Migration characteristics and stock composition of interior Fraser steelhead as determined by radio telemetry, 1996-1999

By: J.R. Renn[1], R.G. Bison[2], J. Hagen[3] and T.C. Nelson[4]

For:

BC Ministry of Water, Land and Air Protection
Fisheries Branch
Southern Interior Region
1259 Dalhousie Drive
Kamloops, BC
V2C 5Z5

September 7, 2001

[1] J. Renn. 328 Peridot St., Logan Lake, BC, V0K 1W0, ph: (250) 523-9668,
e-mail: jrenn@telus.net

[2] R. Bison. BC Ministry of Water, Land and Air Protection, Fisheries Branch, 1259 Dalhousie Drive, Kamloops, BC V2C 5Z5, ph: (250) 371-6244, e-mail: ROBERT.BISON@GEMS4.GOV.BC.CA

[3] J. Hagen. 110 Union St., Nelson BC, V1L 4A2, ph: (250) 352-1752,
e-mail: kootenay_john@hotmail.com

[4] T. Nelson. LGL Limited environmental research associates, 9768 Second Street, Sidney, BC V8L 3Y8, ph: (604) 535-1768, e-mail: tnelson@lgl.com

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

ABSTRACT

A telemetry program was conducted on interior Fraser River steelhead from the early fall of 1996 to the early summer of 1999. The main focus of this study was to deploy radio tags in the fall of each year as far downstream in the mainstem Fraser as possible (and in the ocean in 1996) to study migration behaviour, overwintering behaviour, stock composition and the effectiveness of the various gear types used to deploy radio tags. Radio tags were also deployed in the spring of 1997, 1998 and 1999 to augment the number of fall radio-tagged steelhead for directed studies in spawning tributaries and to study the stock composition of various overwintering areas. Over the 1996/97, 1997/98 and 1998/99 seasons, 207, 54, and 198 radio tags were deployed, respectively. Ocean salmon seiners, commercial gillnetters, experimental selective fishers, in-river gillnetters, and recreational anglers worked with agency staff to catch steelhead for radio tagging. Experimental selective fisheries included a tangle net, an in-river beach seine, and fishwheels.

The Annacis Island tangle net fishery was somewhat inconsistent at capturing and deploying radio tags in steelhead and appeared to have a high latent mortality rate. Some of the mortality associated with the tangle net may be attributed to inconsistent handling of steelhead and its location within the estuary of the Fraser River. The Derby Reach beach seine also had inconsistent results and captured only 8 steelhead throughout its 3 seasons of operation. Overall, the beach seine failed to provide an adequate sample size for analysis. In 1998, the Yale fishwheel deployed nearly as many fall radio tags as lower Fraser River anglers. Because of its upstream location within the watershed, the fishwheel was used mainly to augment radio tag deployment by the lower Fraser fisheries. The fishwheel appears to be very effective at capturing interior Fraser steelhead throughout their run timing and captured the majority of early migrating Chilcotin steelhead. The Yale fishwheel however also had a relatively high mortality rate but this may be improved upon with refinements to its operation.

Using data from capture dates, the Albion chum test fishery, telemetry and microsatellite DNA analysis, it was determined that interior Fraser steelhead enter the Fraser River beginning in mid-September with two main pulses of immigration: the initial pulse occurs in the first week of October and the second pulse occurs in the third week of October. Immigration into the Fraser is complete by late-November. Although all steelhead stocks are represented in both pulses, Chilcotin steelhead comprise a higher proportion of the early pulse whereas Thompson and west Fraser stocks comprise the majority of the later pulse. Migration rates in various sections of the Fraser River between Barnston Island and Lytton varied from a high of 17.73 km/day to a low of 3.75 km/day. Migration rates in 1996 were generally lower than in 1998, likely due to the early onset of cold weather in the fall of 1996. Migration rates appear to be independent of water temperature when mean daily water temperatures exceed 7^0C. Below 7^0C however, migration rates appear to decrease with decreasing water temperatures. Chilcotin steelhead migrate at a higher rate than other interior Fraser steelhead stocks, which further accentuates the difference in their run timing further upstream. The mean run timing date at Hope was on October 26th and October 27th in 1996 and 1998,

respectively. These dates should be representative of the run timing of interior Fraser stocks excluding the earlier timed and faster migrating Chilcotin stock, because of non-representative sampling in the lower Fraser. Although the sample size was small, the peak migration period for Chilcotin steelhead past Lytton appears to occur in mid-October whereas Thompson steelhead arrive in Lytton and immigrate into the Thompson River in early-November. Chilcotin steelhead that overwinter in the Chilcotin River typically enter the river in late-October.

Overwintering distributions in 1996/97 and 1998/99 contrasted significantly. In 1996/97, the highest proportion (56%) of the 64 radio tags detected during the overwintering period were located in the Fraser River downstream of the Nahatlatch/Fraser confluence with 48% being located downstream of Hells Gate. Two large congregations were located immediately downstream of Hells Gate and Saddle Rock; two well-known fish migration hurdles. Only 1.5% of radio-tagged steelhead reached the Chilcotin, 3% overwintered upstream of the Bridge rapids, 9% overwintered in the Fraser between the Nahatlatch confluence and Bridge rapids and 30% overwintered in the Thompson. In 1998/99, migration conditions were favourable up to early-December and radio-tagged steelhead were distributed higher in the watershed; generally congregated near their spawning stream. Only 10% of the 80 radio-tagged steelhead were detected downstream of Hells Gate during the overwintering period. This is in contrast to the 56% and 66% detected downstream of the Nahatlatch confluence in 1996/97 and 1997/98, respectively. The Thompson River contained the highest proportion of overwintering radio-tagged steelhead (48%) while 22% were located in the Fraser between the Nahatlatch confluence and Bridge rapids, 5% were located upstream of the Bridge rapids and 13% were located in the Chilcotin River.

Overwintering mortalities appeared highest in steelhead overwintering in the Fraser Canyon and this may be attributed to harsh environmental conditions, a higher than expected regurgitation/expulsion rate, radio tag induced mortalities and/or a higher than reported harvest in aboriginal fisheries. Overall, overwintering mortalities appeared higher in the Fraser mainstem and lower in the Thompson and Chilcotin Rivers. This may be attributed to the fact that steelhead that overwintered in the mainstem Fraser were further from their natal streams than steelhead that overwintered in the Thompson and Chilcotin Rivers. Steelhead that were radio-tagged close to their natal stream, after having resumed their upstream migration had the lowest mortality rates. Steelhead that were radio-tagged in late-winter in known overwintering areas appeared to suffer a mortality rate similar to fall radio-tagged steelhead that overwintered in the Fraser mainstem.

Through spring radio tagging it was determined that the steelhead overwintering at the Seton/Fraser confluence were composed mainly of Bridge steelhead with a small proportion of Seton and Chilcotin steelhead. The Thompson/Fraser confluence at Lytton was found in 1997 to contain a diverse mixture of overwintering stocks including, Thompson, Nahatlatch, Stein and Bridge steelhead. In 1999 the Thompson/Fraser confluence contained only Stein River steelhead.

Interior Fraser steelhead commenced their upstream migrations in early March and entered their natal streams between the second and third weeks of April. Immigration into natal streams was remarkably consistent throughout the interior Fraser steelhead's range. Only 42% (36 out of 86) of the steelhead radio-tagged in the lower Fraser in the fall of 1996 were detected during the spawning period: 19% (7) were detected in the Fraser upstream of the Nahatlatch, 14% (5) in the mainstem Thompson, 50% (18) in Nicola, 3% (1) in Bonaparte, 6% (2) in Bridge and 8% (3) in Chilcotin. None of the steelhead radio-tagged in the ocean in the fall of 1996 were ever detected in freshwater. Only 14% (2 out of 14) of the steelhead radio-tagged in the fall of 1997 were detected during the spawning period: 50% (1) was detected in the Fraser upstream of the Nahatlatch and 50% (1) in the Chilcotin. Almost 65% (68 out of 105) of the steelhead radio-tagged in the lower Fraser in the fall of 1998 were detected during the spawning period: 7% (5) were detected in the Fraser upstream of the Nahatlatch, 3% (2) in Nahatlatch, 3% (2) in Stein, 1.5% (1) in Seton, 12% (8) in Bridge, 19% (13) in Chilcotin, 9% (6) in Thompson, 29% (20) in Nicola, 6% (4) in Bonaparte, and 10% (7) in Deadman.

Mark/re-capture estimates of spawning stock abundance in 1999 using radio tags deployed in the fall of 1998 tended to be higher than corresponding escapement estimates or enumerations using conventional methods in terminal spawning streams. Positive biases in the mark/re-capture estimates were expected given the nature of mark/re-capture assumption violations. The mark/re-capture method underestimated the Chilcotin steelhead escapement estimate but closely approximated Thompson stock estimates. This was likely caused by the tendency of lower Fraser anglers to deploy marks (radio tags) in Thompson steelhead at a higher rate than Chilcotin steelhead.

Fall radio-tagged steelhead had a kelting rate of 38% in 1997 and 48% in 1999. Spring radio-tagged steelhead had a slightly higher kelting rate: 46% in 1997 and 51% in 1999. Chilcotin steelhead, radio-tagged in the fall of 1998, had a significantly lower kelting rate than Thompson steelhead radio-tagged in the same season. Interior Fraser steelhead migrated downstream at an average rate of 44.3 km/day in 1997 and 30.9 km/day in 1999. The mean exodus date for steelhead at Hope occurred on June 7th in 1997 and on June 2nd in 1999.

INTRODUCTION

Background

Steelhead (*Oncorhynchus mykiss*) are a top management priority for the BC Ministry of Environment, Lands, and Parks (MELP). Steelhead that migrate in late-summer and fall to and through the Fraser River, BC, can be subjected to numerous commercial salmon fisheries and in-river native fisheries and sport fisheries. Current population sizes are thought to be relatively small relative to historical levels. 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. This information, however, has not been available to managers. Assessing the potential for interception on a stock-by-stock basis is obviously aided by run-timing information and exploitation rates for each stock, but prior to 1996 only indirect information was available about the movement and interception of individual fall run steelhead populations into and within the Fraser River (Bison and Renn 1997). Compounding management difficulties is the fact that the dynamics of individual steelhead populations are difficult to monitor, primarily because of the time of year that adults enter natal streams. Steelhead spawn in the spring, and in the snowmelt-driven tributaries of the interior Fraser watershed this coincides with a period of relatively high water and reduced visibility. Population estimates have been based on fence counts where possible or visual counts in less turbid reaches (MELP data on file), but MELP staff have not known the reliability of these estimates.

To address inadequacies in the information available to fisheries managers, MELP in 1996 initiated a multi-year program of radio telemetry-based research into steelhead movement, habitat use, and stock assessment methods for all known stocks utilizing streams in Statistical Regions 3 and 5 (Figure 1). The work, which is ongoing, has been funded primarily by a grant from the Habitat Conservation Trust Fund and the Government of British Columbia, Common Land Information Base Fund, and was initiated with the stated goals of investigating the following:

1. migration patterns and timing within approach waters to the Fraser River and within the Fraser River itself of late summer/fall return steelhead on a stock-specific basis.
2. stock composition of the late summer/fall component of the Fraser River steelhead run (the majority of which are thought to be up-river stocks with natal streams in Regions 3 and 5).
3. timing of and critical habitats for migration and spawning within natal streams, for protection of these habitats and activities as well as for stock assessment purposes.
4. survival rates and fates of steelhead on their spawning migrations, particularly with respect to capture methods.
5. population status where possible for individual stocks.

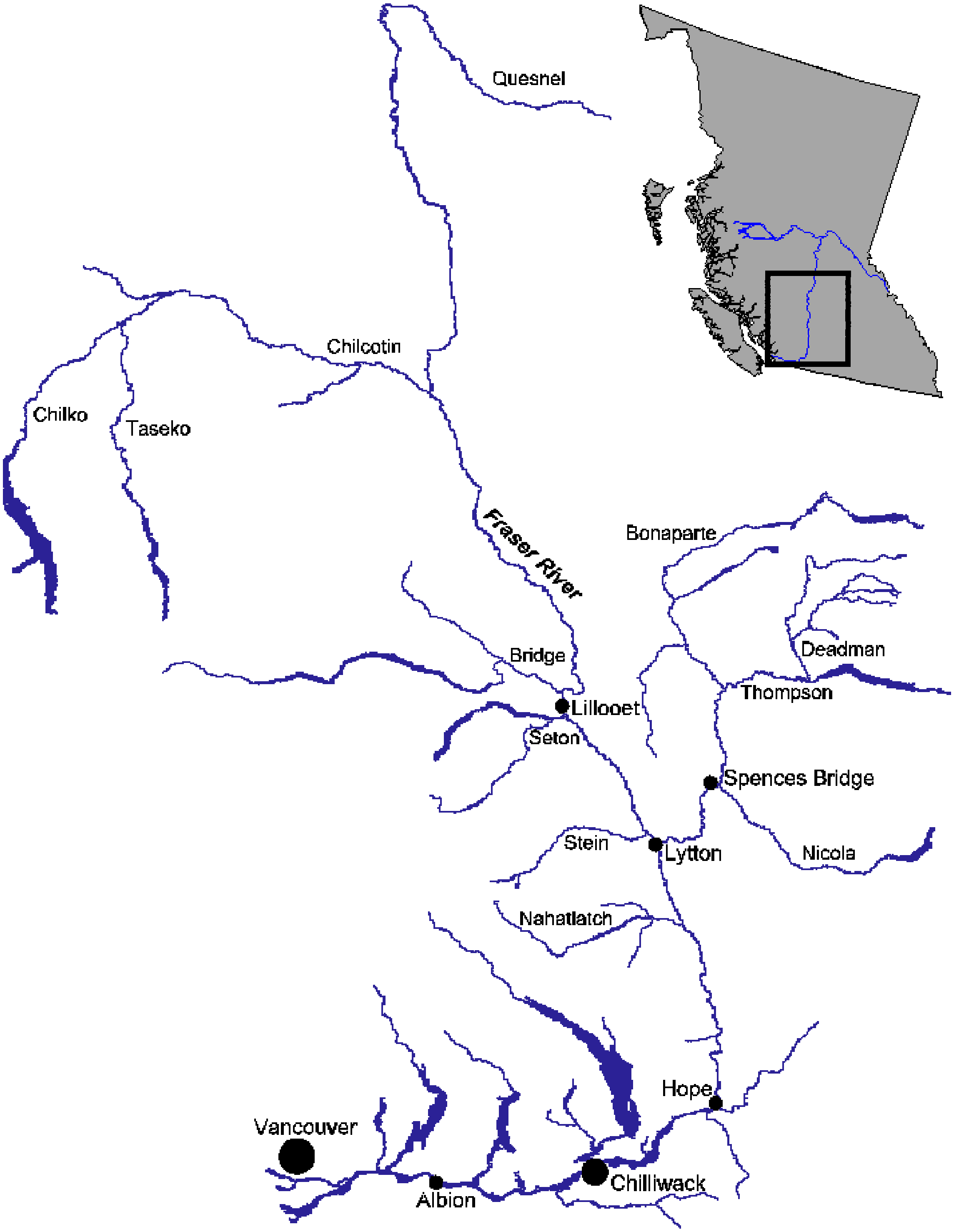

Figure 1. The study area of the interior Fraser steelhead biotelemetry program in relation to the province of British Columbia.

In 1995-96, BC Ministry of Environment received funding to conduct further studies into the migration characteristics of interior Fraser River steelhead through areas where commercial and aboriginal fisheries are known to intercept these steelhead. Staff of the Fisheries Branch, Ministry of Environment and Lands composed a study to address the migration characteristics of Fraser River steelhead using applied biotelemetry techniques. In August 1996, LGL Limited, Sidney BC, was awarded a contract to locate, install, test, and maintain several fixed-station telemetry receiver sites at strategic locations on the mainstem Fraser River, and to secure, manage, and analyze telemetry data collected during the study (Nelson *et al.* 1998). This work, which focused on the 1996 fall run of interior Fraser steelhead, expanded in the winter and early spring of 1997 to include the installation of receiver sites in the Thompson River and Chilcotin River watersheds. Based on the successes of the initial program, interior Fraser steelhead telemetry program was supported and continued in 1997, 1998, and 1999.

This report provides an overview of the telemetry program and specifically treats steelhead movement and stock composition within the Fraser River mainstem as they relate to fisheries management issues. Steelhead movements within specific natal streams (spawning tributaries) are treated in other reports for MELP (Webb *et al*. 2000a; Webb *et al*. 2000b; Hagen 2000; Hagen 2001a; Hagen 2001b; McCubbing *et al*. 2000).

Study Area

The Fraser River watershed drains about one-quarter of British Columbia and is the largest watershed in the province. The river's mainstem originates in the Rocky Mountains near the Alberta border and flows northwest for approximately 350 km before turning south near the city of Prince George. At this point the mainstem flows in a southerly direction approximately 650 km to the town of Hope, where the river turns to flow in a west/southwest direction for approximately 150 km to marine waters in the Strait of Georgia near Vancouver. The annual average discharge of the Fraser River at Hope is about 2,800 m^3/s, but flows can be as high as 15,000 m^3/s during spring freshet and as low as 400 m^3/s in winter (BC Ministry of Environment 1992).

The Fraser River supports substantial populations of chinook (*Oncorhynchus tshawytscha*), sockeye (*O. nerka*), coho (*O. kisutch*), chum (*O. keta*), and pink salmon (*O. gorbuscha*), and steelhead (*O. mykiss*). Steelhead spawn in several tributaries in both the lower Fraser River (downstream of the Fraser Canyon), and the middle Fraser River (from Hope upstream to the Chilcotin River watershed). Few steelhead are believed to spawn in the Fraser River or its tributaries upstream of the Chilcotin River confluence, although there have been reports of possible observations of steelhead in the Quesnel and Blackwater rivers (M. Lirette, MELP Williams Lake, pers. comm.).

Existing Information on the Life History of Interior Fraser Steelhead

Interior Fraser River steelhead are thought to have originated from the central Columbia River basin, east of the Cascade Mountains, and were considered by Behnke (1992) to be redband rainbow trout. This makes them unique in that they are the only anadromous population of redband trout in BC. Behnke (1992) also suggested that all other Fraser River steelhead stocks downstream of Hell's Gate were of coastal origin. Parkinson (1984) used electrophoresis to examine the relative quantities of three different enzymes (SOD, LDH, and AGP) in summer-, fall-, and winter-run steelhead stocks throughout the province. His findings showed considerable difference in the relative quantities of SOD, LDH, and AGP between interior Fraser River stocks and coastal summer-run stocks; this supported the idea that interior Fraser steelhead were unique in their evolutionary history. Parkinson's work, however, demonstrated that Nahatlatch River (upstream of Hell's Gate) steelhead have enzyme concentrations more similar to coastal summer-run stocks (high SOD and low LDH). This suggested that the boundary for redband and coastal steelhead may be further upstream than previously thought and even though it is possible Nahatlatch River steelhead are fall-run, they may be of coastal origin. Parkinson's work also demonstrated the uniqueness of Chilcotin River steelhead. They have high concentrations of LDH and low concentrations of SOD, similar to other interior Fraser River stocks, combined with levels of AGP not found in any other summer-, fall-, or winter-run steelhead population.

In the north Pacific Ocean, interior Fraser steelhead are distributed in a line that parallels the Alaskan coast and extends in a south easterly direction following the Aleutian Islands. This area extends west to 170 ^{0} east longitude, south to approximately 40^0 north latitude and up to 58 ^{0} north latitude in the gulf of Alaska. In the ocean, steelhead occupy areas with surface temperatures ranging from 5 ^{0}C to 14.9 ^{0}C and tend to move north throughout the summer and south throughout the winter in order to remain within this temperature range (Burgner *et al*. 1992). During the time period when maturing steelhead would begin there easterly migration toward the BC coast, steelhead are located between 48^0 north latitude (even with the southern tip of Vancouver Island) and 56^0 north latitude (Gulf of Alaska). The majority of interior Fraser steelhead begin their first migration back to fresh water in the third year of ocean life, entering Juan de Fuca and Johnstone Straits during August, September, and early October (Andrews and Mcsheffrey 1976; Parkinson 1984; R. Bison, MELP Kamloops, pers. comm.). Little is known about the variability of route choice for interior Fraser steelhead, or how this might affect entry timing into the lower Fraser River or exploitation rates in fisheries targeting salmon. It should be noted that Hamilton (1985) demonstrated that the proportion of the Fraser River sockeye salmon run using the Johnstone Strait relative to the proportion using the southern route around Vancouver Island appears to be related to ocean temperatures in the North Pacific. During periods of cold ocean temperatures, Sockeye appear to approach the BC coast at a more northerly latitude, resulting in a higher diversion rate into Johnstone Strait. Similarly, on years with warmer ocean temperatures, diversion rates into the Strait of Juan de Fuca tend to be higher.

Interior Fraser River fall-run steelhead typically enter the lower Fraser River in September, October, and early-November. The Albion Chum Test Fishery CPUE data suggests that there are two main pulses of steelhead that enter the lower Fraser (Bison and Renn 1997). The first and largest peak occurs in the first weak of October, with a smaller secondary peak occurring in the last week of October. Regression analysis of CPUE data against steelhead escapements in the following year suggested that Chilcotin and Nicola River steelhead comprise the bulk of the first peak, with Deadman River steelhead being most represented in the second peak. Anecdotal angling information reported by McGregor (1986) suggests that steelhead begin to show up in the sport fishery near Spences Bridge around the first week of November and a second group seems to show up in the first week of December. This information is also supported by increased catches during these periods even though angler effort remains relatively constant (Antifeau 1976).

Interior Fraser steelhead cease upstream migrations as stream flows and temperatures reach a minimum (December/January) and are known to overwinter throughout the Fraser River mainstem, in the Thompson River below Kamloops Lake and the Chilcotin River (McGregor 1986). Some of these overwintering areas have become well known to sport anglers and, in some cases native fisheries. Baxter and Roome (In prep.) reported on a biotelemetry study in which steelhead tagged during the winter and early spring just downstream of the Seton/Fraser confluence subsequently spawned in the Bridge and Chilcotin Rivers. This demonstrates that interior Fraser steelhead may overwinter a considerable distance from their natal streams. McGregor (1986) pointed out that the proportion of steelhead that overwinter in the Fraser River downstream of the Thompson River confluence was unknown.

Previous studies have shown that, as spring freshet begins (late March and early April), interior Fraser steelhead resume migration and generally enter their natal stream around mid-April to early May (McGregor 1986; Bison 1991; Maricle and McGregor 1993). Spawning usually has begun around the last week in April, peaks around mid-May, and is completed by the first week in June (McGregor 1986). Steelhead have been reported to spend an average of 4-5 days on redds in the Deadman and Bonaparte rivers (McGregor 1986; Bison 1991; Olmstead and Moore 1985). Spence (1980) reported an average redd residency time of 9.7 days for Chilcotin River steelhead, but maintained that this estimate may have been high due to methodology.

Interior Fraser River steelhead are one of the largest and most fecund races of steelhead in the Pacific Northwest (McGregor 1986). Thompson River females that averaged 865 mm in length produced an average of 12,614 eggs per individual; significantly more than any other race of steelhead sampled to date (McGregor 1986). A population of upper Thompson River (Bonaparte) females spawning in 1995, averaged 800 mm in length and 5.2 kg in weight (*n=314*), whereas males averaged 858 mm in length and 5.2 kg in weight (*n=139*; Renn 1995). Nicola River stocks showed an average length of 848 mm for females and 894 mm for males (Ministry of Environment, Kamloops, unpublished data 1997). This is consistent with a common perception among sport fishermen that Nicola River steelhead tend to be larger and more slab sided, whereas upper Thompson River stocks are shorter and more round in appearance. Nahatlatch and Stein River steelhead are also large. Females from the Nahatlatch River averaged 829 mm in length (*SE=11.5 mm, n=22*), males 930 mm (*SE=12.3 mm, n=12*), while Stein River females averaged 828 mm (*SE=8.7 mm, n=21*) and the males 895 mm (*SE=15.1 mm, n=7*) in length (Hagen 2000). West Fraser stocks further to the north, including those from the Bridge and Chilcotin Rivers tend to be slightly smaller. For example, Bridge River steelhead have averaged 726 mm (*SE = 18.0 mm, n = 14*) in length for females and 833 mm for males (*SE = 28.9 mm, n=10*) (Hagen 2001a). Chilcotin River steelhead have averaged 779 mm (*n = 19*) and 851 mm (*n = 16*) for females and males, respectively (Spence 1981).

Once spawning is complete, surviving interior Fraser steelhead return to the ocean as kelts. Little is known regarding kelt emigration. McGregor (1986) reported great difficulty in tracking the outmigration of kelts using radio telemetry, because of the speed at which kelts traveled. Although the percentage of steelhead that exit as kelts has been unknown, the percentage of repeat spawners has been documented as 2.8% for the Thompson and 2.2% for the Chilcotin River (McGregor 1986; Spence 1978). This differs considerably from summer-run steelhead from the Kispiox and Dean Rivers, which have repeat spawning rates of 17.6% and 17.9%, respectively (Whately 1977; Hemus 1974).

Incubation of steelhead eggs takes from 4 to 6 weeks, depending on water temperature. Once hatched, fry generally prefer habitat with a primarily gravel bottom (1 to 10 cm in diameter) and a mean depth of 30 cm. At age 1+, habitat preference changes to a bottom substrate of large gravel/cobble (5 to 10 cm in diameter) and a mean depth of 53 cm (Pearlstone 1976). Due to the relatively high productivity of the Thompson River and its tributaries, the majority of smolting takes place at age 2+ and an average length of 172 mm (pooled 1976-77 data; McGregor 1986). For the Nahatlatch and Stein Rivers, Hebden (1981) found that the majority of smolts were age 3+, possibly due to the lower productivity of these systems. Although little is understood about smolt emigration specific to interior Fraser systems, the majority is believed to take place in spring and summer (McGregor 1986). Unlike other juvenile salmonids, steelhead (which tend to be a larger size at smolting) disperse directly offshore from their natal streams (Burgner *et al*. 1992). Steelhead also disperse more rapidly in a northwesterly direction than do other salmonids. By the end of their first year in the ocean, steelhead will be located as far west as 170^0 east latitude, whereas other salmonids will remain within a belt along the southeastern coast of Alaska, approximately 37 km wide (Burgner *et al*. 1992).

METHODS

Deployment

Handling Methods

Handling methods for steelhead in all fisheries were carried out in essentially the same way. All captured steelhead were first measured for length, girth, in some instances weight and sexed (using secondary sex characteristics). Scale samples were taken (approximately 10 from each side) just dorsal to the lateral line and mid way between the posterior end of the dorsal fin and the anterior end of the anal fin. A small sliver of tissue was also taken from the adipose fin for genetic sampling and preserved in a 95% ethanol solution. The overall condition of fish was assessed based on the presence of wounds, bleeding and general behavior. They were then categorized as vigorous, fair or DOA. Steelhead considered to be in fair condition were measured, sampled, floy-tagged in the base of the dorsal fin and released. Floy tags were florescent orange in colour and contained an identification number and a toll free telephone number to contact fisheries personnel. Steelhead considered to be vigorous were both floy-tagged and radio-tagged with a LOTEK model MCFT-3A or 3B, 3-volt digitally encoded tag (Table 1; Plate 1).

Plate 1. Radio tag insertion into an anesthetized steelhead.

Table 1. Technical specifications and locations of radio tags deployed in interior Fraser steelhead from 1996 to 1999.

Deployment		Radio Tag					
Timing	Location	Model	Frequency (MHz)	Life (days)	Dimensions (mm)	Weight (g)	Code Set
Fall 1996	Area 21- Nitinat - Gill Net	3B - Gastric	149.340	238	14.5 X 43.0	10.5	1993
Fall 1996	Area 21- Nitinat - Gill Net	3B - Gastric	149.380	238	14.5 X 43.0	10.5	1993
Fall 1996	Area 12/13 - Johnstone Strait - Seine	3B - Gastric	149.440	238	14.5 X 43.0	10.5	1993
Fall 1996	Area 21- Nitinat - Seine	Oviduct	149.460	238	14.5 X 43.0	10.5	1993
Fall 1996	Area 12/13 - Johnstone Strait - Seine	Oviduct	149.460	238	14.5 X 43.0	10.5	1993
Fall 1996	Area 12/13 - Johnstone Strait - Seine	Oviduct	149.560	238	14.5 X 43.0	10.5	1993
Fall 1996	Lower Fraser - Chilliwack to Hope	Oviduct	149.460	238	14.5 X 43.0	10.5	1993
Fall 1996	Lower Fraser - Annacis Is. to Yale	3B - Gastric	149.380	238	14.5 X 43.0	10.5	1993
Fall 1996	Lower Fraser - Annacis Is. to Hope	3B - Gastric	149.440	238	14.5 X 43.0	10.5	1993
Fall 1996	Lower Fraser - Annacis Is. to Hope	3B - Gastric	149.460	238	14.5 X 43.0	10.5	1993
Fall 1996	Lower Fraser - Annacis Is. to Hope	3B - Gastric	149.560	238	14.5 X 43.0	10.5	1993
Spring 1997	Stein, Lytton, Lillooet, Hope, Nahatlatch	3B - Gastric	149.340	238	14.5 X 43.0	10.5	1993
Spring 1997	Lytton, Lillooet, Hope, Nahatlatch	3B - Gastric	149.380	238	14.5 X 43.0	10.5	1993
Spring 1997	Stein, Lytton, Lillooet, Nahatlatch	3B - Gastric	149.440	238	14.5 X 43.0	10.5	1993
Spring 1997	Stein, Lillooet, Nahatlatch	3B - Gastric	149.460	238	14.5 X 43.0	10.5	1993
Spring 1997	Stein, Bridge	3B - Gastric	149.500	238	14.5 X 43.0	10.5	1993
Spring 1997	Stein, Lytton, Lillooet	3B - Gastric	149.560	238	14.5 X 43.0	10.5	1993
Fall 1997	Lower Fraser - Annacis Is. to Hope	3A - Gastric	149.540	680	16.0 X 51.0	16.1	1994
Fall 1997	Lower Fraser - Annacis Is. to Hope	3A - Gastric	149.700	680	16.0 X 51.0	16.1	1994
Spring 1998	Chilcotin River System	3A - Gastric	149.540	680	16.0 X 51.0	16.1	1994
Spring 1998	Deadman/Thompson confluence	3A - Gastric	149.700	680	16.0 X 51.0	16.1	1994
Fall 1998	Lower Fraser - Annacis Is. to Yale	3A - Gastric	149.540	680	16.0 X 51.0	16.1	1994
Fall 1998	Lower Fraser - Annacis Is. to Yale	3A - Gastric	149.600	680	16.0 X 51.0	16.1	1994
Fall 1998	Lower Fraser - Annacis Is. to Yale	3A - Gastric	149.700	680	16.0 X 51.0	16.1	1994
Spring 1999	Lytton, Lillooet, Spences Bridge Deadman/Thompson confluence Chilcotin River System	3A - Gastric	149.660	680	16.0 X 51.0	16.1	1994
Spring 1999	Bridge River	3A - Gastric	149.540	680	16.0 X 51.0	16.1	1994
Spring 1999	Spences Bridge Deadman/Thompson confluence	3A - Gastric	149.700	680	16.0 X 51.0	16.1	1994

Eight milliliters of a 1:10 solution of clove oil to ethanol was added to 20 litres of water in a large volume tote to anesthetize steelhead for radio tagging (Anderson *et al*. 1997). Steelhead were placed in the anesthetic until swimming became erratic and equilibrium was lost. The fish was then removed from the anesthetic and either a gastric radio tag was inserted into the stomach or an oviduct tag was inserted into the ovipositor of female steelhead. Anesthetized fish were then allowed to recover in a soft-sided holding tube until vigorous. Steelhead captured in late winter and early spring via angling were radio-tagged without the use of anesthetic due to their lethargic nature in cold water (between 2^{o}C and 6^{o}C).

Marine Deployment – Fall 1996

Steelhead were captured in the ocean in Johnstone Strait (statistical area12), Juan de Fuca Strait (area 20), and Nitinat (area 21) during commercial chum salmon openings and test fisheries (Figure 2). Purse seines were used to capture steelhead in statistical areas 12, 20 and 21. Gill nets were only used to capture steelhead in area 21, during the Nitinat Chum Test Fishery (Anonymous 1997). Steelhead assessed as being in vigorous condition were bio-sampled, floy-tagged, fitted with a radio tag and released.

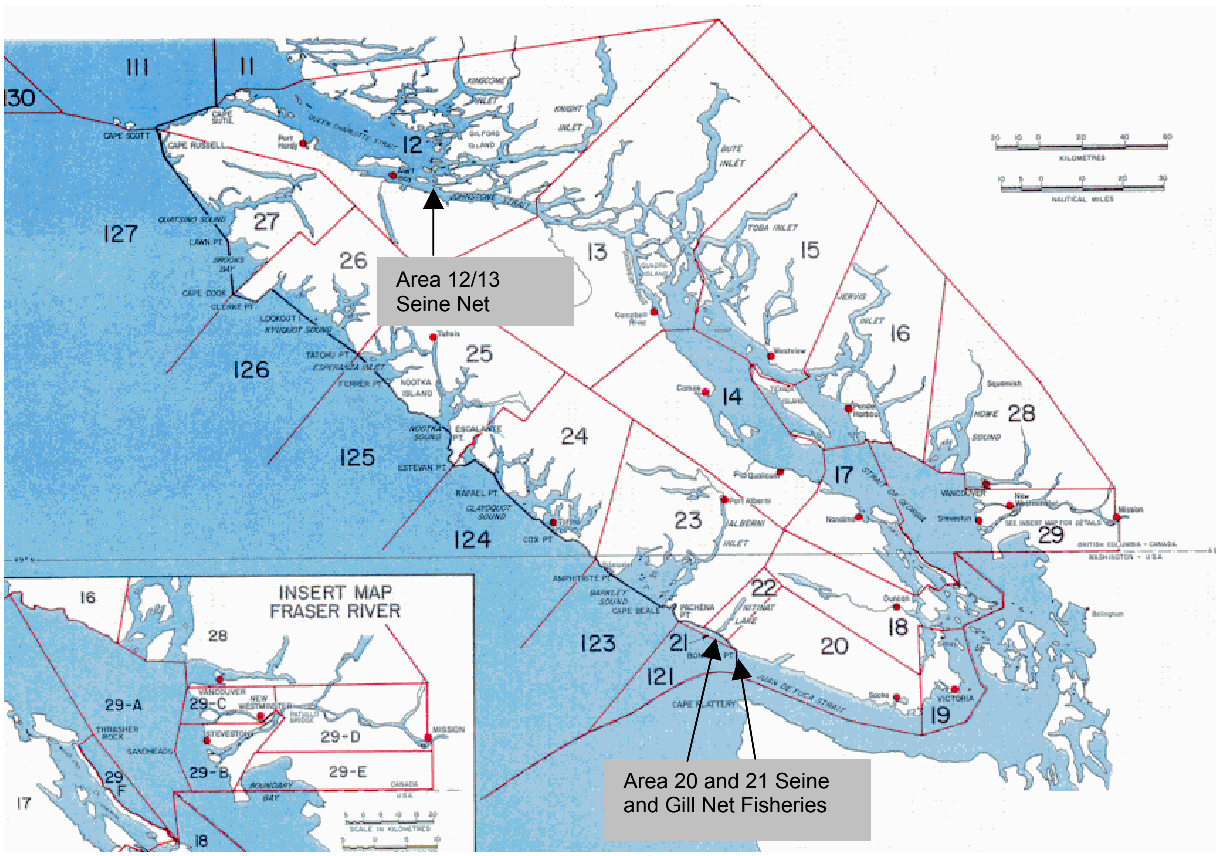

Figure 2. Statistical Areas and locations of marine radio tag deployment in September and October 1996.

Fraser River Deployment - Fall 1996 to 1998

In the fall of 1996 and 1997, the majority of steelhead were captured in the lower Fraser River for radio tagging using a tangle net, a beach seine and angling (applied effort and sport fishery; Figure 3). In 1996, a 24-h aboriginal gill net fishery near Yale was also used as a source of steelhead for radio tagging (J.O. Thomas 1997). In the fall of 1998 a fishwheel, located near Yale was used along with angling, a tangle net and a beach seine to capture and radio-tag steelhead. Captured steelhead that were assessed as being in vigorous condition were bio-sampled, floy-tagged, fitted with a radio tag and released.

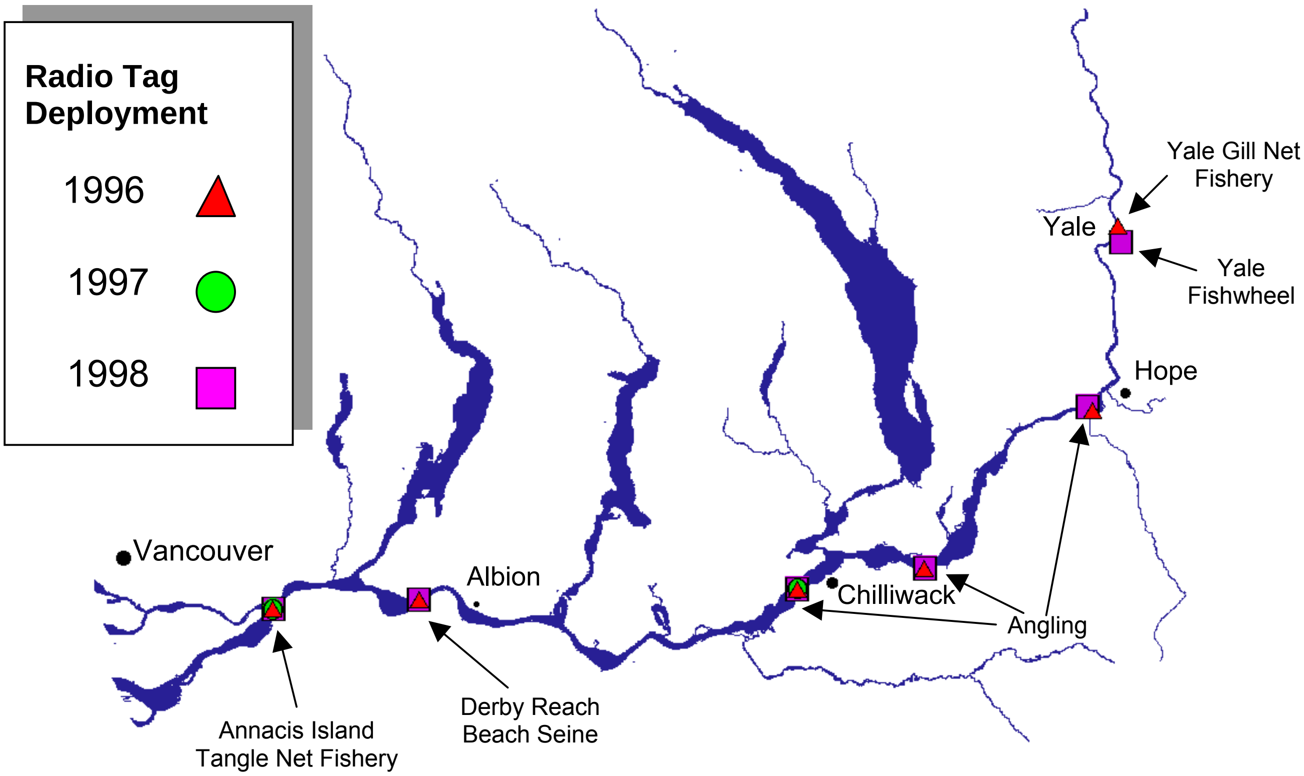

Figure 3. The locations of radio tag deployment in the lower Fraser River in the fall of 1996, 1997 and 1998.

Radio tags were distributed to steelhead in the lower Fraser River in direct proportion to their expected abundance, which was determined from the Albion Chum Test Fishing CPUE pattern for steelhead averaged over the five years prior to the tagging season. Priority was placed on deploying radio tags as far downstream in the Fraser River as possible. During most of the fall upstream migration period in 1996 and 1997, fisheries in the lower Fraser had more radio tags available to them then they could deploy in any given time period. In the fall of 1998, the Yale fishwheel was given surplus radio tags primarily in late-September, early-October and late-November when fisheries further downstream had difficulty deploying an adequate number of radio tags. In the later half of October and early-November anglers were used to deploy the majority of radio tags and often deployed their quota of radio tags for the day in only a few hours.

Tangle Net Fishery (Annacis Island)

An experimental commercial tangle net (or "tooth net") fishery was conducted between the eastern end of Annacis Island and the Pattullo Bridge (Figure 3). A small-mesh gill net (88.9 mm mesh), designed to entangle fish by the kype and fins, was used (J. O. Thomas 1997; Bennett 1999b). The tangle net fishery was conducted between September 23rd and November 10th in 1996, between September 16th and November 17th in 1997 and between in 1998.

Beach Seine Fishery (Derby Reach)

The Katzie Native Band and members of the Fraser River Fishermen's Society conducted a beach seine fishery at Derby Reach (Figure 3). A modified commercial seine net, approximately 275 m (150 fathoms) in length, 12 m deep on the ends, and 18 m deep at the centre was used (J. O. Thomas 1997). The beach seine fishery was conducted between September 23rd and November 7th in 1996, October 1st and November 27th in 1997 and October 1st to November 9th in 1998.

Angling

Efforts to capture steelhead by angling for the purpose of radio tag deployment were conducted between Chilliwack and Hope from September 30th to October 29th in 1996, from September 4th to October 24th in 1997 and from September 21st to November 20th in 1998 (Figure 3).

Gill Net Fishery (Yale)

A gill net fishery at Yale was also used to provide steelhead for radio tag deployment in 1996 (Figure 3). A 20-m by 4-m, 14-cm mesh gill net was set from shore near Siwash Creek (approximately 3 km upstream of Yale). The net was deployed on November 9th and fished for 23.6 h, with two net inspections/fish removals at 8 h and 17 h.

Yale Fishwheel

The Yale First Nations operated a fishwheel near Yale, between September 15th and November 30th, 1998 (Figure 3; Plate 2).

Plate 2. The Yale Fishwheel operated by the Yale First Nations.

Winter and Spring Releases - 1997 to 1999

Steelhead were angled for the purpose of radio tagging in the winter/spring of 1997, 1998 and 1999 to augment the number steelhead radio-tagged in the fall and to study the stock composition of several known, key overwintering areas. In 1997, radio tags were deployed in the Fraser River near Hope, near the Nahatlatch/Fraser confluence, upstream in the Nahatlatch River, near Lytton, upstream in the Stein River, near the Seton/Fraser confluence, upstream in the Seton River and upstream in the Bridge River (Figure 4). In the spring of 1998, radio tags were deployed near the Deadman/Thompson confluence and in the Chilcotin River System. In the spring of 1998, a boat shocker was also used to deploy three radio tags in the Fraser River north of the Chilcotin/Fraser confluence. In the winter/spring of 1999, radio tags were deployed near Lytton, near the Seton/Fraser confluence, in the Bridge River, near the Nicola/Thompson confluence, near the Deadman/Thompson confluence and in the Chilcotin River system.

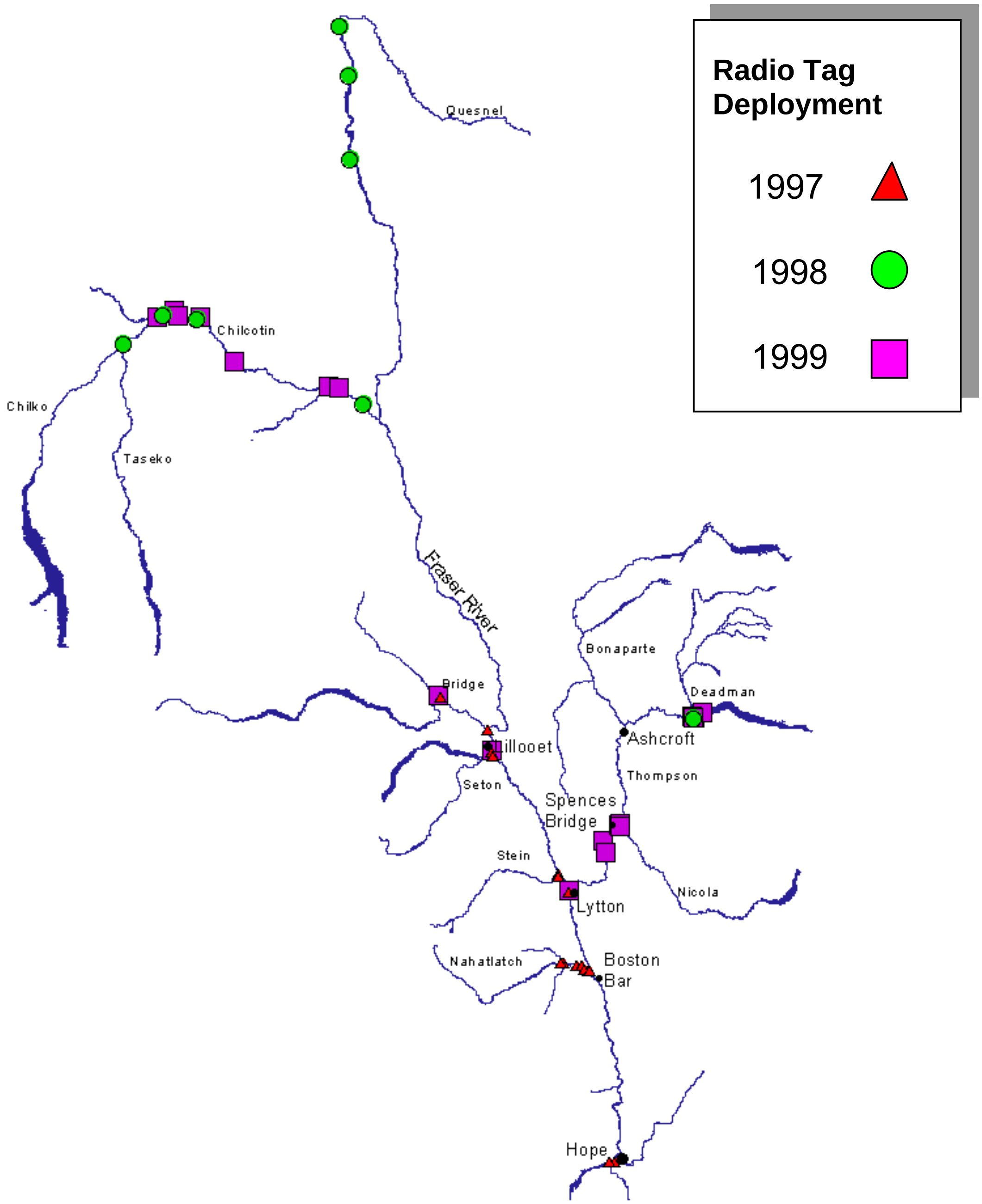

Figure 4. The locations of radio tag deployment from February to May in 1997, 1998 and 1999.

