in Seton water for the winter and, by chance, none of the fall tagged steelhead have overwintered there.

4.4 Kelts

In 1997, only eight (50%) of the 16 steelhead that were tracked in the Bridge and Seton watersheds appear to have survived spawning and emigrated out of the tributary systems. The spawning survival rate was higher in 1999, with thirteen (72%) of the 18 steelhead migrating out of the Bridge and Seton watersheds into the Fraser River. The higher number of mortalities within the spawning tributaries in 1997 can be attributed to the higher proportion of tagged males in the 1996/97 study over the 1998/99 study. Spawning appears to be more arduous on male steelhead than female steelhead. Telemetry data shows the average male steelhead spends more time in the spawning tributaries than female steelhead and suggests many male fish spawned in more than one location.

The water in the Bridge River above the Yalakom River experiences unnaturally low flows as a result of Terzhagi dam and is very clear and low. These conditions appear to add stress to spawning steelhead or make them much more vulnerable to predators, as the mortality rate in this section of stream is much higher than average for radio-tagged

steelhead. Steelhead were considered mortalities or tag regurgitations if they were tracked moving upstream or remained stationary for a prolonged period of time, and weren't detected kelting. In 1997, telemetry data shows three (60%) of the five radio-tagged steelhead that are believed to have spawned in the Bridge River above the Yalakom River were mortalities. The 1999 telemetry data shows four (57%) of the seven radio-tagged steelhead that spawned in the Bridge River above the Yalakom River were mortalities.

4.5 Escapement Estimation

The escapement estimates for the 1999 spawning population are the first appraisals of abundance based entirely based on quantitative estimation techniques and empirical data. Previously, Hebden (1981) reported that the Bridge population did not exceed 200 spawners in the spring of 1980 and that most of the spawning was concentrated in the Bridge River upstream of the Yalakom confluence. Our findings in 1997 and 1999 indicate the spawning distributions are not as concentrated to the upper reach. Both studies suggest that the Bridge population is characteristically in the order of a few hundred spawners.

Precision estimates, expressed as 95% confidence limits, were generally in the order of 40-50% of the MLE's. Considering how limited that data were, the results seem encouraging. Increased sample sizes or incorporation of prior likelihoods by repeating studies on fish distribution, observer efficiency and survey life could reduce uncertainty in future assessments if management objectives warrant more precise estimation. In this assessment, we can say with confidence that the spawning population likely exceeded 200 spawners. Such an appraisal is useful for managing to conservation and biodiversity objectives.

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Appendices

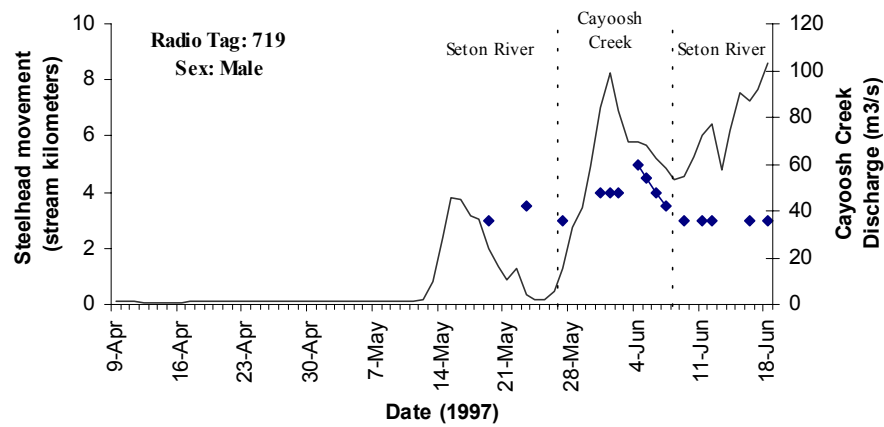
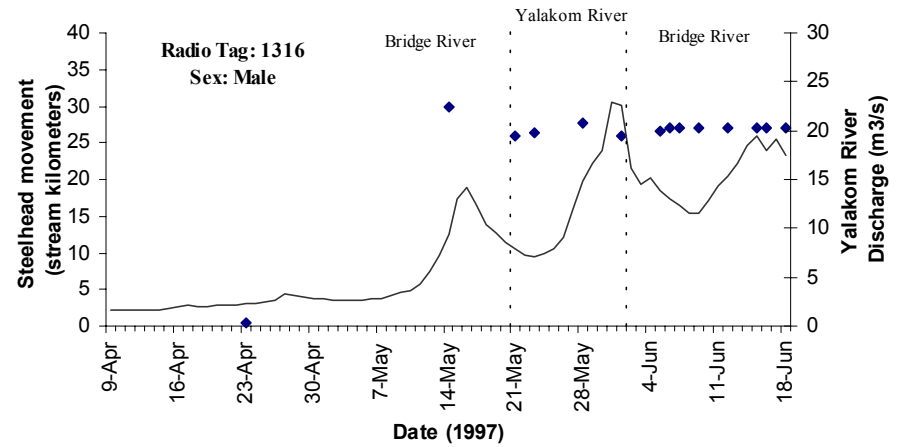
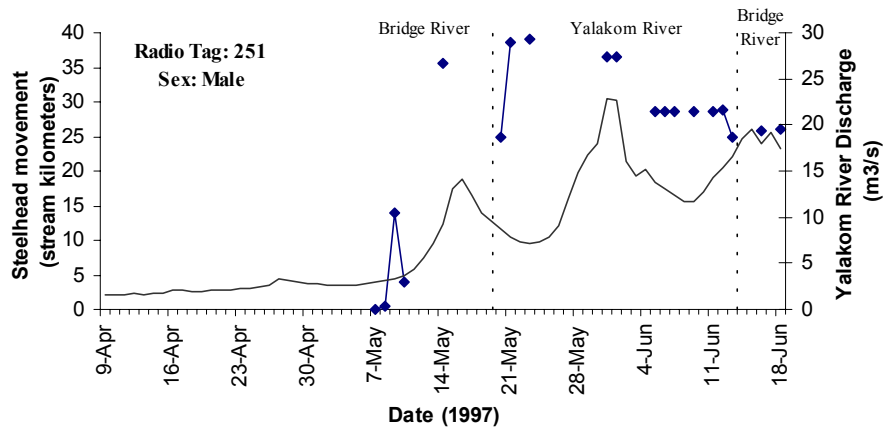
Appendix I. Capture location, biological information and natal stream for 1997 Bridge and Seton watershed radio-tagged steelhead.