Detections

The fall migration of interior Fraser steelhead was primarily monitored through the use of fixed station telemetry along the mainstem Fraser River (Figure 5; Table 2). One exception to this was the fall of 1998, where an angler survey of the Thompson River Steelhead Fishery allowed for bi-weekly truck tracking along the mainstem Thompson River downstream of Kamloops Lake. For the fall migration period fixed stations were located at the confluence's of rivers which were suspected to be used for overwintering, at important political boundaries and at points along the mainstem Fraser that allowed the Fraser to be broken into key reach breaks (e.g. the Hope fixed station marks the start of the Fraser Canyon).

The overwintering period (January to mid March) was monitored exclusively through the use of aerial telemetry. In 1997 and 1999 a series of flights were carried out in short succession along the mainstem Fraser from Annacis Island to well north of the Chilcotin/Fraser confluence, along the Chilcotin River to the Chilcotin/Chilko confluence and along the Thompson mainstem downstream of Kamloops Lake. During these years, flights were also conducted along several tributaries in the lower Fraser (Pitt, Stave, Chehalis, Big Silver, Vedder, Silverhope and Coquihalla) to ensure that the steelhead undetected by the overwintering flight hadn't gone up one of these tributaries. In early spring of 1997, tributaries in the Fraser Canyon deemed as suitable for steelhead were also flown to ensure undetected steelhead hadn't gone up one of these tributaries (Table 3). Overwintering flights were not conducted in 1997/98 because an insufficient number of steelhead were radio-tagged in the lower Fraser to make a viable telemetry program. A flight was conducted however along the mainstem Fraser from Annacis Isaland to north of the Chilcotin/Fraser confluence to track for White Sturgeon on November 15, 1997. This flight was used to simultaneously track for steelhead.

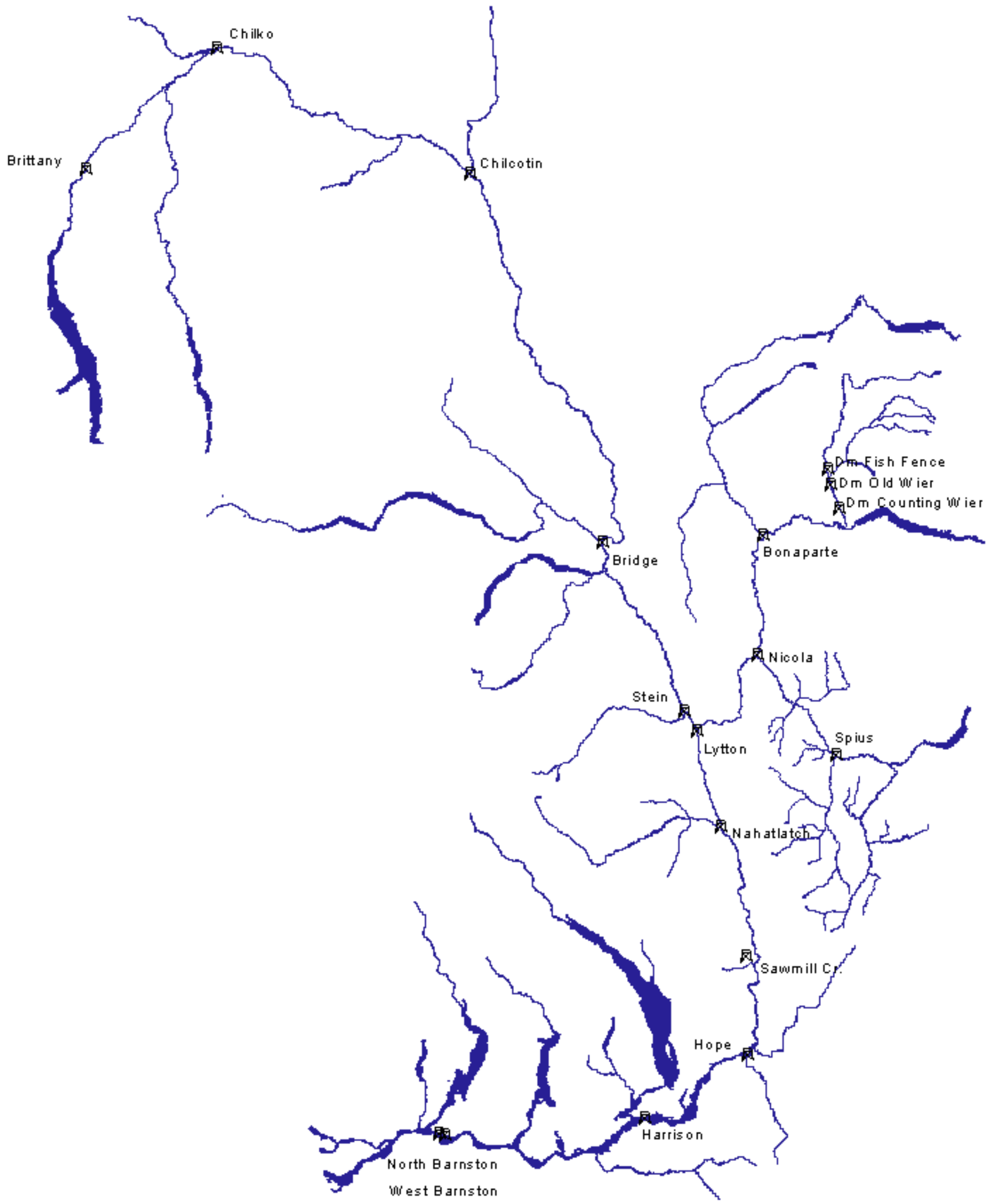

Figure 5. The locations of telemetry stations utilized to track interior Fraser steelhead from 1996 to 1999.

Table 2. The locations and operational dates of telemetry stations utilized to track interior Fraser steelhead from 1996 to 1999.

Location	Number of Antennae	Station Operation Dates Start	Stop	Number of Days
Fraser at West Barnston Island	4	31-Aug-96	17-Dec-96	108
Fraser at North Barnston Island	3	12-Sep-96	20-Dec-96	99
Fraser at North Barnston Island	1	16-May-97	16-Jul-97	61
Fraser at Chilliwack ("Harrison")	2	04-Sep-96	19-Dec-96	106
Fraser at Hope (south side)	2	06-Sep-96	07-Jul-97	304
Nahatlatch/Fraser Confluence	3	24-Sep-96	07-Jul-97	286
Lytton (Thompson River)	2	08-Sep-96	07-Jul-97	302
Nicola/Thompson Confluence	3	28-Feb-97	07-Jul-97	129
Stein/Fraser Confluence	3	25-Feb-97	07-Jul-97	132
Chilcotin/Fraser Confluence	3	10-Sep-96	09-Jul-97	302
Chilko/Chilcotin Confluence	3	02-Mar-97	16-Jul-97	136
Fraser at North Barnston Island	1	27-Aug-97	28-Dec-97	123
Fraser at Chilliwack ("Harrison")	2	12-Oct-97	28-Dec-97	77
Fraser at Hope (south side)	2	21-Sep-97	03-Aug-98	316
Fraser near Sawmill Creek	2	28-Aug-97	27-Dec-97	121
Nahatlatch/Fraser Confluence	3	23-Sep-97	31-Aug-98	342
Lytton (Thompson River)	2	22-Sep-97	21-Jul-98	302
Nicola/Thompson Confluence	3	13-Oct-97	28-Mar-98	166
Deadman - Old Weir Site	2	30-Mar-98	29-Jun-98	91
Deadman - Fence Site	2	30-Mar-98	29-Jun-98	91
Stein/Fraser Confluence	3	22-Sep-97	06-May-98	226
Bridge/Fraser Confluence	3	29-Aug-97	31-Aug-98	367
Chilcotin/Fraser Confluence	3	31-Aug-97	29-Jun-98	302
Chilko - near Bidwell Creek	2	03-Apr-98	29-Jun-98	87
Fraser at North Barnston Island	1	15-Sep-98	19-Oct-98	34
Fraser at Chilliwack ("Harrison")	2	15-Sep-98	23-Dec-98	99
Fraser at Hope (north side)	2	05-Aug-98	19-Jun-99	318
Nahatlatch/Fraser Confluence	3	01-Sep-98	30-Jun-99	302
Thompson/Fraser Confluence	3	20-Oct-98	02-Mar-99	133
Nicola/Thompson Confluence	3	02-Mar-99	30-Jun-99	120
Spius/Nicola Confluence	3	15-Mar-99	07-Jun-99	84
Bonaparte/Thompson Confluence	3	22-Mar-99	21-Jun-99	91
Deadman - Counting Weir Site	2	15-Apr-99	21-Jun-99	91
Stein/Fraser Confluence	3	02-Mar-99	29-Jun-99	119
Bridge/Fraser Confluence	3	01-Sep-98	29-Jun-99	301
Chilcotin/Fraser Confluence	3	20-Nov-98	28-Jul-99	250
Chilko - near Bidwell Creek	2	24-Mar-99	28-Jul-99	126

Table 3. The locations and dates mobile telemetry was used to track interior Fraser steelhead from 1996 to 1999.

Date	Survey Type	Area Surveyed
24-Jan-97	Air	Kamloops Lake to Annacis Island
29-Jan-97	Air	Lytton to Chilcotin/Fraser confluence
10-Mar-97	Air	Nahatlatch/Fraser confluence to Pitt/Fraser confluence; Upper Pitt, Chehalis, Stave, Big Silver
10-Mar-97	Ground	Coquihalla, Silverhope and Vedder
01-Apr-97 to 16-Jun-97	Ground	Lower Nahatlatch - Nahatlatch/Fraser confluence to Hannah Lake
01-Apr-97 to 16-Jun-98	Ground	Lower Stein - Stein/Fraser confluence to cable car (foot)
01-Apr-97	Ground	Lower Nicola - Nicola/Thompson confluence to Spius/Nicola confluence
07-Apr-97	Ground	Lower Nicola - Nicola/Thompson confluence to Sunshine Valley
09-Apr-97	Ground	Seton/Fraser confluence; Thompson/Fraser confluence; Thompson - Lytton to Nicola/Thompson confluence.
16-Apr-97	Ground	Nicola - Nicola/Thompson confluence to Merit; Coldwater - Merit to Kingsvale Interchange; Spius - Spius/Nicola confluence u/s 10 km
23-Apr-97	Ground	Bridge - Bridge/Fraser confluence to 6 km u/s Yalakom/Bridge confluence
29-Apr-97	Ground	Fraser Canyon - Boston Bar to Hope (railroad)
29-Apr-97	Ground	Deadman - Deadman/Thompson confluence u/s to fish fence
30-Apr-97	Ground	Nicola - Nicola/Thompson confluence to Merit; Coldwater - Merit to Kingsvale Interchange; Spius - Spius/Nicola confluence u/s 10 km Bonaparte - fishway to Bon/Thompson confluence.
08-May-97	Ground	Nicola - Nicola/Thompson confluence to Merit; Coldwater - Merit to Kingsvale Interchange; Spius - Spius/Nicola confluence u/s 10 km Bridge - Bridge/Fraser confluence to 6 km u/s Yalakom/Bridge confluence
10-May-97	Ground	Bridge - Bridge/Fraser confluence to 6 km u/s Yalakom/Bridge confluence
12-May-97	Air	Fraser Canyon - Nahatlatch/Fraser confluence to Hope; Ainsley; Anderson; Spuzzum; Yale; Emmory; Coquihalla; Silverhope
13-May-97	Ground	Bridge - Bridge/Fraser confluence to 6 km u/s Yalakom/Bridge confluence Thompson/Fraser confluence
14-May-97	Air	Nicola - Nicola Lake to Nicola/Thompson confluence; Thompson - Lytton to Kamloops Lake; Spius; Maka; Coldwater; Brook Cr
16-May-97	Air	Fraser - Chilcotin/Fraser confluence to Stein/Fraser confluence Stein - Stein/Fraser confluence u/s about 30 km
21-May-97	Ground	Lower Nicola - Nicola/Thompson confluence to Spius/Nicola confluence
22-May-97	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko/Chilcotin confluence Chilko - Chilko/Chilcotin confluence to Chilko Lake
24-May-97	Air	Nicola - Nicola Lake to Spius/Nicola confluence; Spius; Maka; Coldwater; Brook Cr.
25-May-97	Ground	Lower Nicola - Nicola/Thompson confluence to Spius/Nicola confluence Skuhun; Shakan; Nuaitch
27-May-97	Air	Fraser - Lillooet to Stein/Fraser confluence Stein - Stein/Fraser confluence u/s about 30 km; Texas Cr Seton - Seton/Fraser confluence to dam; Cayoosh - Seton to waterfall
28-May-97	Ground	Fraser - Lytton to Boston Bar
06-Jun-97	Ground	Lower Nicola - Nicola/Thompson confluence to Spius/Nicola confluence Skuhun; Shakan; Nuaitch

Table 3. Continued…

Date	Survey Type	Area Surveyed
07-Jun-97	Air	Nicola - Nicola Lake to Spius/Nicola confluence; Spius; Maka; Coldwater; Brook Cr.
23-Apr-97 to 18-Jun-97	Ground	Bridge - downstream of Downton Reservoir; Yalakom - lower 10 km Seton - Seton/Fraser confluence to dam; Cayoosh - Seton to waterfall
15-Nov-97	Air	Fraser - Big Bar to Annacis Island
20-Apr-98 to 29-May-98	Ground	Deadman - Deadman/Thompson confluence to Mowich Lake
	Boat	Thompson - near Deadman/Thompson confluence
30-Apr-98	Boat	Fraser - Quesnel to Soda Creek
06-May-98	Air	Quesnel - Quesnel to Quesnel Lake
07-May-98	Air	Quesnel - Quesnel to Quesnel Lake
12-May-98	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko Lake
21-May-98	Air	Quesnel - Quesnel to Quesnel Lake
27-May-98	Air	Fraser - Williams Lake to Chilcotin/Fraser confluence Chilcotin - Chilcotin/Fraser confluence to Chilko Lake
28-May-98	Air	Quesnel - Quesnel forks to slide mountain
28-Oct-98 to 13-Dec-98	Ground	Thompson - Basque Ranch to Lytton
25-Jan-99	Air	Fraser - Soda Creek to Big Bar
26-Jan-99	Air	Fraser - Qesnel to Chimney Creek; Quesnel River
26-Jan-99	Air	Thompson - Kamloops Lake to Lytton
28-Jan-99	Air	Fraser - Big Bar to Hope
10-Feb-99	Air	Lower Fraser - Hope to Douglas Island; Pitt - Pitt/Fraser confluence to upper Pitt; Allouette - Allouette/Fraser confluence to Allouette Lake Stave - Stave Lake to series of barriers in upper Stave Vedder - Vedder/Fraser confluence to Chilliwack Lake
11-Mar-99 to 11-Jun-99	Ground	Bridge - downstream of Downton Reservoir; Yalakom - lower 10 km Seton - Seton/Fraser confluence to dam; Cayoosh - Seton to waterfall
19-Apr-99 to 13-Jun-99	Ground	Deadman - Deadman/Thompson confluence to Mowich Lake
	Boat	Thompson - near Deadman/Thompson confluence
30-Mar-99 to 17-Jun-99	Ground	Nicola - Nicola/Thompson confluence to Merit; Coldwater - Merit to Kingsvale Interchange; Spius; Maka; Nuaitch; Skuhun; Shackan
29-Mar-99	Air	Fraser - Big bar to Hope; Stein; Bridge; Nahataltch; Seton/Cayoosh
21-Apr-99	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko Lake
30-Apr-99	Air	Bridge; Stein; Fraser - Lytton to Lillooet
10-May-99	Air	Stein; Nahatlatch; Fraser - Boston Bar to Lillooet
17-May-99	Air	Bridge; Stein; Fraser - Lytton to Lillooet
21-May-99	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko Lake; Taseko
28-May-99	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko Lake; Taseko
04-Jun-99	Air	Chilcotin - Chilcotin/Fraser confluence to Chilko Lake; Taseko

For the spring upstream migration period a combination of fixed and mobile telemetry was used to track radio-tagged steelhead. Since most of the remaining viable tags had moved into the interior, fixed telemetry stations were dismantled along the lower Fraser mainstem (downstream of Hope) and new stations were installed at the confluence of some spawning tributaries. In some specialized cases, fixed telemetry stations were installed at specific locations within a tributary to attain run timing and residency time data. Once in the spawning tributaries, radio-tagged steelhead were tracked primarily by mobile telemetry. Although all known spawning tributaries were tracked at some point during the spawning period (mid-May to early-June), the intensity of tracking on each system varied from 2 to 5 tracking sessions per season to daily tracking sessions. Low intensity tracking provided basic stock distribution data within a river system, whereas daily tracking also provided specific spawning locations and residency times within an area.

Kelting was monitored exclusively through the use of fixed telemetry stations along the Fraser mainstem at Nahatlatch, Hope and Barnston Island. The Barnston Island fixed telemetry station was only operational during the kelting season (early-May to late-July) in 1997. The Hope and Nahatlatch fixed telemetry stations were operational during the entire 1997-98 and 1998-99 steelhead telemetry programs.

Telemetry Equipment Setup and Operation

The movements of radio-tagged steelhead were determined using data from telemetry stations and mobile surveys. Because transmitted radio signals are dampened by the ions in salt water, detections of radio tags released in the ocean could only be made after a radio-tagged steelhead had moved upstream in the Fraser River past Annacis Island (salinity >3 ppt; Nelson *et al*. 1994; Nelson and Alexander 1995).

Fixed Telemetry Station Detections

Lotek SRX_400 receivers with CODE LOG W16 and W17 firmware were used in fixed telemetry stations at key locations throughout the Fraser watershed to record the upstream and downstream movements of radio-tagged steelhead (Nelson *et al.* 1998). All telemetry stations consisted of a 12 volt deep cycle battery, a water tight enclosure, a number of directional 4-element Yagi antennas (an 11-element antenna was used at the north Barnston Island site), double insulated coaxial cable fitted with BNC connectors and an ASP-8 antenna switching unit. Some fixed telemetry stations were also outfitted with two Siemens SP-75 solar panels and an ASC 12/12 regulator (Plate 3).

The antenna configuration used at each location depended on the presence/absence of tributaries to the mainstem river. Fixed telemetry stations located at confluence's utilized three, 4-element Yagi antennas: one antenna was aimed upstream on the mainstem river, a second was aimed downstream on the mainstem and a third antenna was aimed upstream on the tributary. Fixed telemetry stations situated on a mainstem river consisted of only two, 4-element Yagi antennas; one aimed upstream and a second aimed downstream on the mainstem river. The direction of travel by passing steelhead outfitted with a radio transmitter was determined by the relative signal strength detected by each antenna, over time (Alexander *et al*. 1996).

Plate 3. A telemetry station set up overlooking the Bonaparte/Thompson confluence.

Receivers at fixed telemetry stations were set up to continuously scan all frequencies in use on a given year. When a steelhead outfitted with a digitally encoded tag moved into detection range, the date, time, channel, code, signal strength and the antenna number were recorded within the receiver's memory. Receiver data was routinely downloaded in hexadecimal format with a lap top computer via a 9-pin serial port and a null modem cable. All raw data collected in 1996 and 1997 from fixed telemetry receivers was managed and summarized by LGL Limited environmental research associates as described by Alexander *et al*. (1996) and Nelson *et al.* (1998). All data collected from 1997 to 1999 was managed using Microsoft Access, Excel and Arc View.

Mobile Surveys

Most aerial telemetry surveys were conducted with a Bell 206 helicopter. A 4-element Yagi antenna was mounted to either the VHF antenna mount on the front of the helicopter or the skid gear. Most flights were conducted with one data-logging SRX_400 receiver and a Magellan 5000 GPS unit. The GPS unit was set up to log positions every 15 seconds. The internal clocks on the receiver and GPS were synchronized before each flight; this allowed the most powerful detection of each fish to be matched up with a corresponding position. The position of each detection was also marked on a 1:250 000 topographic map and recorded on a data sheet as backup. Flights were conducted from 60 m to 150 m above the water at ground speeds ranging from 100 km/h to 160 km/h (Plate 4).

Plate 4. A Bell 206 helicopter equipped for tracking steelhead.

On one occasion, a Cessna 172 fixed-wing aircraft was used to conduct an aerial survey. This flight was conducted using one (data-logging) SRX_400 receiver and a two-element Yagi antenna mounted to the wing strut. The aircraft flew at an average ground speed of 110 km/h and an altitude of 150 m. Detections of individual steelhead and their respective positions were recorded on a 1:250 000 topographic map and a data sheet.

All ground-based telemetry was conducted with one SRX_400 receiver and a two-element Yagi antenna. The antenna was mounted on an expendable pole, fastened to the roof rack of a truck, hand held for tracking on foot or on one occasion a railroad repair truck (Table 3). Detections of individual steelhead and their respective positions were recorded on 1:50 000 topographic maps and data sheets along with the appropriate river km. An access database containing a UTM for each 100m of stream was then used to link together the stream km determined with ground telemetry to a corresponding UTM determined via GIS.

All mobile data was managed using Microsoft Access, Microsoft Excel and Arc View.

Data Analysis

Calculation of Migration Rates

Migration times for radio-tagged steelhead migrating upstream past the Barnston, Harrison, Hope, Nahatlatch and Chilcotin fixed telemetry stations were calculated by subtracting the date and time of the last detection at a fixed telemetry station from the date and time of the first detection at the next station, immediately upstream. Downstream migration times were calculated in a similar fashion except the last detection at a fixed station was subtracted from the first detection at the next station, immediately downstream. The rate of travel was then calculated by dividing the distance between fixed telemetry stations by the migration time between those stations.

Data Analysis of Stock Specific Migration Times

Mean upstream migration rates were calculated for the sections of Fraser River extending from Harrison to Hope, Hope to the Nahatlatch/Fraser confluence and from the Nahatlatch/Fraser confluence to Lytton for individual stocks. Analysis of variance (ANOVA) was performed to determine whether the stocks had significantly different migration times (in days) between select telemetry stations. F-tests were used to compare the variances of migration times of Chilcotin versus Nicola steelhead. Finally, *t*-tests were used to compare mean migration times of Chilcotin versus Nicola steelhead (Zar 1984).

Calculation of Average water Temperature during Migration

The average water temperatures of the Fraser River during migration between the Barnston, Harrison, Hope, Nahatlatch and Lytton telemetry stations were calculated for each individual steelhead where possible. These were calculated by averaging the mean daily water temperatures of the Fraser River for the dates an individual steelhead was between two telemetry stations.

Peterson Mark/Re-capture Analysis

A Peterson mark/re-capture analysis was performed on steelhead captured and radio-tagged in the lower Fraser in the fall of 1998 and subsequently detected (re-captured) during the 1999 spawning period. Steelhead captured and radio-tagged at the Yale Fishwheel in 1998 were not used because radio tags were not available for deployment by the Fishwheel for the entire interior Fraser steelhead run timing. The Deadman and Bonaparte Rivers were used to establish a marked to unmarked ratio because of the relatively accurate escapement estimations that could be made in these river systems. In the Bonaparte River, a fishway approximately 2 km upstream from the confluence was used to estimate steelhead escapement (Bennett 1999a). A Logie 2100 resistivity fish counter was used to estimate steelhead escapement in the Deadman River (McCubbing *et al*. 2000). To obtain the ratio of marked to unmarked steelhead the combined escapements of the Deadman and Bonaparte Rivers was divided by the combined number of fall deployed radio-tagged steelhead present in these two rivers.

A mark/re-capture analysis was not performed on fall radio-tagged steelhead from 1996 because of the extremely low ratio of marked to unmarked steelhead in the Bonaparte and Deadman Rivers in the spring of 1997.

Contingency Table Analysis of Kelting Rates

Contingency table analyses (using Chi-square) were performed to determine if there were significant differences between the kelting rates of Chilcotin and Thompson steelhead stocks among escapement years. These were compared for both the 1996/1997 and 1998/1999 escapement years for the combined sample of fall- and spring-tagged fish. For each year's sample, the kelting rate for Chilcotin steelhead was used as the observed ratio and the combined kelting rates from all Thompson stocks was used to generate an expected ratio (Zar 1984).

Contingency table analysis (using Chi-square) was also used to compare kelting rates between the 1996/1997 and 1998/1999 escapement years for individual stocks. Fall- and spring radio-tagged steelhead were compared in separate tests. In both cases, data from the 1998/99-telemetry season was used as the observed ratio and data from the 1996/97-telemetry season was used to generate the expected ratio (Zar 1984).

Finally, Contingency table analyses (using Chi-square) were used to compare kelting rates for fall-and springtime-tagged steelhead within individual stocks. Comparisons were made for both the 1996/1997 and 1998/1999 escapement years. In both cases, data from steelhead radio-tagged in the fall was used as the observed ratio and data from steelhead radio-tagged in the spring was used to generate the expected ratio (Zar 1984).

RESULTS

1996/97 Telemetry Program

Fall Deployment

From September 10th to November 10th, 1996, a total of 125 radio tags were deployed in adult steelhead potentially of interior Fraser origin. Radio tags were deployed in the marine environment as far away as Johnstone Strait (Area 12/13) and as far upstream in the Fraser River as Yale, BC (see Methods; Figure 3).

Marine Deployment

Out of the 125 radio tags deployed in the fall of 1996, 18 (14%) were deployed in Johnstone Strait (Area 12/13) seine fisheries and 21 (17%) were deployed in Juan de Fuca (Nitinat - Area 21) seine and gill net fisheries. (Figures 2, 6 and 7). Of the 21 radio tags deployed in Juan de Fuca Strait, 13 (62%) were applied in steelhead captured by seining and 8 (38%) were applied in steelhead captured by gill netting.

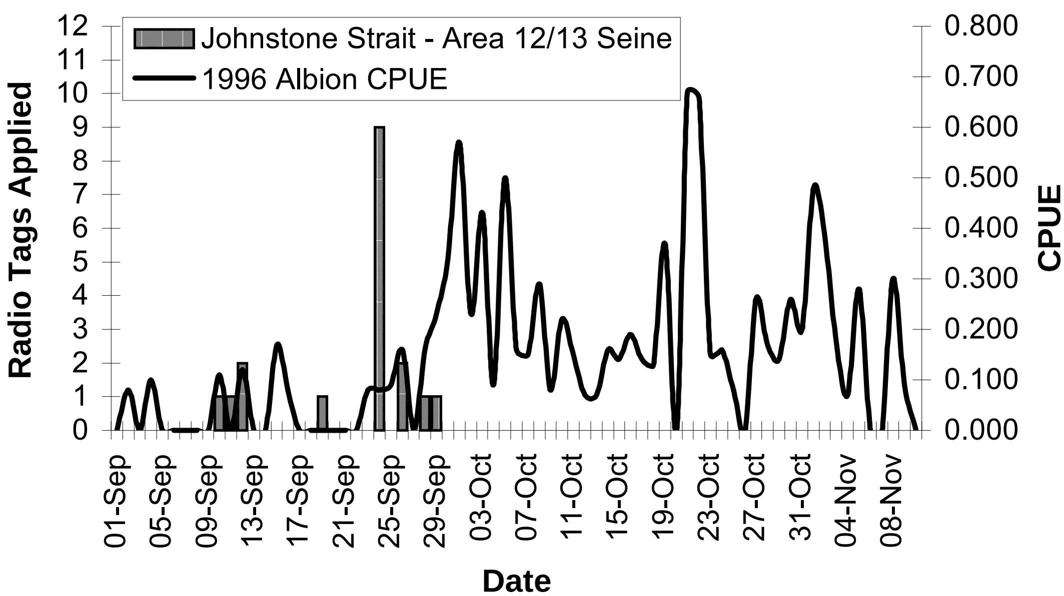

Figure 6. The temporal distribution of radio tags deployed in Johnstone Strait (Area 12/13) seine fisheries in the fall of 1996 in relation to the Albion chum test fishing CPUE.

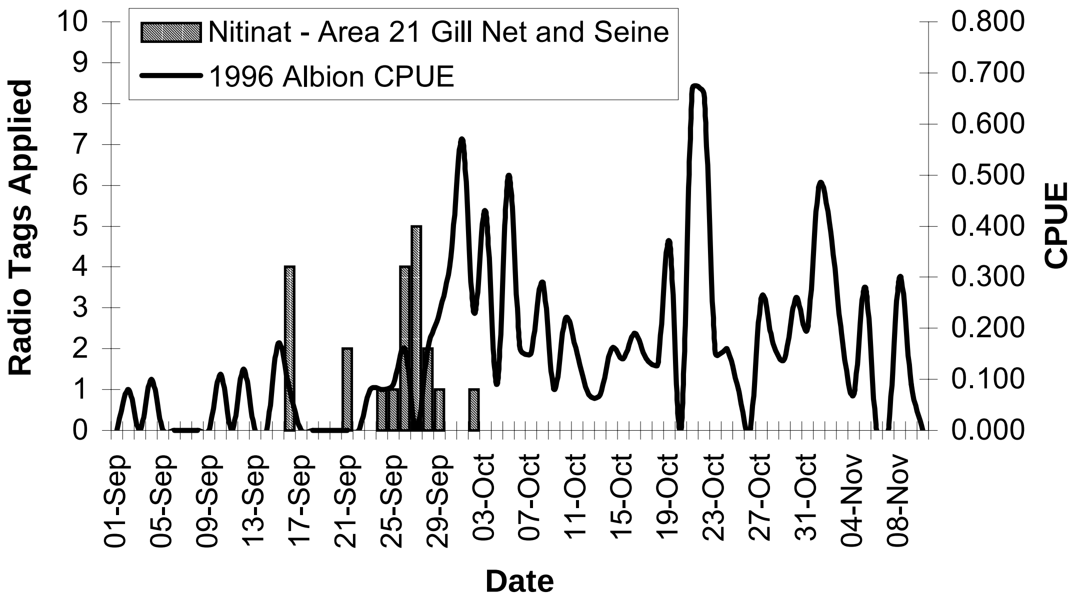

Figure 7. The temporal distribution of radio tags deployed in Juan de Fuca (Area 21) gill net and seine fisheries in the fall of 1996 in relation to the Albion chum test fishing CPUE.

Lower Fraser River Deployment

Out of 125 radio tags deployed in the fall of 1996, 29 (23%) were deployed in steelhead captured with an experimental tangle net fishery, 4 (3%) were deployed by the Derby Reach beach seine fishery, 50 (40%) were captured and deployed between Chilliwack and Hope by angling, and 3 (2%) were deployed in steelhead captured in an aboriginal gill net fishery (Figures 3, 8, 9, 10 and 11).

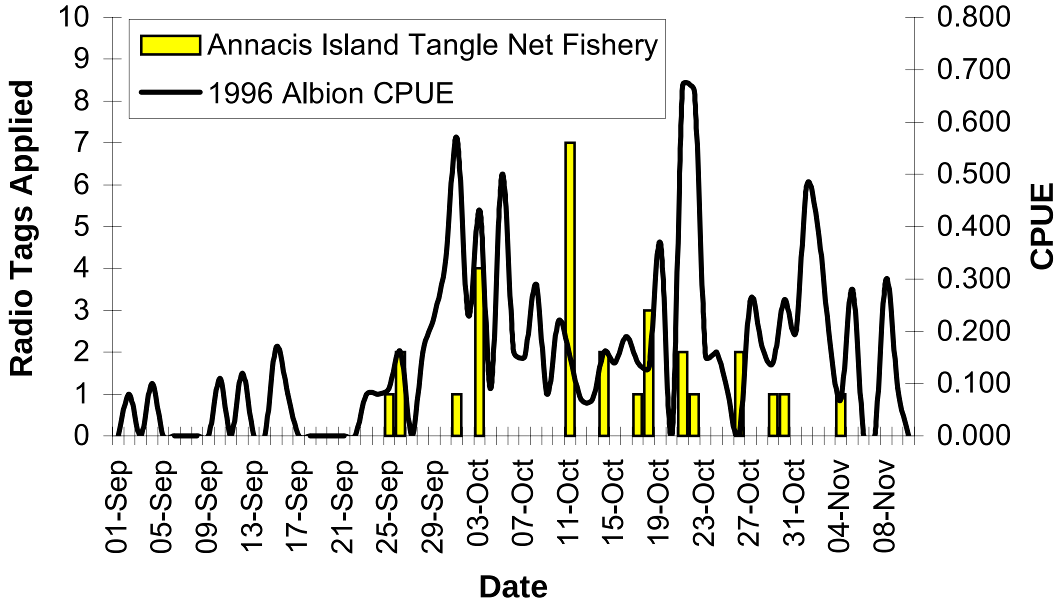

Figure 8. The temporal distribution of radio tags deployed in the Annacis Island tangle net fishery in the fall of 1996 in relation to the Albion chum test fishing CPUE.

The tangle net fishery appears to have captured steelhead throughout the complete range of interior Fraser steelhead run timing. Other than October 11th, numbers of steelhead caught in the tangle net closely follows peaks in abundance as indicated by the CPUE of the Albion chum test fishery (Figures 3 and 8). Increased catches in the tangle net generally precede spikes in the Albion CPUE by approximately 1 to 3 days. This is possibly due to the 35-river km separating the two fisheries.

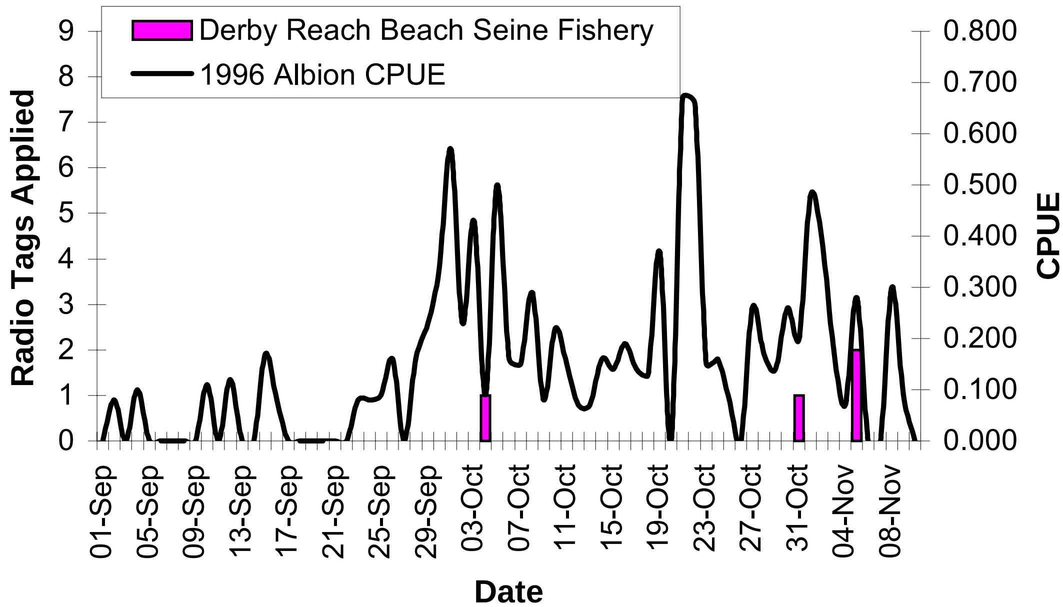

Figure 9. The temporal distribution of radio tags deployed in the Derby Reach beach seine fishery in the fall of 1996 in relation to the Albion chum test fishing CPUE.

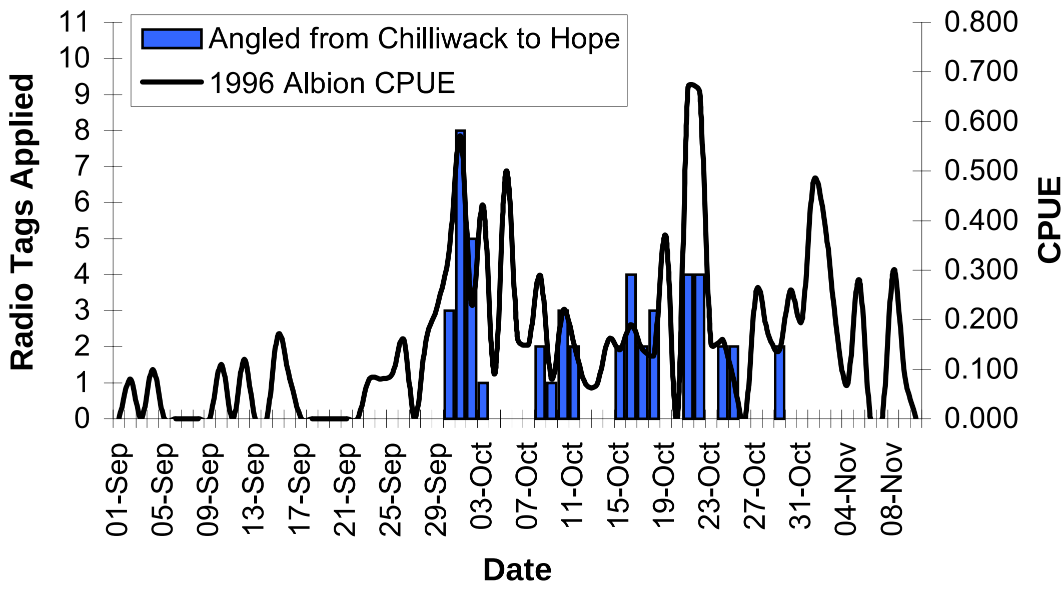

Figure 10. The temporal distribution of radio tags deployed via angling between Chilliwack and Hope in the fall of 1996 in relation to the Albion chum test fishing CPUE.

Angling was the most successful capture method during the month of October when the two largest peaks occur in the Albion CPUE (Figures 3 and 10). However, no radio tags were deployed by angling in the month of November when a smaller, third peak occurs in the Albion CPUE. Although angling took place approximately 50-km upstream of the Albion Chum Test Fishery there appears to be no lag time between high angler catches upstream and peaks in the Albion CPUE.

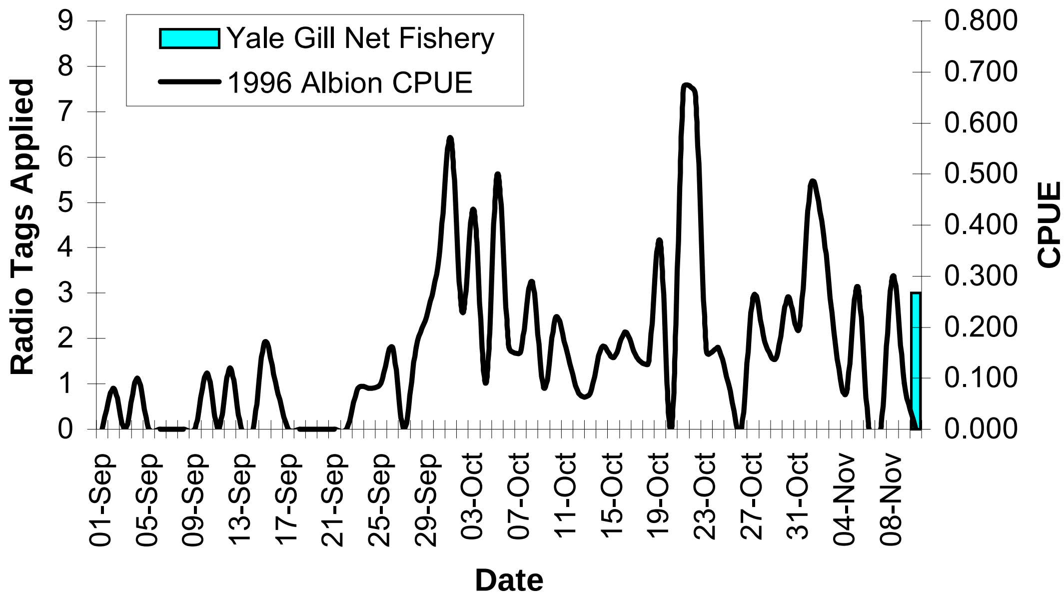

Figure 11. The temporal distribution of radio tags deployed by a 24-hour aboriginal gill net fishery in the fall of 1996 in relation to the Albion chum test fishing CPUE.

Deployment Summary

A total of 125 radio tags were deployed in the fall of 1996: 39 in marine fisheries and 86 in fresh water fisheries. None of the 39 radio tags deployed in the marine environment were detected by any means entering the Fraser River. All of the migration data that follows was gathered from the 86 radio tags deployed in the lower Fraser River.

Fraser Water Temperatures and Discharge

In the central interior of BC, the month of November 1996 was the second coldest on record for the past 20 years (Environment Canada, data on file, 1997). Water temperatures in the Fraser River dropped steadily from 17.6 ^{0}C on September 1st to 0.4^{0}C on November 22nd. Overall, mean daily water temperatures remained below 4^{0}C from mid-November 1996 until early April 1997. The early onset of arctic front conditions in the fall of 1996 and prolonged cold weather throughout the winter resulted in above average low and high elevation snow packs. In 1997, spring freshet was earlier than average and discharge rate remained high for a prolonged period. In the Fraser River, freshet began in mid-April and peaked in the first week of June (Figure 12).

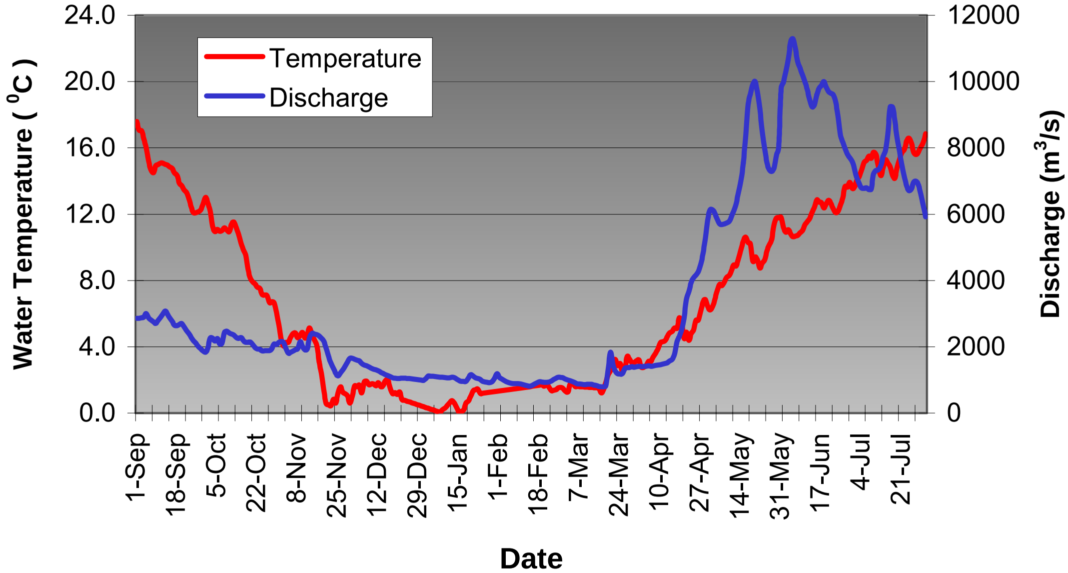

Figure 12. Daily mean water temperature and discharge of the Fraser River taken at Qualark, 1996/97.

Migration Rate

Migration rates of radio-tagged steelhead varied by area with the fastest migration rates occurring in the area monitored furthest downstream. Radio-tagged steelhead migrated between Barnston and Harrison in 3.83 days. This translates into an average migration rate of 17.8 km/day, although the sample size between these two points is relatively small. Interestingly, the distance between the Harrison/Fraser confluence and Hope required on average 9.43 days to travel, at an average migration rate of only 4.3 km/day. Migration through the Fraser Canyon took 15.63 days at an average migration rate of 4.8 km/day. Although the gradient of the Fraser River through the canyon is steeper than the section downstream of Hope, the average migration rate in the canyon was very similar. The slowest migration rate recorded, 3.8 km/day, occurred between the Nahatlatch/Fraser confluence and Lytton. An average of 8.41 days was required to migrate through this section of the Fraser River. Migration times between Barnston Island and the Harrison/Fraser confluence had the narrowest range, while the other 3 locations (which also had larger sample sizes) all had similar, but much wider ranges (Table 4).