Radio-tag	Capture Location	Method	Date	Sex	Length (cm)	Girth (cm)	Spawning Stream	Comments
204	Thompson/Fraser confl.	angling	06-Feb-97	male	995	480	Bridge	
209	Seton/Fraser confl.	angling	04-Mar-97	female	830	405	Bridge	
214	Seton/Fraser confl.	angling	16-Apr-97	female	650	325	Bridge	
217	Seton/Fraser confl.	angling	16-Apr-97	male	810	375	Bridge	
408	Seton/Fraser confl.	angling	04-Mar-97	female	880	420	Bridge	
430	Seton/Fraser confl.	angling	04-Mar-97	male	875	415	Bridge	
706	Chilliwack - Henderson's	angling	16-Oct-96	female	710	372	Bridge	
831	Chilliwack - Bowman's Bar	angling	30-Sep-96	female	805	390	Bridge	
1317	Seton/Fraser confluence	angling	28-Feb-97	female	860	420	Bridge	
1319	Seton/Fraser confluence	angling	27-Feb-97	female	870	420	Bridge	
1380	Seton power outflow	angling	05-Mar-97	male	870	450	Bridge	
251	Seton/Fraser confl.	angling	22-Apr-97	male	660	315	Yalakom	
1316	Seton/Fraser confluence	angling	04-Mar-97	male	680	315	Yalakom	
719	Thompson/Fraser confl.	angling	19-Feb-97	male	920	440	Cayoosh	
1331	Seton/Fraser confluence	angling	19-Feb-97	female	670	327	Seton	
203	Seton/Fraser confluence	angling	27-Feb-97	female			Fraser u/s Nahatlatch	
206	Bridge - 300 m u/s Fraser	angling	02-May-97	female	785	380	Fraser u/s Nahatlatch	Possibly spawned Seton/Fraser confl.
210	Seton/Fraser confluence	angling	22-Apr-97				Fraser u/s Nahatlatch	Recapture. 1 st Capture 16-Apr-97
230	Seton/Fraser confl.	angling	04-Mar-97	male	880	400	Fraser u/s Nahatlatch	Possibly spawned Bridge/Fraser confl.
480	Seton/Fraser confluence	angling	04-Mar-97	male			Fraser u/s Nahatlatch	
720	Seton/Fraser confluence	angling	17-Apr-97				Fraser u/s Nahatlatch	Possibly spawned Bridge/Fraser confl.
756	Seton/Fraser confluence	angling	17-Apr-97				Fraser u/s Nahatlatch	
1318	Seton/Fraser confluence	angling	05-Mar-97				Fraser u/s Nahatlatch	
1328	Seton/Fraser confluence	angling	28-Feb-97	female	780	360	Fraser u/s Nahatlatch	Possibly spawned Bridge/Fraser confl.
401	Thompson/Fraser confl.	angling	13-Feb-97	male	780	370	N/A	Disappeared after tagging
405	Bridge River	angling	05-May-97	unknown			N/A	Disappeared after tagging
431	Thompson/Fraser confl.	angling	05-Feb-97	male	995	440	N/A	Disappeared after tagging
717	Seton/Fraser confluence	angling	17-Apr-97				N/A	Disappeared after tagging
1058	Bridge - d/s Br/Yal confl.	angling	08-May-97	female	820	420	N/A	Reacted badly to tagging
1308	Seton/Fraser confluence	angling	22-Apr-97				N/A	Disappeared after tagging
1379	Seton/Fraser confluence	angling	22-Apr-97	male	895	410	N/A	Regurgitated tag or died

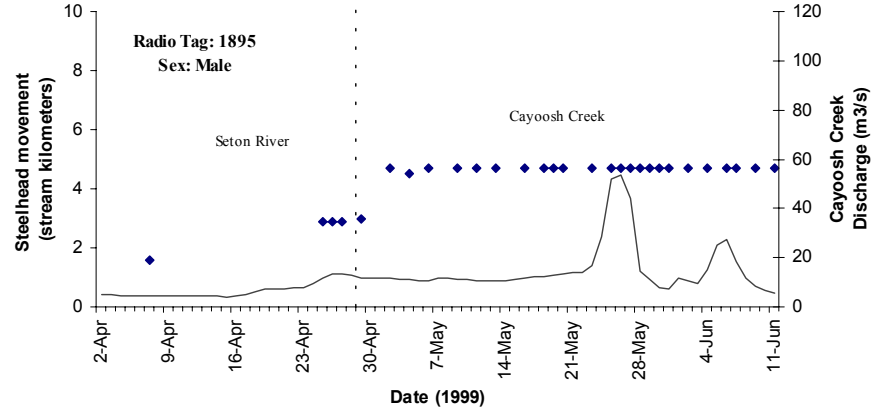
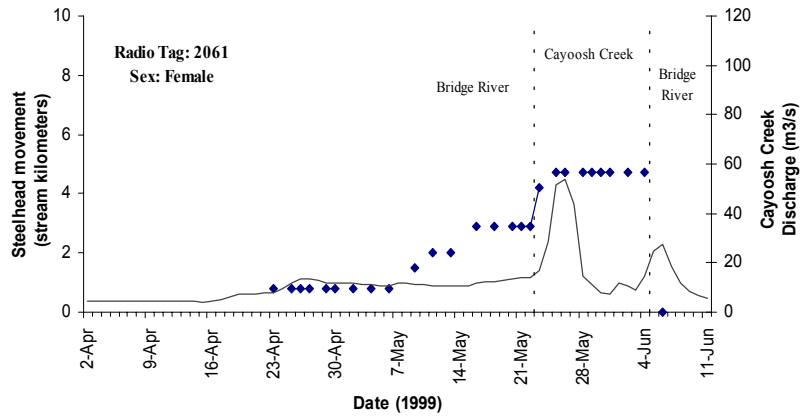
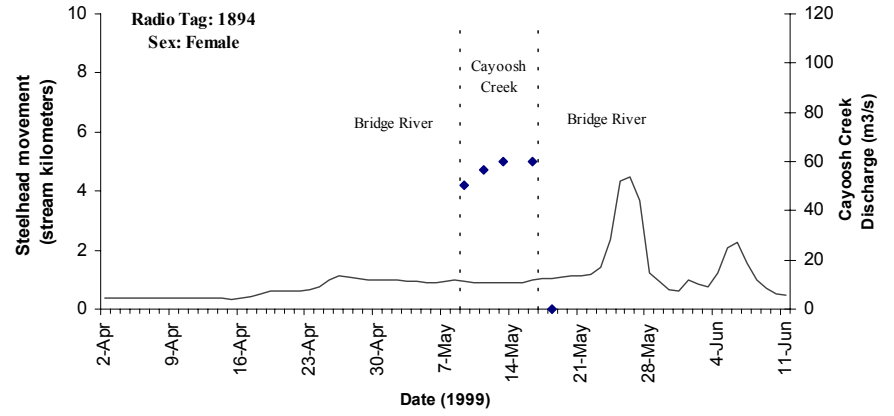
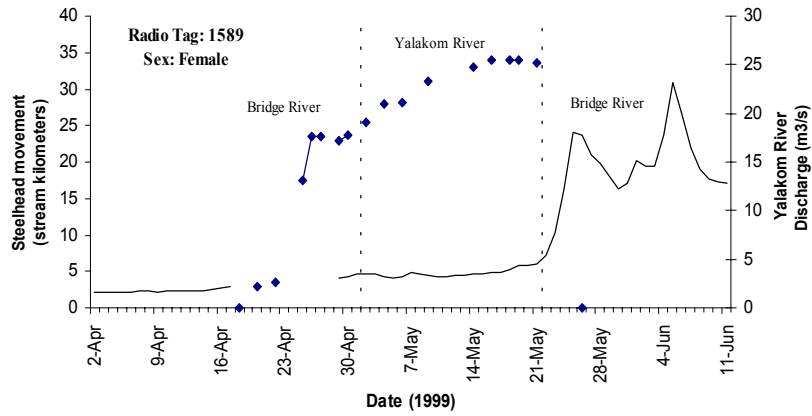
Appendix II. Capture location, biological information and natal stream for 1999 radio tagged steelhead.

Radio-tag	Capture Location	Method	Date	Sex	Length (cm)	Girth (cm)	Spawning Stream	Comments
1251	Bridge/Yalakom confl.	angling	21-May-99	female	660	310	Bridge	
1254	Yale Fishwheel	fishwheel	10-Oct-98	female	766	370	Bridge	
1274	Agassiz Bridge	angling	9-Oct-98	male	870	440	Bridge	
1543	Annacis Island	tangle net	23-Oct-98	female	780	410	Bridge	
1592	Agassiz Bridge	angling	23-Oct-98	female	741	356	Bridge	
1880	Bridge/Yalakom confl.	angling	6-May-99	female	820	385	Bridge	
1892	Seton/Fraser confl.	angling	12-Mar-99	female	780	420	Bridge	
1893	Seton/Fraser confl.	angling	25-Mar-99	female	760	375	Bridge	
1896	Seton/Fraser confl.	angling	7-Mar-99	female	680	360	Bridge	
1897	Seton/Fraser confl.	angling	7-Mar-99	male	760	405	Bridge	
1898	Seton/Fraser confl.	angling	7-Mar-99	male	820	410	Bridge	
1899	Seton/Fraser confl.	angling	28-Mar-99	female	765	380	Bridge	
2059	Yale Fishwheel	fishwheel	14-Oct-98	female	863	410	Bridge	
2084	Chilliwack	angling	16-Oct-98	female	730	395	Bridge	
1589	Agassiz Bridge	angling	5-Nov-98	female	660	320	Yalakom	
1894	Seton/Fraser confl.	angling	21-Mar-99	female	815	440	Cayoosh	
1895	Seton/Fraser confl.	angling	22-Mar-99	male	935	445	Cayoosh	
2061	Yale Fishwheel	fishwheel	16-Oct-98	female	773	385	Cayoosh	
18100	Seton/Fraser confl.	angling	30-Mar-99	female	810	380	N/A	Disappeared after tagging
1886	unknown						N/A	Disappeared after tagging.
1253	Yale Fishwheel	fishwheel	10-Oct-98	male	897	444	Fraser - u/s Bridge	
1242	Yale Fishwheel	fishwheel	15-Oct-98	male	893	416	Fraser – Bridge area	Possibly spawned Bridge/Fraser confl.
1890	Seton/Fraser confl.	angling	5-Mar-99	female	710	330	Fraser – Bridge area	Possibly spawned Bridge/Fraser confl.
1574	Agassiz Bridge	angling	31-Oct-98	male	870	450	Chilcotin	
1871	Seton/Fraser confl.	angling	23-Feb-99	male	830	410	Chilcotin	
1891	Seton/Fraser confl.	angling	6-Mar-99	female	750	380	Fraser u/s Chilcotin	
2057	Yale Fishwheel	fishwheel	15-Oct-98	male	808	401	Fraser u/s Chilcotin	
18101	Seton/Fraser confl.	angling	17-Apr-99	male	860	430	Fraser d/s Lillooet	

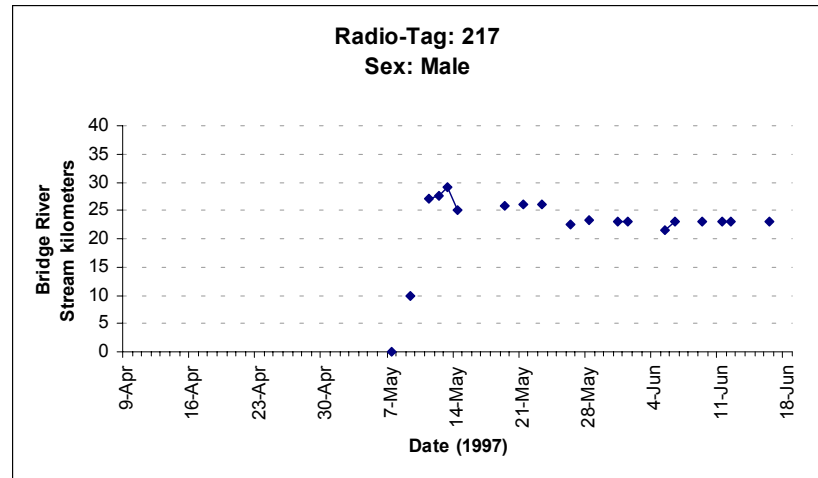
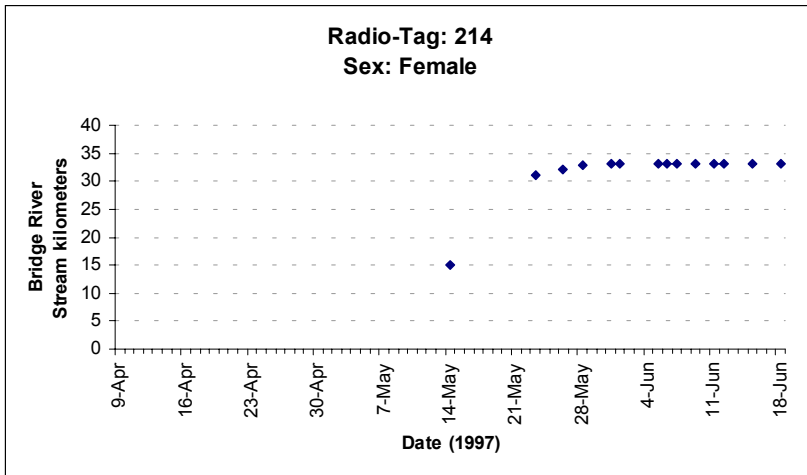
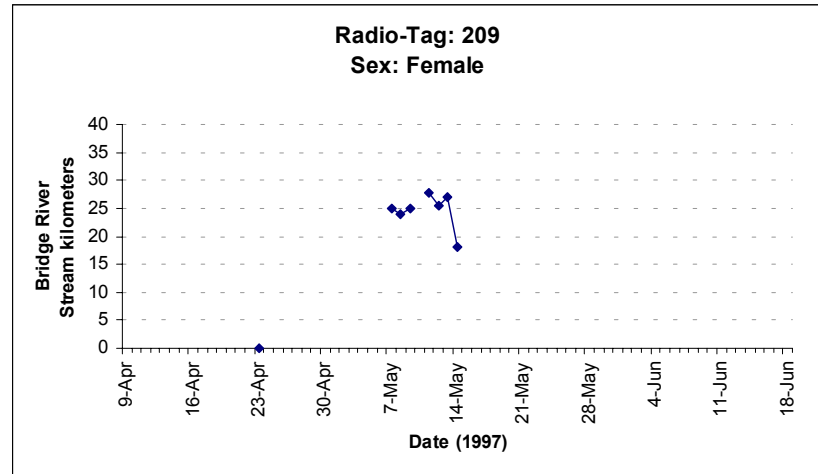
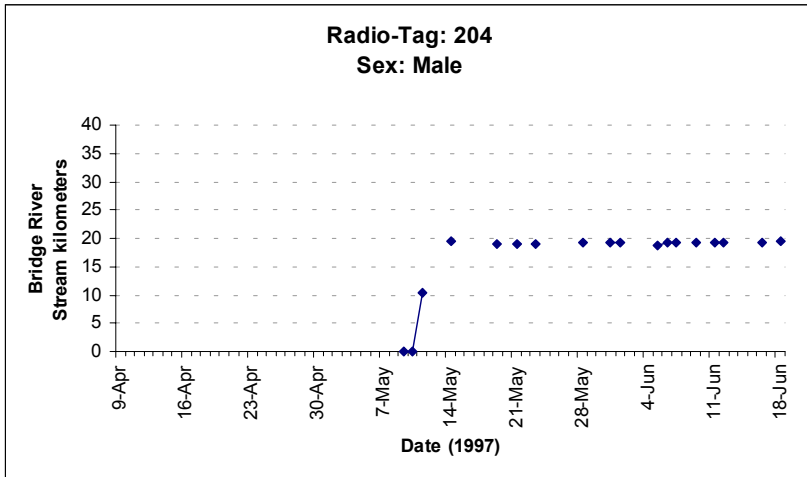
Appendix III. Stream flow vs. steelhead movement for 1997 spawning radio-tagged steelhead.