Table 4. The average migration times, distances traveled and average migration rates of radio-tagged interior Fraser River steelhead between telemetry stations along the Fraser River in the fall of 1996.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)
Barnston Is. to Harrison	68	3.83	17.73	7	0.623	2.35 - 7.30
Harrison to Hope	41	9.43	4.35	43	1.314	1.47 - 41.16
Hope to Nahatlatch	75	15.63	4.80	24	1.991	4.30 - 34.50
Nahatlatch to Lytton	31.5	8.41	3.75	19	2.206	1.31 - 41.06

Note: In the fall of 1996, there were no telemetry stations at the Stein/Fraser or Bridge/Fraser confluences. Also at this time, the Lytton telemetry station was located along the Thompson River, approximately 500 m upstream of the Thompson/Fraser confluence, and only detected steelhead that had already entered the Thompson River. Therefore, the migration times between Nahatlatch and Lytton are primarily from Thompson River stocks. The only radio-tagged steelhead to enter the Chilcotin River in the fall of 1996 was not detected by the Lytton telemetry station.

Fall Run Timing Past Telemetry Stations

Run timing past the Barnston telemetry station occurred between the end of September and the third week of November, with a median migration date of October 27th (*n=9*). Radio-tagged steelhead appeared to migrate past the station at a fairly constant rate without any obvious peak in abundance (Figure 13).

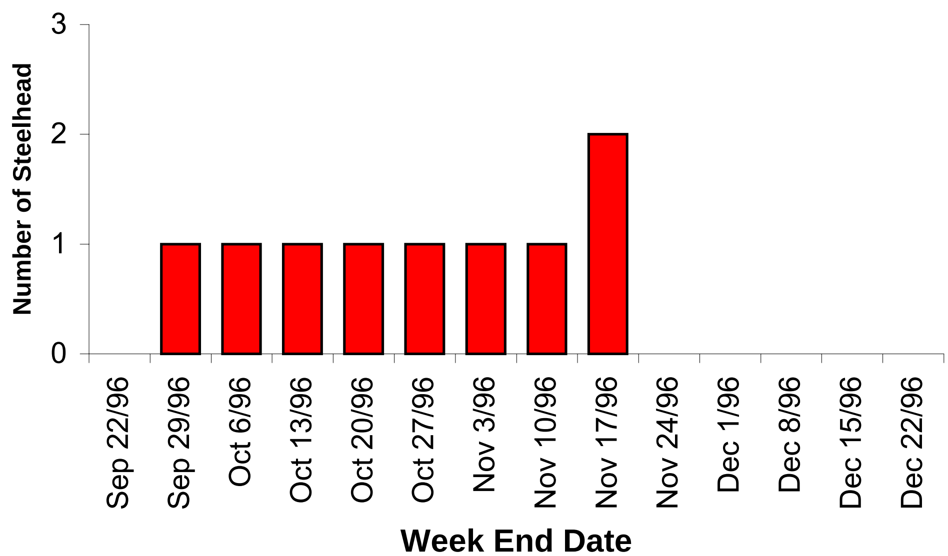

Figure 13. The upstream run timing of interior Fraser River steelhead past the Barnston Island telemetry station in the fall of 1996.

The migration of interior Fraser steelhead past the Harrison telemetry station showed a more normal distribution throughout the month of October with a sharp rise in abundance early in November and a median migration date on October 26th (*n=22*; Figure 14).

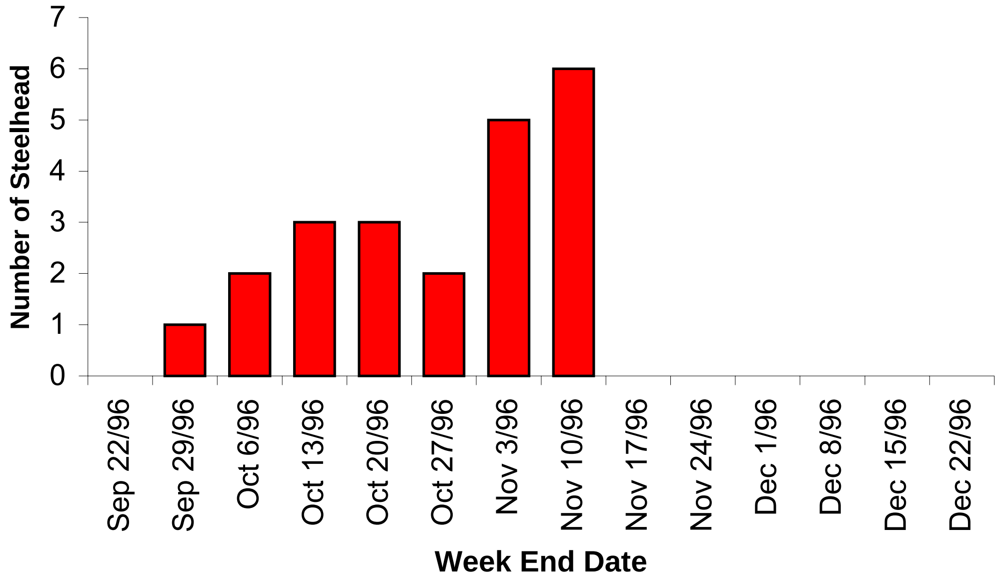

Figure 14. The upstream run timing of interior Fraser River steelhead past the Harrison telemetry station in the fall of 1996.

The earliest steelhead arrived in the Hope area in the first week of October. Migration through the Hope area appeared to be normally distributed, with a mean migration date on October 26th (*SE=1.88, n=49*) and a median migration date on October 24th. Most steelhead had moved upstream of Hope by mid-November but a small number continued to migrate past the Hope telemetry station well into December. The Hope telemetry station was located far enough upstream to record the run timing of the majority of steelhead captured in the fall 1996 telemetry program (Figure 15).

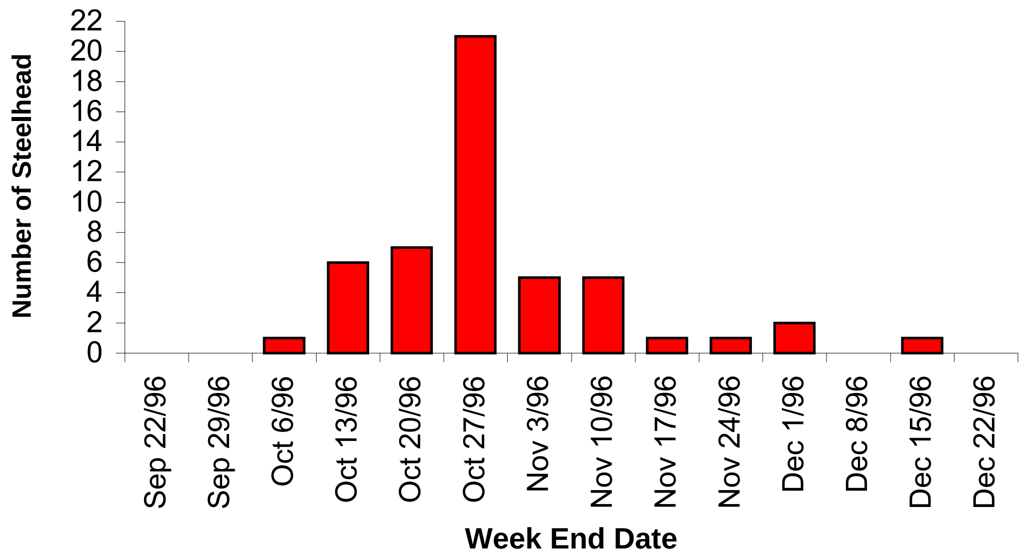

Figure 15. The upstream run timing of interior Fraser River steelhead past the Hope telemetry station in the fall of 1996.

Run timing past the Nahatlatch telemetry station demonstrated that the earliest steelhead to migrate through the Fraser Canyon in the fall of 1996 did so in the second week of October (Figure 16). It also appears that travel through the Fraser Canyon stopped by mid-December, with a peak date occurring on November 5th (*SE=2.85, n=27*) and a median migration date on November 7th.

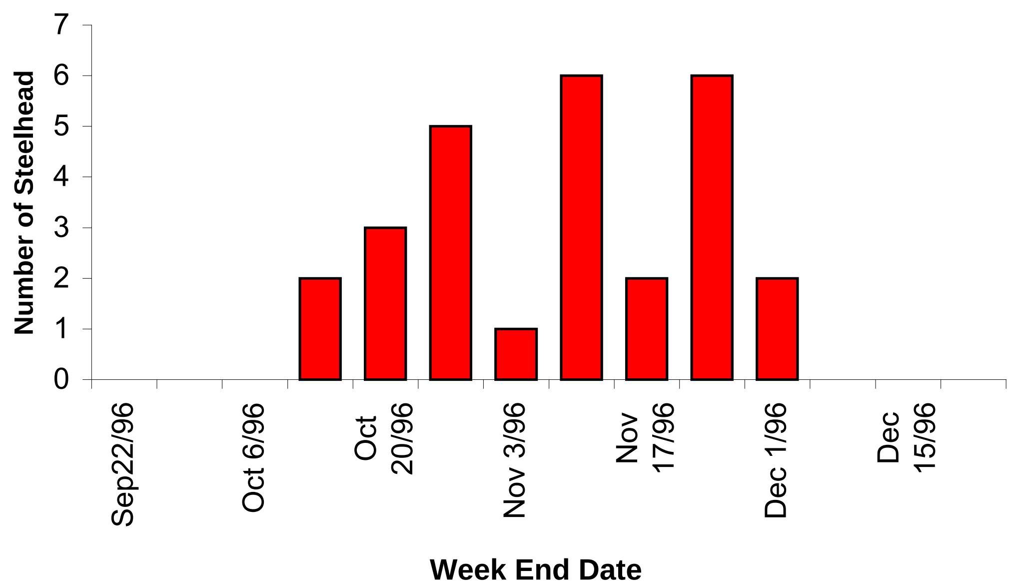

Figure 16. The upstream run timing of interior Fraser River steelhead past the Nahatlatch telemetry station in the fall of 1996.

In the fall of 1996, only one radio-tagged steelhead managed to migrate into the Chilcotin River system to overwinter. This steelhead was captured near Chilliwack on October 2nd and was recorded entering the Chilcotin River on October 24th, covering a distance of approximately 350 km in 22 days. (a migration rate of 15.9 km/day).

Fall Re-captures

During the fall migration period, a total of 7 (8.1% of the 86 fall radio-tagged steelhead) radio-tagged steelhead were re-captured, of which 5 (71%) were live released. Anglers in the Thompson River sport fishery reported the re-capture of 2 radio-tagged steelhead while another angler in Chilliwack reported the re-captured 1 radio-tagged steelhead. Two steelhead were re-captured in the Albion chum test fishery and 2 more were caught in an aboriginal food fishery which occurred in the Fraser River between Hope and Sawmill Creek. The two steelhead re-captured in the aboriginal food fishery were killed and the radio tags were returned and re-deployed (Figure 17).

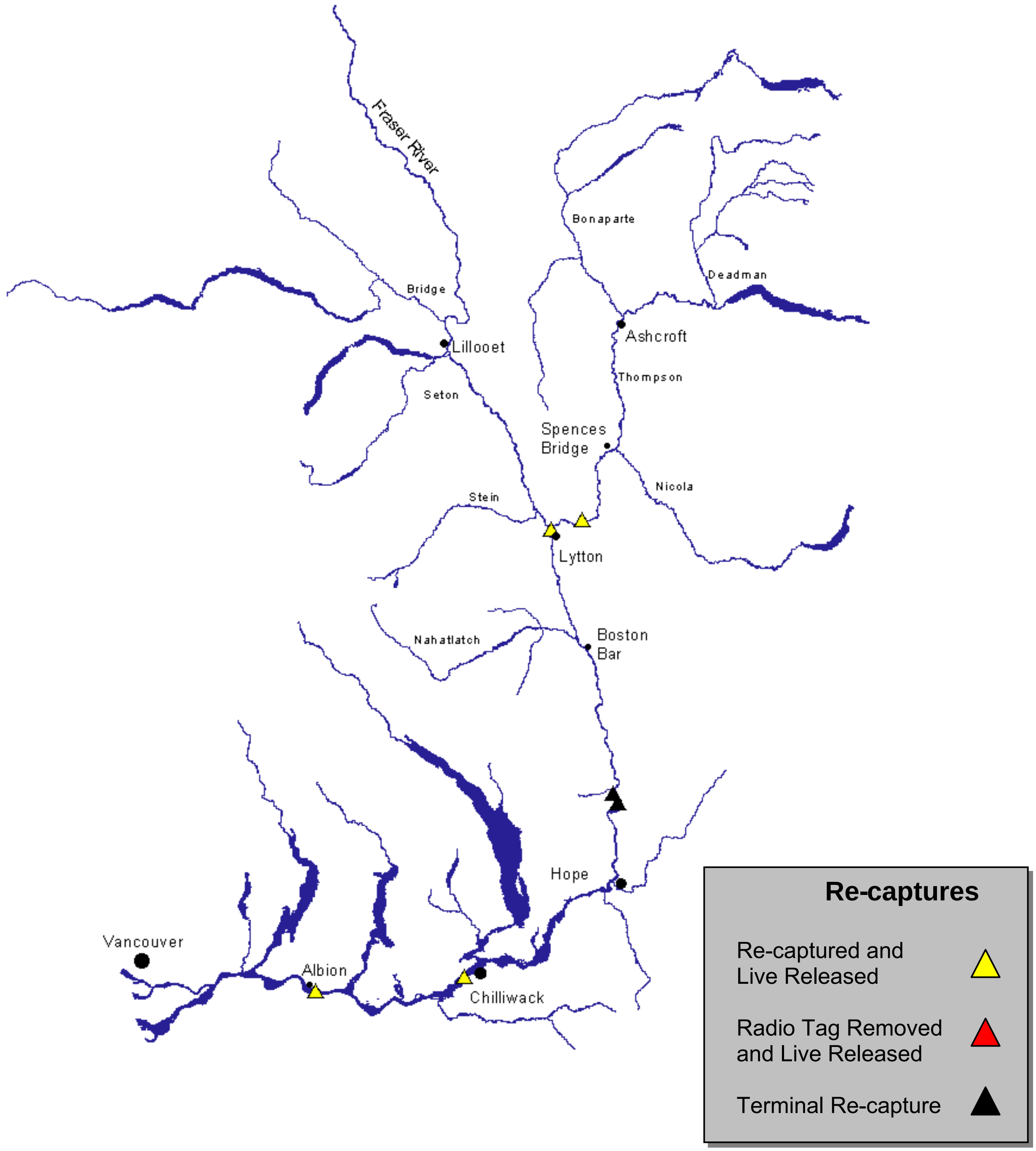

Figure 17. The location of radio-tagged steelhead, re-captured in the fall of 1996.

Overwintering Distribution

Of the 86 radio tags deployed in the lower Fraser River, 64 (74%) were detected during the overwintering period from late January to early March. Out of the 64 steelhead detected during the overwintering period, 36 (56%) were detected downstream of the Nahatlatch/Fraser confluence. The remaining 28 (44%) radio-tagged steelhead that entered the interior prior to the onset of overwintering were distributed as follows: 8 (29%) were detected in the Fraser River between the Nahatlatch/Fraser and Chilcotin/Fraser confluence's; 1 (4%) was detected entering the Chilcotin River; and 19 (68%) were detected in the Thompson River (Figure 18).

Spring Deployment

To augment the number of fall radio-tagged steelhead and determine the stock composition of several key overwintering locations, 82 additional radio tags were deployed in the late winter/ early spring period of 1997. Out of the 82 radio tags deployed, 7 were deployed in the Hope area between February 11th and 15th and 20 were deployed in the Nahatlatch River between March 7th and April 16th. Further upstream, 21 radio tags were deployed in the Lytton (Thompson/Fraser confluence) area between February 5th and March 17th and 9 were deployed in the Stein River on April 15th and April 18th. In the Lillooet area, 22 were deployed near the Seton/Fraser confluence between February 19th and April 22nd and 3 were deployed in the Bridge River between May 2nd and 8th (Figure 4).

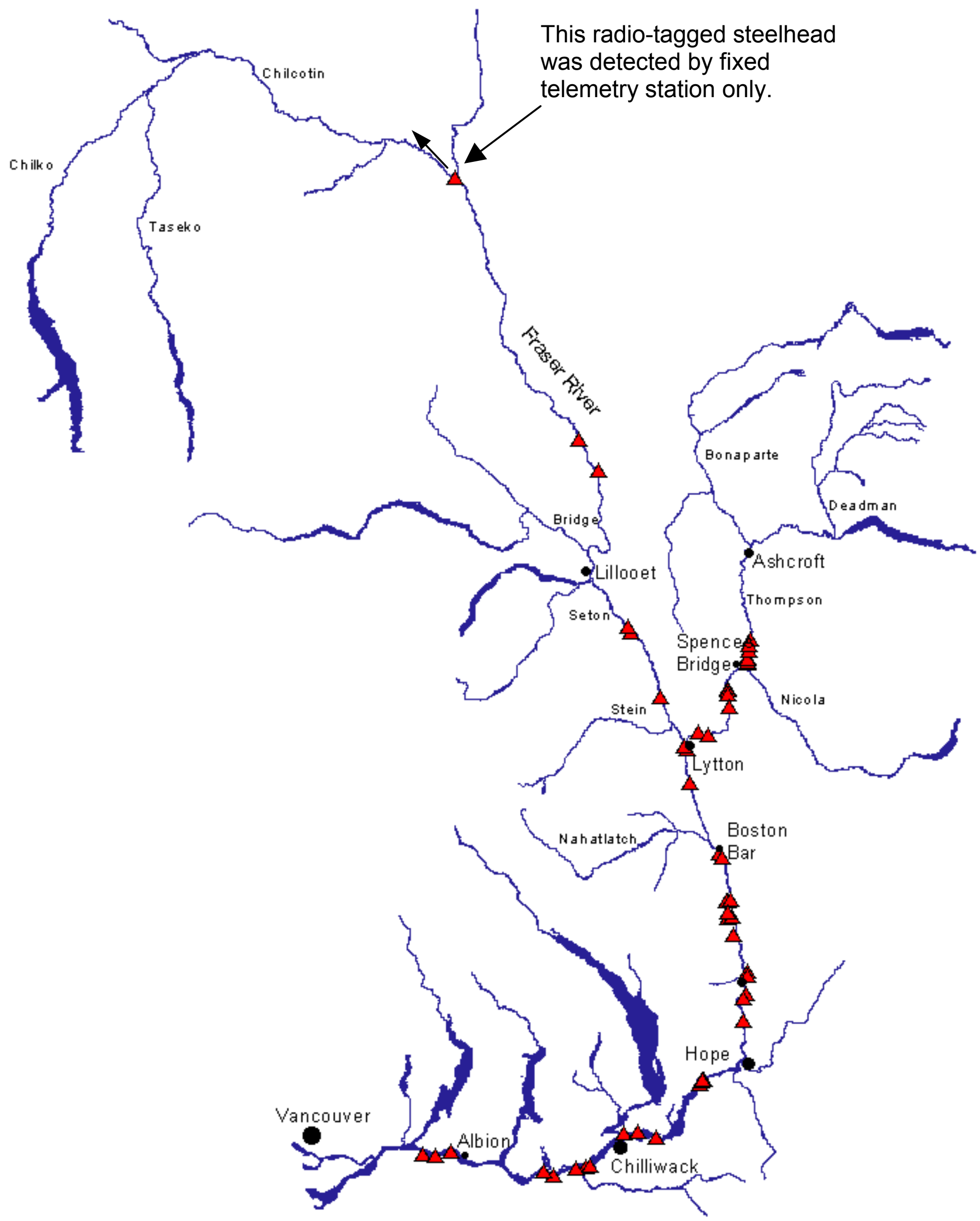

Figure 18. The location of fall radio-tagged steelhead detected by aerial telemetry during the overwintering period (January to mid-March, 1997)

Spring Movement into Spawning Tributaries

The resumption of upstream migration after the overwintering period did not occur at the same time for each of the telemetry station locations. In the Hope area, 2 steelhead passed the telemetry station in the late winter period: one radio-tagged steelhead migrated past the telemetry station in the week ending February 16th and a second fish passed in the week ending March 30th. At the Nahatlatch telemetry station, 7 radio-tagged steelhead migrated upstream in the Fraser River, past the telemetry station, from late March to early June, with a median migration date on April 25th. Four steelhead, radio-tagged near the Nahatlatch/Fraser confluence moved upstream into the Nahatlatch on the week ending April 13th and had a median migration date on April 10th (Figure 19).

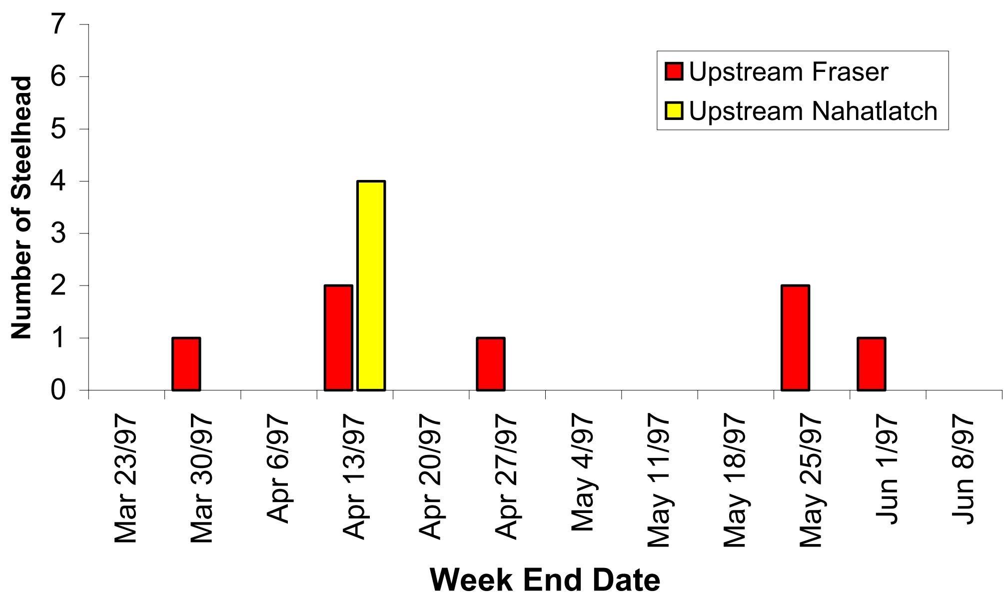

Figure 19. The upstream run timing of interior Fraser River steelhead past the Nahatlatch telemetry station in the spring of 1997.

The upstream migration of steelhead past the Lytton telemetry station has a much broader run timing than many of the other telemetry stations (Nelson *et al.* 1998). Radio-tagged steelhead entered the Thompson at a consistent rate from early February right through until early June, never more than 1 radio-tagged fish entering on any given week (Figure 20). This resulted in a median date for spring migration into the Thompson River on March 25th (*n=9*). It should be noted that in 1997 the Lytton telemetry station was located along the Thompson River approximately 500 m upstream of the Thompson/Fraser confluence and could not monitor steelhead in the Fraser River.

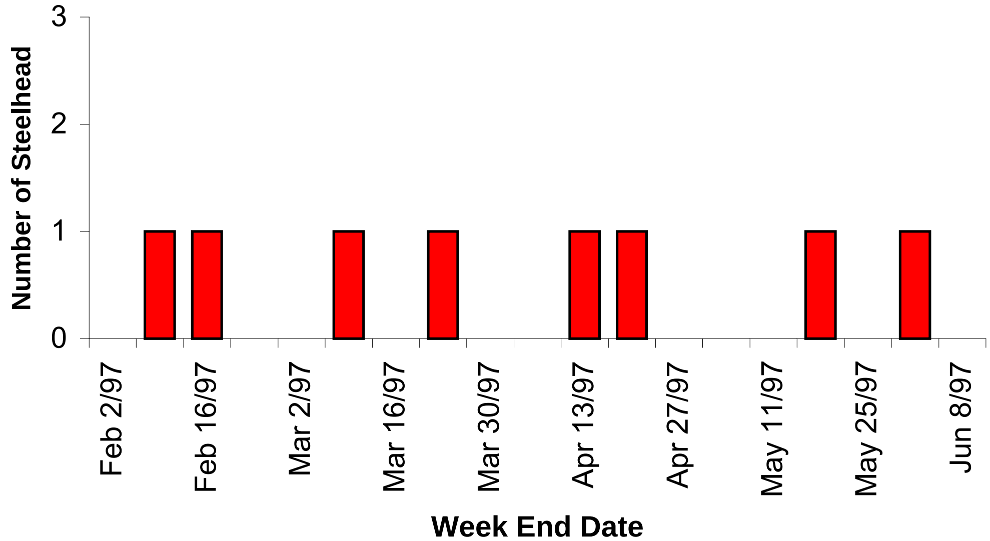

Figure 20. The upstream run timing of interior Fraser River steelhead past the Lytton telemetry station in the spring of 1997.

Radio-tagged steelhead entered the Nicola River as early as the first week in March with some fish entering as late as mid-May (Figure 21). The mean date for steelhead immigration into the Nicola River occurred on April 10th (*SE=4.61, n=17*) with a median migration date on April 9th. Only 2 steelhead migrated past the Nicola telemetry station to move upstream in the Thompson, with both fish moving past the station prior to peak Nicola immigration (a median migration date on March 22nd).

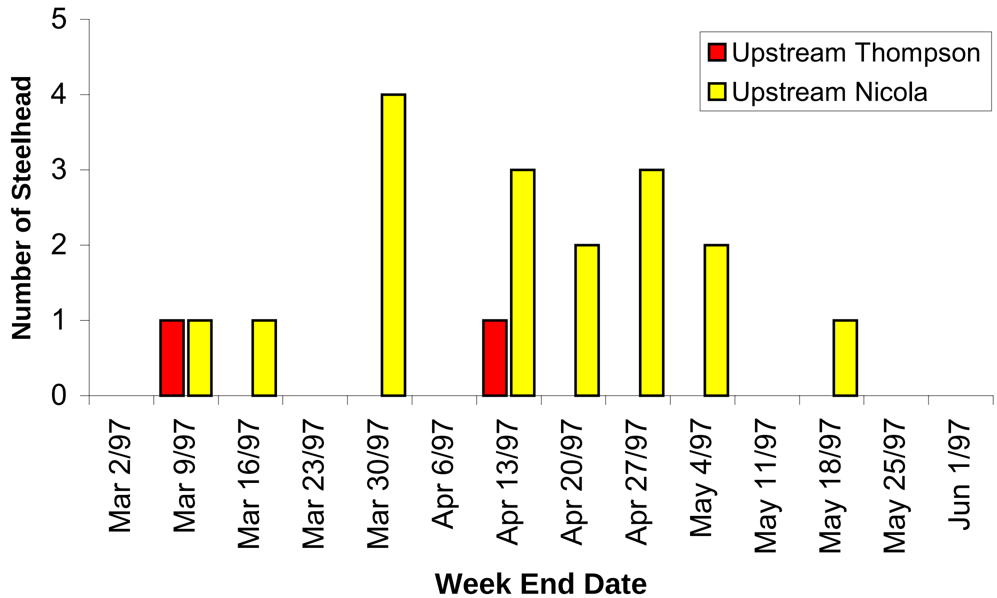

Figure 21. The upstream run timing of interior Fraser River steelhead past the Nicola telemetry station in the spring of 1997.

Radio-tagged steelhead entered the Stein River starting in late March and continued entering through to mid-May, with a median migration date on April 28th (*n=4*; Figure 22). Migration upstream in the Fraser River, past the telemetry station, appeared to be slightly earlier than immigration into the Stein (a median migration date on April 10th; *n=6*). In both cases, determining a peak migration date is difficult due to the small sample sizes.

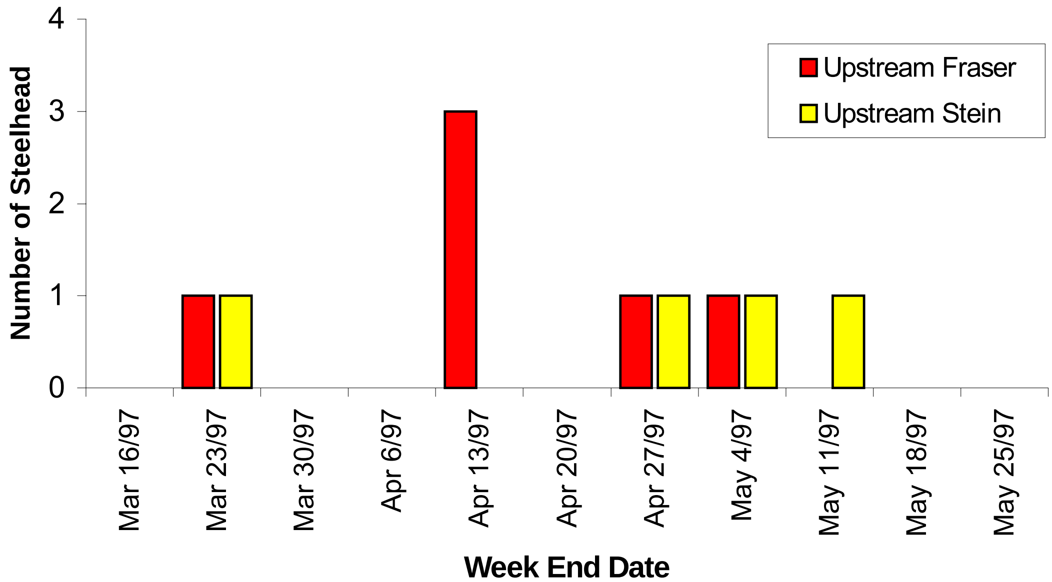

Figure 22. The upstream run timing of interior Fraser River steelhead past the Stein telemetry station in the spring of 1997.

Only 2 radio-tagged steelhead migrated past the Chilcotin telemetry station in the spring of 1997. Both of these fish entered the Chilcotin on the week ending May 18th and subsequently entered the Chilko River on the week ending May 25th. Median migration dates for the Chilcotin and Chilko were May 16th and May 22nd respectively.

Spring Re-captures

A total of 13 (4 fall-tagged and 9 spring-tagged) radio-tagged steelhead were re-captured from February 28th to May 12, 1997. Nine (69%) of these steelhead were live released (2 fall-tagged and 7 spring-tagged) and 4 (31%) were harvested in aboriginal food fisheries (2 fall-tagged and 2 spring-tagged). Of the 9 steelhead that were live released, 2 (both fall-tagged) were re-captured at the Bonaparte Fishway and both of these had regurgitated their radio tags but retained their floy tags. Five of the steelhead that were live released were re-captured by MELP anglers while trying to deploy additional radio tags; 2 were in the Lytton area, 1 was in the Stein River and 2 were near the Seton/Fraser confluence. Sport anglers re-captured the remaining 2 live release steelhead. In one case, where a radio-tagged steelhead was re-captured in the Nahatlatch River, the angler removed the radio tag accidentally. In the second case an angler cut the radio tag antenna off of a steelhead re-captured in the Seton River, mistaking it for a piece of heavy monofilament (Figure 23).

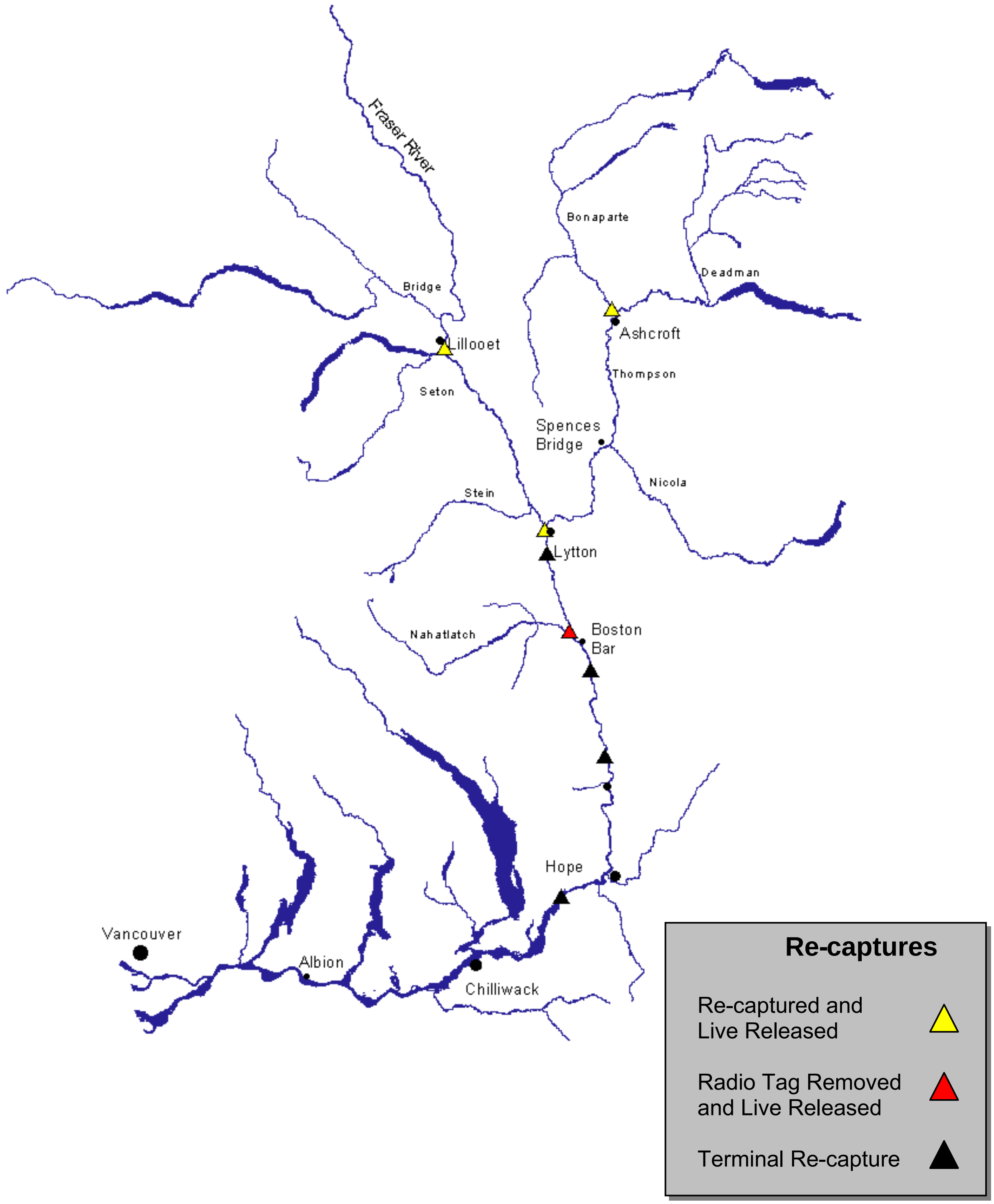

Figure 23. The locations of radio-tagged steelhead re-captured in spring 1997.

Spawning Distribution

Radio Tags Deployed in Fall 1996

Out of the 82 fall radio-tagged steelhead that could potentially enter a tributary monitored by telemetry, 44 (54%) were not detected during the spawning period. Out of the 38 (46%) steelhead that were detected during the spawning period, 18 (50%) entered the Nicola or one of its tributaries (Figure 24). A total of 5 (15%) steelhead entered one of the Fraser tributaries monitored by telemetry with 3 (9%) entering the Chilcotin system and 2 (6%) entering the Bridge River system (Figure 25).

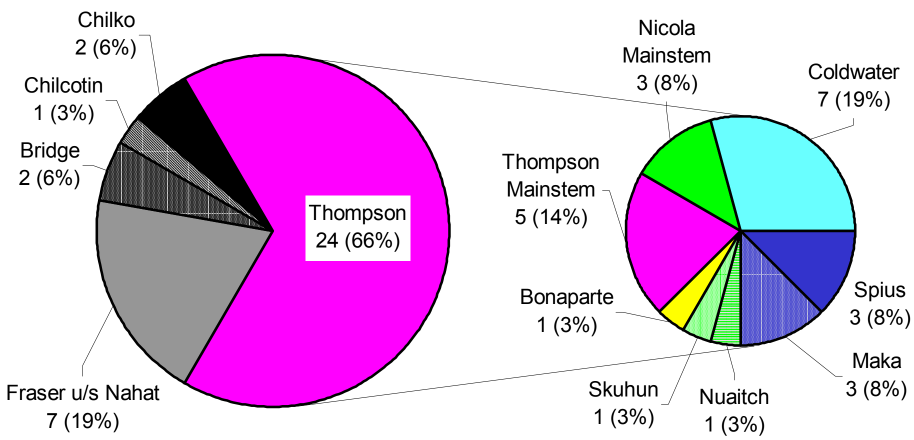

Figure 24. The number and percent of steelhead radio-tagged in the fall of 1996 that were detected in tributaries monitored by telemetry during the spawning period.

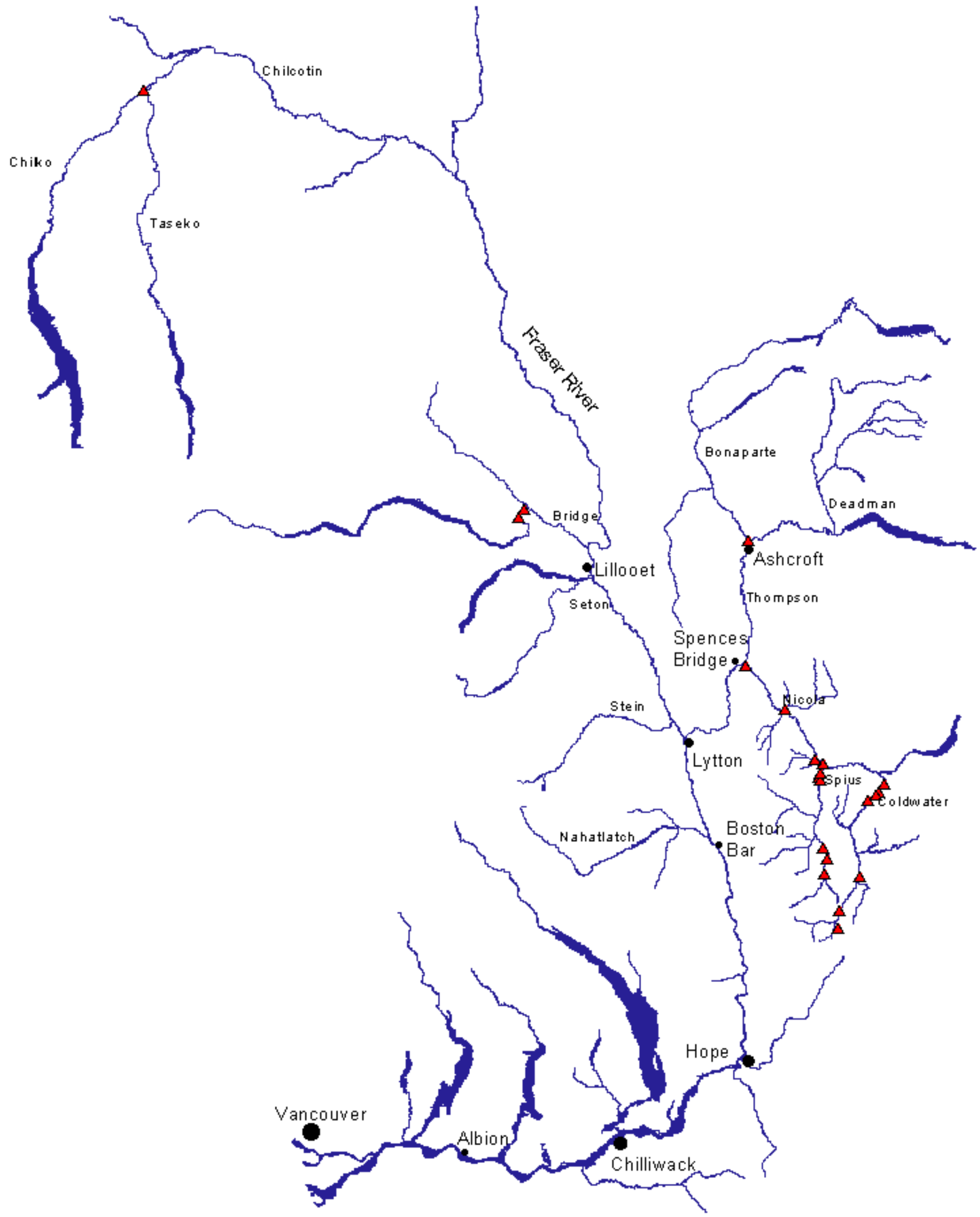

Figure 25. The location of steelhead, radio-tagged in the fall of 1996, detected during the spawning period (mid-April to mid-June) in 1997.

Most radio-tagged steelhead that appeared to have spawned successfully overwintered near their natal stream. Most (77% or 27 out of 35) of the steelhead that were detected downstream of the Nahatlatch/Fraser confluence during the overwintering period never migrated upstream of that point in the spring. These fish were never detected in potential spawning tributaries downstream of the Nahatlatch/Fraser confluence, either. Out of the 8 steelhead that did eventually move upstream of the Nahatlatch/Fraser confluence, only 3 (38%) entered recognized steelhead spawning tributaries (Table 5).

Table 5. The spawning distribution of steelhead radio-tagged in the fall of 1996 in relation to their overwintering distribution.

Overwintering Location	Total	Natal Stream: Unknown	Fraser upstream of Nahatlatch	Bridge	Chilcotin	Thompson	Nicola	Bonaparte
Fraser - downstream of Harrison	8	8						
Fraser - Harrison to Nahatlatch	27	19	4			1	3	
Fraser - Nahatlatch to Chilcotin	8		3	2	2	1		
Chilcotin	1				1			
Thompson	19					3	15	1
Total	63	27	7	2	3	5	18	1

Note: Although the Thompson and Fraser Rivers are not considered natal streams, they are used to designate the highest upstream detection of a radio-tagged steelhead during the spawning period. Radio-tagged steelhead that were not detected upstream of the Nahatlatch/Fraser confluence during the spawning period were classified as unknown. The total refers to the number of steelhead detected in a particular overwintering location that had the potential to enter a spawning tributary.

Radio Tags Deployed in Late-Winter/Spring 1997

The locations used for deploying radio tags in the late-winter/spring of 1997 are somewhat analogous to the overwintering distribution of steelhead radio-tagged in the fall of 1996. A comparison of deployment locations versus natal streams for spring radio-tagged steelhead provides stock composition information for these important areas. In the spring of 1997, 17 (68%) out of 25 of the steelhead radio-tagged in the Lillooet area were detected spawning in the Bridge or Seton Rivers. The remaining 8 radio-tagged steelhead were not detected in any telemetry monitored tributaries during the spawning period. The Lytton area (Thompson Fraser confluence) appeared to hold a diverse mixture of stocks in the spring of 1997. Four (19%) out of the 21 steelhead radio-tagged here entered the Stein River; 4 (19%) more entered the Bridge and Seton Rivers; and 4 (19%) entered the Thompson River system. The remaining 9 steelhead, radio-tagged in the Lytton area, were never detected in a tributary monitored by telemetry during the spawning period (Table 6).

Table 6. The spawning distribution of steelhead radio-tagged in the spring of 1997 in relation to the deployment location.

Capture Location	Total	Natal Stream: unknown	Fraser upstream of Nahatlatch	Nahatlatch	Stein	Seton	Bridge	Thompson	Deadman	Nicola
Hope	5	4		1						
Nahatlatch	19			18	1					
Stein	9				9					
Lytton	21		9		4	1	3	1	1	2
Lillooet	25		8			2	15			
Total	79	4	17	19	14	3	18	1	1	2

Kelt Behavior

Downstream Run Timing

In 1997 telemetry station data suggested that kelts appeared to begin their return to the ocean in about mid-May. The out-migration period appeared to last until early July, with the majority exiting in mid-June. Due to their high rate of migration, kelts have a similar run timing past all of the telemetry stations (Figures 26, 27 and 28). A mean emigration date for radio-tagged kelts past the Nahatlatch telemetry station occurred on May 28th (*SE=3.59, n=14*) and a median emigration date occurred on May 26th. In Hope, a mean emigration date occurred on June 7th (*SE=2.16, n=38*) and a median emigration date occurred on June 11th. Kelt emigration past the Barnston Island telemetry station did not appear to approximate a normal distribution, with a median emigration date occurring on June 12th (*n=20*).

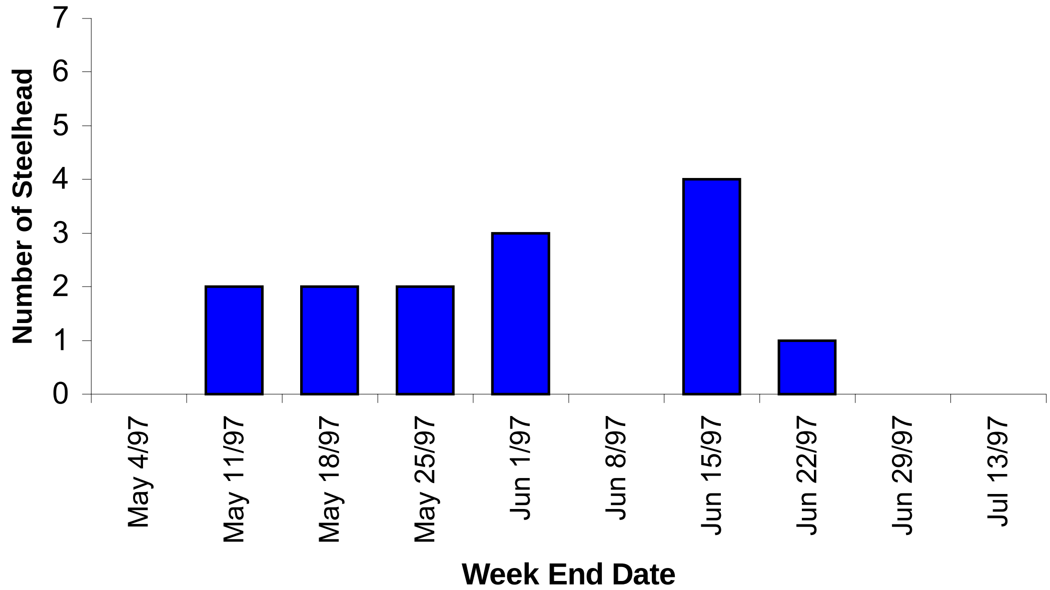

Figure 26. The downstream run timing of interior Fraser steelhead past the Nahatlatch telemetry station in early summer, 1997.