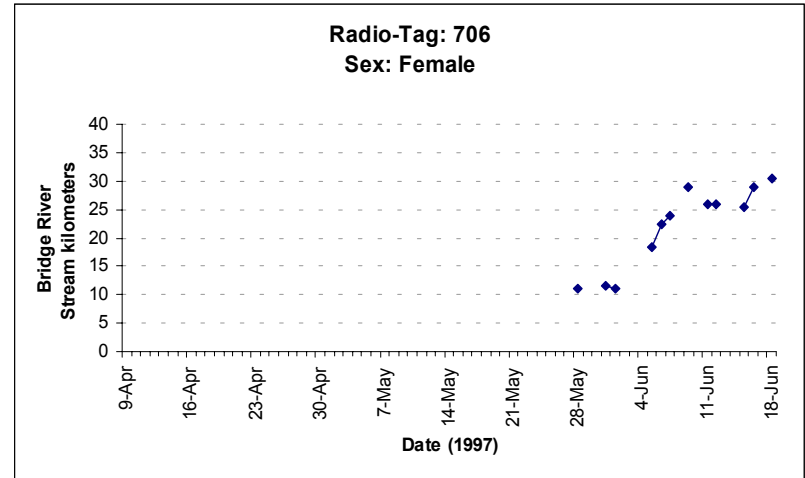
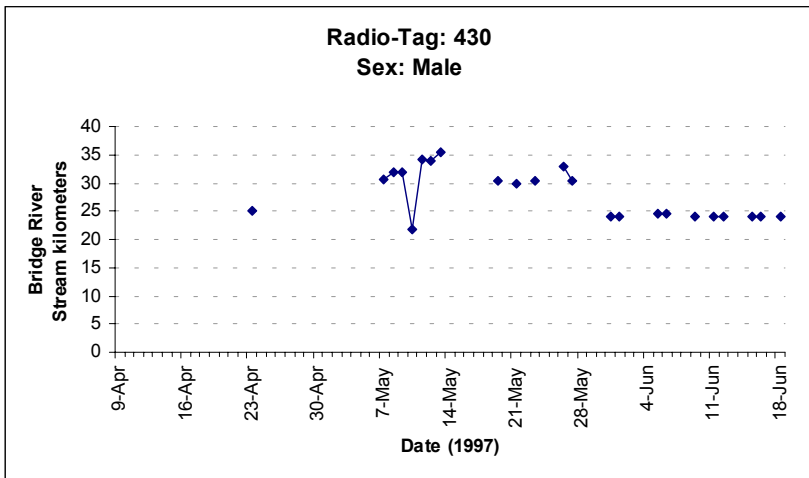
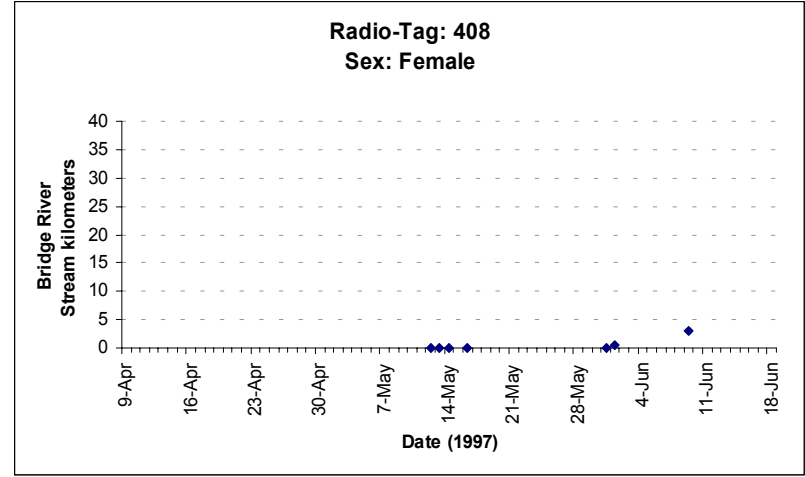
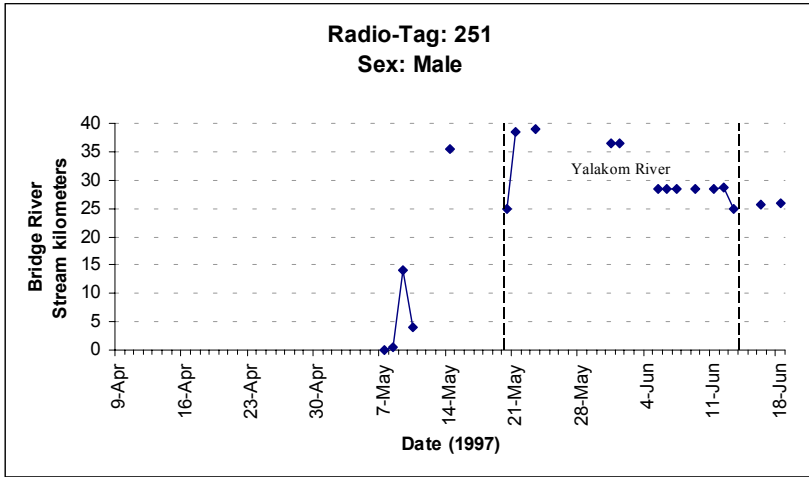
Appendix IV. Stream flow vs. steelhead movement for 1999 spawning radio-tagged steelhead.



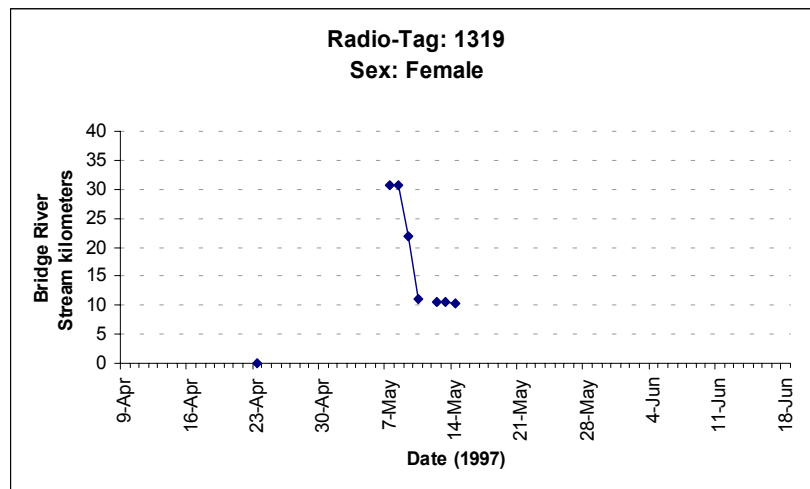
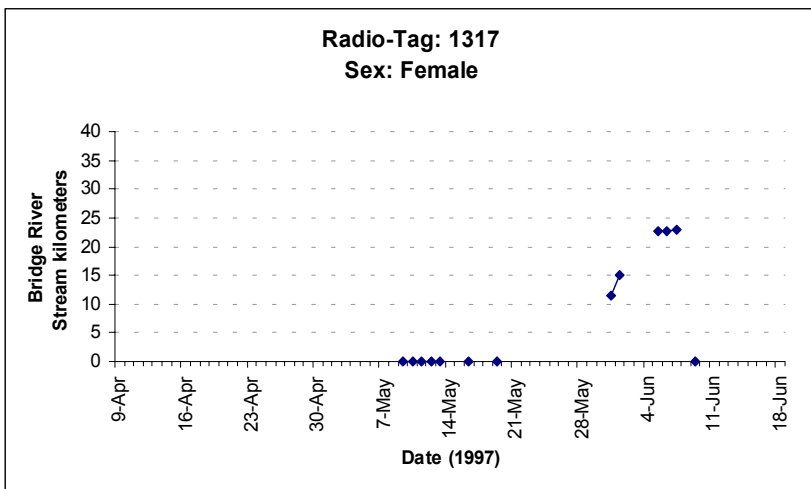
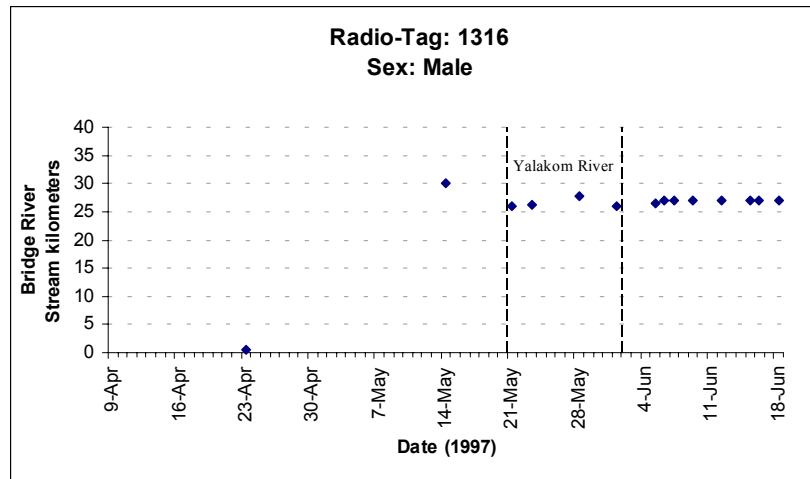
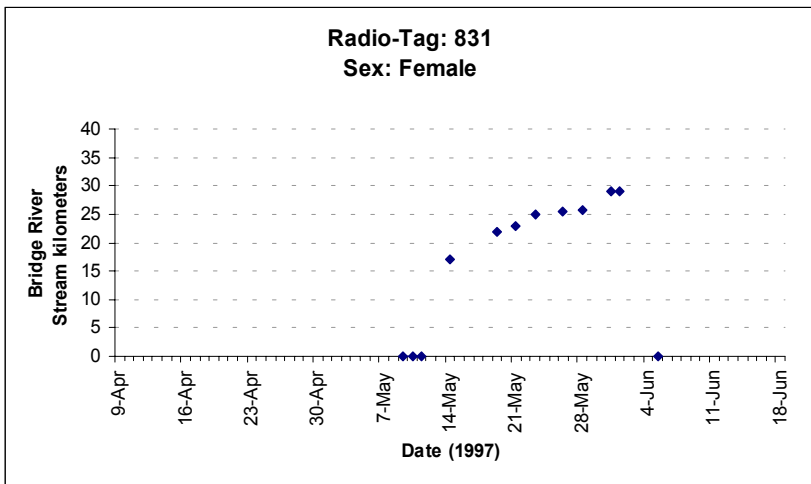
Appendix V. Movement graphs of 1997 Bridge and Seton River radio-tagged steelhead