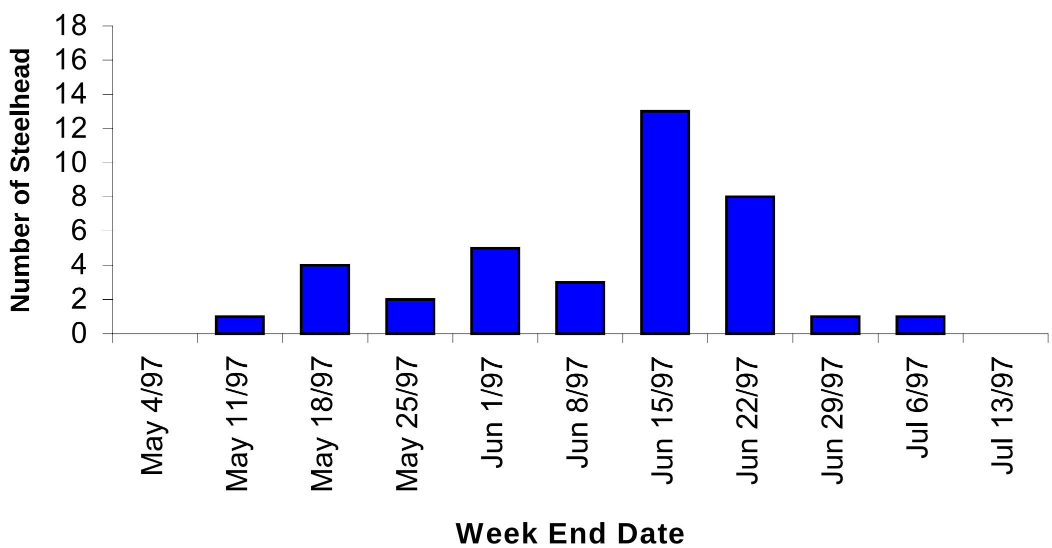

Figure 27. The downstream run timing of interior Fraser steelhead past the Hope telemetry station in early summer, 1997.

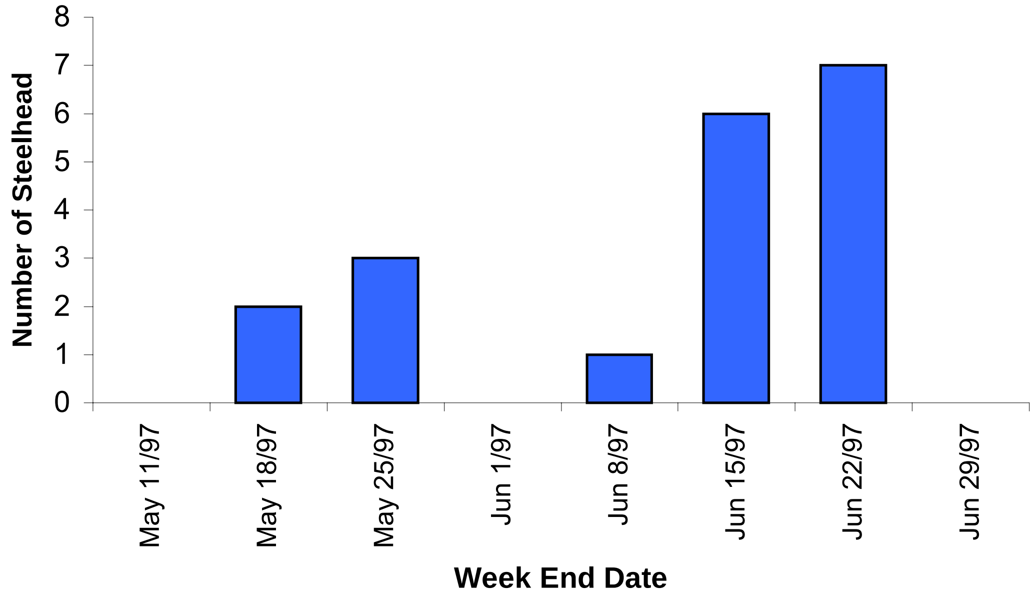

Figure 28. The downstream run timing of interior Fraser steelhead past the Barnston Island telemetry station in early summer, 1997.

Downstream Migration Rates

Kelts appeared to migrate at a high rate downstream. The downstream average migration rate in the Thompson was 14 km/day, although sample sizes were small. The downstream migration rates in the Fraser appear to increase as the steelhead move further downstream. Between Lytton and Nahatlatch and Stein and Nahatlatch the average migration rates are 42 km/day and 28.4 km/day respectively. Through the Fraser Canyon (from the Nahatlatch/Fraser confluence to Hope) the average migration rate increased to 49 km/day. In the lower Fraser, from Hope to Barnston Island, steelhead migration rates averaged 87.2 km/day. Overall, it takes approximately 4 days for an interior Fraser kelt to travel from Lytton downstream through the Fraser to Barnston Island (Table 7).

Table 7. The distance, average number of days and average migration rates for interior Fraser steelhead migrating downstream past telemetry stations in early summer, 1997.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)		
Nicola to Lytton	35	2.45	14.3	2	1.79	0.67	-	4.24
Lytton to Nahatlatch	31.5	0.75	42.3	1	na			
Stein to Nahatlatch	37.5	1.32	28.4	4	0.41	0.46	-	2.37
Nahatlatch to Hope	75	1.53	49.1	15	0.31	0.24	-	3.81
Hope to Barnston Is.	109	1.25	87.5	17	0.19	0.60	-	2.97

Note: In 1997, there were no kelts from the Chilcotin River system and there was no telemetry station at the Bridge/Fraser confluence.

Kelting Rates

Although sample sizes for all but Nicola steelhead stocks were small, kelting rates for steelhead radio-tagged in the fall of 1996, appear to average 38%. Kelting rates for steelhead which were never detected in a known spawning tributary during the spawning period are much lower, at 7% (Table 8), raising the possibility of pre-spawning mortality in these cases. Although Chilcotin steelhead appear to have a very low kelting rate, there is no significant difference between the kelting rate of Chilcotin steelhead and the combined kelting rate of Thompson steelhead (*Chi Square =2.18, P=0.140*).

Table 8. The kelting rates for various stock groupings of interior Fraser River steelhead radio-tagged in the fall of 1996.

Category	River System	Kelts	Radio-Tagged Steelhead	Kelt Rate
Recognized Spawning Tributaries	Bridge	1	2	50%
	Chilcotin	0	3	0%
	Nicola	8	18	44%
	Bonaparte	0	1	0%
	Average of All Systems			**38%**
Unrecognized Spawning Tributaries	Thompson	1	5	20%
	Fraser downstream of Nahatlatch	2	44	5%
	Fraser upstream of Nahatlatch	1	7	14%
	Average of All Systems			**7%**
	Overall Average			**16%**

Kelting rates for steelhead radio-tagged in the spring of 1997 were slightly higher than the fall radio-tagged steelhead, with an average of 46%. This difference however, was not significant (*Chi Square =0.698, P=0.403*). Once again, the kelting rate for fish that did not enter a recognized spawning tributary is considerably lower than for the recognized tributaries, at 27% (Table 9).

Table 9. The kelting rates for various stock groupings of interior Fraser River steelhead radio-tagged in the late winter/early spring of 1997.

Category	River System	Kelts	Radio-Tagged Steelhead	Kelt Rate
Recognized Spawning Tributaries	Nahatlatch	10	19	53%
	Stein	5	14	36%
	Bridge/Seton	9	21	43%
	Nicola	2	2	100%
	Average of All Systems			**46%**
Unrecognized Spawning Tributaries	Thompson	0	1	0%
	Fraser downstream of Nahatlatch	3	4	75%
	Fraser upstream of Nahatlatch	3	17	18%
	Average of All Systems			**27%**
	Overall Average			**41%**

1997/98 Telemetry Program

Fall Deployment

From September 17th to November 8th, 1997, a total of 14 radio tags were deployed in adult steelhead of interior Fraser origin (Figures 3 and 29). Radio tag distribution correlated with small peaks in the Albion CPUE. The Albion test fishing results in 1997 were very different from the test fishing results of 1996. The first large peak in the test-fishing index, which typically occurs in the first week of October, was missing entirely and the second peak in late October only had a maximum CPUE of 0.220 steelhead per thousand fathom-minutes. This compares with a maximum CPUE of 0.700 steelhead per thousand fathom-minutes from the same time period in 1996. The cumulative test-fishing index from 1997 was the third lowest over a 19 year period of record. Only the tangle net fishery near Annacis Island and angling between Hope and Chilliwack captured steelhead for radio tagging in the fall of 1997. The tangle net fishery deployed 9 (64%) radio tags with the majority being captured in the third week of October (Figure 30). Anglers deployed only 5 (36%) radio tags in a sporadic fashion from late-September through to early-November (Figure 31).

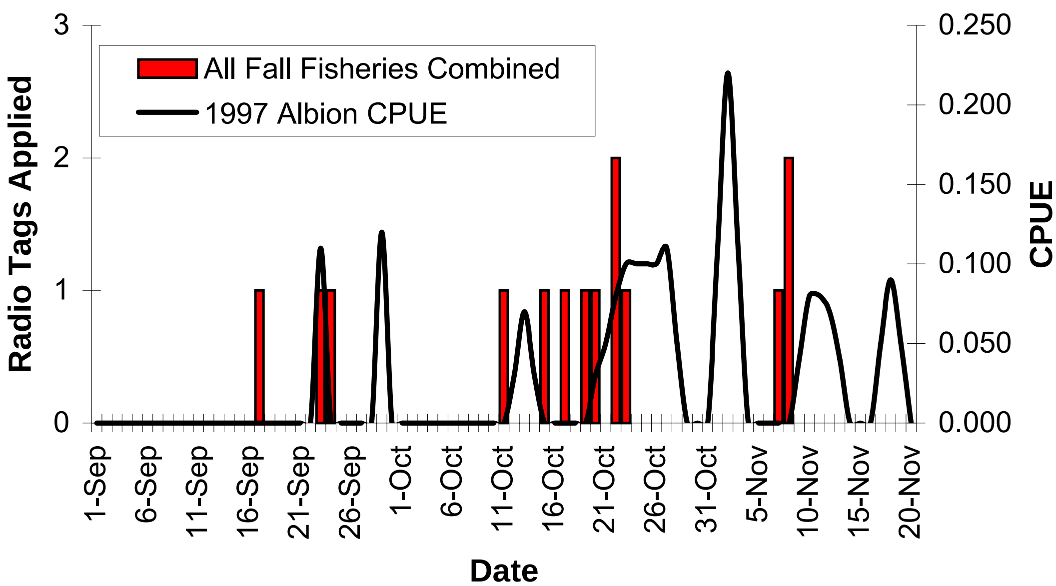

Figure 29. The temporal distribution of radio tags deployed in mature steelhead in the fall of 1997 in relation to the Albion chum test fishing CPUE.

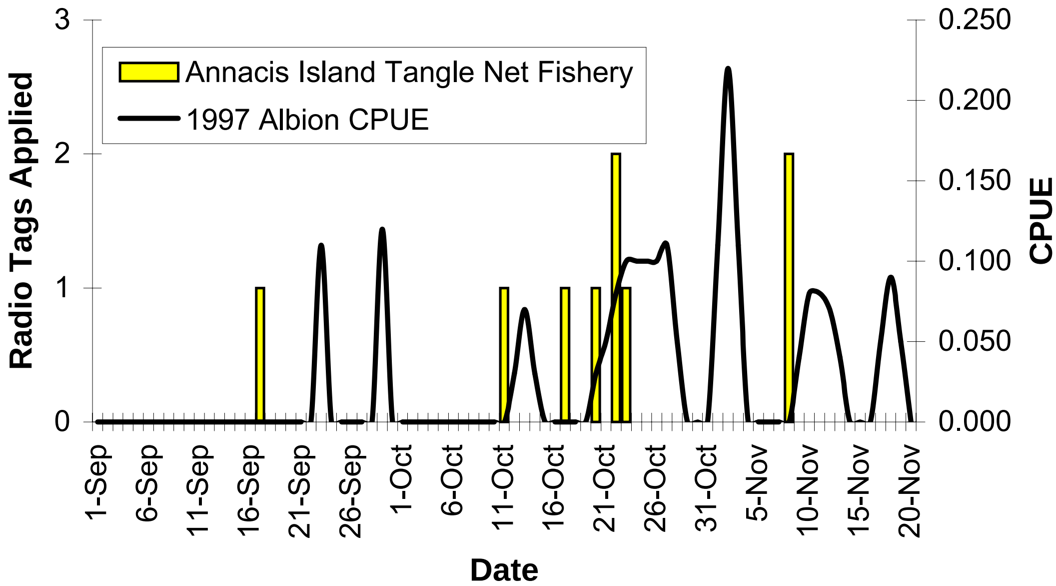

Figure 30. The temporal distribution of radio tags deployed by the Annacis Island tangle net fishery in the fall of 1997 in relation to the Albion chum test fishing CPUE.

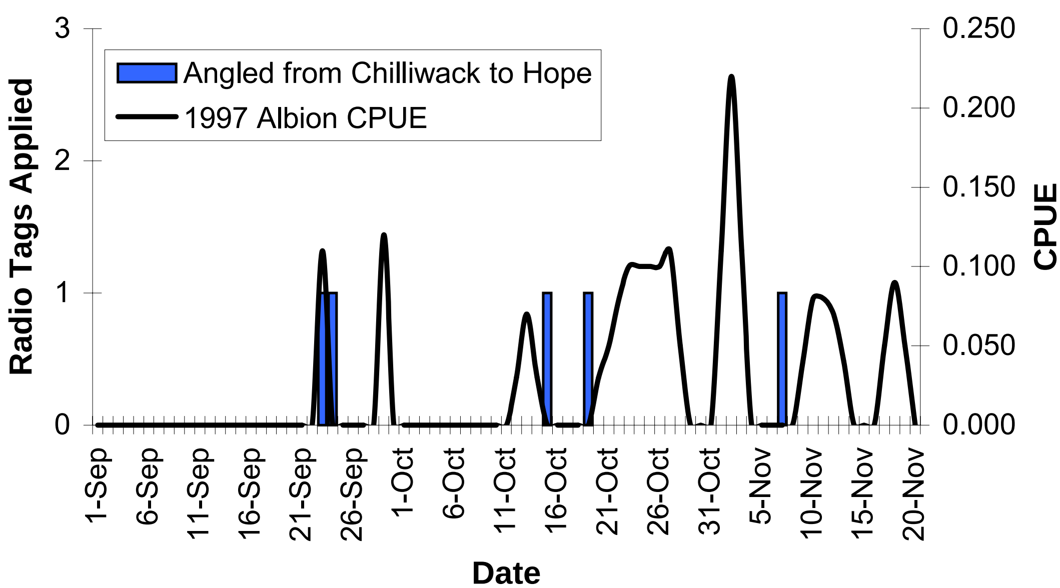

Figure 31. The temporal distribution of radio tags deployed by angling in the fall of 1997 in relation to the Albion chum test fishing CPUE.

Fraser Water Temperature and Discharge

In the central interior of BC, the month of November 1997 was the second warmest on record for the past 20 years (Environment Canada 1997). In the 1997/98 season, average water temperatures in the Fraser did not drop below 4^0C until early December and climbed back above 4^0C by mid-March.

In the winter of 1997/98, both high and low elevation snowpacks were below normal. Although water levels in the fall of 1997 were quite high, freshet in the Fraser River did not begin until late-April of 1998 with a maximum discharge of approximately 6800 m^3/s occurring in early-June (Figure 32).

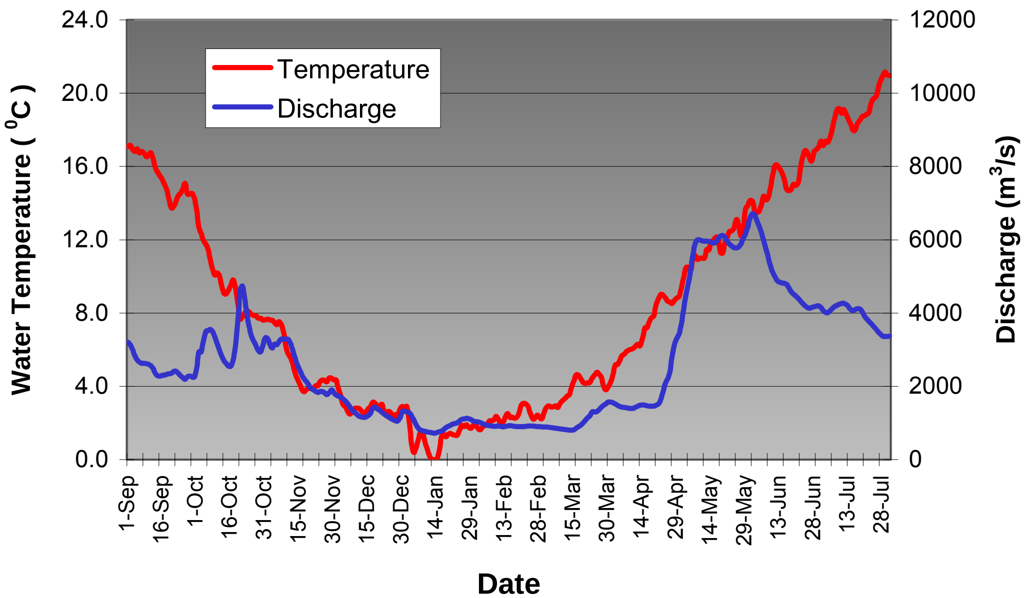

Figure 32. Daily mean water temperature and discharge of the Fraser River taken at Qualark, 1997/98.

Migration Rates

In the fall of 1997, radio-tagged steelhead migrated between the Harrison/Fraser confluence and Hope telemetry stations at an average migration rate of 4.2 km/day and took an average of 9.7 days to complete this section of the Fraser River. Average migration rates for radio-tagged steelhead throughout the remainder of the Fraser River are as follows: 16.7 km/day from Hope to the Nahatlatch/Fraser confluence; 24.7 km/day from the Nahatlatch/Fraser to the Stein/Fraser confluence; 14.5 km/day from the Stein/Fraser to the Bridge/Fraser confluence; and 16.9 km/day from the Bridge/Fraser to the Chilcotin/Fraser confluence. Sample sizes in all cases were very small and only 2 steelhead were recorded upstream of the Nahatlatch/Fraser confluence. Although the average migration rates of radio-tagged steelhead upstream of Hope seem much higher than in 1996, they are still within the range of values recorded in 1996 (Tables 7 and 10). During this period the Lytton telemetry station was located along the Thompson River, approximately 500 m upstream of the Thompson/Fraser confluence and only detected steelhead that had already entered the Thompson River. In the fall of 1997, no radio-tagged steelhead entered the Thompson River. Therefore, only migration rates from the Nahatlatch to the Stein telemetry stations are shown.

Table 10. The average migration times, distances traveled and average migration rates of radio-tagged interior Fraser River steelhead between telemetry stations along the Fraser River in the fall of 1997.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)
Harrison to Hope	41	9.7	4.2	3	1.76	7 - 13
Hope to Nahatlatch	75	4.5	16.7	2	0.50	4 - 5
Nahatlatch to Stein	37	1.5	24.7	2	0.50	1 - 2
Stein to Bridge	58	4.0	14.5	2	0.00	4 - 4
Bridge to Chilcotin	135	8.0	16.9	1	na	na

Fall Run Timing Past Telemetry Stations

In the fall of 1997 only 3 steelhead were recorded moving upstream past the Harrison telemetry station. All 3 of these fish moved past the station on the week ending October 29th (median migration date on October 26th). A total of 6 radio-tagged steelhead were recorded on their upstream migration at the Hope station. Two of these steelhead migrated upstream in the last week of September with 4 more passing the station throughout November (Figure 33). This resulted in a median migration date past the Hope telemetry station on October 29th.

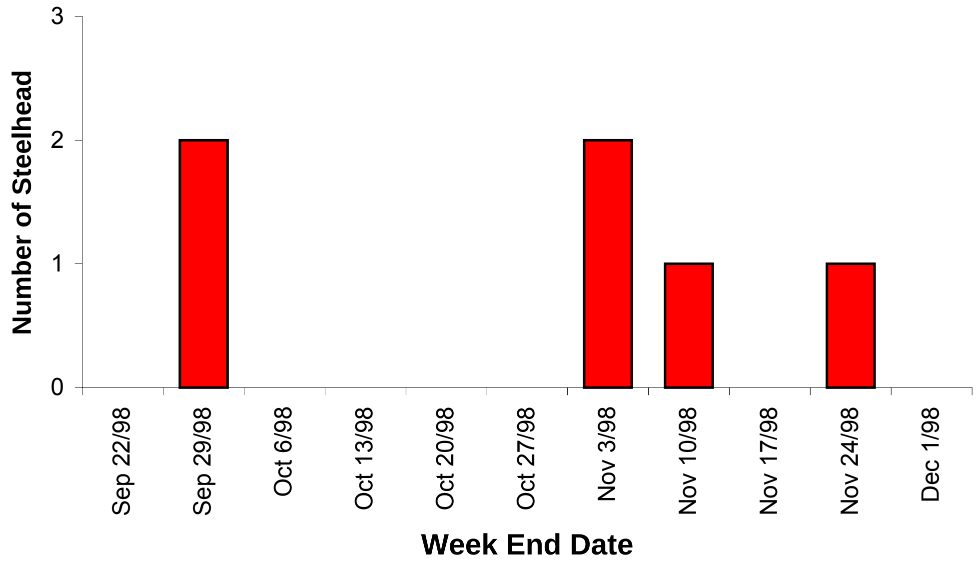

Figure 33. The run timing of interior Fraser steelhead past the Hope Telemetry Station in the fall of 1997.

In the fall of 1997 a telemetry station along the Fraser River near Sawmill Creek was also operational. Four steelhead migrated past this station; 2 in late-September and 3 in late-November/early-December, with a median migration date on October 24th (Figure 34).

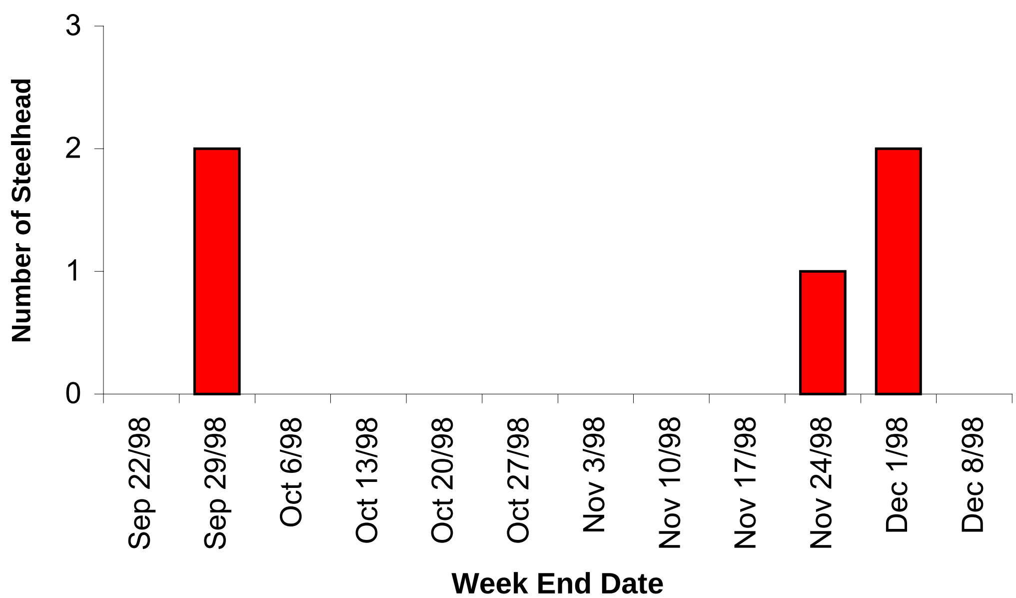

Figure 34. The run timing of interior Fraser steelhead past the Sawmill Creek Telemetry Station in the fall of 1997.

Only 2 (14%) out of the 14 fall radio-tagged steelhead, migrated upstream of the Nahatlatch Fraser confluence. Both of these steelhead migrated past the Nahatlatch and Stein telemetry stations on the week ending October 6th. On the week ending October 13th they passed the Bridge telemetry station, with only one of these steelhead managing to enter the Chilcotin River on October 16th.

Fall Re-captures

There were no reported re-captures in the fall of 1997.

Overwintering Distribution

Due to poor tagging success, designate overwintering flights were not undertaken. Instead a flight to track sturgeon on November 15th was used to simultaneously track for steelhead.

Only 6 (43%) out of 14 fall radio-tagged steelhead were detected during late November. Out of these 6, 2 (33%) were detected near the Harrison/Fraser confluence, 2 (33%) were detected in the Fraser Canyon between Yale and Sawmill Creek, 1 (17%) was detected approximately 10 km upstream of the Bridge/Fraser confluence and 1 (17%) was last detected via the Chilcotin telemetry station entering the Chilcotin River (Figure 35).

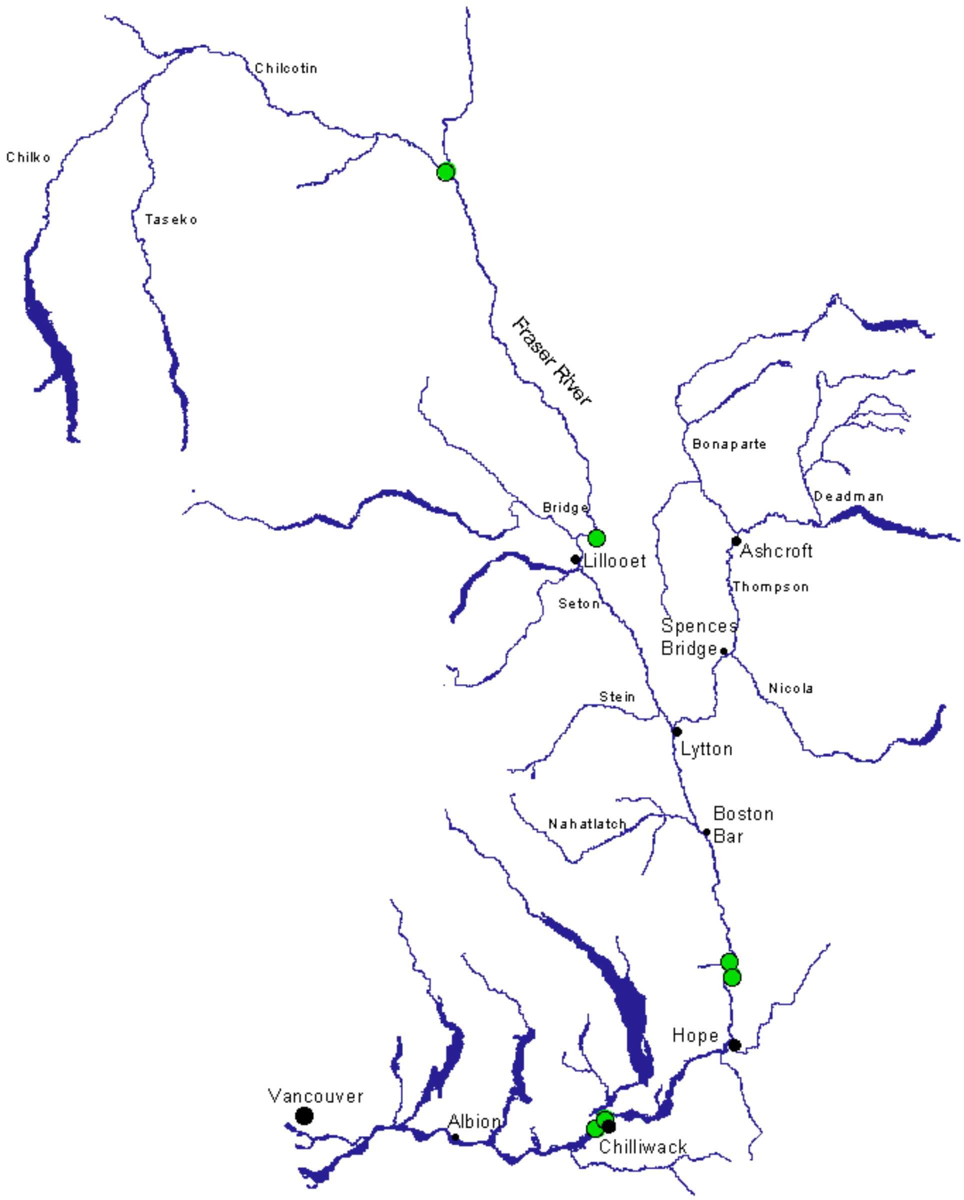

Figure 35. The location of fall radio-tagged steelhead detected by aerial telemetry on November 15, 1997.

Spring Deployment

In the spring of 1998, radio tags were deployed near the Deadman and in the Chilcotin River systems to study spawning distribution and residency times. Twenty-one radio tags were deployed near the Deadman/Thompson confluence from March 26th to April 26th and 16 radio tags were deployed in the Chilcotin River system from March 17th to May 8th. The only exception to this was the deployment of 3 radio tags in the Fraser River from Marguerite upstream to the Quesnel/Fraser confluence, approximately 90-km to 200-km upstream of the Chilcotin/Fraser confluence (Figure 4). These 3 radio tags were deployed on April 23rd and 24th, 1998.

Spring Movement into Spawning Tributaries

The only two telemetry stations to record upstream movement into tributaries in the spring were the Chilcotin and Chilko telemetry stations. Two steelhead (tagged in the Fraser upstream of Marguerite) entered the Chilcotin River on the weeks ending May 4th and May 11th (median date on May 4th), although it is known that Chilcotin steelhead overwinter within the Chilcotin itself. The Chilko telemetry station had 7 steelhead pass by in the first 3 weeks of May and enter the Chilko River. The mean migration date for steelhead to enter the Chilko River occurred on May 8th (*SE=1.64, n=7*), with a median date occurring on May 9th (Figure 36).

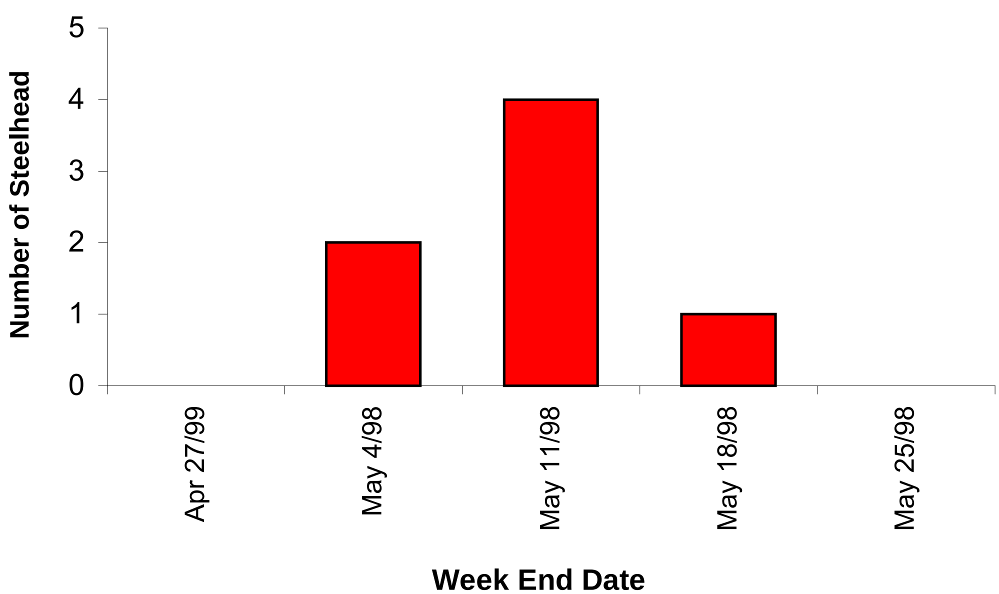

Figure 36. The upstream run timing of interior Fraser River steelhead past the Chilko telemetry station in the spring of 1998.

Spring Re-captures

Only 1 re-capture was reported during the 1997/98-telemetry program. A fall radio-tagged steelhead was re-captured on April 18, 1998, in the Fraser River near Boston Bar in an aboriginal food fishery.

Spawning Distribution

Radio Tags Deployed in Fall 1997

Out of the 6 fall radio-tagged steelhead that had the potential to utilize a monitored tributary, 4 (66%) did not enter a tributary monitored by telemetry during the spawning period (Figure 37). All 4 of these steelhead were detected via aerial telemetry downstream of the Nahatlatch/Fraser confluence during a flight on November 15th. One (17%) radio-tagged steelhead was detected entering the Chilcotin River (via telemetry station) in October of 1997 but was never detected during the spawning period. This steelhead was considered to be from Chilcotin stock although its specific origin could not be determined. The only other steelhead to migrate upstream of the Nahatlatch/Fraser confluence in the fall of 1997 was detected during the spawning period in the same location as it was the previous November. This fish either expelled its tag or died approximately 10 km upstream of the Bridge/Fraser confluence (Table 11).

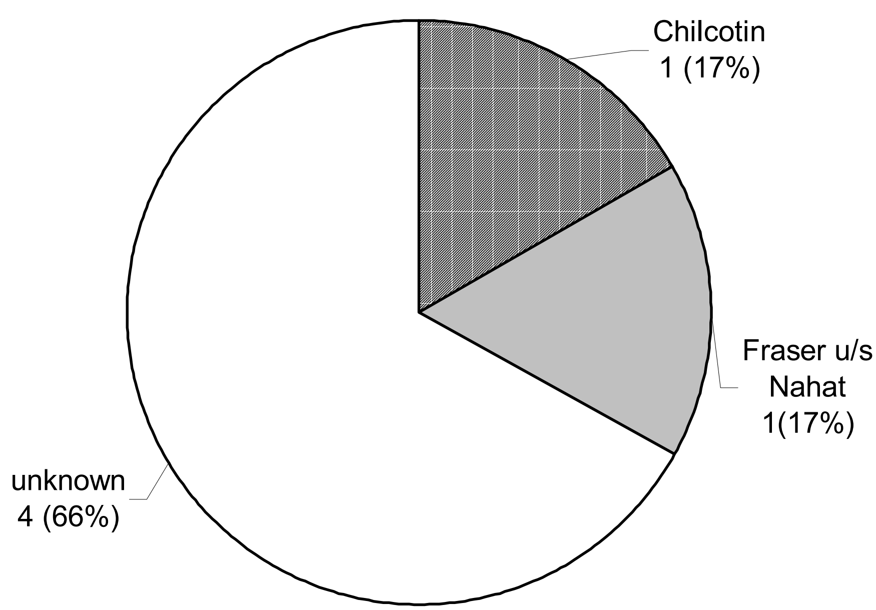

Figure 37. The number and percent of steelhead radio-tagged in the fall of 1997 that were detected in tributaries monitored by telemetry during the spawning period.

Table 11. The spawning distribution of steelhead radio-tagged in the fall of 1997 in relation to their overwintering distribution.

Overwintering Location	Total	Natal Stream: Unknown	Fraser upstream of Nahatlatch	Chilcotin
Fraser - downstream of Harrison	1	1		
Fraser - Harrison to Nahatlatch	3	3		
Fraser - Nahatlatch to Chilcotin	1		1	
Chilcotin	1			1
Total	6	4	1	1

Note: Although the Fraser River is not considered a natal stream it is used to designate the highest upstream detection of a radio-tagged steelhead during the spawning period. Radio-tagged steelhead that were not detected upstream of the Nahatlatch/Fraser confluence during the spawning period were classified as unknown. The total refers to the number of steelhead detected in a particular overwintering location that had the potential to enter a spawning tributary.

Radio Tags Deployed in Late-Winter/Spring 1998

The spawning distribution of steelhead radio-tagged in the spring of 1998 follows a relatively predictable pattern, since a large portion of the radio tags were deployed directly into or very near a known spawning tributary (Table 12).

Out of the 40 radio tags deployed in the spring, 21 were deployed near the Deadman/Thompson confluence and 16 were deployed in the Chilcotin River system. Out of the 21 radio tags deployed near the Deadman/Thompson confluence 2 (10%) spawned in Criss Creek, with the remainder (90%) spawning in the mainstem Deadman River. Fourteen (88%) of the 16 radio tags deployed in the Chilcotin River entered the Chilko River, with 2 (12%) remaining in the Chilcotin mainstem. Of the 3 radio-tagged steelhead captured in the Fraser River between Marguerite and the Quesnel/Fraser confluence: two (66%) of these steelhead moved downstream over 100 km to enter the Chilcotin River system and spawn in the Chilko River. The remaining steelhead (33%) from this group entered the Quesnel River to spawn (Table 12).

Table 12. The spawning distribution of steelhead radio-tagged in the spring of 1998 in relation to the deployment location.

Capture Location	Total	Natal Stream: Deadman	Criss	Chilcotin	Chilko	Quesnel
Deadman/Thompson confluence	21	19	2			
Chilcotin River system	16			2	14	
Fraser North	3				2	1
Total	40	19	2	2	16	1

Kelt Behavior

Downstream Run Timing

In 1998, radio-tagged kelts migrated downstream through the Fraser Canyon starting in late May and concluding in mid-June. The majority of radio-tagged steelhead appeared to exit in the week ending May 25th. The downstream run timing past the Nahatlatch (*n=10*) and Hope (*n=9*) telemetry stations was nearly identical, with median migration dates occurring on May 22nd and May 23rd respectively (Figures 38 and 39).

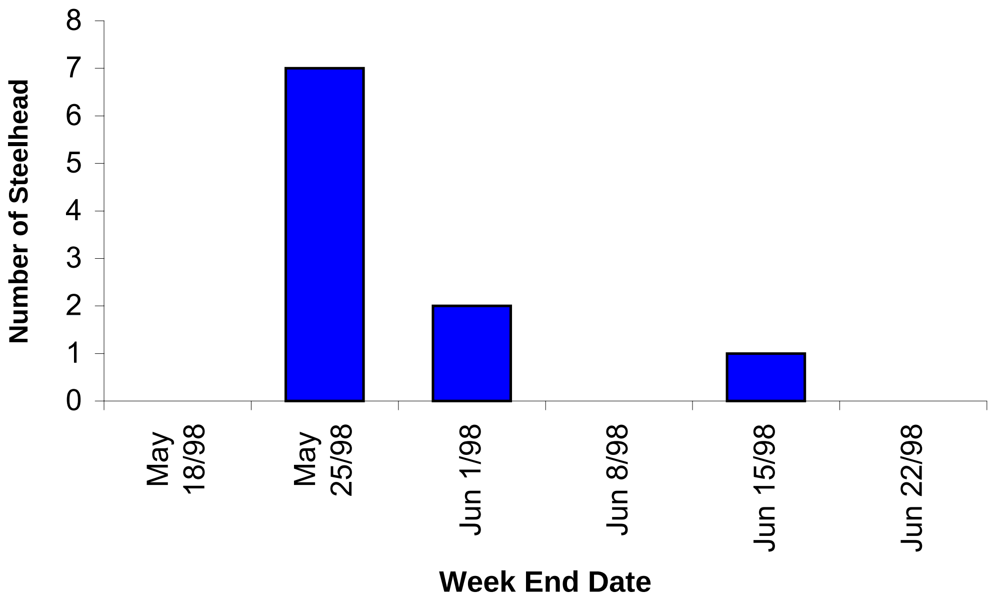

Figure 38. The downstream run timing of interior Fraser steelhead past the Nahatlatch telemetry station in early summer, 1998.

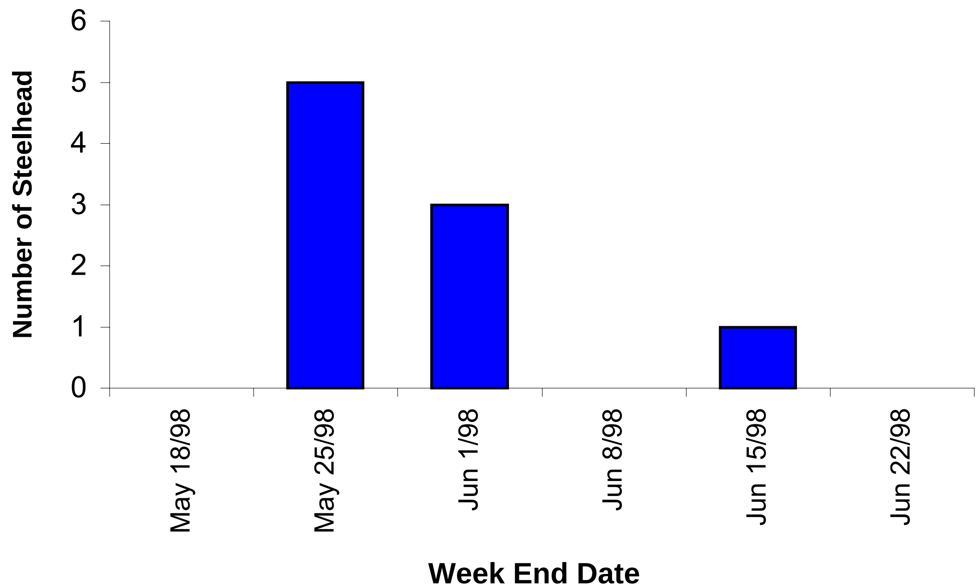

Figure 39. The downstream run timing of interior Fraser steelhead past the Hope telemetry station in early summer, 1998.

Downstream Migration Rate

Only one radio-tagged kelt was detected at both the Chilcotin and Bridge telemetry stations. This steelhead took just over 4 days to travel the 132 river km at an average migration rate of 31.7 km/day. The average downstream migration rate between the Bridge and Nahatlatch telemetry stations increased considerably, with an average migration rate of 105 km/day. Exiting Deadman River steelhead traveled at a slower average migration rate of 37.3 km/day from the Lytton to the Nahatlatch telemetry station. The highest average migration rates once again occurred further downstream. Steelhead migrated downstream from the Nahatlatch to the Hope telemetry station at an average migration rate of 115 km/day (Table 13).

Table 13. The distance, average number of days and average migration rates for interior Fraser steelhead migrating downstream past telemetry stations in early summer, 1998.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)		
Chilcotin to Bridge	132	4.16	31.7	1	na		na	
Bridge to Nahatlatch	94.5	0.90	105.1	3	0.128	0.74	-	1.15
Lytton to Nahatlatch	31.5	0.85	37.3	5	0.287	0.27	-	1.65
Nahatlatch to Hope	75	0.65	115.5	9	0.097	0.36	-	1.34

Kelting Rates

Only one radio-tagged steelhead from the fall of 1997 entered a recognized steelhead spawning tributary (the Chilcotin River). This steelhead also made a downstream migration. None of the other fall radio-tagged steelhead were detected migrating downstream past Hope in the early summer of 1998.

Steelhead, with radio-tags deployed in the spring of 1998 showed relatively low kelting rates. The Quesnel and Chilcotin Rivers had kelting rates of 0% and 17% respectively. The Deadman River had a somewhat higher kelting rate of 29% (Table 14). There was no significant difference in the kelting rates of Chilcotin and Deadman steelhead, radio-tagged in the spring of 1998 (*Chi Square = 1.25, P=0.264*).

Table 14. The kelting rates for various stock groupings of interior Fraser River steelhead radio-tagged in the late-winter/early spring of 1998.

River System	Kelts	Radio-Tagged Steelhead	Kelt Rate
Quesnel	0	1	0%
Chilcotin	3	18	17%
Deadman	6	21	29%
Average of All Systems			**23%**

1998/99 Telemetry Program

Fall Deployment

From September 13th to November 23rd, 1998, a total of 105 radio tags were deployed in adult steelhead in the Fraser River mainstem, downstream of Yale (Figures 3 and 40). One radio tag was also applied on December 15, 1998 in the Nahatlatch River (Hagen 2000). For clarity, only the temporal distribution of radio tags deployed in the lower Fraser River will be presented in this section.

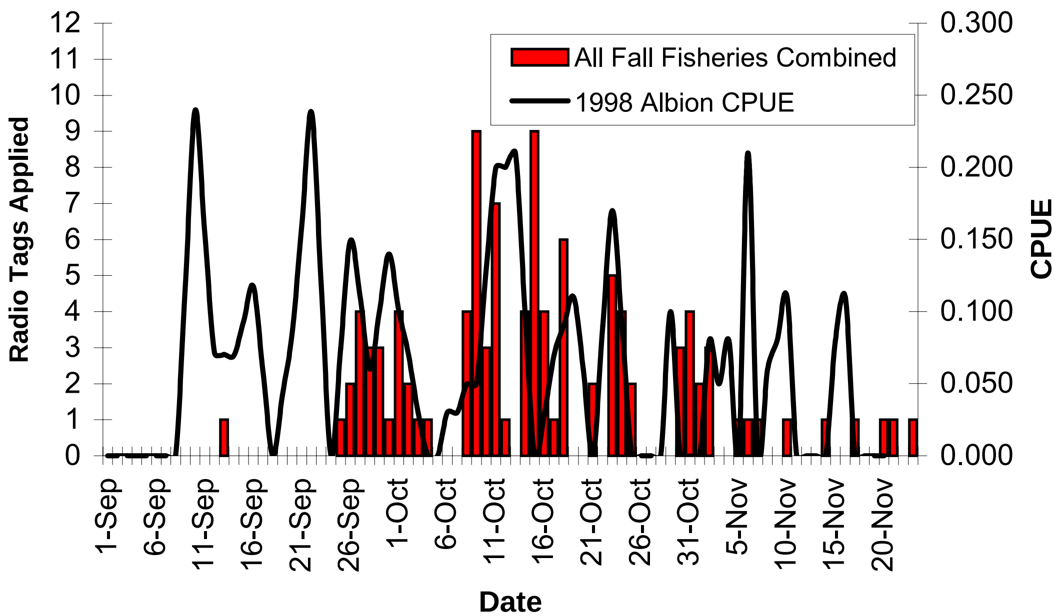

Figure 40. Temporal distribution of radio tags deployed in mature steelhead in the fall of 1998 in relation to the Albion Chum Test Fishing CPUE.