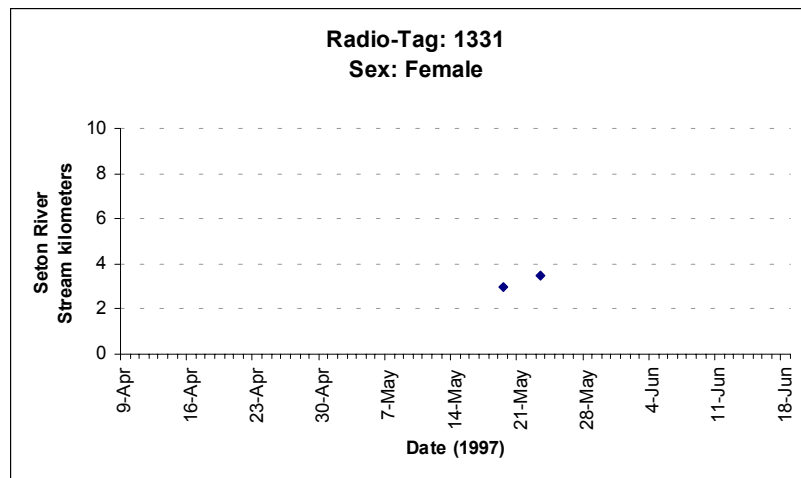
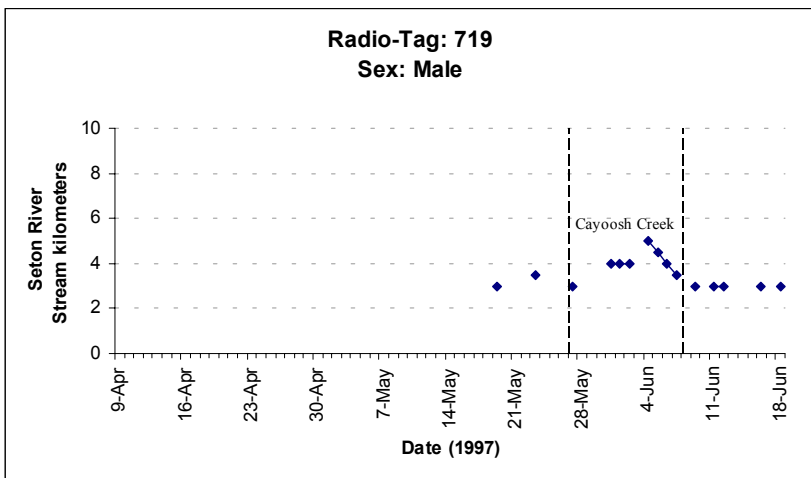
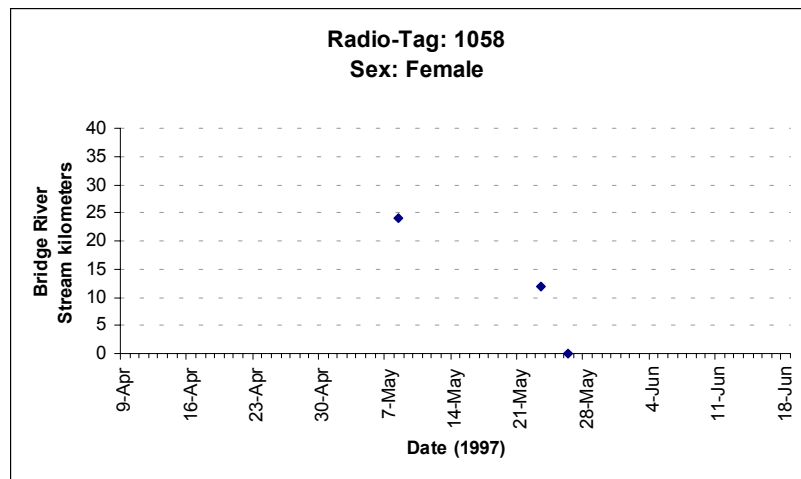
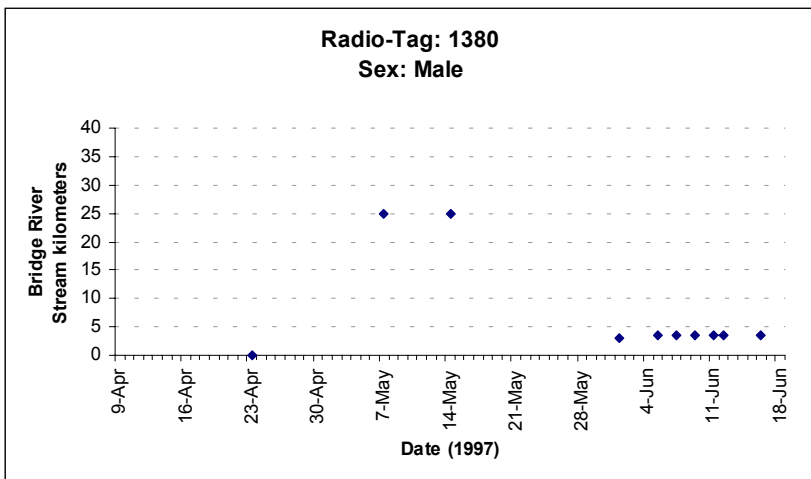
Appendix V. Movement graphs of 1997 Bridge and Seton River radio-tagged steelhead



Appendix V. Movement graphs of 1997 Bridge and Seton River radio-tagged steelhead