Tag deployment in the fall of 1998 generally follows the test-fishing index after the third week in September. There appears to be a peak in abundance in early September that is not well represented by radio tags. When comparing the temporal distribution of radio tags between years it is important to note the scale of the Albion CPUE axis. In 1996, CPUE's reached nearly 0.70 steelhead per thousand fathom-minutes whereas in 1998, CPUE's reached only 0.25 steelhead per thousand fathom-minutes.

Out of the 105 radio tags deployed in the lower Fraser in the fall of 1998, 16 (15%) were deployed by the tangle net fishery near Annacis Island, 3 (3%) were deployed in the Dearby Reach beach seine fishery, 47 (45%) were deployed between Hope and Chilliwack by anglers and 39 (37%) were deployed by a fishwheel operated in the Fraser Canyon, near Yale (Figures 41, 42, 43 and 44).

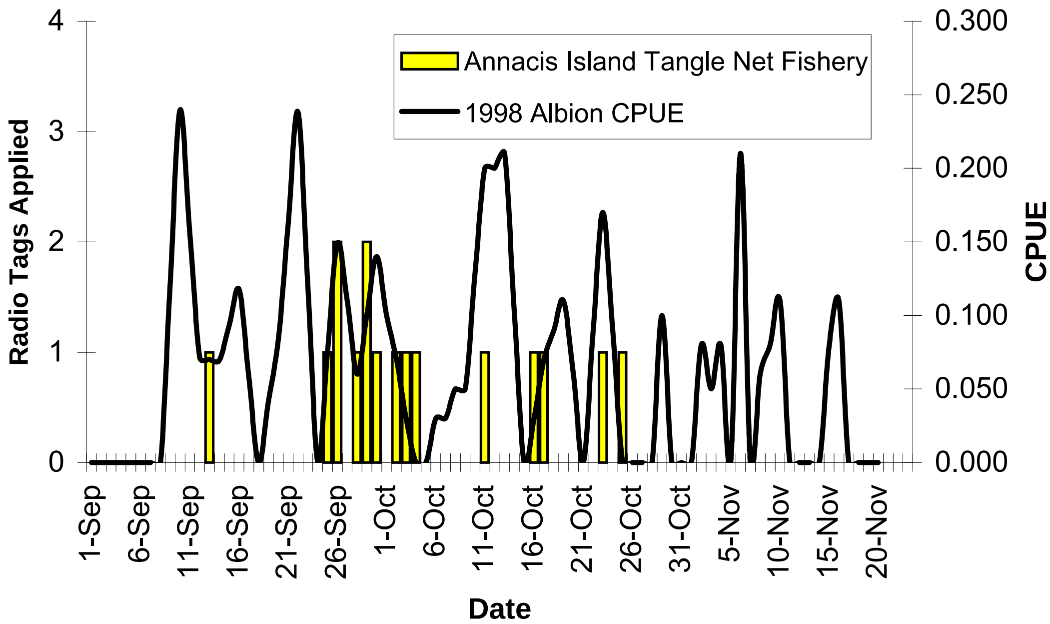

Figure 41. Temporal distribution of radio tags deployed in Annacis Island tangle net fishery in the fall of 1998 in relation to the Albion chum test fishing CPUE.

The tangle net appears to have had the most success deploying radio tags during late-September/early-October but also deployed a few radio tags in late-October. Similar to 1996 results, increased catches by the tangle net fishery precedes spikes in the Albion CPUE by 1 to 3 days (Figures 8 and 41).

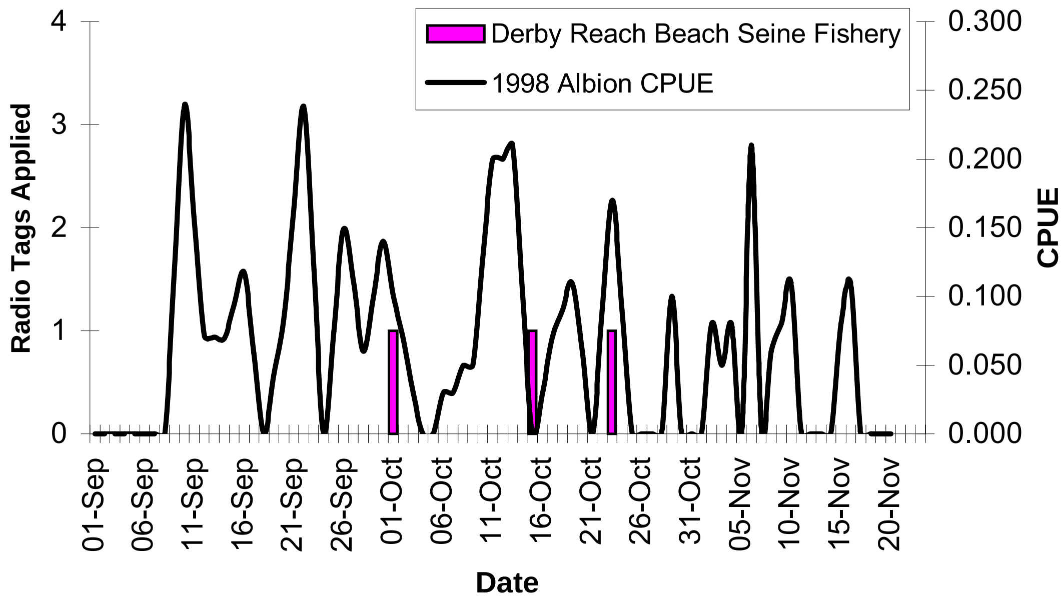

Figure 42. Temporal distribution of radio tags deployed in the Derby Reach beach seine fishery in the fall of 1998 in relation to the Albion chum test fishing CPUE.

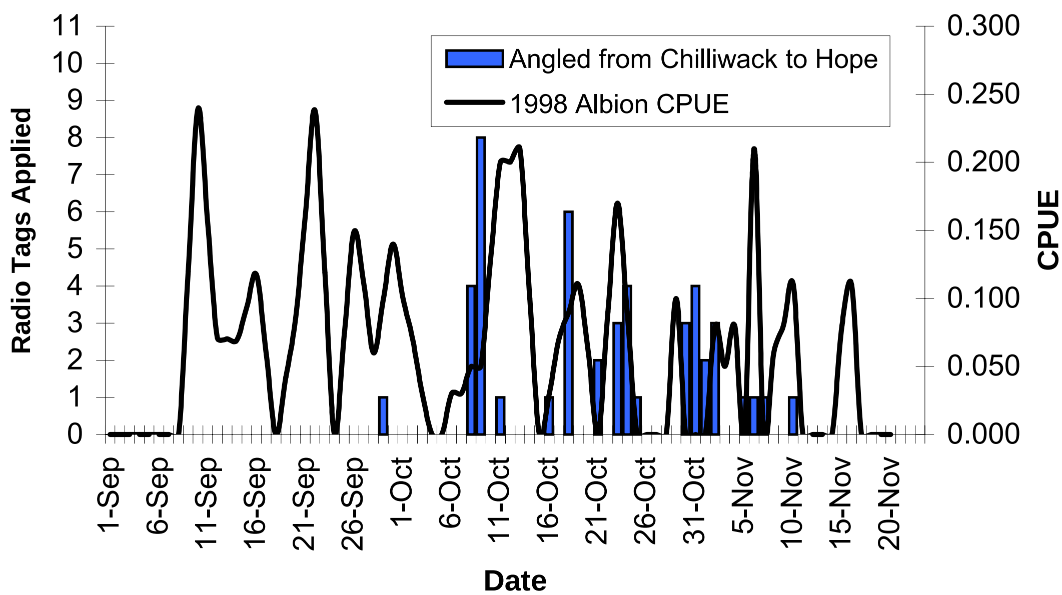

Figure 43. Temporal distribution of radio tags deployed by anglers between Chilliwack and Hope in the fall of 1998 in relation to the Albion chum test fishing CPUE.

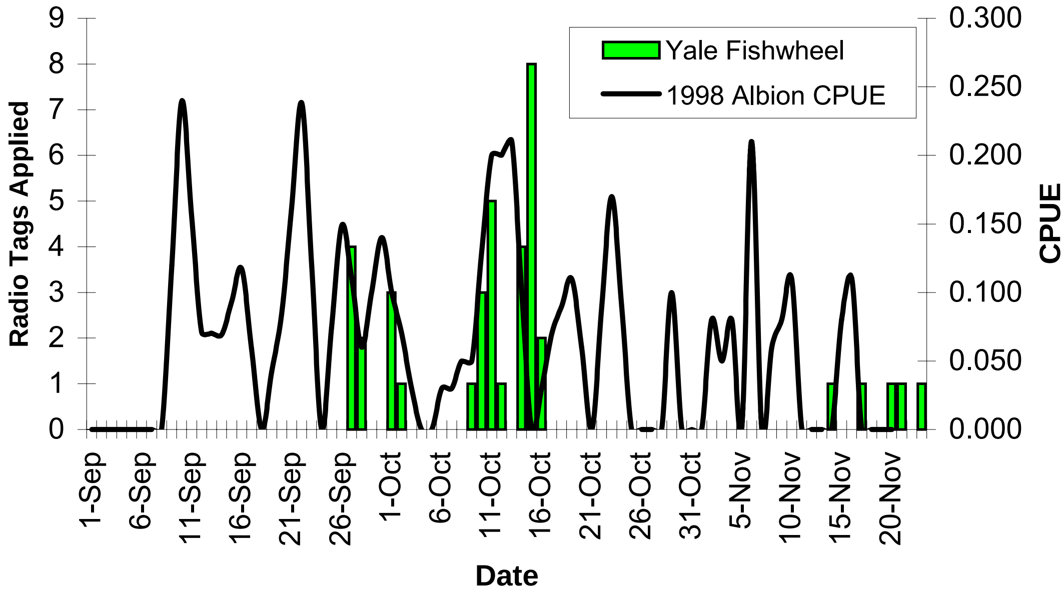

Figure 44. Temporal distribution of radio tags deployed by the Yale Fishwheel in the fall of 1998 in relation to the Albion Chum Test Fishing CPUE.

Fraser Water Temperature and Discharge

The fall of 1998 was relatively warm and as a result, Fraser River water temperatures remained above 4 ^{0}C until mid-November, a full month later than in 1996 (Figure 44). Although the fall and winter of the 1998/99 season was relatively mild, high elevation snowpack levels were very high. A cool spring in 1999 however, delayed the onset of freshet until mid-May. This is in contrast to the mid-April onset of freshet in the spring of 1997 (Figure 12).

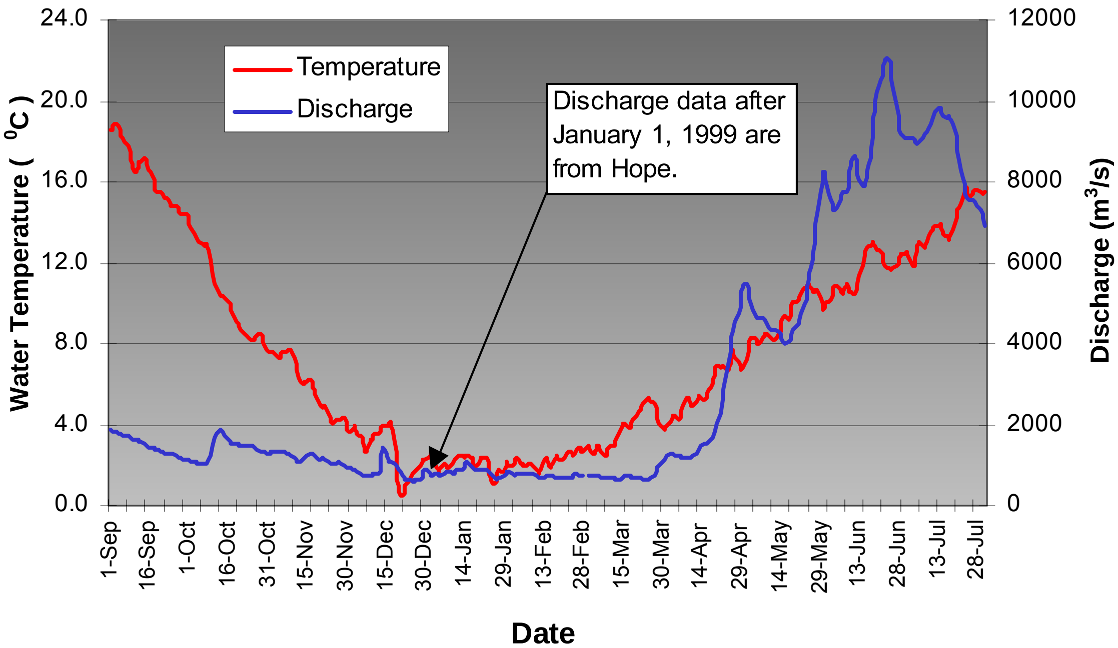

Figure 45. Daily mean water temperatures and discharge of the Fraser River taken at Qualark in 1998 and at Hope after January 1, 1999.

Migration Rate

In the fall of 1998, radio-tagged steelhead traveled from the Harrison/Fraser confluence to Hope at and average migration rate of 7.63 km/day, taking on average 5.37 days to cover the 41-km distance. This stretch of the Fraser River has the lowest migration rates in each of the 3 years telemetry studies were conducted even though it is likely one of the easiest to navigate in terms of gradient and water temperatures (Table 15).

Table 15. The average migration times, migration rates and distances traveled by radio-tagged interior Fraser River steelhead between telemetry stations along the Fraser River in the fall of 1998.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)
Harrison to Hope	41	5.37	7.63	14	0.686	1.35 - 9.92
Hope to Nahatlatch	75	8.01	9.36	45	0.767	2.54 - 27.59
Nahatlatch to Lytton	31	2.04	15.22	47	0.291	0.72 - 12.96
Lytton to Bridge	64	3.97	16.12	1	na	na

Migration between Hope and the Nahatlatch/Fraser confluence took an average of 8.01 days at an average migration rate of 9.36 km/day. Upstream of the Nahatlatch/Fraser confluence, migration rates appeared to increase. Radio-tagged steelhead traveled from the Nahatlatch/Fraser confluence to Lytton at an average migration rate of 15.22 km/day, taking an average of 2.04 days to complete the distance. Due to an equipment malfunction at the Bridge telemetry station, only one steelhead was tracked between Lytton and the Bridge/Fraser confluence. This lone steelhead had a migration rate of 16.12 km/day and completed the 64-km distance in just less than 4 days. In all cases, migration rates in the fall of 1998 appear faster than in the fall of 1996 and with lower variance. It is difficult however, to make direct comparison between years because of the variations in sample size, sampling (capture) methods and the stock composition of samples. In 1996 the vast majority of fall radio-tagged steelhead were of Thompson origin whereas in 1998 there is a much higher portion of Chilcotin steelhead in the samples.

Fall Run Timing Past Telemetry Stations

In the fall of 1998, radio-tagged steelhead migrated past the Harrison telemetry station at a relatively constant rate with no clear peak in abundance. The range of dates of steelhead passing the station span a full 3 months, from the 3rd week in September to the 3rd week in November, with a median migration date on October 22nd (*n=8*; Figure 46).

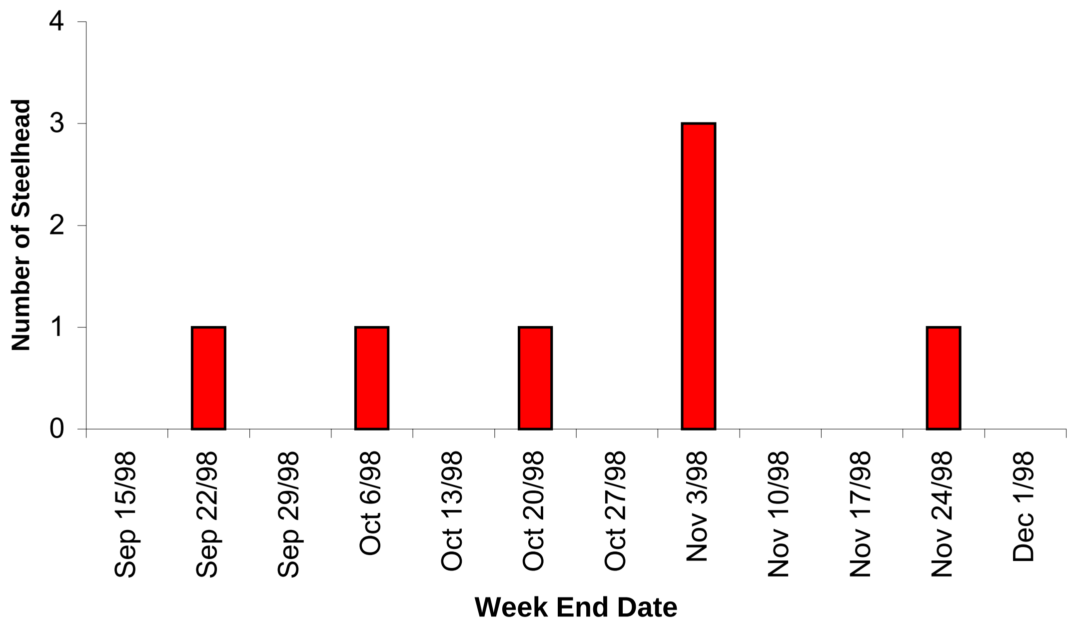

Figure 46. The upstream run timing of interior Fraser River steelhead past the Harrison telemetry station in the fall of 1998.

Since fewer steelhead were captured downstream of Harrison in 1998, the sample size of steelhead migrating past the station is much smaller than in 1996. Both 1996 and 1998 seem to show a slight peak in abundance in the first week in November (Figures 14 and 46).

Run timing past the Hope telemetry station in 1998 appears to be similar to that of 1996. The peak run timing date in 1998 was on October 27th (*SE=1.54, n=48*), one day later than in 1996 (Figure 15). Run timing dates in 1998 ranged from early-October to late-November, with a median migration date occurring on October 28th (Figure 47).

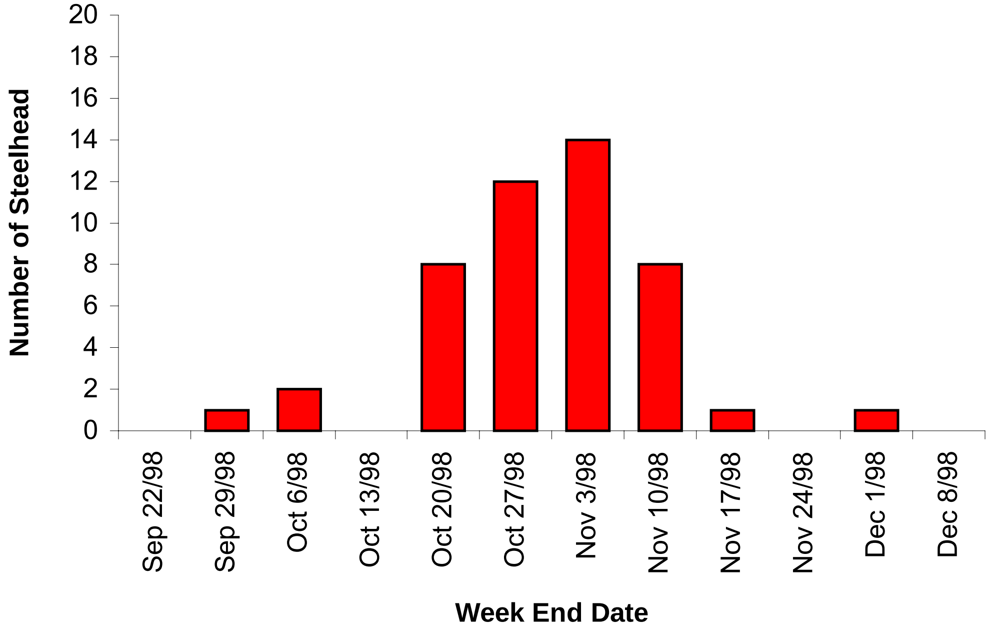

Figure 47. The upstream run timing of interior Fraser River steelhead past the Hope telemetry station in the fall of 1998.

In the fall of 1998, steelhead radio-tagged by the Yale Fishwheel (37% of the total captured) were not detected by the Hope telemetry station. This is in contrast to 1996 results, when the Hope telemetry station had the potential to detect 98% of the radio tags deployed in the fall.

The majority of radio-tagged steelhead migrated past the Nahatlatch telemetry station from the 1st week in October to the 3rd week in November, with a peak run timing date on October 30th (*SE=2.02, n=70*), nearly one week earlier than in 1996 (Figures 16 and 48). The median migration date at the Nahatlatch telemetry station occurred on October 29th in 1998, approximately 9 days earlier than the median date from 1996.

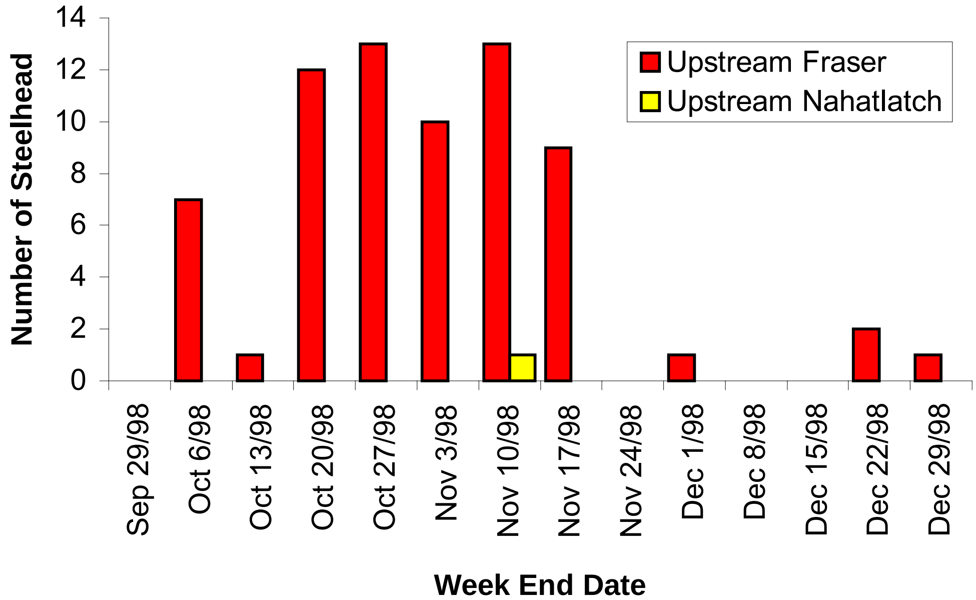

Figure 48. The upstream run timing of interior Fraser River steelhead past the Nahatlatch telemetry station in the fall of 1998.

Run timing in 1996 also appeared somewhat truncated, with migration past the fixed station coming to an abrupt halt in early December. In 1998 however, small groups of steelhead continued to migrate past the station right through the month of December. In 1998, the Nahatlatch telemetry station also recorded the first fall radio-tagged steelhead to enter the Nahatlatch River.

In 1998, the Lytton telemetry station was relocated to cover both the Fraser and Thompson Rivers. It was installed and operating on October 20, 1998 and appears to have missed several radio-tagged steelhead migrating upstream in the Fraser River and therefore it is difficult to determine a mean or median migration date for these steelhead (Figure 49). Steelhead appear to enter the Thompson River later than steelhead migrating upstream in the Fraser, with a mean migration date occurring on November 10th (*SE=3.06, n=34*). The median migration date for radio-tagged steelhead entering the Thompson River occurred on November 6th. Steelhead entering the Thompson River in 1998 demonstrated a much more definitive and earlier peak in their run timing than in 1996 (Figures 20 and 49).

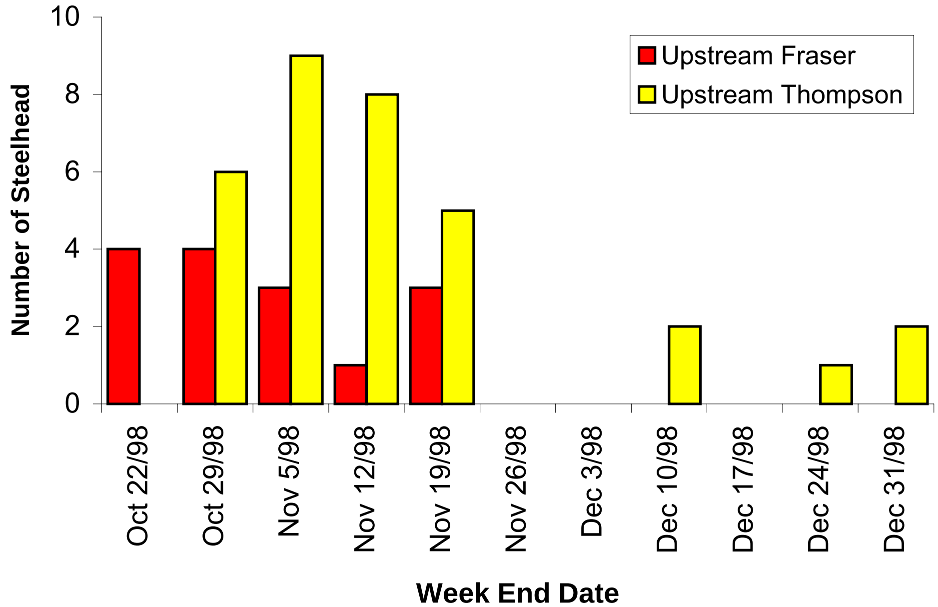

Figure 49. The upstream run timing of interior Fraser River steelhead past the Lytton telemetry station in the fall of 1998.

Radio-tagged steelhead were detected migrating past the Bridge/Fraser confluence at a constant rate starting in early-October and continuing until the 2nd week in November (Figure 50).

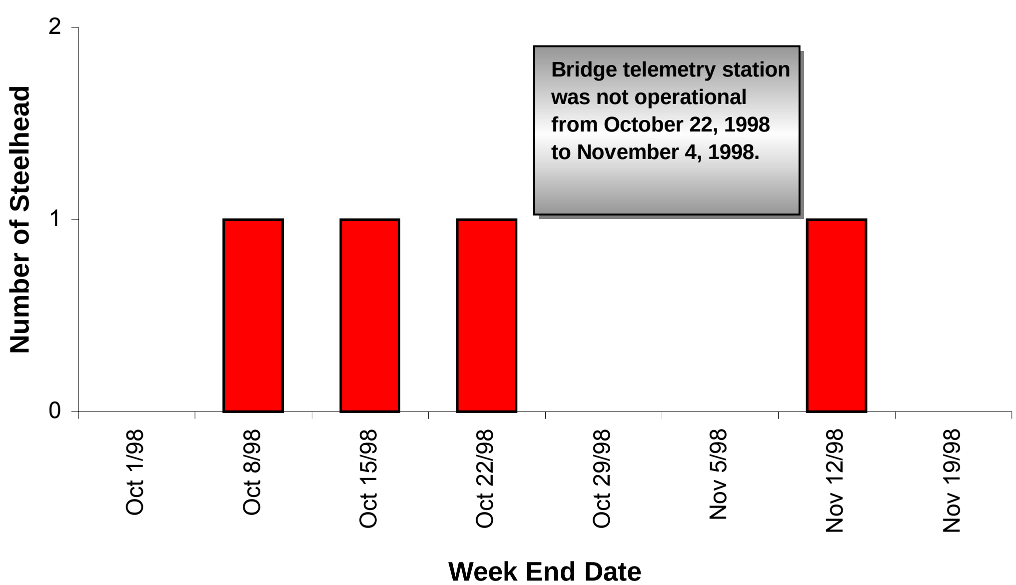

Figure 50. The upstream run timing of interior Fraser River steelhead past the Bridge telemetry station in the fall of 1998.

It is likely that the peak migration time for steelhead travelling upstream in the Fraser past the Bridge telemetry station occurred shortly after the telemetry receiver in that station malfunctioned and was being serviced (late-October/early-November). Eight fall radio-tagged steelhead were located in the Chilcotin and Fraser Rivers upstream of this station that were not detected by it, and are assumed to have passed by during the period the receiver was not in operation. As a result, mean and median migration dates were not calculated.

The Chilcotin telemetry station was installed and operational on November 20th, 1998 but did not detect any radio-tagged steelhead in the fall of 1998. However, a tracking flight on that date showed that all radio-tagged steelhead that entered the Chilcotin River that fall had already done so.

Fall Re-captures

During the fall migration period, 5 (4.7%) of the 106 fall radio-tagged steelhead were reported as re-captured. All steelhead re-captured in the fall were live released. One angler caught steelhead had its radio tag accidentally removed and was no longer detectable. Overall, 3 steelhead were re-captured by anglers in the Thompson River near Skihist Park, at the Thompson/Fraser confluence in Lytton and in the Chilcotin River. One radio-tagged steelhead was re-captured by the fishwheel in Yale and another was re-captured in a gill net in the Fraser River near the Stave/Fraser confluence (Figure 51).

Overwintering Distribution

Out of the 106 radio tags deployed in the fall of 1998, 80 (75%) were detected by aerial telemetry during the overwintering period from late-January to early-March. Out of the 80 radio-tagged steelhead detected during the overwintering period, 8 (10%) were detected in the Fraser River downstream of the Nahatlatch/Fraser confluence. This is in contrast to the 56% and 66% detected downstream of the Nahatlatch/Fraser confluence in the 1996/97 and 1997/98 seasons respectively. Of the 72 steelhead that overwintered upstream of the Nahatlatch/Fraser confluence, 2 (3%) overwintered in the Nahatlatch River itself, 20 (28%) overwintered in the Fraser River from the Nahatlatch/Fraser confluence to the Chilcotin/Fraser confluence and 10 (14%) overwintered in the Chilcotin River system. Two (3%) radio-tagged steelhead were detected during the overwintering period in the Fraser River upstream of the Chilcotin/Fraser confluence and 38 (53%) radio-tagged steelhead overwintered in the Thompson River (Figure 52).

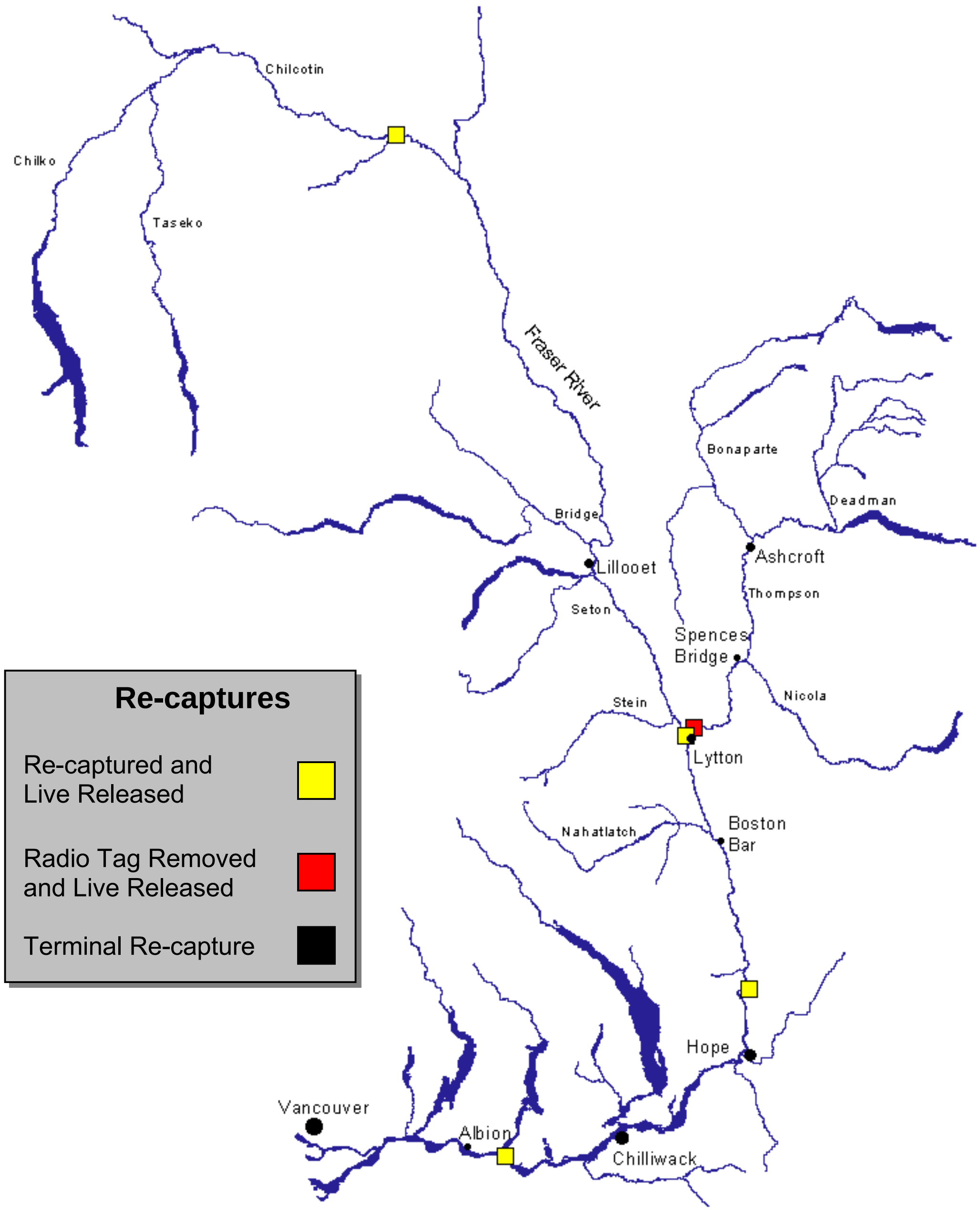

Figure 51. The location of radio-tagged steelhead re-captured in the fall of 1998.

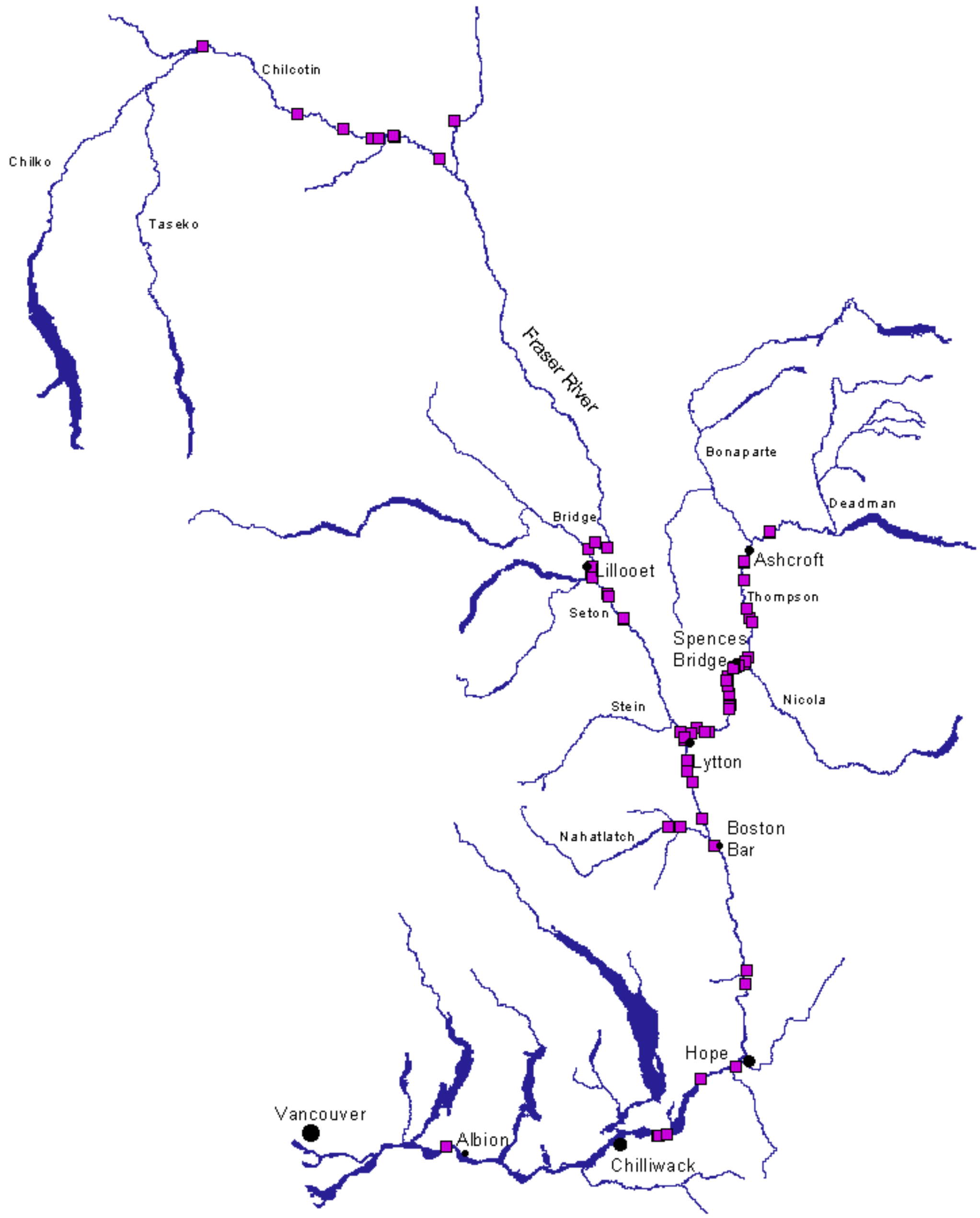

Figure 52. The location of fall radio-tagged steelhead detected by aerial telemetry during the overwintering period (January to mid-March, 1999).

Spring Deployment

To augment the number of radio-tagged steelhead entering spawning tributaries for stock assessment purposes (Hagen 2000; Hagen 2001a; Hagen 2001b; McCubbing *et al.* 2000; Webb *et al.* 2000a; Webb *et al.* 2000b) and to further study the stock composition of key overwintering areas, 93 radio tags were deployed in the late-winter/early spring of 1999. Out of the 93 radio tags, 13 were deployed in the Lytton area from February 24th to March 19th, 14 were deployed near the Seton/Fraser confluence from February 23rd to April 17th, 2 were deployed near the Bridge/Yalakom confluence on May 6th and 21st and 20 were deployed in the Chilcotin River system from March 12th to May 4th. In the Thompson River, 20 were deployed in the Spences Bridge area from March 3rd to April 13th and 24 were deployed near the Deadman/Thompson confluence from March 23rd to May 12th (Figure 4).

Spring Movement into Spawning Tributaries

The resumption of upstream migration after the overwintering period occurred in a relatively consistent fashion at most telemetry stations in the spring of 1999. With the exception of the Nahatlatch and Chilcotin Rivers, the peak of entry timing into monitored spawning tributaries was during the 3rd week of April .

Only one radio-tagged steelhead entered the Nahatlatch River during the upstream migration period, on April 11th. The Lytton telemetry station also only detected one steelhead during this period, moving upstream in the Thompson on March 1st. The Lytton station would have likely detected more radio-tagged steelhead moving upstream during this period but it was dismantled and re-assembled at the Nicola/Thompson confluence on March 2nd. Once operational, the Nicola telemetry station began recording movement immediately in the first week of March and detected radio-tagged steelhead migrating past it up until the 3rd week in May (Figure 53). Radio-tagged steelhead moving upstream in the Thompson past the Nicola station had a median migration date on April 9th ($n=10$). Radio-tagged steelhead were detected entering the Nicola River approximately 2 weeks later than radio-tagged steelhead migrating upstream in the Thompson, with a mean migration date on April 12th ($SE=2.53$, $n=36$) and a median migration date occurring on April 18th.

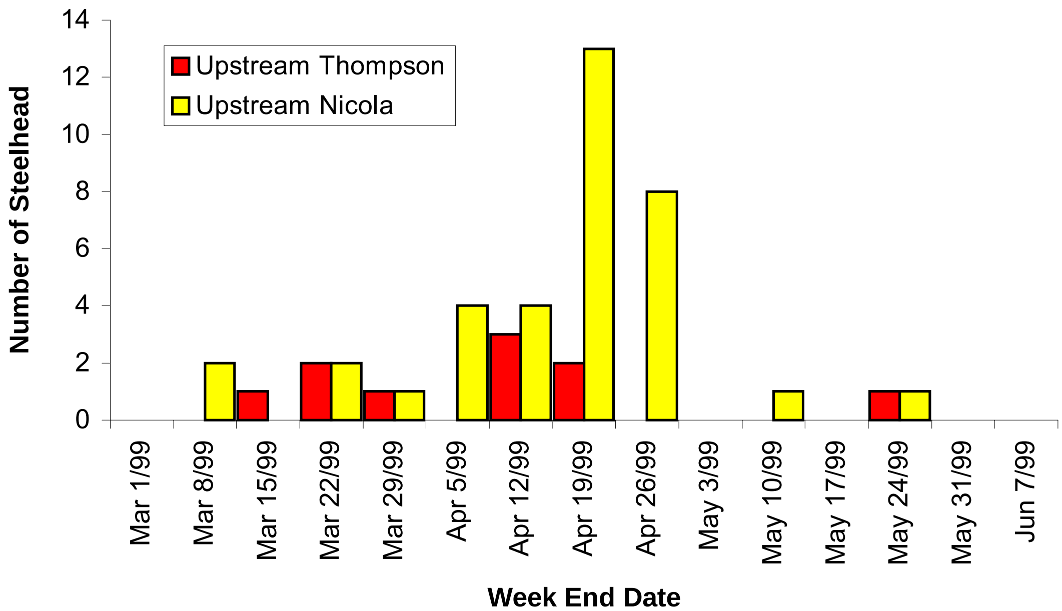

Figure 53. The upstream run timing of interior Fraser River steelhead past the Nicola telemetry station in the spring of 1999.

The majority of radio-tagged steelhead were detected by the Bonaparte telemetry station over a period of 3 weeks, from mid-April to the first week in May. The mean migration date for steelhead migrating upstream in the Thompson past the Bonaparte station occurred on April 20th (*SE=3.02, n=5*). Radio-tagged steelhead migrating upstream in the Thompson past the Bonaparte telemetry station had a median migration date on April 21st, only one day earlier than the median migration date for radio-tagged steelhead entering the Bonaparte River (*n=7*; Figure 54).

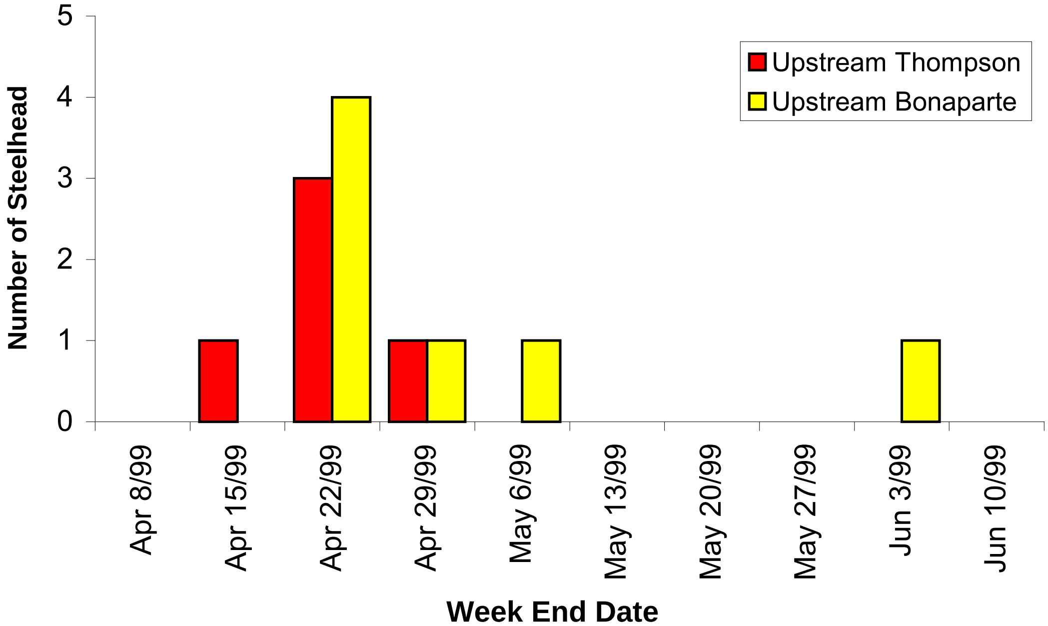

Figure 54. The upstream run timing of interior Fraser River steelhead past the Bonaparte telemetry station in the spring of 1999.

Run timing past the Stein telemetry station appeared similar to that of the Nicola (Figure 55). Only 2 radio-tagged steelhead were detected migrating upstream in the Fraser past the Stein station. These two steelhead moved past the station in the later half of March, with a median date occurring on March 19th. Radio-tagged steelhead entered the Stein from late March through to early May with a mean date occurring on April 7th (*SE=4.30, n=10*) and a median date occurring on April 10th.

The Bridge telemetry station detected the majority of steelhead entering the Bridge River from early-April to early-May. Telemetry results from 1999 show a very abrupt peak in the 3rd week of April, with a mean date occurring on April 21st (*SE=3.16, n=12*) and a median date occurring on April 18th. In sharp contrast to upstream migration patterns at other stations, the run timing of steelhead moving upstream in the Fraser River past the Bridge telemetry station had a median date on May 12th (n=6). At all other confluence's, radio-tagged steelhead destined for tributaries further upstream began upstream migration in the mainstem prior to migration into the tributary. Upstream migration past the Bridge telemetry station however, occurred approximately 3 weeks later than the peak run timing for steelhead entering the Bridge River (Figure 56).