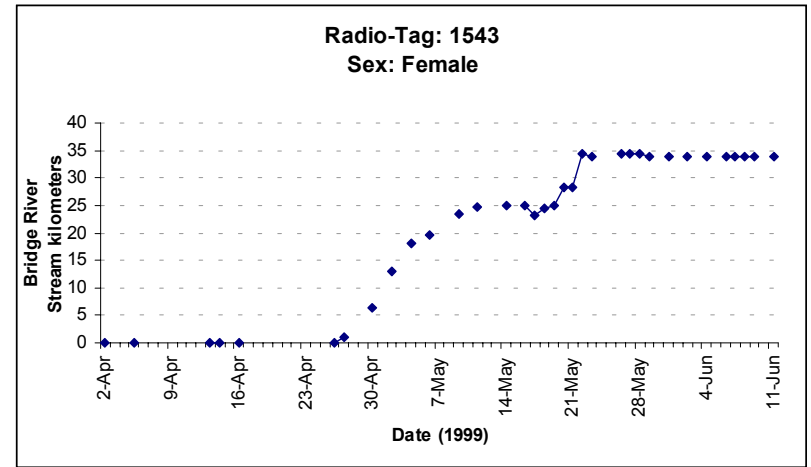
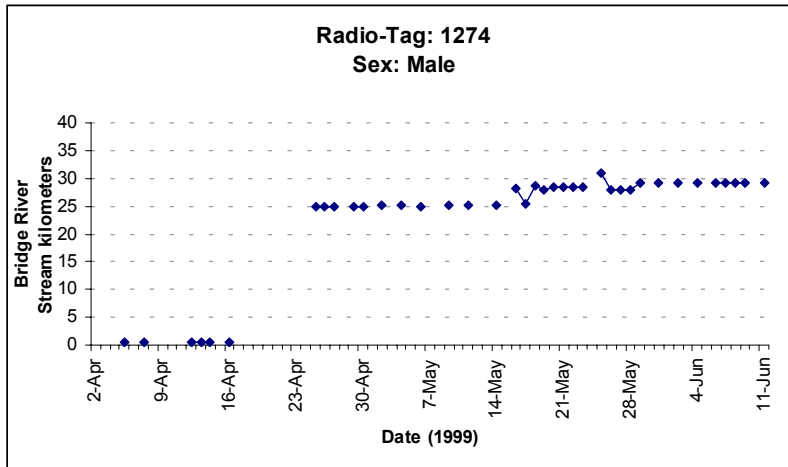
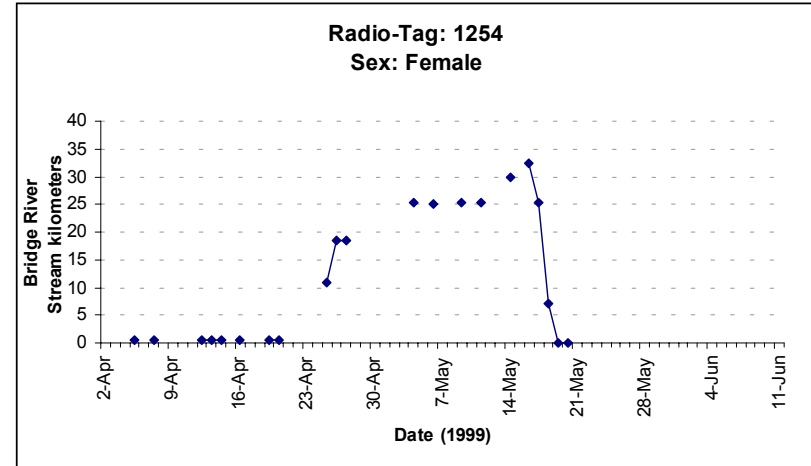
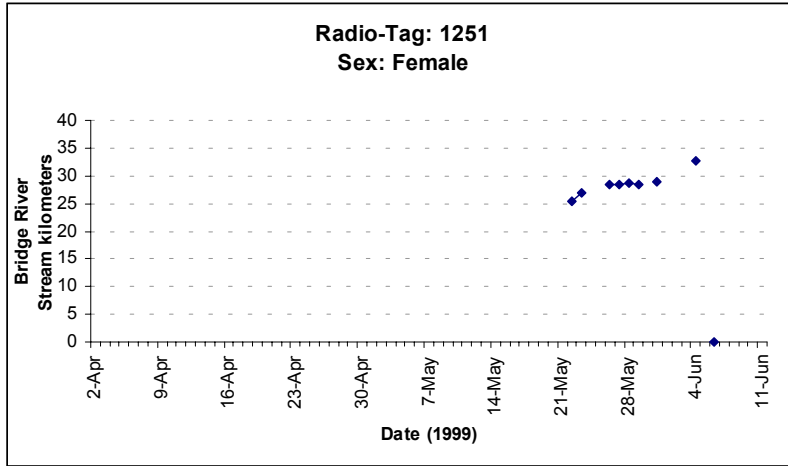


Appendix V. Movement graphs of 1997 Bridge and Seton River radio-tagged steelhead

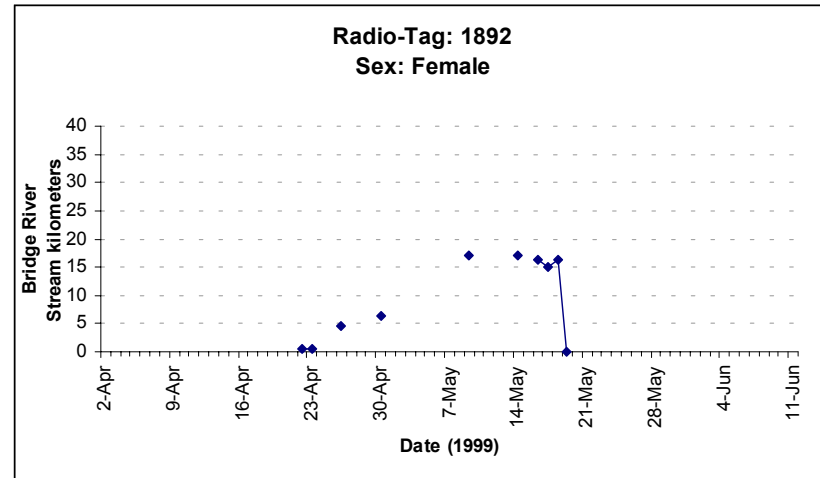
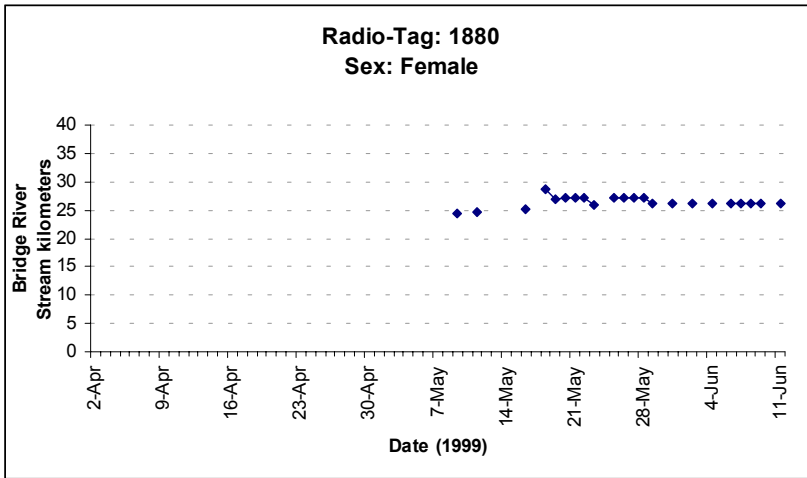
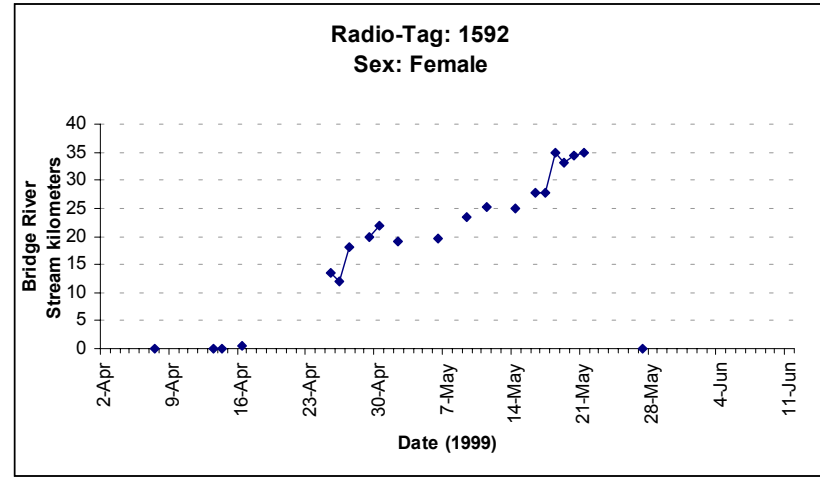
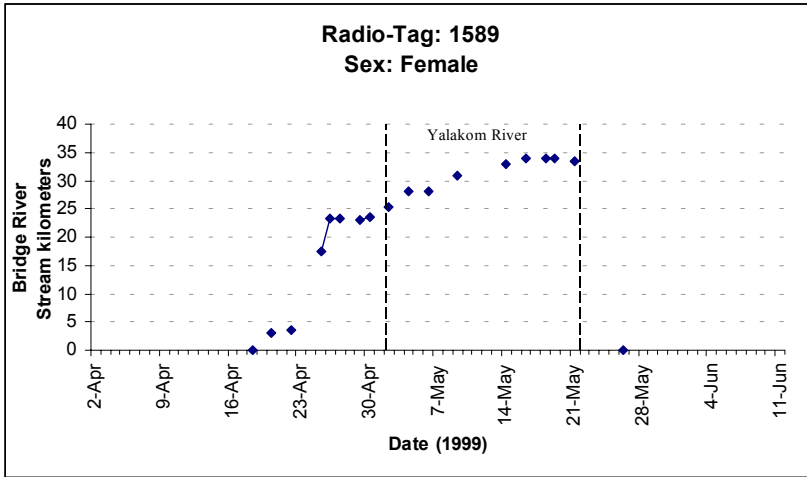


The upstream kilometers for steelhead 719 and 1331 are from the mouth of the Seton River. The upstream kilometers for all other steelhead are from the mouth of the Bridge River. Steelhead 1058 appears to have reacted badly to tagging.

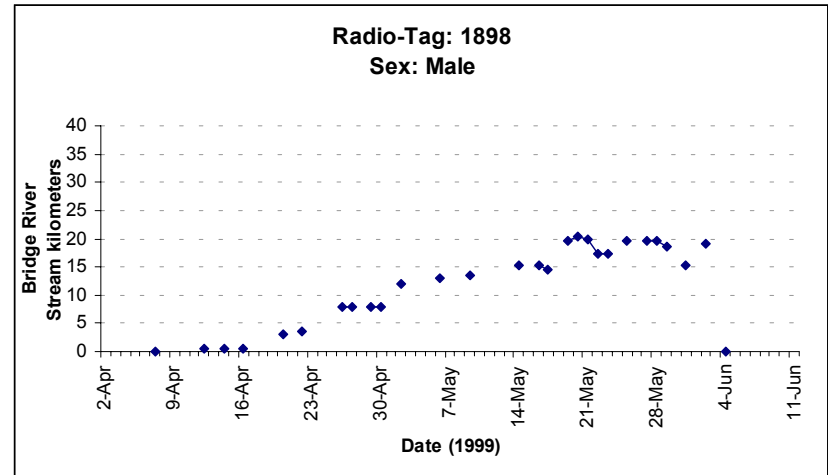
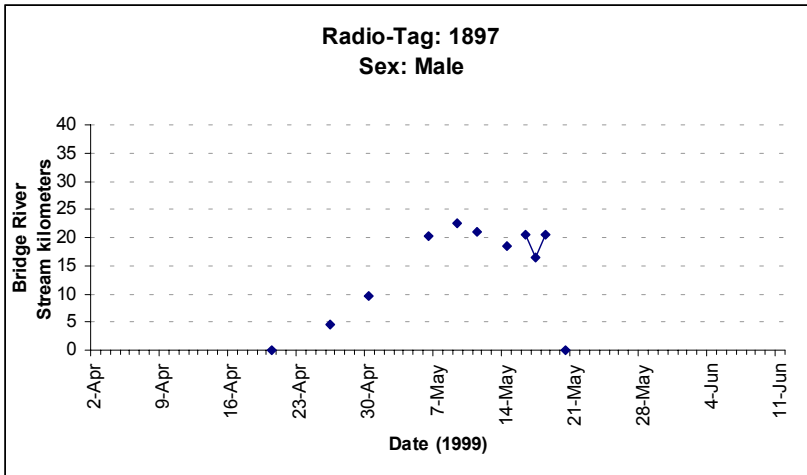
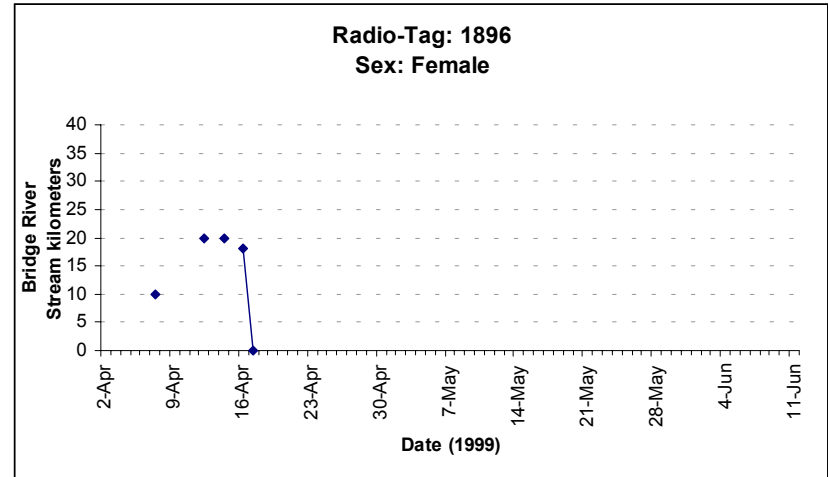
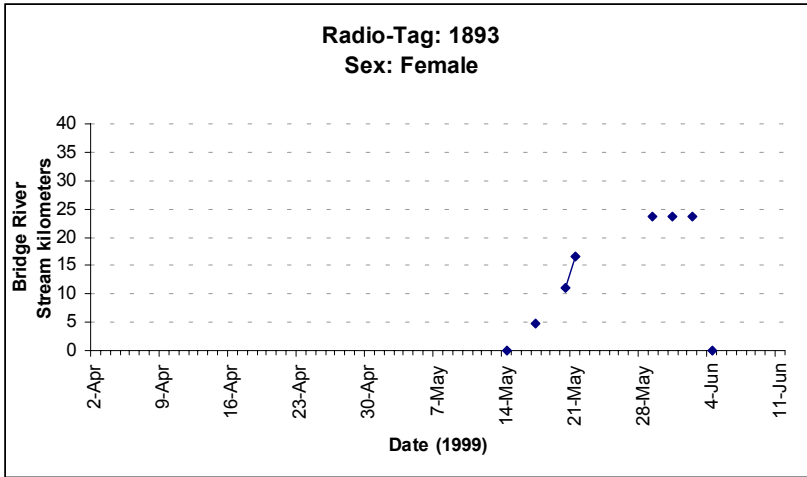
Appendix VI. Movement graphs of 1999 Bridge and Seton River radio-tagged steelhead