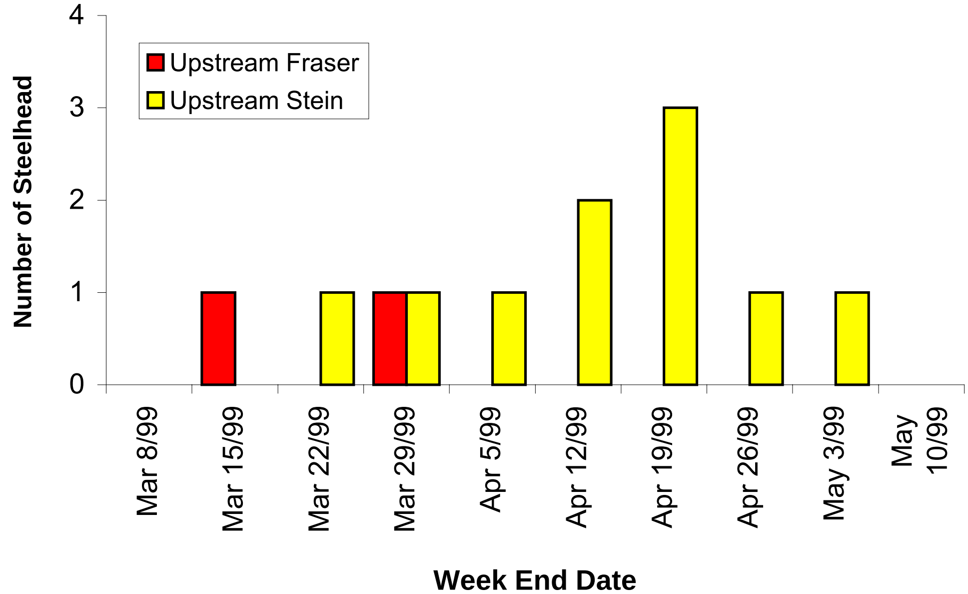

Figure 55. The upstream run timing of interior Fraser River steelhead past the Stein telemetry station in the spring of 1999.

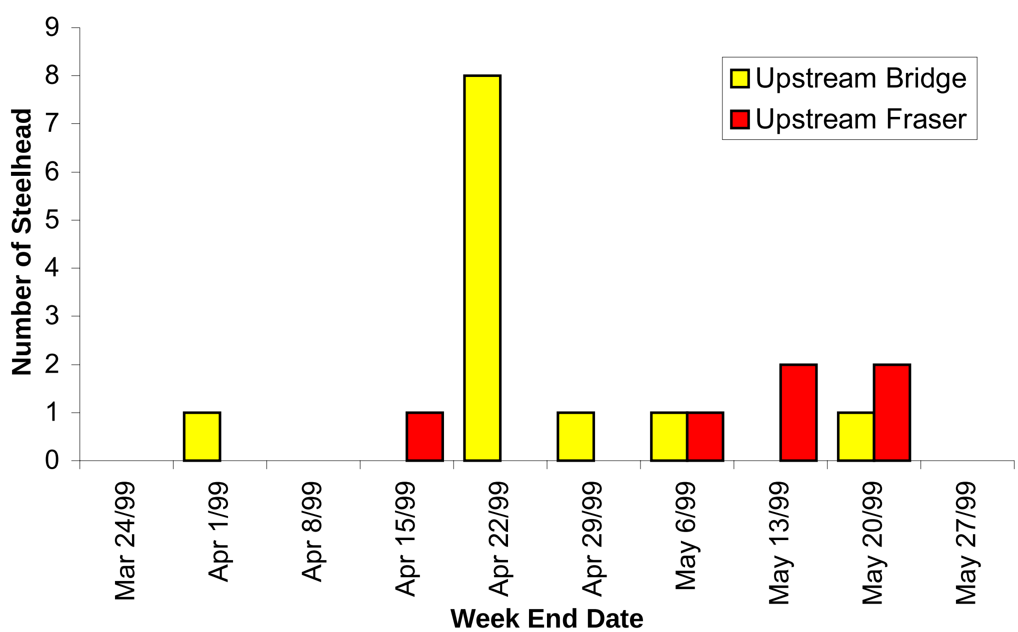

Figure 56. The upstream run timing of interior Fraser River steelhead past the Bridge telemetry station in the spring of 1999.

The run timing data collected by the Chilcotin telemetry station was considerably different than the other telemetry stations. Radio-tagged steelhead were detected migrating upstream into the Chilcotin from mid-May to mid-June, with a median date on May 27th (*n=4*). Although the sample size is too small to determine a mean migration date, it would appear that radio-tagged steelhead entered the Chilcotin River a full month later than any other tributary. This is similar however to the run timing data from 1997, where 2 steelhead entered the Chilcotin River on the week ending May 18th. One steelhead was also detected moving upstream in the Fraser past the Chilcotin station on June 2nd (Figure 57). Although a spawning location for this steelhead was never determined, it was later detected moving downstream past the Chilcotin telemetry station on June 28th.

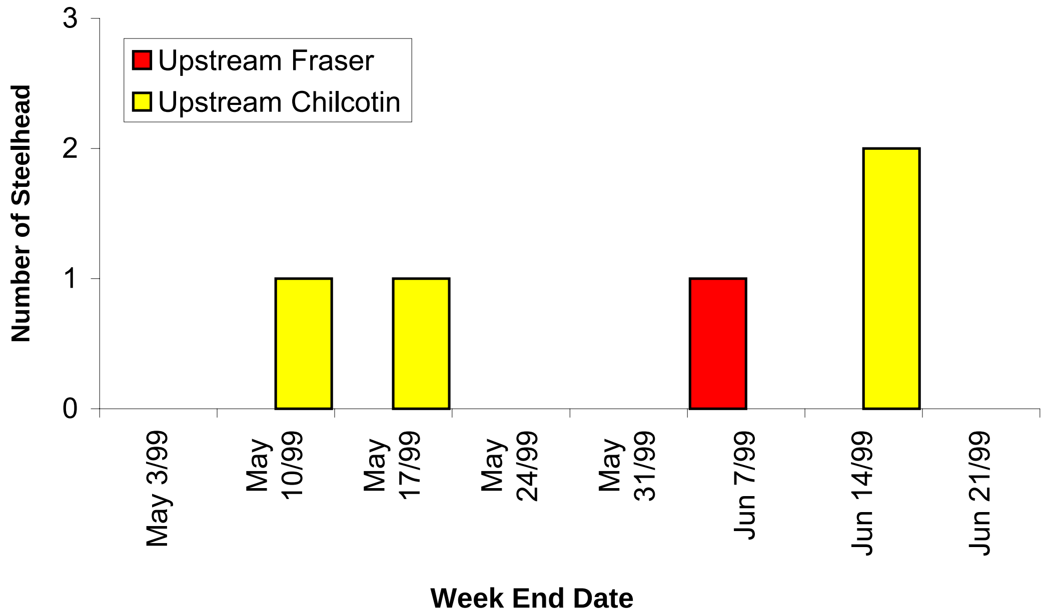

Figure 57. The upstream run timing of interior Fraser River steelhead past the Chilcotin telemetry station in the spring of 1999.

Spring Re-captures

A total of 10 radio-tagged (5 fall-tagged and 5 spring-tagged) steelhead were re-captured from March 3rd to June 5th, 1999. Out of the 10 re-captured steelhead, 4 (40%) were killed and 6 (60%) were live released. Out of the 4 radio-tagged (2 fall-tagged and 2 spring-tagged) steelhead that were re-captured and killed, 3 occurred in the Lytton area and 1 occurred to a kelt in the Yale area in aboriginal food fisheries. Out of the 6 radio-tagged (3 fall-tagged and 3 spring-tagged) steelhead that were live released, 3 were re-captured at the Bonaparte Fishway and 3 were re-captured by MELP anglers. MELP anglers re-captured radio-tagged steelhead near the Seton/Fraser confluence, the Thompson/Fraser confluence and in the Stein River (Figure 58).

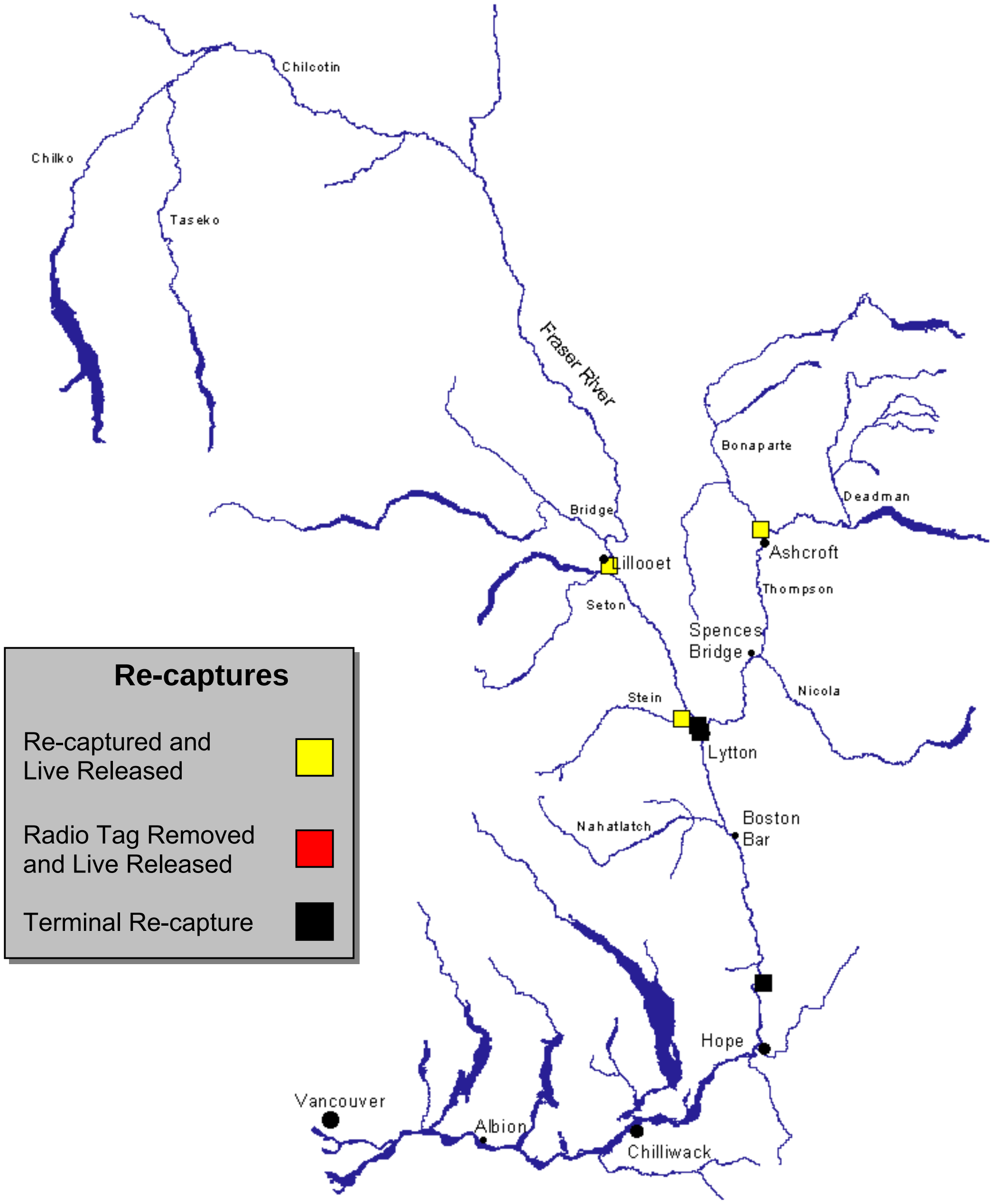

Figure 58. The locations of radio-tagged steelhead re-captured in 1999.

Spawning Distribution

Radio Tags Deployed in Fall 1998

Out of the 104 fall radio-tagged steelhead that could potentially enter a tributary monitored by telemetry, 35 (34%) were not detected upstream of the Nahatlatch/Fraser confluence during the spawning period. Of the remaining 69 (66%) radio-tagged steelhead, 37 (54%) entered the Thompson River or one of it's tributaries and 32 (46%) were detected in Fraser River upstream of the Nahatlatch confluence or one of it's tributaries. The relatively even split between Fraser and Thompson stocks in the fall 1998 radio-tagged sample is in contrast to the uneven split in 1996, which saw 66% of all fall radio-tagged steelhead enter the Thompson or one of it's tributaries. Of the 69 fall radio-tagged steelhead detected upstream of the Nahatlatch/Fraser confluence, 20 (29%) were detected in the Nicola system, 7 (10%) were detected in the Deadman system, 4 (6%) were detected in the Bonaparte River and 6 (9%) were last detected in the Thompson River mainstem. In the Fraser tributaries, 3 (4%) were detected in the Nahatlatch River, 2 (3%) were detected in the Stein River, 9(13%) were detected in the Bridge/Seton River systems, 13 (19%) were detected in the Chilcotin River system and 5 (7%) were last detected in the Fraser River upstream of the Nahatlatch/Fraser confluence. The diversity of river systems where fall radio-tagged steelhead were detected in the 1998/99 season, is much greater than in the 1996/97 season, where 50% of all fall radio-tagged steelhead were detected in the Nicola River system (Figures 59 and 60).

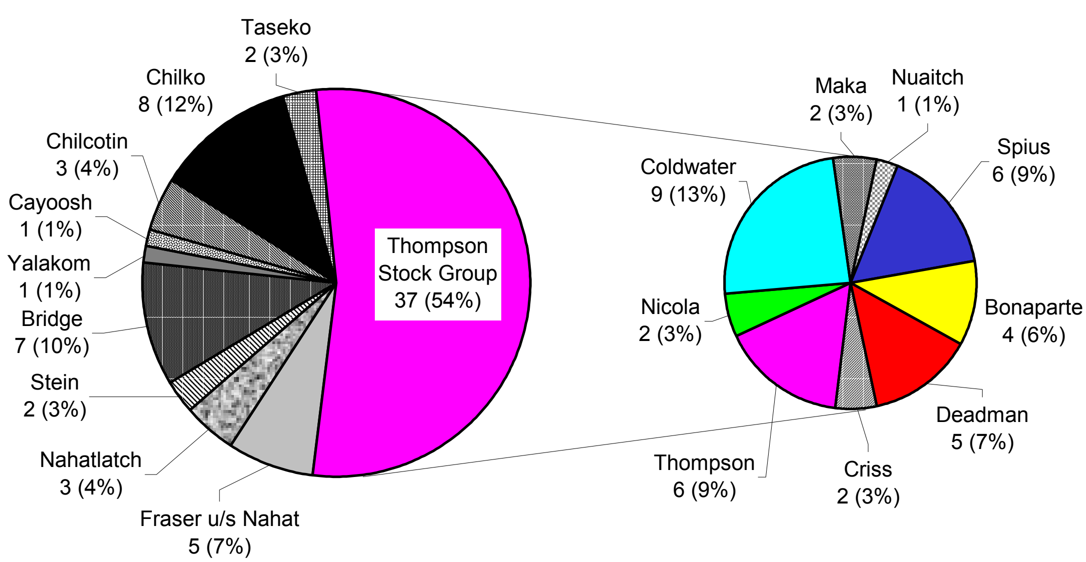

Figure 59. The number and percent of steelhead, radio-tagged in the fall of 1998, that were detected in tributaries monitored by telemetry during the spawning period.

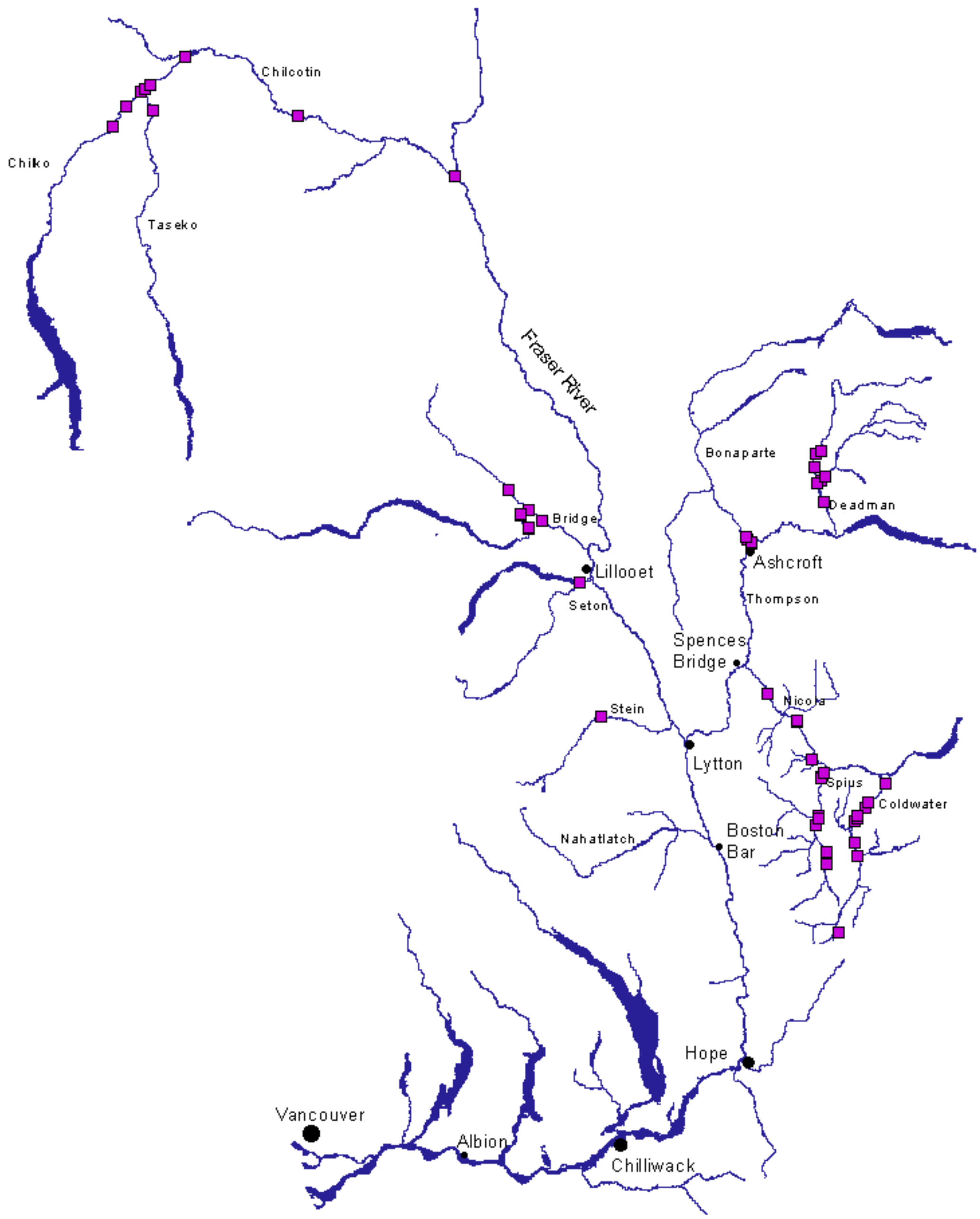

Figure 60. The location of steelhead, radio-tagged in the fall of 1998, detected during the spawning period (mid-April to mid-June) in 1999.

As was the case for the 1996/1997-escapement year, most steelhead that appeared to successfully spawn in a known spawning tributary overwintered near their natal stream. Exceptions to this are two radio-tagged steelhead that overwintered in the Thompson River and spawned in the Bridge and Nahatlatch Rivers. As was the case during each of the two telemetry years, steelhead that were detected downstream of the Nahatlatch/Fraser confluence during the overwintering period had a very low rate of success at ascending the Fraser Canyon and spawning in a known, monitored tributary. In the 1998/99 telemetry season, none of the 8 steelhead that were detected downstream of the Nahatlatch/Fraser confluence during the overwintering period were ever detected upstream of that point (Table 16).

Table 16. The spawning distribution of steelhead radio-tagged in the fall of 1998 in relation to their overwintering distribution.

Overwintering Location	Total	Natal Stream: Nahatlatch	Fraser u/s Nahatlatch	Stein	Bridge/Seton	Chilcotin	Thompson	Nicola	Bonaparte	Deadman	Unknown
Fraser - downstream of Harrison	1										1
Fraser - Harrison to Nahatlatch	7										7
Nahatlatch	2	2									
Fraser - Nahatlatch to Chilcotin	20		5	2	8	1		2			2
Chilcotin	10					10					
Fraser - upstream of Chilcotin	2					2					
Thompson	37	1			1		6	18	4	7	
Total	79	3	5	2	9	13	6	20	4	7	10

Note: Although the Thompson and Fraser Rivers are not considered natal streams, they are used to designate the highest upstream detection of a radio-tagged steelhead during the spawning period. Radio-tagged steelhead that were not detected upstream of the Nahatlatch/Fraser confluence during the spawning period were classified as unknown. The total refers to the number of steelhead detected in a particular overwintering location that had the potential to enter a spawning tributary.

Radio Tags Deployed in the Late-Winter/Spring of 1999

Areas of deployment such as the Seton/Fraser confluence and the Thompson/Fraser confluence are of particular interest because of the potential diversity of stocks holding in these areas. Out of the 11 steelhead radio-tagged in the Lytton area, 8 (73%) entered the Stein River, 1 (9%) was last detected in the Thompson River and 2 (18%) were last detected in the Fraser upstream of the Nahatlatch/Fraser confluence. In the Lillooet area, 16 steelhead were radio-tagged; 11(69%) entered the Bridge/Seton River systems, 1(6%) entered the Chilcotin River system and 4 (25%) were last detected in the Fraser River upstream of the Nahatlatch/Fraser confluence (Table 17).

Table 17. The spawning distribution of steelhead radio-tagged in the spring of 1999 in relation to their capture location.

		Natal Stream							
Capture Location	Total	Fraser u/s Nahatlatch	Stein	Bridge/Seton	Chilcotin	Thompson	Nicola	Bonaparte	Deadman
Lytton	11	2	8			1			
Lillooet	16	4		11	1				
Chilcotin R. System	20				20				
Spences Br. Area	20					2	16	1	1
Dm/Thomp confl.	24					3		1	20
Total	91	6	8	11	21	6	16	2	21

Kelt Behaviour

Downstream Run Timing

The downstream run timing for exiting kelts in 1999 was very similar to that of 1997. Kelts began their return migration to the ocean in mid-May, with a peak emigration in early-June. The downstream migration of kelts appeared to continue until early-July. The mean run timing date for exiting kelts at Nahatlatch occurred on June 3rd (*SE=1.93, n=46*), with a median date occurring on June 4th (Figures 61). Similarly, Hope had a mean run timing date for exiting kelts on June 2nd (*SE=1.40, n=60*), with a median date also occurring on June 4th (Figure 62). Some kelts likely passed undetected by the Hope telemetry station in 1999, since it was disassembled on June 19th due to high water conditions. This may explain why the mean migration date of exiting kelts at the Nahatlatch telemetry station occurred one day later than the Hope telemetry station, even though the Hope telemetry station was 75-km further downstream.

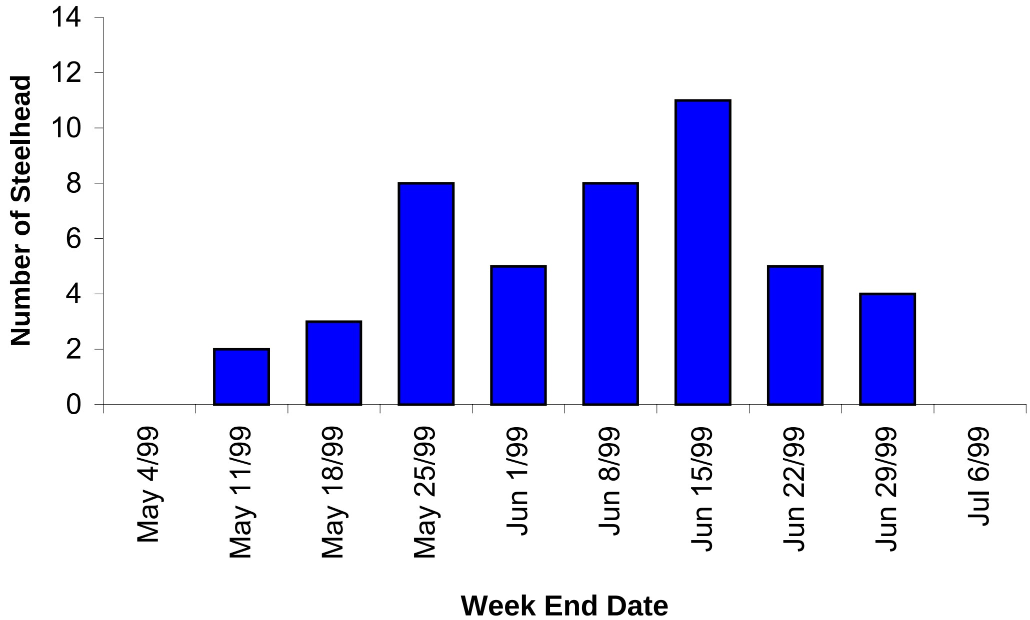

Figure 61. The downstream run timing of interior Fraser steelhead past the Nahatlatch telemetry station in early summer, 1999.

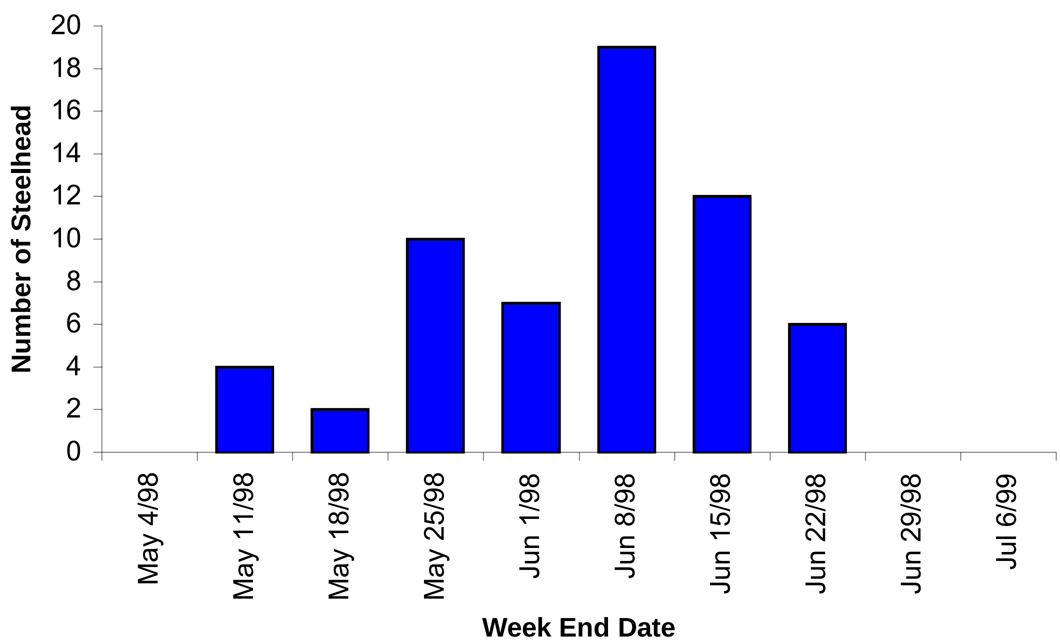

Figure 62. The downstream run timing of interior Fraser steelhead past the Hope telemetry station in early summer, 1999.

Downstream Migration Rate

Since telemetry stations in 1998/99 were not set up in the same locations as in 1997/98 or 1996/97, it is difficult to make direct comparisons on the downstream migration rates of kelts. In areas were there is consistency in telemetry station operation, downstream migration rates across years seem similarly very rapid (Tables 7, 13 and 18). In 1997, the Nicola to Lytton migration rate was 14.3 km/day, compared with 13.8 km/day from Bonaparte to Nicola in 1999. In 1997, the Stein to Nahatlatch average migration rate was 28.4 km/day and in 1999 it was 24.7 km/day. In 1999, 6 radio-tagged steelhead traveled from the Chilcotin to the Bridge telemetry station in just over 3 days at an average migration rate of 42.1 km/day. In 1998, the lone kelt from the Chilcotin River took just over 4 days at an average migration rate of 31.7 km/day to cover the same distance; well within the range of the 1999 sample. The most variability in downstream migration rates appears to occur in the Fraser Canyon, between the Nahatlatch and Hope telemetry stations. Radio-tagged steelhead migrated downstream through this section at average migration rates of 87.5 km/day, 115.5 km/day and 68.7 km/day in 1997, 1998 and 1999 respectively.

Table 18. The average migration times, migration rates and distances traveled downstream by radio-tagged interior Fraser River steelhead between telemetry stations along the Fraser River in the early-summer of 1999.

Location	Distance (km)	Mean (days)	Migration Rate (km/day)	n	SE (days)	Range (days)
Chilcotin to Bridge	132	3.14	42.1	6	0.72	1.35 - 6.09
Bridge to Stein	57	5.00	11.4	10	2.28	0.21 - 20.48
Stein to Nahatlatch	37.5	1.52	24.7	19	0.68	0.11 - 13.29
Bonaparte to Nicola	36	2.62	13.8	17	0.79	0.18 - 9.80
Nicola to Nahatlatch	66.5	2.72	24.5	20	0.65	0.21 - 9.19
Nahatlatch to Hope	75	1.09	68.7	35	0.26	0.24 - 9.11

Kelting Rates

The overall kelting rate for steelhead that were radio-tagged in the fall of 1998 and subsequently detected in a known spawning tributary was 48%. This was 10% higher than the kelting rate for steelhead radio-tagged in the fall of 1996 and subsequently detected in a known spawning tributary. The difference between years however, was not significant (*Chi Square = 2.36, P= 0.124*). Kelting rates for fall radio-tagged steelhead that did not appear to make it into known spawning tributaries was only 2% in 1999 compared with 7% in 1997. Chilcotin River steelhead appeared to have a consistently lower kelting rate than other spawning tributaries further downstream (Tables 8 and 19). The radio-tagged sample from the fall of 1998, however, is the only sample where Chilcotin steelhead had a significantly lower kelting rate than the combined kelting rate of Thompson steelhead stocks (*Chi Square = 12.6, P= 0.000382*).

Table 19. The kelting rates for various stock groupings of interior Fraser River steelhead, radio-tagged in the fall of 1998.

Category	River System	Kelts	Radio-Tagged Steelhead	Kelt Rate
Recognized Spawning Tributaries	Chilcotin	2	13	15%
	Bridge/Seton	5	9	56%
	Stein	1	2	50%
	Nahatlatch	1	3	33%
	Deadman	4	7	57%
	Nicola	13	20	65%
	Average of All Systems			**48%**
Unrecognized Spawning Tributaries	Thompson	0	6	0%
	Fraser upstream of Nahatlatch	1	5	20%
	Fraser downstream of Nahatlatch	0	35	0%
	Average of All Systems			**2%**
	Overall Average			**27%**

Kelting rates for steelhead radio-tagged in the spring appear to be consistently higher than the same group of fall radio-tagged steelhead in the 1996/97 and 1998/99 seasons, although the difference was not found to be significant (*Chi Square = 0.698, P= 0.403 and Chi Square = 0.176, P= 0.675,* respectively). In 1999, the kelting rate for spring radio-tagged steelhead that were not detected in a recognized spawning tributary was 0%, much less than the 27% recorded in 1997 (Tables 9 and 20).

Table 20. The kelting rates for various stock groupings of interior Fraser River steelhead, radio-tagged in the spring of 1999.

Category	River System	Kelts	Radio-Tagged Steelhead	Kelt Rate
Recognized Spawning Tributaries	Chilcotin	8	21	38%
	Bridge/Seton	7	11	64%
	Stein	5	8	63%
	Deadman	9	21	43%
	Bonaparte	0	2	0%
	Nicola	11	16	69%
	Average of All Systems			**51%**
Unrecognized Spawning Tributaries	Thompson	0	6	0%
	Fraser upstream of Nahatlatch	0	6	0%
	Fraser downstream of Nahatlatch	0	0	0%
	Average of All Systems			**0%**
	Overall Average			**44%**

Tag Fates

Oviduct Tags

Oviduct tags were only deployed in the fall of 1996. Out of the 39 radio tags applied in marine fisheries that year, 20 (51%) were oviduct tags. Since none of the radio tags deployed in marine fisheries were ever detected, it is impossible to compare the performance of gastric and oviduct radio tags in this environment. In fresh water however, 2 (2.3%) out of the 86 radio-tagged steelhead were outfitted with oviduct tags and 3(3.5%) were double-tagged with gastric and oviduct tags. The steelhead outfitted with oviduct tags alone showed no movement and were recorded as regurgitated/expelled (Table 21). The 3 steelhead outfitted with both a gastric and an oviduct tag were last detected via the gastric tag's signal only, demonstrating that the oviduct tags in these steelhead had also been expelled.

Overall Tag Fates from 1996 to 1999

The number of radio-tagged steelhead that did not spawn in a telemetry monitored tributary but were detected kelting by the Hope telemetry station were considered to be radio-tagged steelhead that had spawned in an unmonitored tributary. Radio tags that were detected numerous times in the same location or detected in the same location as they were captured several months later were considered to be regurgitated/expelled radio tags. Finally, radio-tagged steelhead that had shown some upstream movement followed by only downstream movement prior to the spawning period were considered mortalities (Table 21).

Table 21. The fates of all steelhead radio-tagged from 1996 to 1999.

Fates of Radio-Tagged Steelhead	Radio Tag Deployment Period											
	Fall 1996		Spring 1997		Fall 1997		Spring 1998		Fall 1998		Spring 1999	
Fate	n	%	n	%	n	%	n	%	n	%	n	%
Known												
Re-captured and Killed or Tag Removed	6	7%	3	4%	1	7%	0	0%	2	2%	2	2%
Probable												
Spawned in Monitored Tributary	24	28%	57	70%	1	7%	37	93%	58	55%	79	85%
Spawned in Unmonitored Tributary	4	5%	6	7%	0	0%	0	0%	1	1%	0	0%
Regurgitated/Expelled or Removed	5	6%	5	6%	0	0%	2	5%	4	4%	3	3%
Mortality	7	8%	0	0%	4	29%	0	0%	11	10%	0	0%
Unknown	40	47%	11	13%	8	57%	1	3%	30	28%	9	10%
Total	86		82		14		40		106		93	

The relative proportions of radio-tagged steelhead in each fate category were highly variable among years, and this is likely indicative of yearly environmental variations, variation in the types of radio tags used and variations in the tag deployment methods. The 1997/98 season was the most unusual with only 7% of the fall radio-tagged steelhead spawning in telemetry-monitored tributaries. In the fall of 1996, only 28% of radio-tagged steelhead spawned in telemetry-monitored tributaries and in the fall of 1998 this rate doubled with 55% spawning in telemetry-monitored tributaries. Regurgitation/expulsion rates appear relatively consistent for all years, although it may be higher in the 1996/97 season. This difference may be due in part to the dimensions of the gastric radio tag model used and the use of oviduct tags (see Methods; Table 1). Re-capture rates also seem to be slightly higher in the 96/97 season than in the 98/99 season, with 7% of fall 1996 radio tags and 4% of spring 1997 radio tags being re-captured. This compares with 2% from each of the fall 1998 and spring 1999 radio-tagged samples. In general, re-captures in the 1996/97 season occurred further downstream than in the 1998/99 season. (Figures 17, 23, 51 and 58). The number of radio-tagged steelhead that did not spawn in telemetry-monitored tributaries was also slightly higher in the 1996/97 season. In the 1997/98 and 1998/99 seasons the number of steelhead that did not spawn in telemetry-monitored tributaries was negligible. In the fall of 1996 and the spring of 1997, the number of steelhead that failed to spawn in a telemetry-monitored tributary was 5% and 7% respectively. Mortality rates for the fall-1996 and fall-1998 radio-tagged samples also seam quite consistent at 8% and 10% respectively. The mortality rate for the fall of 1997 is considerably higher at 29%, although the sample size for this year is relatively small. A dramatic proportion of radio-tagged steelhead from each sample year had unknown fates. Nearly half (47%) of the radio-tagged steelhead from the fall-1996 sample had unknown fates, 57% from the fall-1997 sample and 28% from the fall-1998 sample. The proportions of the spring radio-tagged samples with unknown fates was substantially lower.

Fates of Radio-Tagged Steelhead Captured by Different Gear Types

In the fall of 1996, the tangle net fishery appeared to have the highest percentage of its deployed radio tags enter a monitored tributary, with 31%. Anglers had 28% of their radio tags deployed enter a monitored tributary and the beach seine had 25%. Steelhead captured and radio-tagged via gill net had the highest apparent mortality with 67% and the tangle net had the second highest mortality with 14% of its deployed radio tags showing downstream movement after a short period of upstream movement. In the gear types other than the gill net, the number of radio-tagged steelhead in the unknown fate category makes up the majority of the sample. This is likely indicative of the environmental conditions in the fall of 1996 but in the case of the tangle net there may be some technical reasons for this. The tangle net operates in an area of the Fraser where the salt concentrations are high enough to prohibit radio transmission. Because of this, radio-tagged steelhead can only be detected upstream of the fishery and many of the radio tags deployed by the tangle net did not travel far enough upstream after radio tagging to be detected by the Barnston telemetry station. It is likely that the tangle net fishery would have a much higher documented mortality rate if radio transmitters were detectable downstream of the fishery. Anglers appear to have the highest regurgitation rates of all gear types but as previously mentioned in the results, all of the oviduct tags deployed were expelled and angling was the only deployment method to deploy oviduct tags (Table 22).

Table 22. The fate of radio-tagged steelhead captured by each gear type in the fall of 1996.

Fates of Radio-Tagged Steelhead	Gear Type								
	Tangle Net		Beach Seine		Angled		Gill Net		Total
Fate	n	%	n	%	n	%	n	%	
Known									
Re-captured and Killed or Tag Removed	3	10%	0	0%	2	4%	1	33%	6
Probable									
Spawned in Bridge	0	0%	0	0%	2	4%	0	0%	2
Spawned in Chilcotin	2	7%	0	0%	1	2%	0	0%	3
Spawned in Nicola	6	21%	1	25%	11	22%	0	0%	18
Spawned in Bonaparte	1	3%	0	0%	0	0%	0	0%	1
Spawned in Unmonitored Tributary	0	0%	0	0%	4	8%	0	0%	4
Regurgitated/Expelled or Removed	0	0%	0	0%	5	10%	0	0%	5
Mortality	4	14%	0	0%	1	2%	2	67%	7
Unknown	13	45%	3	75%	24	48%	0	0%	40
Total	29		4		50		3		86

In the fall of 1997, angling was the only method to produce a radio-tagged steelhead that entered a monitored tributary. Sample sizes for all gear types are very low making comparisons difficult. The tangle net had a high mortality rate once again, with 33%. All of the remaining steelhead radio-tagged via tangle net (67%) had an unknown fate (Table 23).

Table 23. The fate of radio-tagged steelhead captured by each gear type in the fall of 1997.

Fates of Radio-Tagged Steelhead	Gear Type						
	Tangle Net		Beach Seine		Angled		Total
Fate	n	%	n	%	n	%	
Known							
Re-captured and Killed or Tag Removed	0	0%	0	0%	1	25%	1
Probable							
Spawned in Chilcotin	0	0%	0	0%	1	25%	1
Spawned in Unmonitored Tributary	0	0%	0	0%	0	0%	0
Regurgitated or Removed	0	0%	0	0%	0	0%	0
Mortality	3	33%	1	100%	0	0%	4
Unknown	6	67%	0	0%	2	50%	8
Total	9		1		4		14

In the fall of 1998, the tangle net once again had the highest percentage of radio-tagged steelhead in the unknown fate category, with 69%. Anglers had the lowest percentage in the unknown fate category, with 19% and the Yale Fishwheel had the second lowest, with 23% in the unknown fate category. Angling appeared to have the highest percentage of it's deployed radio tags (73%) enter monitored tributaries. The fishwheel was second in this category with 49% of its radio-tagged steelhead entering monitored tributaries. The beach seine and the tangle net had the lowest percentage of their radio-tagged steelhead enter monitored tributaries, with 33% and 19% respectively. Overall, the number of steelhead in the unknown fate category in 1998 was less than in 1996. There were also lower overall rates of mortality, regurgitations/expulsions and spawning in unmonitored tributaries in 1998 relative to 1996 (Table 24).

Table 24. The fate of radio-tagged steelhead captured by each gear type in the fall of 1998.

Fates of Radio-Tagged Steelhead	Gear Type								
	Tangle Net		Beach Seine		Angled		Yale Fishwheel		Total
Fate	n	%	n	%	n	%	n	%	
Known									
Re-captured and Killed or Tag Removed	1	6%	0	0%	0	0%	1	3%	2
Probable									
Spawned in Stein	0	0%	0	0%	1	2%	1	3%	2
Spawned in Nahatlatch	0	0%	0	0%	3	6%	0	0%	3
Spawned in Bridge/Seton	1	6%	0	0%	4	8%	4	10%	9
Spawned in Chilcotin	1	6%	0	0%	2	4%	10	26%	13
Spawned in Nicola	1	6%	0	0%	16	33%	3	8%	20
Spawned in Bonaparte	0	0%	0	0%	3	6%	1	3%	4
Spawned in Deadman	0	0%	1	33%	6	13%	0	0%	7
Spawned in Unmonitored Tributary	0	0%	0	0%	0	0%	1	3%	1
Regurgitated or Removed	0	0%	0	0%	3	6%	1	3%	4
Mortality	1	6%	1	33%	1	2%	8	21%	11
Unknown	11	69%	1	33%	9	19%	9	23%	30
Total	16		3		48		39		106

Looking at all the years combined several patterns become apparent:

1. Angler caught steelhead seem to have a higher rate of regurgitation than other gear types but it is still within the range reported in other telemetry studies (Hooton 1986).

2. A large percentage of the radio-tagged steelhead captured via tangle net, travel primarily downstream after being handled.

3. There appears to be an inability of anglers to capture Chilcotin steelhead and tendency for anglers to capture Thompson steelhead.

4. The reverse appears to be true of the Yale Fishwheel. In all, 26% of the steelhead radio-tagged at the fishwheel were of Chilcotin stock but only 11% were of Thompson origin. This may be misleading however since the fishwheel did not have radio tags available for deployment in the later half of October when Nicola steelhead appear to migrate through the Fraser Canyon.

It appears that the success of different gear types varies throughout the tagging period. Success in this case is used in terms of the telemetry study and refers to radio-tagged steelhead that entered a recognized spawning tributary. The tangle net appears to have the largest percentage of its radio-tagged steelhead enter a spawning tributary if these fish were captured in late-September and early-October (Figure 63).

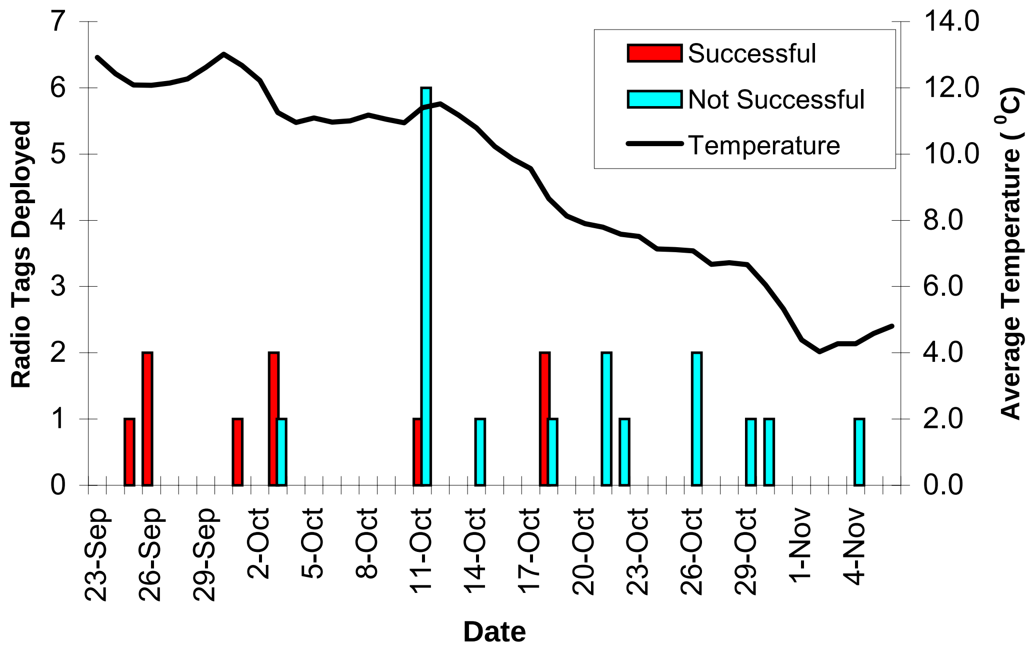

Figure 63. The number of steelhead captured and radio-tagged via tangle net in 1996 to successfully enter a recognized spawning tributary and the mean daily water temperature of the Fraser River.

In 1998, the tangle net only had 3 of its radio-tagged steelhead (n=16) enter a recognized spawning tributary. Two out of the 3 successful radio-tagged steelhead were captured in late-September and 1 was captured in late-October.

In both 1996 and 1998, the proportion of steelhead radio-tagged by anglers that entered a recognized spawning tributary did not seem as dependent on the time of year as the tangle net. It appears however that steelhead radio-tagged by angling in late-October and early November are the least likely to enter a recognized spawning tributary (Figures 64 and 65).