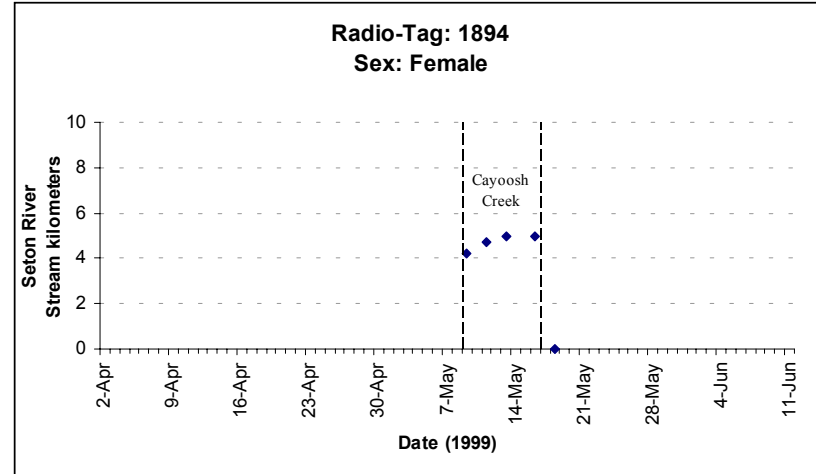
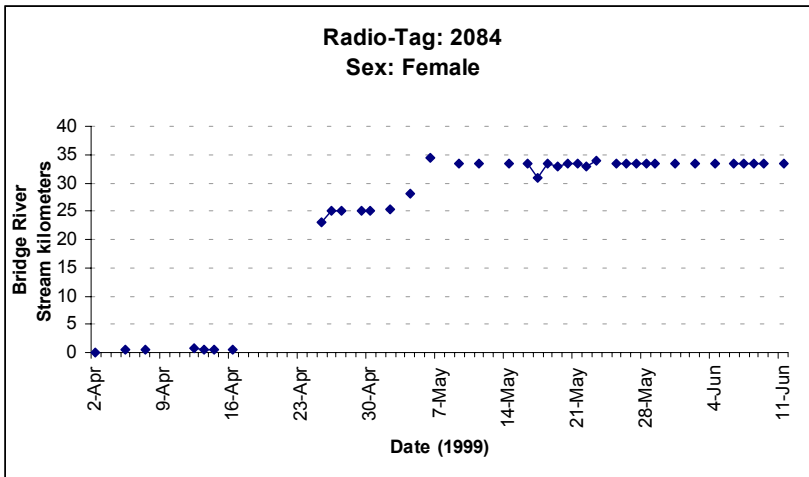
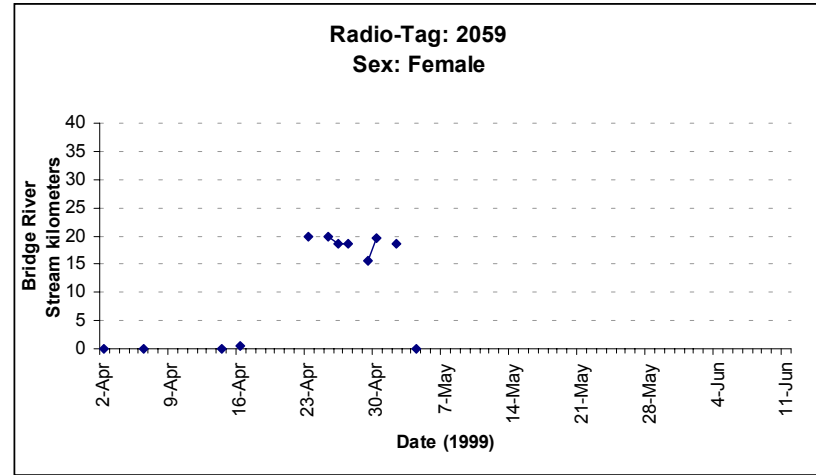
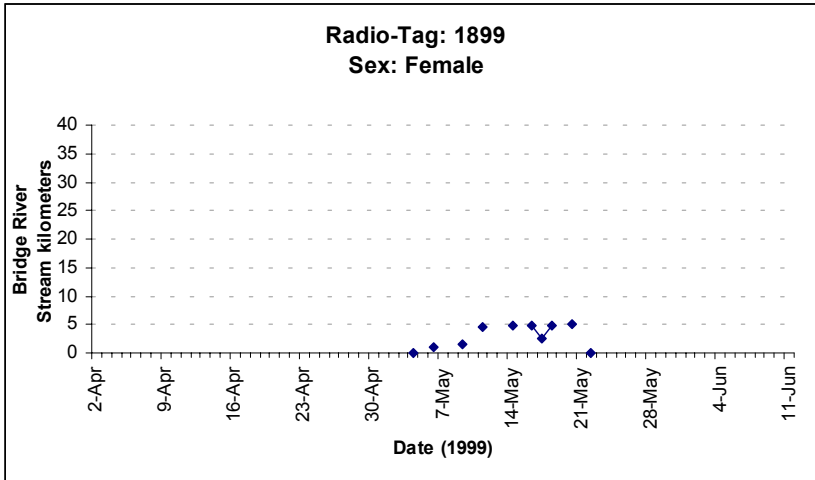
Appendix VI. Movement graphs of 1999 Bridge and Seton River radio-tagged steelhead



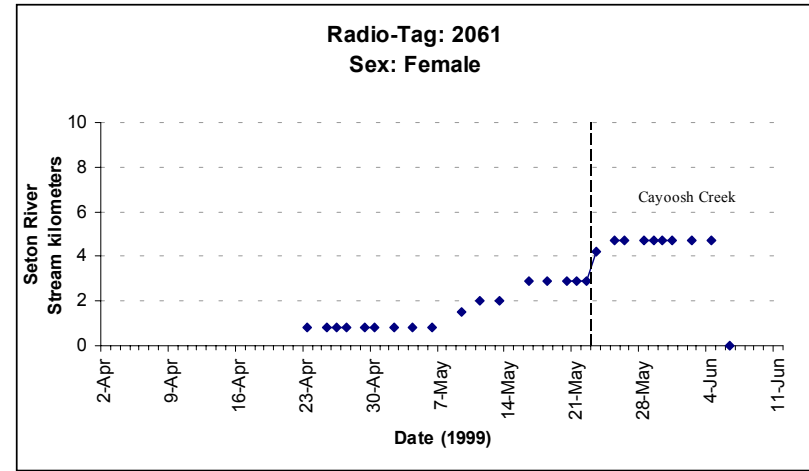
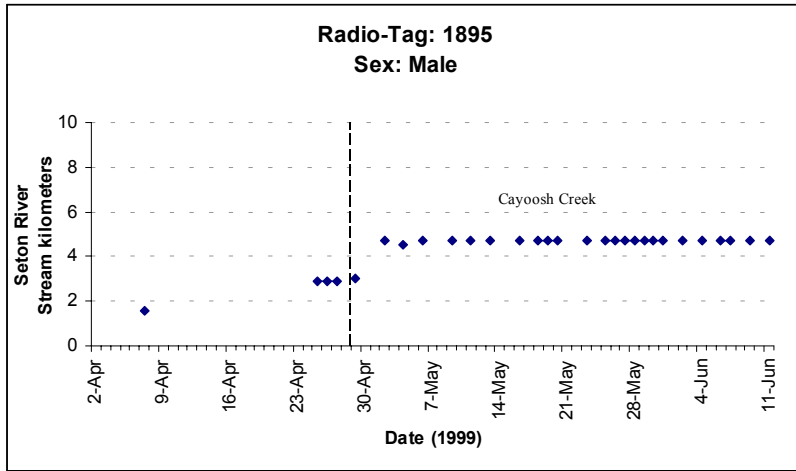
Appendix VI. Movement graphs of 1999 Bridge and Seton River radio-tagged steelhead



Appendix VI. Movement graphs of 1999 Bridge and Seton River radio-tagged steelhead



Appendix VI. Movement graphs of 1999 Bridge and Seton River radio-tagged steelhead



The upstream kilometers for steelhead 1894, 1895, and 2061 are from the mouth of the Seton River. The upstream kilometers for all other steelhead are from the mouth of the Bridge River.

Appendix VII. Escapment Estimation Data

Appendix VII(i). Periodic count data.

Date	Day	Number of spawners observed
27-Apr-99	44	18
7-May-99	54	31
14-May-99	61	32
18-May-99	65	14
21-May-99	68	15

Appendix VII(ii). Survey life data.

n	Days
1	12
2	12
3	6
4	8
5	10

Appendix VII(iii). Observer efficiency data (v).

Radio tags present	Radio tags observed	v
2	2	1
5	2	0.4
2	0	0
3	1	0.333333333