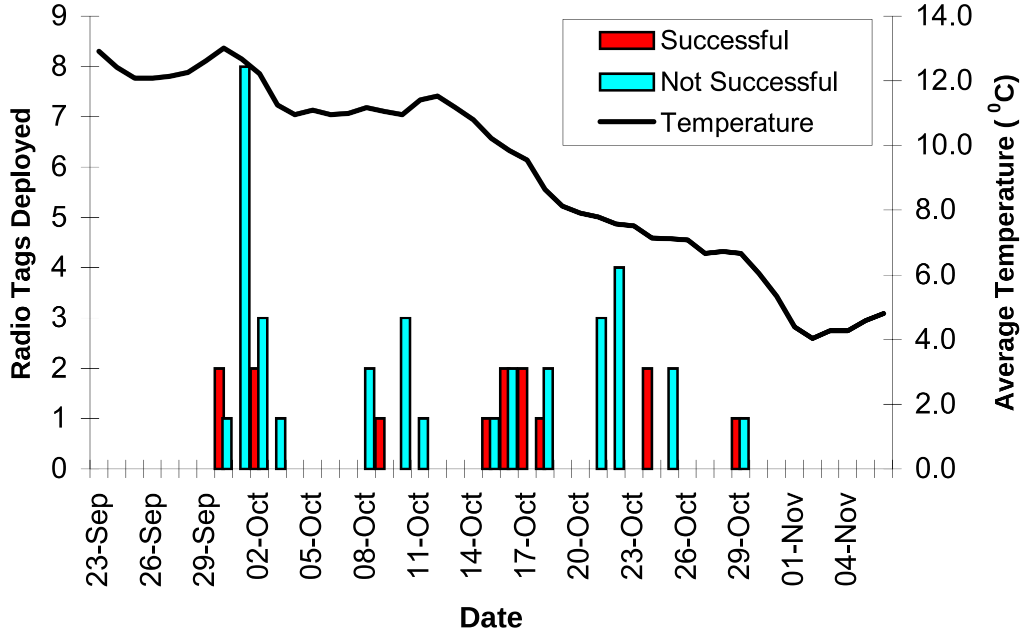

Figure 64. The number of steelhead captured and radio-tagged via angling in 1996 to successfully enter a recognized spawning tributary and the mean daily water temperature of the Fraser River.

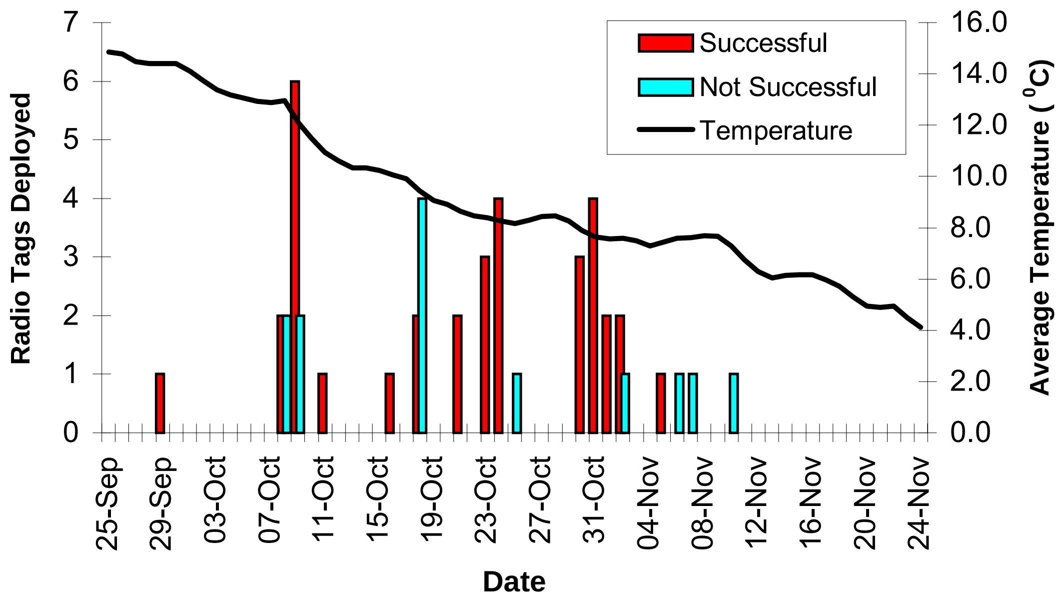

Figure 65. The number of steelhead captured and radio-tagged via angling in 1998 to successfully enter a recognized spawning tributary and the mean daily water temperature of the Fraser River.

The steelhead radio-tagged by the Yale Fishwheel during the second week of October had the highest rate of success at entering a recognized spawning tributary. Unlike the 1996 tangle net, steelhead captured by the fishwheel in late September appear less likely to reach a recognized spawning tributary. Similar to other gear types, steelhead radio-tagged at the fishwheel late in the season are also less likely to reach a recognized spawning tributary (Figure 66).

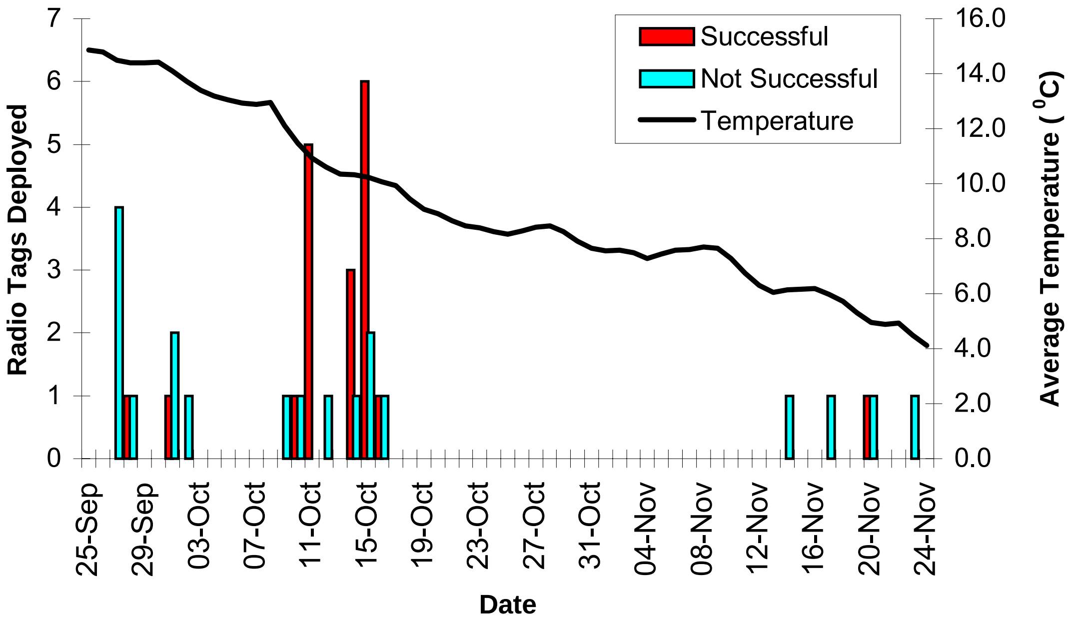

Figure 66. The number of steelhead captured and radio-tagged via the Yale Fishwheel in 1998 to successfully enter a recognized spawning tributary and the mean daily water temperature of the Fraser River.

<u>Stock Specific Migration Behaviour in 1996</u>

Migration Rate

Earlier in the results section migration rates between telemetry stations for all stocks combined were presented. In this section, the analysis will be similar except average migration rates and times will be presented for each stock.

The average migration rates between telemetry stations for fall-1996 radio-tagged steelhead appear quite variable between individual stocks (Tables 25, 26 and 27).

Table 25. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Barnston and Harrison telemetry stations in 1996.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)		
Nicola	2	17.3	3.93	0.754	3.17	-	4.68
Bonaparte	1	24.3	2.79	na	2.79	-	2.79

Table 26. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Harrison and Hope telemetry stations in 1996.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)		
Bridge	2	6.5	6.29	3.388	2.90	-	9.67
Chilcotin	3	9.9	4.13	1.025	2.81	-	6.15
Thompson	3	8.9	4.63	1.547	1.68	-	6.92
Nicola	12	4.3	9.63	1.548	3.10	-	22.30
Bonaparte	1	17.5	2.34	na	2.34	-	2.34

Table 27. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Hope and Nahatlatch telemetry stations in 1996.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)		
Bridge	2	8.7	8.66	3.549	5.11	-	12.21
Chilcotin	3	14.6	5.13	0.497	4.23	-	5.95
Thompson	4	3.5	21.18	4.335	14.10	-	32.27
Nicola	14	4.7	16.05	2.457	5.99	-	34.58
Bonaparte	1	5.7	13.08	na	13.08	-	13.08

An ANOVA failed to show that there is more variation between stocks than there is among individual stocks at each location ($F=0.285$, $P=0.771$ for Barnston to Harrison, $F=1.08$, $P=0.398$ for Harrison to Hope and $F=1.75$, $P=0.169$ for Hope to Nahatlatch). However, Chilcotin and Nicola steelhead appear to stand out on opposite ends of the spectrum. Chilcotin steelhead consistently have one of the fastest average migration rates and the narrowest range of migration times between all telemetry stations. This is in contrast to Nicola steelhead, which tend to have one of the slowest average migration rates and the broadest range of migration times between all telemetry stations. Only between the Hope and Nahatlatch telemetry stations however, did an F-test demonstrate a significant difference between the variances of the migration times of Chilcotin and Nicola steelhead (*F=113.9, P=0.00873*). This is also the only location where a *t*-test showed a statistical difference between Nicola and Chilcotin mean migration times (*t=4.36, P=0.000329*).

Migration Rates at Various Water Temperatures

In 1996 there were two locations where sample sizes were large enough to compare migration rates of individual stocks at various water temperatures. In the section of Fraser River between the Harrison and Hope telemetry stations, steelhead stocks were recorded migrating in average water temperatures that ranged from 5 ^{0}C to 12 ^{0}C. Overall, migration rates were highest at the coldest water temperatures. Chilcotin steelhead appeared to migrate earlier and as a result traveled in water temperatures within a range of 9 ^{0}C to 12 ^{0}C. Nicola steelhead were separated into two distinct groups as were the two Bridge River steelhead, migrating in water temperatures with ranges of 7 ^{0}C to 8 ^{0}C and 10 ^{0}C to 12 ^{0}C. All of the steelhead that were last detected in the Thompson River migrated in the coldest temperature range, from 5 ^{0}C to 8 ^{0}C (Figure 67).

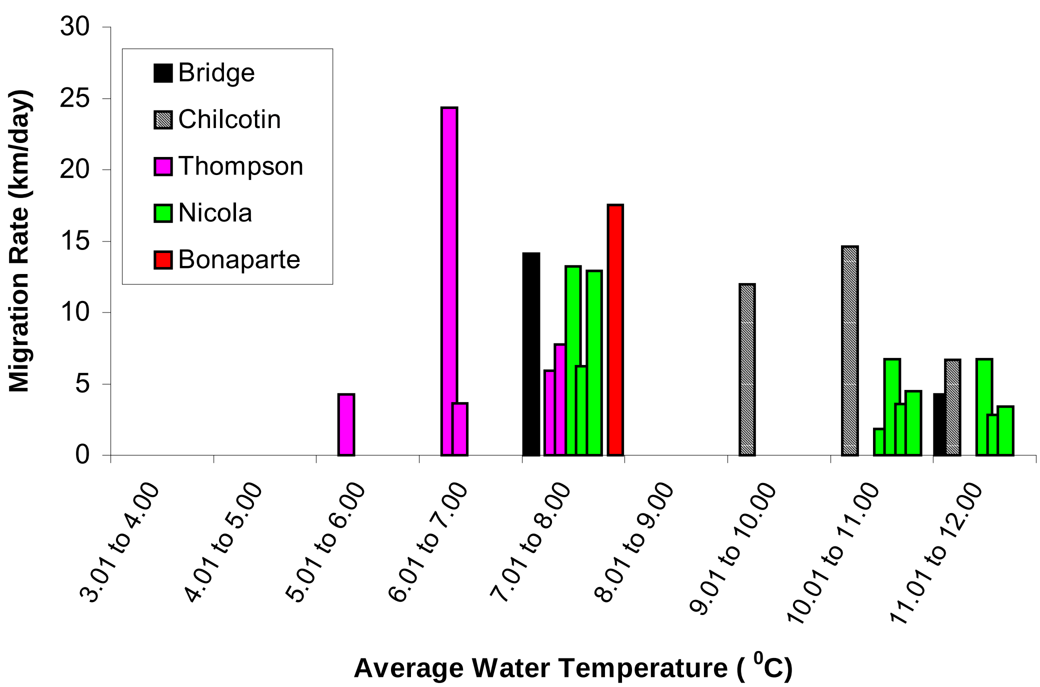

Figure 67. The migration rates of interior Fraser steelhead at different water temperatures between the Harrison and Hope telemetry stations in 1996.

Conversely, the migration of radio-tagged steelhead in the Fraser Canyon between the Hope and Nahatlatch telemetry stations was most rapid at highest water temperatures. The range of temperatures where migration took place widened considerably (3 ^{0}C to 12

^{0}C). Nicola steelhead appeared to travel through the widest range of temperatures (3 ^{0}C to 11^{0}C) whereas Chilcotin steelhead continued to migrate in a warmer temperature range (7 ^{0}C to 12^{0}C). Migration rates dropped dramatically once the water temperature dropped below 6^{0}C but migration rates remained fairly consistent between a temperature range of 7 ^{0}C to 11 ^{0}C (Figure 68).

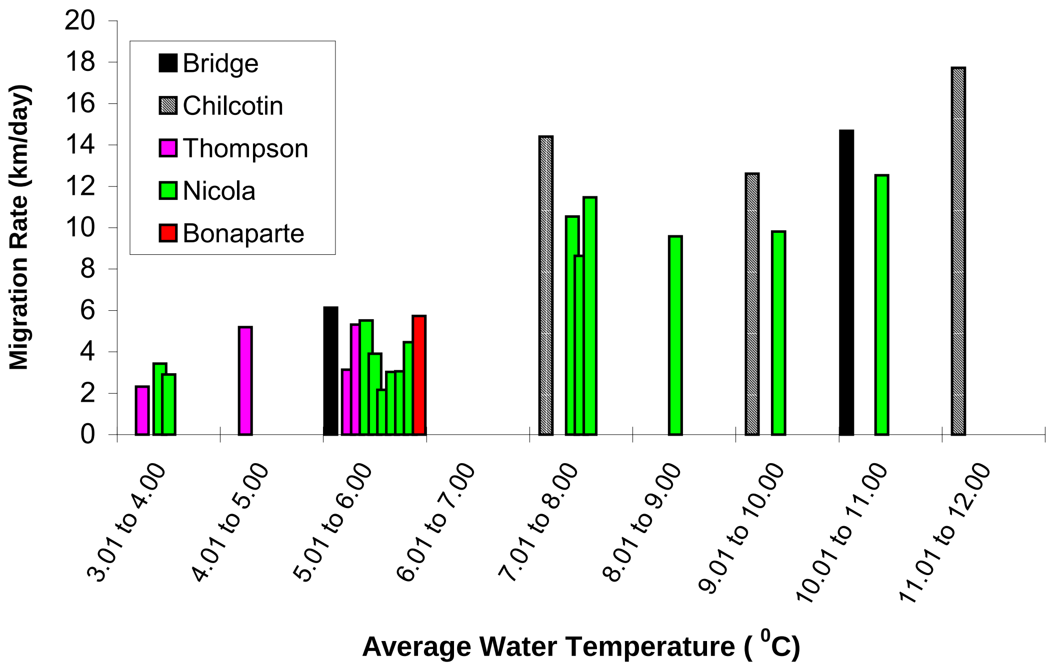

Figure 68. The migration rates of interior Fraser steelhead at different water temperatures between the Hope and Nahatlatch telemetry stations in 1996.

Stock Specific Run Timing

Run timing of individual stocks was observed in two different locations. Although there may be inherent sampling biases in the capture methods used and a spatial separation in the capture sites (from Annacis Island to Hope), date of capture provides an approximation of run timing. Nicola steelhead appeared to have the broadest range of run timing, migrating through the lower Fraser from the late-September to early-November. The Nicola run timing curve appears bi-modal in nature, with one peak occurring in the 1st week in October and another peak occurring in the 3rd week of October. The two Bridge River steelhead also appeared to migrate at these peak periods. The few Chilcotin steelhead that were radio-tagged in 1996, appeared to have a peak migration in the 1st week of October and are not represented in the later half of October (Figure 69).

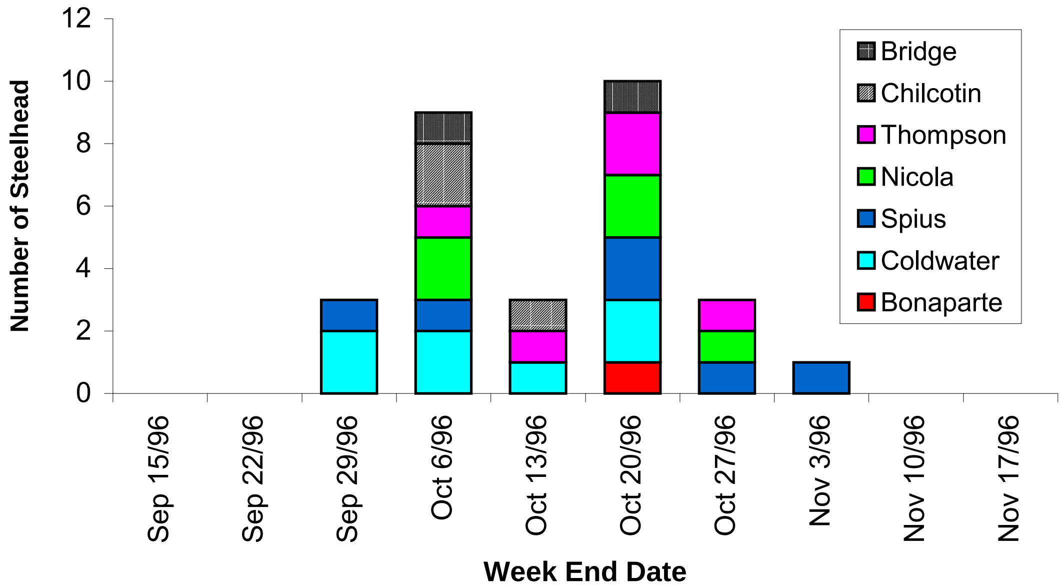

Figure 69. The run timing of interior Fraser steelhead as determined by capture date in the lower Fraser River, 1996.

The second location where stock specific run timing was observed was the Nahatlatch telemetry station. The Nahatlatch telemetry station is located far enough downstream to detect all interior Fraser stocks and it is far enough upstream to include radio-tagged steelhead from all capture locations. The Nahatlatch telemetry station may also be considered the boundary where migrating steelhead exit the Fraser Canyon and enter the interior of the province.

Chilcotin steelhead, which were captured near the early portion of the lower Fraser run timing curve, also made up the earliest portion of the Nahatlatch run timing curve and had a median date that occurred on October 19th (n=3). Thompson steelhead stocks are much more varied in their run timing however, and migrated past the Nahatlatch telemetry station from late-October to early-December, with a median date that occurred on November 9th (n=19). In 1996/97, four steelhead of Thompson River origin did not pass the Nahatlatch telemetry station until spring of the following year and had a median run timing date that occurred on April 17th (Figure 70).

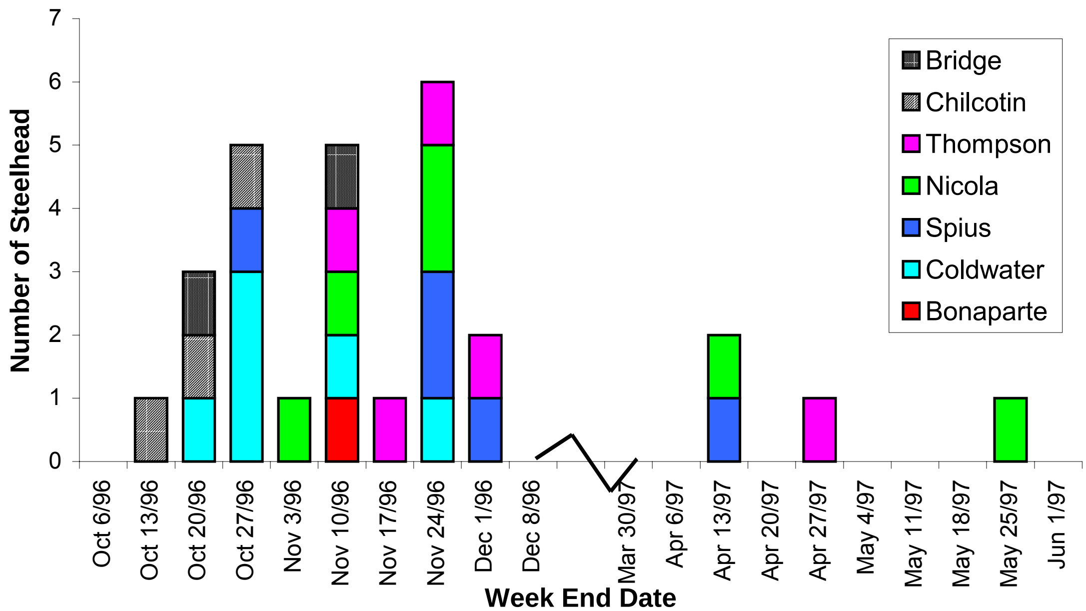

Figure 70. The run timing of interior Fraser steelhead as determined by the Nahatlatch telemetry station, 1996.

Stock Specific Migration Behaviour in 1998

Migration Rate

The average migration rates between telemetry stations in 1998 appear to have narrower ranges and as a result lower variability than in 1996 (Tables 28, 29 and 30).

Table 28. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Harrison and Hope telemetry stations in 1998.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)		
Bridge	2	7.3	5.64	2.01	3.63	-	7.65
Chilcotin	2	19.6	2.09	0.74	1.35	-	2.84
Thompson	3	6.6	6.19	2.07	2.77	-	9.92
Spius	2	8.8	4.65	1.93	2.72	-	6.57

Table 29. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Hope and Nahatlatch telemetry stations in 1998.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)
Nahatlatch	2	13.8	5.45	0.28	5.17 - 5.73
Bridge	5	8.8	8.49	1.00	5.89 - 11.14
Chilcotin	3	17.9	4.18	0.99	2.54 - 5.97
Thompson	6	11.8	6.36	0.73	4.86 - 9.80
Nicola	18	7.7	9.70	1.70	4.18 - 27.59
Bonaparte	3	11.6	6.48	1.45	3.58 - 7.98
Deadman	7	11.1	6.76	0.84	3.92 - 10.79

Table 30. The average migration rates and times for interior Fraser steelhead stocks in the Fraser River between the Nahatlatch and Lytton telemetry stations in 1998.

Stock	n	Migration Rate (km/day)	Mean (days)	SE (days)	Range (days)
Bridge	6	15.4	2.01	0.25	1.25 - 2.78
Chilcotin	6	26.8	1.16	0.18	0.72 - 1.89
Thompson	6	21.6	1.44	0.17	1.06 - 1.96
Nicola	16	12.6	2.46	0.73	1.00 - 12.95
Bonaparte	3	24.5	1.27	0.26	0.96 - 1.77
Deadman	6	13.2	2.36	0.79	0.97 - 6.24

Similar to 1996, an ANOVA for 1998 migration times failed to show more variation between stock migration times than among individual stock migration times ($F=0.861$, $P=0.519$ for Harrison to Hope, $F=0.857$, $P=0.520$ for Hope to Nahatlatch and $F=0.533$, $P=0.713$ for Nahatlatch to Lytton). Once again however, Nicola and Chilcotin steelhead appear to stand out on opposite ends of the spectrum. Chilcotin steelhead consistently take fewer days to travel between fixed stations and have the narrowest range of travel times between fixed stations than all other interior stocks. Nicola steelhead generally take the most number of days and demonstrate the widest range of travel times between telemetry stations. Statistically, the difference in variances between these two stocks is only significant between the Nahatlatch and Lytton telemetry stations ($F=43.8$, $P=0.000280$). The mean travel times for Chilcotin and Nicola steelhead were determined to be significantly different between the Hope and Nahatlatch telemetry stations only ($t=2.80$, $P=0.0133$).

Migration Rates at Various Water Temperatures

In 1998, there were 3 locations where sample sizes were large enough to compare stock specific migration rates at various temperatures. Between the Harrison and Hope telemetry stations, interior Fraser steelhead traveled in water temperatures that ranged from 7 ^{0}C to 15 ^{0}C. Between these two locations, Thompson stocks appeared to migrate at the highest rate in the 8 ^{0}C to 9 ^{0}C range and decreased their migration rate in warmer temperature ranges. The migration rates of Chilcotin steelhead however, appeared to increase with water temperature (Figure 71).

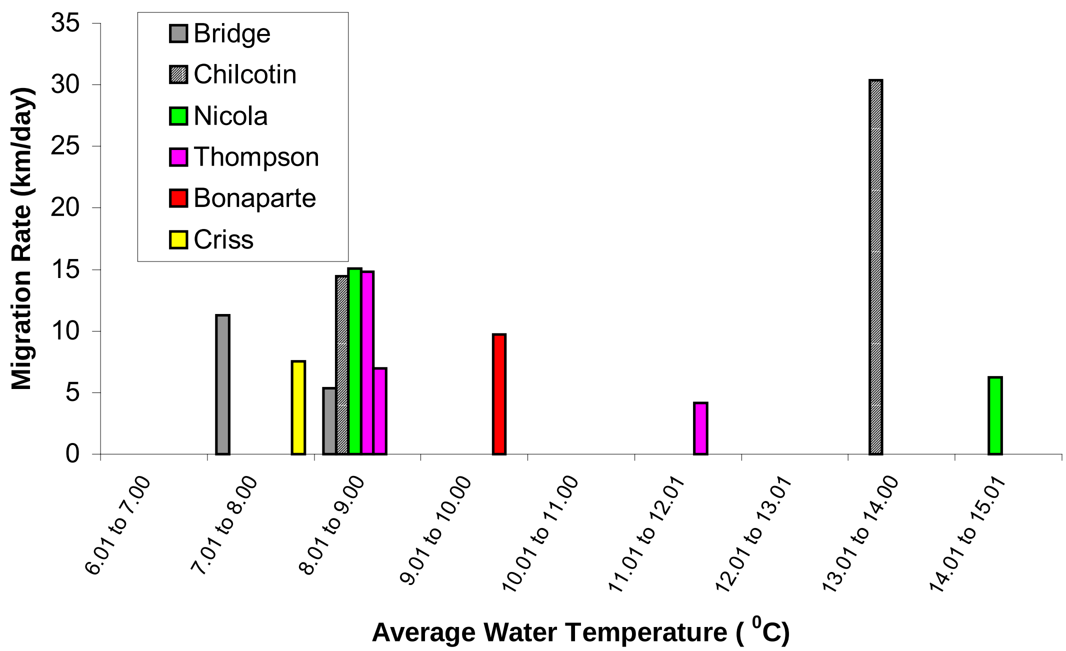

Figure 71. The migration rates of interior Fraser steelhead at different water temperatures between the Harrison and Hope telemetry stations in 1998.

Between the Hope and Nahatlatch telemetry stations, migration rates appeared to be similar across all temperatures. In 1998, the majority of interior Fraser steelhead migrated within a water temperature range of 7 ^{0}C to 9 ^{0}C, with extreme values as low as 5 ^{0}C and as high as 14 ^{0}C. Chilcotin steelhead migrated at a higher rate in colder water temperatures, whereas all other stocks had relatively consistent migration rates across all temperatures (Figure 72).

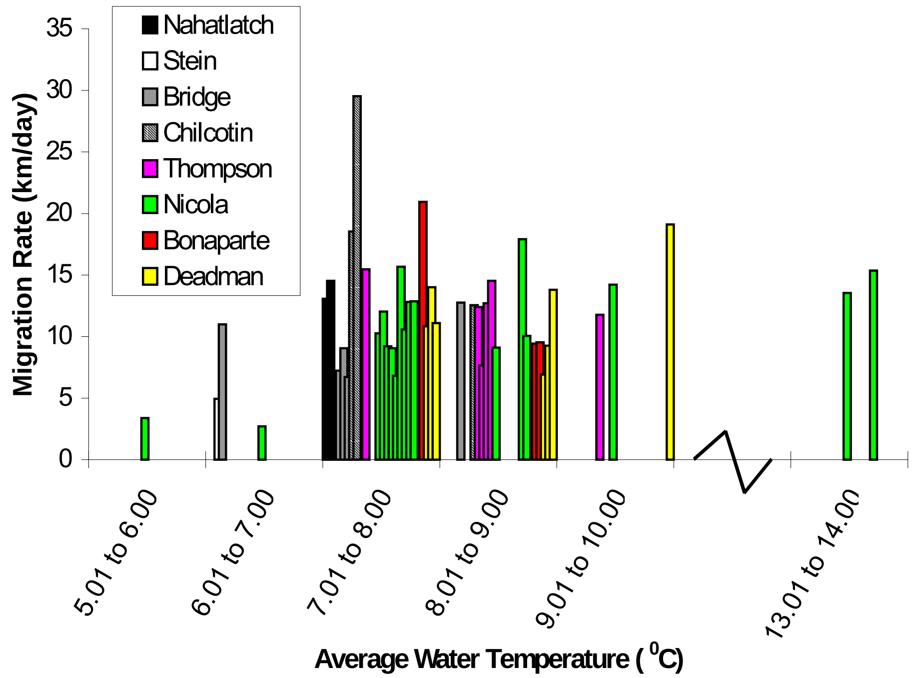

Figure 72. The migration rates of interior Fraser steelhead at different water temperatures between the Hope and Nahatlatch telemetry stations in 1998.

Between the Nahatlatch and Lytton telemetry stations, there appears to be a tight clustering of all stocks between the 6 ^{0}C to 9 ^{0}C temperature range, with one steelhead in the 1 ^{0}C to 2 ^{0}C temperature range. Once again Chilcotin steelhead migrated at a higher rate in colder water temperatures. The migration rate of all other stocks seems to vary directly with the average water temperature. Unlike 1996, Chilcotin steelhead in 1998 did not appear to travel in warmer water temperatures than other interior Fraser stocks (Figure 73).

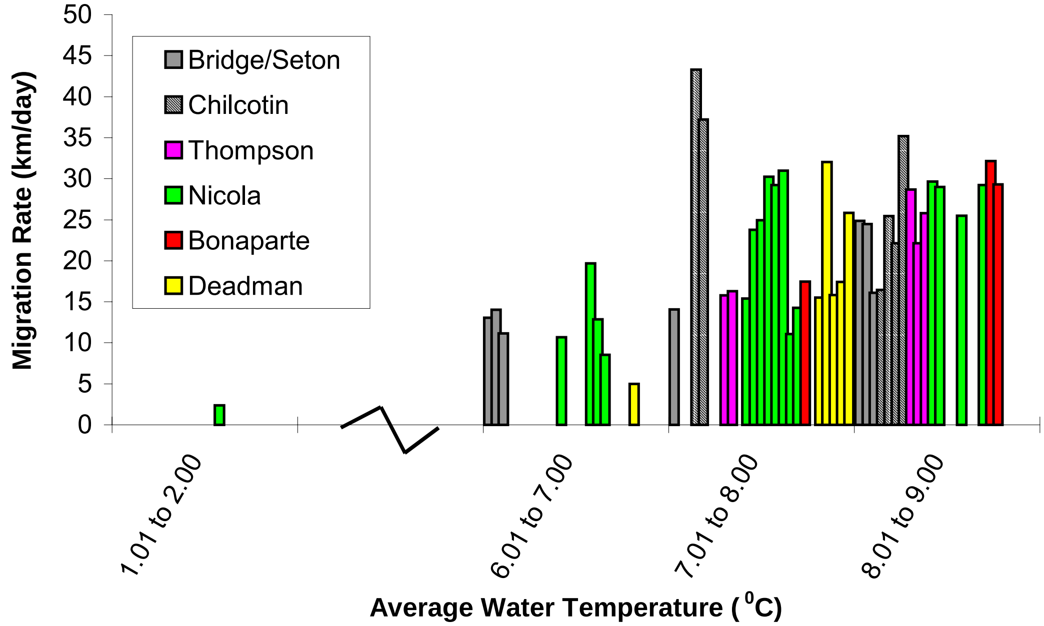

Figure 73. The migration rates of interior Fraser steelhead at different water temperatures between the Nahatlatch and Lytton telemetry stations in 1998.

Stock Specific Run Timing

In 1998, the run timing of interior Fraser steelhead appears to have a narrower range than in 1996. Although Chilcotin steelhead are more abundant in the early portion of the run timing curve (prior to mid-October) they are relatively evenly distributed throughout. This however, may be due to the distance between capture locations. Most of the Chilcotin steelhead were captured by the Yale Fishwheel; 51 km upstream of the angler caught (mostly Thompson stocks) steelhead. Overall, interior Fraser steelhead appear to peak in the lower Fraser in the 3rd week of October, with a migration period that spans from mid-September to mid-November (Figure 74).

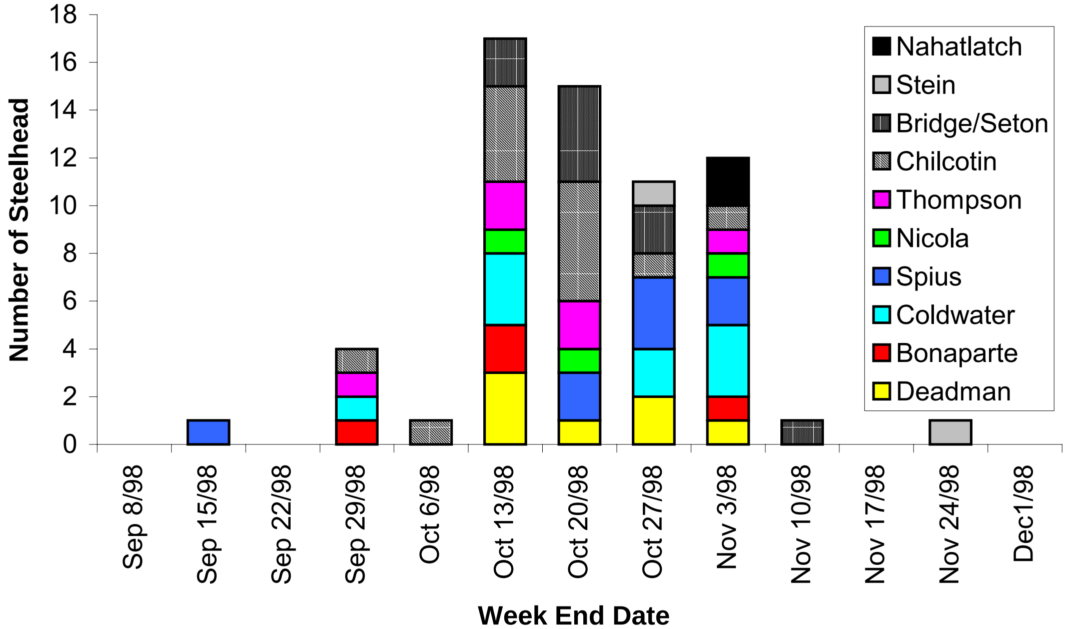

Figure 74. The run timing of interior Fraser steelhead as determined by capture date, 1998.

Stock specific differences in interior Fraser steelhead run timing past the Nahatlatch telemetry station were not as accentuated in 1998 as in 1996. Once again, Chilcotin steelhead migrated past the Nahatlatch telemetry station in the early portion of the run, from early-October to early-November, with a median run timing date that occurred on October 19th (*n=13*). All other interior stocks peaked one to two weeks later than this in early-November, with a migration period from early-October to late-November. Bridge River steelhead had a median date that occurred on November 7th (n=8). Similarly, Stein (n=2) and Nahatlatch (n=2) steelhead had median migration dates that occurred on November 7th and November 9th, respectively. Nicola (n=19) steelhead had a median migration date that occurred on November 6th and Deadman (n=7) steelhead had a median migration date that occurred on November 2nd. Bonaparte (n=4) steelhead appeared to have a slightly earlier run timing with a median migration date that occurred on October 26th. Two interior Fraser steelhead migrated past the Nahatlatch telemetry station in December but unlike the 1996/97-telemetry project, no steelhead migrated past the telemetry station in the following spring (Figure 75).

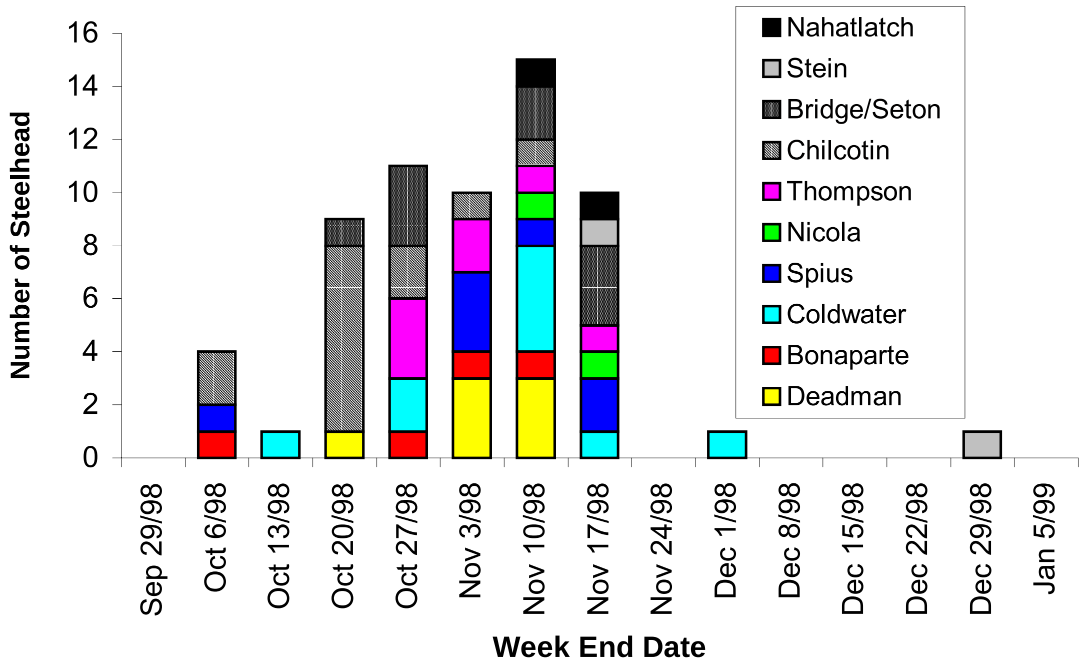

Figure 75. The run timing of interior Fraser steelhead as determined by the Nahatlatch telemetry station, 1998.

DISCUSSION

Radio Tag Deployment

Marine Radio Tag Deployment, Fall 1996

Perhaps one of the most striking results from the three years of radio telemetry data was the consistently high proportion of radio-tagged steelhead whose fates could not be determined. Despite efforts to minimize handling stress and locate all active radio tags, the proportion of radio-tagged steelhead with undetermined fates was nearly as high as those with determined fates. Even more dramatic was the complete failure of marine deployment efforts during the fall of 1996.

To begin to understand the disappearance of the 39 marine deployed radio tags all potential sources of tag loss must be examined. Initially, 20 oviduct radio tags were deployed in Areas 12, 13 and 21 via seining and 11 gastric tags were deployed in Areas 12 and 13 via seining. Eight gastric radio tags were deployed with gill nets in Area 21. From results obtained in freshwater, all 5 of the oviduct tags deployed were expelled very near their original tagging location (see Results page 89). Because of this high expulsion rate, the sample size of viable tags deployed in the marine environment is immediately reduced from 39 gastric and oviduct tags to only 19 gastric tags. Out of these 19 gastric tags, 8 were deployed via gill net in Area 21 (Nitinat Chum Test Fishery). Beere (1989) found that Skeena River steelhead captured in a gill net and radio-tagged had a mortality rate of approximately 86%. However, anesthetic was not used in the Skeena study and the steelhead were captured near the estuary[1]. Because of these differences, the assumption that the mortality rate found in the Skeena is similar to that of the steelhead captured via gill net in Area 21 may not be accurate. If however the mortality rates from this study are comparable to that found in the Skeena, it may be possible to attribute the loss of marine radio-tagged steelhead from Area 21 to high mortality and small sample size alone. Alternatively, it has been suggested that the majority of steelhead captured by gill net and radio-tagged in Area 21 were from stocks other than Fraser River. However, mixed stock analysis of microsatellite DNA samples taken from steelhead captured in the 1996 Nitinat Chum Test Fishery demonstrated that 86% were from interior Fraser stocks (Beacham 1999). Therefore, the possibility that these steelhead were from other non-Fraser stocks is highly unlikely.

Steelhead captured in a seine net and live released also suffer a mortality rate, although not nearly as severe as those captured via gill net. Spence (1989) reported a mortality rate among seine captured and radio-tagged Skeena steelhead (without the use of anesthetic) of approximately 30%. If the radio tagging conducted on seine captured steelhead in Areas 12 and 13 had a similar mortality rate then a reasonable sample size should have been detected somewhere within the Fraser watershed. Once again, an alternative theory is that a large portion of the steelhead captured in Johnstone Strait

[1] Steelhead captured in estuaries may be in a compromised state and appear to have a lower survival rate when released in comparison to steelhead captured in a completely freshwater environment (Dana Atagi and Mark Beere, MELP Smithers, pers. comm.).

Fisheries were destined for river systems other than the interior Fraser. However, Parkinson (1984) demonstrated that interior Fraser stocks tend to dominate the composition of steelhead captured in Johnstone Strait during the month of September. A difference in the tagging methodology between this study and the studies near the mouth of the Skeena River was the use of clove oil as an anesthetic. However, mortality directly attributed to the use of clove oil seems unlikely. Baxter and Hagen (1997) found that pen reared steelhead in a marine environment suffered no significant increase in mortality rates when exposed to clove oil, than a group exposed to CO_2 (Alka Seltzer), and a control group that was only handled. These experimental findings suggest that clove oil used in salt water, as an anesthetic does not directly cause mortality in steelhead. Clove oil may however have other undetermined affects, which could not be determined in an experimental setting, such as increasing a steelhead's short-term susceptibility to predators.

Predation by marine mammals may explain why some of the gastric radio-tagged steelhead failed to reach the Fraser River. Steelhead radio-tagged in freshwater, whether anesthetic is used or not, usually stop their upstream migration immediately after radio tagging. The usual pattern of movement is one of downstream movement followed by a stationary period usually exceeding one or two days followed by the resumption of upstream migration (R. Bison, MELP Kamloops, pers. comm.). Steelhead are undoubtedly affected by the procedure and it seems reasonable that this affect may cause them to be more vulnerable to predation. As stated, the use of anesthetic could further increase vulnerability to predation. While radio tagging in both the Nitinat and Johnstone Strait, a variety of marine mammals were observed particularly in Johnstone Strait. An abundance of marine predators in clear water marine environments may have caused steelhead captured near Nitinat and in Johnstone Strait to suffer higher mortality rates than reported in the Skeena studies (Beere 1989; Spence 1989).

Although the above factors may all be important causes of tag loss, it remains a challenge to explain the disappearance of all 39 of the saltwater-deployed radio tags. The 100% expulsion rate of oviduct tags observed in freshwater suggest that the number of potentially viable radio tags released in the ocean was immediately reduced by over 50%. A proportion of the remaining gastric radio tags may have also been expelled but at a much lower rate; generally less than 10% (Hooton and Lirette 1986; Koski *et al*. 1995). High mortality rates (86%) suffered by steelhead captured in gillnets and a more moderate mortality rate (30%) suffered by steelhead captured in seine nets would also further reduce the potential sample size of gastric radio-tagged steelhead to enter freshwater (Beere 1989; Spence 1989). These known factors combined should leave a remaining sample of approximately 8 radio-tagged steelhead to enter freshwater. The question remains then as to the relative contributions of predation, mortality due to capture in seine and gill nets, or some other unknown factors to the loss of marine deployed radio-tags.

Selective Fisheries

Annacis Island Tangle Net

The Annacis Island tangle net was operated throughout the interior Fraser steelhead telemetry program in the fall of 1996, 1997 and 1998, with inconsistent results. The first year of operation (fall 1996) provided by far the best results of the 3 years, but in each year the combined total of unknown fates and mortalities ranged from 59% to 100% with the vast majority of these (45% to 69%) coming from the unknown fates category (Tables 22, 23 and 24). In each year, a large portion of the steelhead radio-tagged by the tangle net fail to move upstream immediately after release. Due to the inability to detect radio tags downstream of the Annacis Island capture site (due to high salinity), these radio-tagged steelhead were considered to have unknown fates. Since steelhead are iteroparous, it is possible that the stress induced by capture in the tangle net and handling caused these steelhead to return to the ocean in an attempt to spawn the following year. However, interior Fraser steelhead arriving at the mouth of the Fraser River have already traveled over 3000 km and it is unlikely these fish would invest so much of their resources and not attempt spawning. The physiological changes undergone by steelhead on their return migration to freshwater are poorly understood and it may be possible that by the time interior Fraser steelhead reach the estuary, their fate is sealed and the maturation process cannot be reversed. It is likely that the majority of steelhead that failed to move upstream after being captured via tangle net were mortalities. If so, the tangle net would appear to have had a mortality rate that was fairy consistent with the 86% mortality rate of Skeena steelhead captured via gill net in an estuary as reported by Beere (1989).

As a test of a selective gear type, locating the tangle net in the Fraser River Estuary, may have put it at a disadvantage relative to other selective fisheries. As previously noted (in footnote [1]), steelhead captured in an estuary appear to be in a compromised state and suffer a higher mortality rate than steelhead captured further upstream (Dana Atagi and Mark Beere, MELP Smithers, pers. comm.). There were also inconsistencies in the year to year results for the lower Fraser tangle net fishery. In the fall of 1996 the tangle net had the highest proportion of its radio-tagged steelhead enter spawning tributaries that were monitored by telemetry. In 1997 however, none of the steelhead captured and radio-tagged via tangle net were even detected upstream of the Nahatlatch/Fraser confluence and in 1998 only 3 radio-tagged steelhead captured via tangle net entered a monitored spawning tributary (Tables 22, 23 and 24). Since the success of radio-tagged steelhead from other gear types generally improved over time (specifically from 1996 to 1998), it is doubtful that the declining success of the tangle net was due to environmental conditions. It is more likely that a change in the handling of steelhead or the operation of the tangle net caused an increase in the mortality of steelhead captured via tangle net in 1997 and 1998.

The tangle net appears to have had better success with steelhead captured and radio-tagged in late-September than with steelhead captured and radio-tagged in late-October of 1996 (Figure 63). Unlike angling, the apparent lack of success of steelhead radio-tagged via tangle net late in the season in 1996 is not due to environmental conditions.

Only 1 out of the 20 (5%) steelhead considered to have been alive in the Fraser Canyon during the overwintering period was captured via tangle net. This may suggest that steelhead entering the Fraser late in the season are less fit and may suffer a higher mortality than steelhead that arrive earlier. An equally likely scenario is that steelhead radio-tagged later in October are more susceptible to commercial and native chum fisheries that occur throughout the lower Fraser and Fraser Canyon in late-October and November (Appendix XI in Renn 2001). This trend of poorer success of late radio-tagged steelhead was also apparent in angling and fishwheel results from 1998, although success rates for these fisheries declined later, in late-October and November (Figures 65 and 66). The difference in the timing of the decline in success may be due to the further upstream positioning of these fisheries within the watershed relative to the tangle net. Since the Annacis Island tangle net operated the furthest downstream of all the selective gear types, it is possible that a higher proportion of radio tags deployed in late-October were lost simply because these steelhead must travel a longer gauntlet of commercial and Native fisheries.

Overall, it is somewhat difficult to critically assess the performance of the tangle net due to inconsistent results from year to year and relatively small sample sizes. It appears however, that the mortality rate of steelhead captured in the tangle net and released is too high for it to be considered a viable “selective fishing” alternative. It is possible that moving its location further upstream, out of the Fraser estuary, could reduce the mortality rate of the tangle net. This would also facilitate the monitoring of any radio tags deployed and allow for a more accurate evaluation of the fishery. Finally, the methodology for handling steelhead and/or the overall operation of the tangle net need to be re-evaluated and standardized. Whether these recommendations have the potential to significantly reduce the mortality rate of steelhead captured in the tangle net remains in question.

Derby Reach Beach Seine

The Derby Reach Beach Seine is another difficult selective fishery to assess because of the small sample size of steelhead captured and radio-tagged each year. While operating in the fall of 1996, 1997 and 1998, the beach seine only radio-tagged a total of 8 steelhead, with only two (25%) of these successfully entering a monitored spawning tributary. The largest percentage of radio-tagged steelhead (50% or 4) captured by the beach seine were determined to have unknown fates, with the remaining 25% (2) considered to be mortalities. This lack of success is somewhat surprising since beach seines operated in other locations to capture and radio tag steelhead have produced good results with low mortality rates (Al Caverly, MELP Kamloops, pers. comm.). Since the gear type has been proven effective in capturing steelhead unharmed, it is possible that the gear itself is not responsible for some of the mortalities and subsequent radio tag loss. This portion of radio tag loss then may be attributed to mortalities caused by handling stress. As with the tangle net, some of the unknown fates may be attributed to steelhead being captured and killed in lower Fraser/Fraser Canyon fisheries and not reported to ministry staff. As a final consideration, 2 out of a total of 4 radio tags in the unknown fate category were last detected in the Fraser Canyon in the fall of 1996/early winter 1997. Since 56% of the radio-tagged steelhead, detected in the late winter/early spring of

1997, did not migrate upstream past the Nahatlatch/Fraser confluence, the loss of these tags may not be a result of gear type but a result of environmental conditions. If these same two steelhead had managed to migrate into the interior and successfully enter a monitored spawning tributary then the beach seine would have had a success rate of 50% instead of 25%, further illustrating the problem of small sample size.

Fall Angling from Chilliwack to Hope

Although not an experimental selective fishing method per se, results from angled steelhead provided a means of comparison between capture methods, particularly since angling has been used for many years to successfully deploy radio tags (Spence 1980; Hooton and Lirette 1986). In the fall of 1996 when migration conditions were not favourable, only 28% of the radio tags deployed by anglers in the lower Fraser were later detected in a monitored spawning tributary. This is a very low proportion in comparison to other steelhead telemetry studies (Spence 1980; Hooton and Lirette 1986). A much larger percentage (48%) fell into the unknown fate category, which is a result shared by the tangle net and beach seine fisheries in 1996. However, unlike the tangle netted steelhead, a relatively high proportion of angled steelhead which were considered to have unknown fates, reached the Fraser Canyon in 1996 (16/24 or 66% compared to 2/13 or 15% for tangle netted steelhead). This suggests that steelhead radio-tagged in different locations using different gear types may have suffered different fates or possibly suffered similar fates in different locations. In the fall of 1998 when migration conditions were more favourable, only 19% of the steelhead radio-tagged by anglers had unknown fates, with 72% entering monitored spawning tributaries.

What is most striking about using angling as a fall capture method in the lower Fraser, is its apparent inability to catch Chilcotin steelhead. In 1996 and 1998, anglers only managed to capture 1 and 2 Chilcotin steelhead respectively. In 1996 the tangle net captured 2 Chilcotin steelhead even though its total catch was slightly more than half that of anglers. In 1998 the Yale fishwheel captured 10 Chilcotin steelhead even though it deployed fewer radio tags than anglers. Lower Fraser anglers also appear to have difficulty catching steelhead in late September and early October suggesting that this is the portion of the interior Fraser steelhead run timing curve dominated by Chilcotin steelhead. Conversely, the Yale fishwheel, operating 75 km upstream of the lower Fraser Anglers had relatively high catches during late September and early October. This suggests that Chilcotin steelhead have some type of behavior characteristic that makes them less susceptible to angling while they migrate through the lower Fraser River. This becomes an important point in a later discussion regarding the assumptions for using radio-tagged steelhead as marks for a mark/re-capture stock enumeration.

Yale Aboriginal Gill Net Fishery, 1996

The aboriginal gill net fishery in 1996 was used as a last chance effort to deploy more fall radio tags and to see first hand its effectiveness at capturing steelhead. In 24 hours the gill net captured 7 steelhead: three of these were dead on arrival, 1 steelhead was in poor condition and only spaghetti-tagged, and 3 steelhead were radio-tagged. Two of the 3 radio tagged steelhead were determined to be mortalities; once again showing the high mortality rates in gill net captured steelhead also found by Beere (1989). Interestingly, the only steelhead to survive was captured in another aboriginal gill net the following spring and it's radio tag had been regurgitated.

Yale Fishwheel, 1998

The Yale Fishwheel was used primarily to augment the number of radio tags deployed in late September, early October and again in mid-November. The stock composition of its catch appears to favour Chilcotin steelhead and contains a very small percentage of Thompson steelhead. This apparent tendency to capture Chilcotin steelhead however is likely due to the unavailability of radio tags for deployment by the fishwheel in the later half of October. It is quite likely that if radio tags had been available throughout October and early November, the fishwheel would have captured a much higher proportion of Thompson steelhead. Although CPUE’s were not calculated for any of the gear types, the fishwheel would have likely had highest and proved to be a very effective means for capturing steelhead.

The mortality rate demonstrated by the fishwheel was considerably higher than angling but appears to be similar to other reported mortality rates for steelhead captured in fishwheels, operated under similar circumstances (Alexander et. al. 1996). Many of these mortalities occurred in late September/early October when daily mean water temperatures exceeded 12^0C (Figure 66; Table 24). Although mortalities at this time may be a result of increased stress due to higher water temperatures it may have also been caused by inexperienced operators. Since the fishwheel was operated for the first time in 1998, it is possible that it’s operational and fish handling procedures needed fine-tuning before steelhead could be captured and handled efficiently. This may be the reason that during mid-October the success of radio tags deployed by the fishwheel increased greatly. Interestingly, in mid-November, the success of radio-tagged steelhead drops off once again despite the fact that the technician applying radio tags remained the same. Angled steelhead from the fall of 1998 also showed a similar pattern: steelhead captured late in the season did not reach a spawning tributary. It is possible that these late arriving steelhead were less fit individuals and were not likely to reach a spawning tributary even if they were not captured and radio-tagged. As previously mentioned, it is also possible that these late arrivals were more susceptible to Aboriginal chum fisheries occurring in the Fraser Canyon during the month of November (Appendix XI in Renn 2001). Finally, late arriving steelhead may end up overwintering further downstream than their earlier arriving counterparts. This would leave them more susceptible to unpredictable environmental conditions in the spring and/or early Aboriginal chinook fisheries.

The number of radio-tagged steelhead in the unknown fate category captured by the fishwheel was only slightly higher than those captured via angling whereas the regurgitation rate of radio tags seems slightly lower for fishwheel captured steelhead. It is possible that some of the regurgitated radio tags and some of the mortalities from the fishwheel are reported as unknown fates. Due to the depth of water in the Fraser Canyon, a regurgitated radio tag that sinks to the bottom would become undetectable and subsequently categorized as an unknown fate. Similarly, mortalities that sink rather than move downstream past a fixed telemetry station may also be recorded as unknown fates.

The fishwheel seems to operate quite efficiently in the Fraser Canyon and has potential as a selective gear type. It appears that with careful fish handling and operating procedures, the mortality of live released steelhead could be reduced. Fishwheels that have been operating in the Nass River for several years appear to be very effective at both capturing target species and having a low mortality on by-catch species such as steelhead (Dana Atagi, MELP Smithers, pers. comm.).

Radio Tag loss in the Fraser Canyon 1996/97

In the fall of 1996, early onset of arctic frontal conditions caused water temperatures to plummet in early November; almost a full month earlier than most years (Figure 12). It is likely that the cold water temperatures at this time affected steelhead migration through the Fraser canyon and ultimately their spawning success. A total of 23 steelhead were known to be in the Fraser Canyon during the overwintering period. One of these steelhead was captured in a native gillnet the following spring. Out of the 22 remaining radio-tagged steelhead, 8 migrated upstream past the Nahatlatch/Fraser confluence later in the spring. This left 14 steelhead in the Fraser Canyon, of which 2 were subsequently detected as kelts by the Hope telemetry station. In all, 12 out of 23 (52%) of the radio-tagged steelhead that were known to have entered the Fraser Canyon disappeared. To keep track of the radio-tagged steelhead in the Fraser Canyon, 2 overwintering flights were conducted on January 24th and on March 10th. When it appeared that very few of the radio-tagged steelhead were migrating upstream past the Nahatlatch telemetry station, a third flight was conducted on May 12th to determine if many of the radio-tagged steelhead had entered one of the tributaries in the Fraser Canyon. The telemetry flights on January 24th and March 10th detected 15 radio tags and 18 radio tags respectively, suggesting that at this point in time no removal or tag loss was occurring. The flight conducted on May 12th however only located 6 radio-tagged steelhead in the mainstem Fraser and did not locate any radio-tagged steelhead in Fraser Canyon tributaries. Prior to May 12th, 3 of the radio-tagged steelhead had moved upstream past the Nahatlatch telemetry station and 1 had been re-captured, leaving a possible 19 radio tags for detection on the May12th flight. Thirteen radio-tagged steelhead were not detected on that flight and these radio tags must have been removed or had become undetectable between March 10th and May 12th.

A portion of the loss of radio tag reception between March 10th and May 12th can be explained by the tracking conditions. The Fraser Canyon in general was one of the more difficult stretches of river tracked during this study. This section is canyonous and deep, with large boulders and bedrock that can ground out radio signals. On the January 24th flight, the Fraser River discharge was 1010 m^3/s and on the March 10th flight it was even lower at 826 m^3/s. On the May 12th flight however, the Fraser River had a discharge of 5960 m^3/s; an increase of approximately 6 fold. In the Fraser Canyon an increased discharge of this magnitude and the accompanying increase in water depth would likely make detection much more difficult. These early freshet conditions would tend to increase the conductivity of the water, also making detection more difficult (Tom Lewendoski, Lotek, pers. comm.). It is questionable however whether this difficulty would also be experienced on radio tags that were in live steelhead. On The May 12th flight, 3 of the 6 radio-tagged steelhead detected, subsequently migrated upstream past the Nahatlatch telemetry station. Two of the remaining 3 steelhead detected were later recorded as kelts by the Hope telemetry station. This suggests that live radio-tagged steelhead were still detectable even in poorer tracking conditions and that a large portion of the undetected radio tags were either expelled, removed or still within steelhead that were dead and in deep water.

The number of unreported radio-tagged steelhead captured in aboriginal gill net fisheries in the Fraser Canyon remains in question. Two radio-tagged steelhead were reported as being re-captured in aboriginal gill nets in November of 1996. Aboriginal gill net chum fisheries occurring around this time reported catching a total of approximately 175 steelhead (Appendix XI in Renn 2001). Tag loss in the Fraser Canyon however appeared to occur in the spring of 1997. It is possible that the radio tags from steelhead re-captured in gill nets during the fall were removed and thrown in the shallow margins of the river. These radio tags would likely remain detectable under low water conditions and gradually become undetectable as water levels rise. Gill net fisheries also occur in the spring for chinook salmon and in 1997 these fisheries began on March 2nd, with 15 steelhead and 1 Chinook salmon reported captured (Anonymous 1997b). These spring fisheries coincided much better with the tag loss experienced in the Fraser Canyon. During this time however only 1 radio-tagged steelhead was reported re-captured in a Native gill net in the Fraser Canyon.

A higher regurgitation rate than reported may also be responsible for some of the radio tag loss in the Fraser Canyon in 1996/97. Once again, regurgitated tags may remain detectable in low water conditions and then gradually appear to go missing as water levels and conductivity rises. Three out of the 11 (27%) re-captured steelhead that were radio-tagged in the fall of 1996 were reported to be missing their radio tags at the time of re-capture. This regurgitation rate is considerably higher than was tabulated by mobile data alone in Table 21 of the Results (page 89). This same high regurgitation rate does not seem to show up in re-capture data from steelhead radio-tagged in the fall of 1998. However, a different model of radio tag (that was 1.5 mm smaller in diameter) was used in 1996 than in 1998, which may explain an increase in regurgitation rates for fall radio-tagged steelhead (Table 1). This does not explain why steelhead radio-tagged in the spring of 1997, with the same smaller radio tags as used in the fall of 1996, did not show a increase in regurgitation rates. It is possible that high regurgitation rates did not show up in steelhead radio-tagged in the spring of 1997 because the digestive track of these steelhead was more atrophied. This may allow for a physically tighter fit of the radio tags or make it more difficult for steelhead to actually regurgitate/expel the radio tag.

It is also possible that a large percentage of the steelhead forced to overwinter in the Fraser Canyon in 1996 died. As mentioned previously, only 8 out of a possible 22 (36%) radio-tagged steelhead actually managed to migrate upstream past the Nahatlatch telemetry station and only 3 managed to enter a recognized spawning tributary. It is unlikely that the 5 steelhead that did not enter a recognized tributary spawned successfully, since they did not enter the interior until late May/early June and were never detected near a suitable spawning tributary. What is interesting is that 2 out of the 5

(40%) were detected as kelts by the Hope telemetry station. As mentioned in the tangle net discussion, steelhead are iteroparous and may have the ability to return to the ocean and delay spawning until the following season. In either case, the poor spawning success of the radio-tagged steelhead that overwintered in the Fraser Canyon in 1996/97 suggests that the environmental conditions faced must have depleted their physiological resources considerably. Out of the 8 steelhead that had the physiological reserves to migrate upstream out of the canyon, only 3 appeared to have the remaining reserves to successfully spawn. Although the cold water temperatures seen in the fall of 1996 are somewhat rare (Environment Canada, data on file, 1997), it appears that overwintering in the Fraser Canyon is strongly selected against and likely plays an important role in shaping the run timing and overwintering strategies of interior Fraser steelhead.

Stock Specific Run Timing and Migration Behavior

Although none of the radio tags deployed in the ocean in 1996 entered fresh water, the capture information provides some clues as to the run timing of interior Fraser steelhead through Johnstone and Juan de Fuca Straits. In Areas 12 and 13 (Johnstone Strait) steelhead captures peaked in approximately the final week of September. Although genetic testing was not performed on the samples taken here, Parkinson (1984) determined through electrophoresis that the majority of steelhead captured in Johnstone Strait in September were of interior Fraser origin and possibly a large proportion of these were Chilcotin steelhead. Andrews and McSheffrey (1976) also found that a large race of steelhead migrated through Johnstone Straits in the month of September. In Area 21 of Juan de Fuca Strait, catch data of interior Fraser steelhead (as determined by analysis of microsatellite DNA) in the Nitinat Chum Test Fishery also showed a rise in abundance in the final week of September (Beacham 1999).

As with run timing in the ocean, much of the knowledge of interior Fraser steelhead run timing in fresh water is through historic anecdotal information. The Albion chum test fishery is one of the few sources of information regarding the run timing of interior Fraser steelhead but cannot by itself provide stock specific run timing information. The test fishery itself is also geared to mainly catch chum salmon and the CPUE for steelhead is often derived from only a few fish. This makes the CPUE data very sporadic. Bison and Renn (1997) found that by using an 8 day moving average, the Albion CPUE on most years show 4 peaks in abundance: a small peak occurs in mid-September, a second larger peak occurs in early October, a third large peak occurs in the third week of October and a fourth, much smaller peak, occurs in early November (Figures 6, 29 and 40). The relative size of these peaks varies from year to year but the timing remains relatively consistent. Combining this type of data with the telemetry capture data provides a general outline for stock specific run timing.

There are some difficulties determining stock specific run timing in the lower Fraser. To begin with, the capture locations used are spread out over a wide geographic. As a result the sample size of radio-tagged steelhead detected by lower Fraser telemetry stations is small and often shows no definite peak in abundance. This is mainly true in 1998, when the fishwheel was used as a method of radio tag deployment. In 1996 most of the deployment was done by anglers and the tangle net so there was reasonable run timing data gathered by the Harrison telemetry station but the relative distribution of radio tags to individual stocks in 1996 appears to have been biased towards the Nicola stock. In 1998 the sample size for individual stocks was higher, but because much of the capture was done further upstream, the number of steelhead detected moving upstream past the Harrison (the only telemetry station in the lower Fraser in 1998) telemetry station was very small (Figure 46). For the purpose of this discussion, stock specific run timing will be determined by using 1998 capture data that has been transformed in an effort to standardize capture dates by each gear type to one location. Capture data from 1996 and genetic test results from steelhead captured in the Albion chum test fishery in 1996 will be used as a comparison.

In a previous discussion, it was established that anglers tended to capture Thompson stocks and the Yale Fishwheel disproportionately captured Chilcotin steelhead. Unfortunately, these two gear types are located approximately 55 km and 120 km from the site of the Albion test fishery, respectively. Using migration rates calculated between the Harrison and Hope and the Hope and Nahatlatch telemetry stations in 1998 and the migration rates calculated between the Barnston and Harrison telemetry stations in 1996, a distance from each gear type in terms of days to Albion can be calculated (Tables 4 and 15). Using these values the Yale Fishwheel is approximately 15 days of steelhead travel time upstream from Albion on the lower Fraser River. Anglers are approximately 3 days of travel time upstream of Albion and the Tangle Net is approximately 1 day downstream (Figure 76).

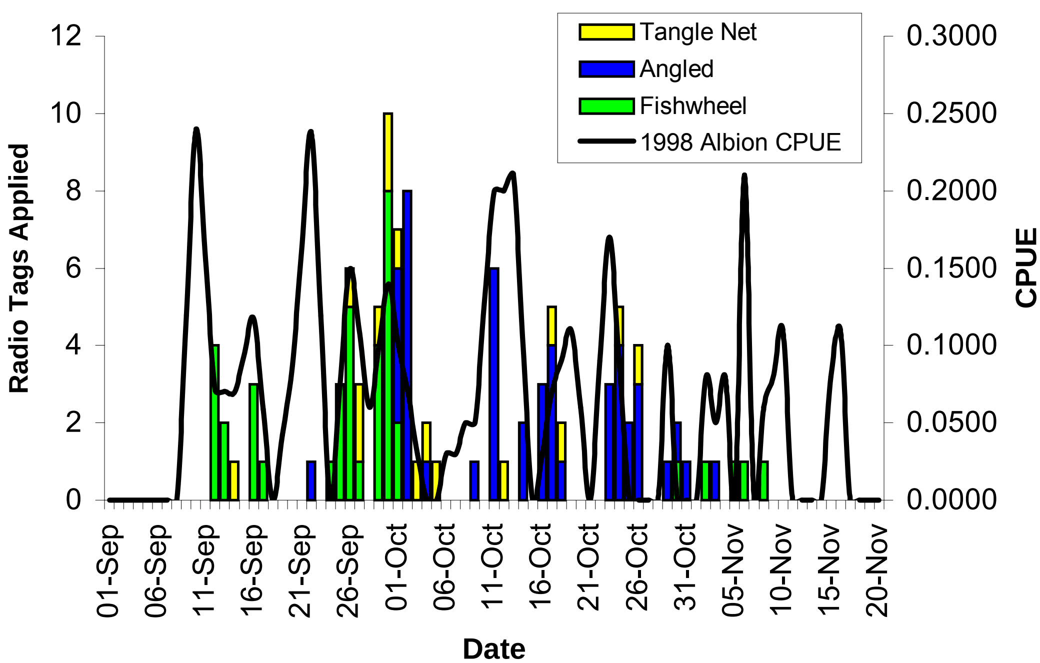

Figure 76. The temporal distribution of radio tags deployed in adult steelhead in the fall of 1998 in relation to the Albion Chum Test Fishing CPUE. Dates of capture for each gear type have been transformed to approximate a date of capture at Albion using migration rates calculated by telemetry station data from 1996 and 1998.

After the transformation of capture dates the spikes seen in the Albion CPUE match up much more closely to high capture rates by the various gear types. The Yale Fishwheel captured steelhead that appeared to make up the small spike in the Albion CPUE that occurs in mid-September and the majority of the second large peak that occurs in early October. Anglers appeared to capture steelhead that are mainly responsible for the third large peak in Albion CPUE that occurs around the third week in October and to a lesser extent, the second peak, that occurs in early October. The tangle net captured steelhead throughout the run timing but unfortunately the success of it's radio-tagged steelhead in 1998 was too low to provide an adequate sample size from individual stocks. Since the steelhead captured and radio-tagged by anglers in 1998 were made up of approximately 50% Thompson stocks then the majority of the late-October peak in the run timing curve generated by Albion CPUE data, is made up of Nicola, Bonaparte and Deadman steelhead. Conversely, the first mid-September peak and the second, early October peak are made up of Yale Fishwheel captured steelhead, which are predominantly made up of the Chilcotin stock. No Deadman steelhead were captured by the fishwheel, although they comprised 13% of the angler catch, suggesting that their run timing is slightly later than Nicola or Bonaparte steelhead. Bridge steelhead were captured evenly by both anglers and the fishwheel suggesting that this stock is evenly distributed throughout the run timing curve but on average may have a slightly earlier run timing than Thompson steelhead. Nahatlatch steelhead were captured only by anglers and Stein steelhead were captured by both gear types (fishwheel and angling). The capture dates for both of these stocks however were in late October and early November, suggesting that these stocks are most prevalent in the fourth small peak seen in many years in the Albion CPUE data (Figure 76). It is also possible that the latest peak seen in the Albion CPUE also contains steelhead from other lower Fraser winter run stocks.

In general, the genetic test results derived from steelhead captured in the 1996 Albion chum test fishery agree with the stock specific run timing scenario developed from telemetry data with a few exceptions (Sue Pollard, MELP Victoria, pers. comm.). The Nicola stocks appear to dominate all of the sampling time blocks, especially Spius steelhead (Figure 77). Nahatlatch steelhead also seem to be disproportionately represented in the Albion test fishery samples and appear to have an escapement that is similar in magnitude to the Chilcotin stock. Radio tag distribution data however shows this to be very unlikely although radio tags deployed in late October and early November are often unsuccessful. Perhaps a large portion of these steelhead are from the Nahatlatch stock. Interior Fraser steelhead run timing through the lower Fraser River encompasses nearly 2 months, from mid-September to mid-November and although each stock has a period when they are most abundant in the lower Fraser, all stocks are represented throughout this broad run timing curve. This is somewhat different than other salmonids, which tend to have run timing curves with smaller standard deviations. Interior Fraser steelhead however, only need to travel upstream to a suitable overwintering location and will not spawn until the following spring. This may allow for a variety of migration strategies. Selection pressure for interior Fraser steelhead run timing presumably does not come from the timing of spawning as much as it comes from environmental conditions during migration. Data from 1996/97 indicated that overwintering in the Fraser Canyon is not a highly viable option and that reproductive success is very low.

The Fraser Canyon is clearly a migration hurdle for interior Fraser steelhead and for Bridge, Nahatlatch, Stein and Thompson steelhead it is likely the only migration hurdle encountered in the fall. Chilcotin steelhead however, travel a much greater distance and also encounter a migration hurdle at the Bridge Rapids (Figure 1). In the later part of November the Chilcotin River itself may have cold enough water temperatures to become a thermal barrier to upstream migration. The extra hurdles encountered by Chilcotin steelhead are likely reflected in their slightly earlier run timing and also in their faster migration rates.

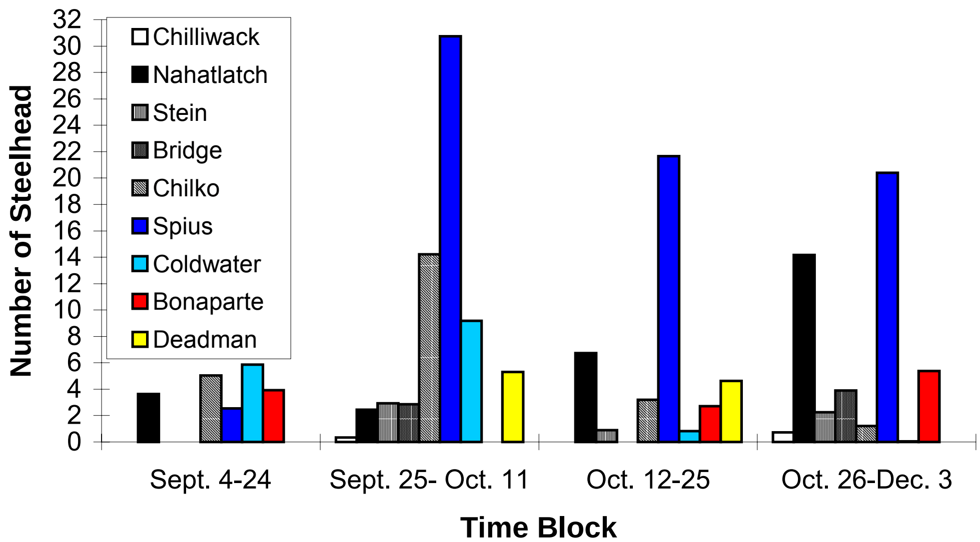

Figure 77. The stock composition of steelhead captured by the Albion Chum Test Fishery in 1996 as determined by microsattelite DNA analysis.

The Albion test fishery CPUE data as well as the capture data suggests that steelhead arrive in the lower Fraser in pulses. It is unclear as to whether these pulses are caused by the behavior of steelhead or by environmental conditions in the ocean or Fraser estuary. Ocean temperatures, currents, tide cycles and the route taken by steelhead around Vancouver Island may all be factors that affect interior Fraser steelhead run timing in the lower Fraser. As interior steelhead migrate upstream past Hope the run timing curve appears to smooth out and more closely resemble a normal distribution, with a standard deviation of approximately 10 days and a peak date on October 27th (Figures 15 and 47). In order to do this, late arriving steelhead would have to migrate at a higher rate than would early arrivals. In fact, Thompson steelhead and in particular Nicola steelhead appeared to increase their migration rates between the Harrison and Hope telemetry stations as water temperatures cool (Figures 67 and 71). Chilcotin steelhead however, arrive slightly earlier and maintain high migration rates during a time of warmer water temperatures. This suggests that early arriving Thompson stocks and possibly Bridge stocks, tend to mill in the lower Fraser, thereby slowing their migration rate. This may be one of the reasons anglers tend to selectively catch Thompson stocks over Chilcotin stocks. Milling Thompson steelhead that arrived in the lower Fraser early along with some later arrivals, may tend to concentrate in the lower Fraser, making them an easier target for anglers compared with the early arriving, faster migrating Chilcotin steelhead. This type of migration behaviour by Thompson steelhead may suggest that temperature is an environmental cue that influences run timing. It may be a gauge for interior steelhead to correctly time migration and avoid being trapped in the Fraser Canyon. Milling in the lower Fraser may also be a way of optimizing swimming performance. It may be more efficient for interior Fraser steelhead to migrate through difficult waters (such as the Fraser Canyon) at a specific temperature range, which appears to be between 7^0C and 10^0C (Figures 68 and 72). Early arriving Thompson steelhead may simply be waiting for water temperatures to cool into an optimum range. As mentioned previously, Chilcotin steelhead have other migration hurdles besides the Fraser Canyon and may not have the option of waiting for optimal temperatures or may have a different optimal temperature for swimming than Thompson steelhead.

In the Fraser Canyon in 1996, steelhead migration rates appeared to be closely correlated with average water temperatures and the range of temperatures which steelhead migrated in was much greater than in 1998. This presumably occurred because of the rapid drop in water temperatures in the Fraser Canyon in the fall of 1996 (Figure 12). In 1998 however the vast majority of steelhead migrated through the Fraser Canyon between 7^0C and 10^0C and showed relatively consistent migration rates throughout this temperature range. In 1996, steelhead that migrated in this temperature range also showed a consistent migration rate, although below an average temperature of 7^0C, migration rates fell quickly. Once again Chilcotin steelhead migration rates through the Fraser Canyon appeared higher than Thompson and Bridge stocks. This phenomenon was even more pronounced in 1996 when water temperatures plummeted. Arriving slightly earlier than some Thompson steelhead and migrating at a high rate through the lower Fraser, allowed Chilcotin steelhead to travel through the Fraser Canyon before water temperatures dropped significantly.

Because of the difference in migration behaviour between stocks, the stock specific run timing curve at the Nahatlatch/Fraser confluence has a slightly different appearance (Figures 16 and 48) relative to run timing data from the lower Fraser. Chilcotin steelhead, which arrived slightly earlier and migrated at a more consistent and higher rate, almost exclusively occupy the early part of the run timing curve. Thompson and Bridge steelhead occupy the middle and later portions of the curve and the few Nahatlatch and Stein steelhead are among the latest to arrive. The run timing curve at Nahatlatch also appears to become truncated both in 1996 and in 1998. In 1996, this may be explained by the inability of steelhead to migrate through the Fraser Canyon beyond a certain date. In 1998, the run timing curve is also truncated despite much warmer water temperatures which would have allowed steelhead to migrate through the Fraser Canyon well into December. This may suggest that steelhead have been highly selected to migrate through the Fraser Canyon prior to a certain time. As mentioned previously, this type of accuracy would likely require that steelhead use environmental cues to monitor their progress and adjust their migration rates accordingly. It appears that given an opportunity interior Fraser steelhead will migrate at a rate that allows them to pass through the Fraser Canyon prior to the middle of November and on most years water temperatures will remain high enough to allow this.

Upstream of the Nahatlatch/Fraser confluence, the differences in migration behaviour between Chilcotin and other Interior Fraser steelhead remains evident. In 1998, there was a statistically significant difference between the variances of the migration times for Chilcotin and Nicola steelhead travelling between the Nahatlatch and Lytton telemetry stations (Table 30). This may have been due in part to the relative distance of each stock to their overwintering locations and it may also have been due to water temperatures. As Nicola steelhead near Lytton, they are getting close to their overwintering location (Thompson River) and some individuals may begin to slow their migration rates. This is also true for Bridge and Stein River steelhead, which overwinter in the Fraser mainstem upstream of Nahatlatch and at the Thompson/Fraser confluence. At Lytton however, Chilcotin steelhead are only half way to the Chilcotin/Fraser confluence and continue to maintain a higher and more consistent migration rate. Also, the peak of the run timing of Chilcotin River steelhead past the Nahatlatch/Fraser confluence is approximately a month earlier than the latest arriving Nicola steelhead. This allows Chilcotin and early arriving Nicola steelhead to migrate in much warmer water temperatures than the later arriving Nicola steelhead. Although early arriving Nicola steelhead do not appear to migrate through this section of the Fraser as quickly as Chilcotin steelhead, they have the opportunity to migrate at a higher rate than later arriving Nicola steelhead, causing the wide variation in Nicola steelhead migration times (Figure 75; Table30).

On most years, interior Fraser steelhead begin arriving at their overwintering locations in early November. This timing appears quite consistent for all stocks regardless of the distance migrated. In 1996, Thompson steelhead began entering the Thompson River in late October and peaked near the end of November. In 1998 Thompson steelhead entered the Thompson River around the same time as in 1996 but peaked in the first week of November. In 1998 the peak period for steelhead entering the Thompson River was also much shorter and more pronounced. It is likely these differences in the duration and peak of the run timing curve for steelhead entering the Thompson were caused by the differences in water temperatures in the fall of 1996 and 1998. Run timing into the Thompson River as determined by telemetry also matches well with angler effort patterns in the Thompson River sport fishery (Steve Maricle, MELP Kamloops, pers. comm.). Unfortunately there is much less data on the arrival dates of Chilcotin steelhead to the Chilcotin River in the fall. There are only 2 Chilcotin steelhead recorded entering the Chilcotin River via telemetry station: one was detected on October 24th, 1996. And the second was on October 16, 1997. In 1998, 10 Chilcotin steelhead overwintered in the Chilcotin River but none were detected by the telemetry station that was set up at the Chilcotin/Fraser confluence on November 20th. A flight on that date showed that the radio-tagged steelhead that used the Chilcotin River for overwintering during that year had already reached overwintering locations. Most of these steelhead were detected by the Lytton telemetry station and all of them by the Nahatlatch telemetry station. It appears that Chilcotin steelhead migrate through Lytton in the third week of October. Assuming a migration time from Lytton to the Chilcotin confluence of a week to 10 days, Chilcotin steelhead should arrive at the Chilcotin/Fraser confluence in the last week of

October. This is similar to the Chilcotin steelhead recorded in 1996 and 1997, and matches well with the timing of a sport fishery that occurs around Hanceville in early November (Rob Dolighan, MELP Williams Lake, pers. comm.). The Nahatlatch River also appears to be utilized for overwintering although data for the time of entry into the Nahatlatch is very limited. The only steelhead recorded entering the Nahatlatch in the fall was detected on November 7, 1998. Evidence from angling however suggests that the majority of Nahatlatch steelhead do not overwinter in the Nahatlatch itself but in the mainstem Fraser. Stein and Bridge steelhead appear to exclusively overwinter in the mainstem Fraser, upstream of the Nahatlatch. Unlike stocks that enter a Fraser tributary, less run timing data is available for stocks that overwinter in the mainstem because sport fisheries are either non-existent or very small.

Overwintering Behaviour

In general, interior Fraser steelhead are thought to prefer overwintering in areas with suitable water conditions that are close to their natal streams. In 1996, many interior Fraser steelhead appeared to overwinter much further downstream than in 1998. This can be seen both in the actual overwintering locations of radio tags as well as in the timing and locations of re-captures (Figures 18 and 52). In 1998, water temperatures remained higher throughout the fall and specifically in the month of November, which appears to be a critical month for migration (Figures 45). Higher November temperatures allowed a higher percentage of steelhead to overwinter closer to their natal streams in 1998 than in 1996. In 1998, 10 out of 13 (77%) fall radio-tagged Chilcotin steelhead overwintered within the Chilcotin River system. In 1996, only 1 out of 3 (33%) fall radio-tagged Chilcotin steelhead overwintered in the Chilcotin, possibly a result of colder water conditions in the fall. Thompson stocks have a somewhat similar result. In 1996, 19 out of 24 (79%) fall radio-tagged Thompson steelhead overwintered in the Thompson River and in 1998, 35 out of 37 (95%) fall radio-tagged Thompson steelhead overwintered in the Thompson River mainstem. Within the Thompson River itself, Nicola steelhead tend to overwinter in the area just downstream of Spences Bridge but in 1996, some Nicola steelhead overwintered further upstream than in 1998, despite the cooler water temperatures (Figure 18). It is possible that the cold weather conditions in 1996 also lowered the effort by Thompson River sport fisherman, allowing some steelhead to move upstream without the interruption and other possible negative affects associated with sport capture. Upper Thompson River stocks (Bonaparte and Deadman) also appear to overwinter relatively close to their natal streams although no fall radio-tagged steelhead was ever detected more than 6 km upstream of Ashcroft (Figure 52). In 1998, 4 out of 7 (57%) fall radio-tagged Deadman steelhead and 3 out of 4 (75%) fall radio-tagged Bonaparte steelhead overwintered upstream of Martel in the Thompson River mainstem. In 1996, the only fall radio-tagged upper Thompson steelhead (Bonaparte) overwintered at Martel. All Bridge steelhead radio-tagged in the fall overwintered upstream of Lytton in the Fraser mainstem with 5 out of 9 (56%) overwintering upstream of the Texas Creek/Fraser confluence. The only two fall radio-tagged Stein steelhead both overwintered upstream of Lytton in the Fraser mainstem very close to the Stein/Fraser confluence. Finally, the two Nahatlatch steelhead radio-tagged in the fall of 1998, overwintered in the Nahatlatch mainstem and in the lower Thompson River. However, these findings of steelhead overwintering near their natal stream contain a large unknown component. Many of the radio-tagged steelhead that were detected during the overwintering period did not enter a known spawning tributary. Since the natal streams of these steelhead are unknown it is impossible to determine how far they were from their natal stream during the overwintering period. Some steelhead detected during the overwintering period may have been hundreds of kilometers from their natal stream. The fact that the majority of radio-tagged steelhead to successfully enter a monitored tributary, overwintered close to that tributary suggests that this behaviour may be important for survival.

Another interesting behaviour displayed by migrating radio-tagged steelhead was the tendency of Chilcotin steelhead to overshoot the Chilcotin River and overwinter in the Fraser mainstem upstream of the Chilcotin/Fraser confluence. This tendency was not apparent in any of the other stocks to the same degree as in Chilcotin steelhead. This was evidenced by two steelhead that were radio-tagged in the spring of 1998, 100 and 130 km upstream of the Chilcotin/Fraser confluence, and subsequently entered the Chilcotin River. Another steelhead, radio-tagged in the fall of 1998, overwintered approximately 12 km upstream of the Chilcotin/Fraser confluence but was found later in the spring over 100 km upstream of the Chilcotin/Fraser confluence. Since one steelhead was detected spawning in the Quesnel River, it is possible that these overshoots are attracted to other steelhead and are following them a considerable distance before turning around. This type of behaviour however was not detected near the Thompson/Fraser confluence where Thompson steelhead could be attracted to and follow Bridge steelhead. It is also possible that these overshoots are an accident of migration and may represent a mechanism for establishing new stocks.

Late-winter radio-tagging results also provided some clues as to the overwintering behaviour of interior Fraser steelhead. In most instances late-winter and early-spring radio tagging was done in areas where steelhead were thought to overwinter. In the Thompson and Chilcotin Rivers, these areas are well known to anglers and were the overwintering location of some radio-tagged steelhead. The Thompson/Fraser confluence and the Seton/Fraser confluence were also thought to be key overwintering areas except none of the fall radio-tagged steelhead overwintered in these areas. Spring telemetry demonstrated that fall radio-tagged Bridge steelhead did migrate through the Seton/Fraser confluence in early-March but it is unclear as to the length of time they spent holding in this area. This suggests that the Seton/Fraser confluence and the Thompson/Fraser confluence may be interception points for migrating steelhead more so than they are areas where overwintering steelhead concentrate as previously suspected. Late-winter angling near Hope in 1997 also provided interesting overwintering information despite the relatively poor success of the steelhead radio-tagged there. Seven radio tags were applied to steelhead in mid-February near Hope with only one of these entering a monitored tributary; the Nahatlatch River. A flight conducted on March 10, 1997 found 5 of these steelhead in the mainstem Fraser upstream of Hope. Two were later captured in Native gill net fisheries. Interestingly, the 4 steelhead that remained in the Fraser Canyon throughout the spawning period were detected as kelts by the Hope telemetry station in late-May and June, suggesting that these steelhead may have spawned in a Fraser Canyon tributary or at least survived the spawning season. This also suggests that in 1996/97 some Nahatlatch steelhead overwintered in the lower Fraser or possibly even entered the Fraser in late winter. This demonstrates that it was possible for steelhead to migrate through the Fraser Canyon in the spring of 1997, although if several of the radio tags were destined for the Nahatlatch River, it also demonstrates how difficult migrating through the Fraser Canyon was in 1997. Despite angling efforts in Hope, the majority of Nahatlatch steelhead in 1997 were angled near the Nahatlatch/Fraser confluence suggesting that most Nahatlatch steelhead overwintered in the Fraser mainstem near the Nahatlatch/Fraser confluence. Although no directed studies were performed on Nahatlatch steelhead in 1998/99, angling in the Nahatlatch River in the late-fall of 1998 was used to capture 3 steelhead. Only 1 of these steelhead was radio-tagged and this steelhead was subsequently detected during the spawning period in the Nahatlatch River. This suggests that in 1998/99 some Nahatlatch steelhead overwintered in the Nahatlatch mainstem and may also be an example of the yearly variation in overwintering locations.

Overwintering Mortality

To study the issue of overwintering mortality, tag fate data, presented earlier in the results, must be re-analyzed. The data presented in tables 31 and 32 are essentially the same as in Tables 5, 6, 11, 12, 16 and 17 in the Results section, except the perspective is geared towards the percentage of missing radio-tagged steelhead from overwintering and tagging locations. Although the potential reasons for a radio tag loss are numerous and have already been discussed, to simplify this discussion, it will be assumed that most radio-tagged steelhead with unknown fates are mortalities. When analyzed in this manner a number of patterns emerge.

Table 31. The percent of fall radio-tagged steelhead (n) out of the total number detected during the overwintering period (N) that had unknown fates.

Tagging Period	Overwintering Location	Unknown Fates 1996/97			1997/98			1998/99		
		n	N	%	n	N	%	n	N	%
Fall										
	Fraser Canyon	14	22	64%	2	2	100%	0	2	0%
	Fraser mainstem upstream of Nahatlatch	3	8	38%	1	1	100%	5	20	25%
	Thompson	2	19	11%				6	37	16%
	Chilcotin River System	0	1	0%	0	1	0%	1	10	10%

Table 32. The percent of spring radio-tagged steelhead (n) out of the total number captured in an area (N) that had unknown fates.

Tagging Period	Tagging Location	Unknown Fates 1997			1998			1999		
		n	N	%	n	N	%	n	N	%
Spring										
	Lytton - Thompson/Fraser confluence	9	21	43%				3	11	27%
	Lillooet - Seton/Fraser confluence	8	21	38%				4	14	29%
	Thompson mainstem near Spences Bridge							2	18	11%
	Deadman/Thompson confluence				0	18	0%	1	14	7%
	Chilcotin River System				2	16	13%	2	21	10%

The first trend to emerge is that steelhead captured and radio-tagged in early spring, just prior to entering their natal tributary, tended to show a much lower mortality rate than steelhead captured in late winter or the previous fall. This is true for Deadman steelhead, which appeared to overwinter in the Thompson downstream of Ashcroft but were captured and radio-tagged at the Deadman/Thompson confluence after they had resumed their upstream migration. This is also true for many of the steelhead captured in the early spring in the Chilcotin River and the steelhead captured in the Thompson River in early spring.

The second pattern to emerge is that steelhead radio-tagged in late winter prior to resuming their upstream migration suffered a similar mortality rate as did steelhead that were radio-tagged in the fall and overwintered in a similar area. Fall radio-tagged steelhead that were detected in the Fraser River upstream of the Nahatlatch/Fraser confluence suffered a 38% and 27% mortality rate in the 1996/97 and 1998/99 seasons respectively, similar to steelhead radio-tagged in the late-winter near Lytton and Lillooet. This suggests that steelhead overwintering in the mainstem Fraser upstream of the Nahatlatch/Fraser confluence suffer a mortality rate that that is highly variable from year to year whereas the mortality rate suffered by steelhead overwintering in the Thompson is much less variable. Steelhead that overwinter in the Thompson River suffer a mortality rate that appears to range from 11% to 16%. This is similar to the 10% mortality suffered by steelhead that overwintered in the Chilcotin River in 1998/99 and the 11% mortality rate incurred by Sustut steelhead overwintering in Sustut Lake (Mark Beere, MELP Smithers, pers. comm.). Once again these variations in mortality rates from location to location may be related to the distance a steelhead overwinters from their natal stream. In general, radio-tagged steelhead detected overwintering in the Fraser upstream of Nahatlatch may still be a long way from their spawning tributary, unlike steelhead overwintering in the Thompson or Chilcotin Rivers. Yearly variations in mortality rates may also be related to the distance steelhead overwinter from their natal streams. As previously discussed, weather conditions in the fall of 1996 caused many steelhead to overwinter further from their natal streams than in 1998. This may have resulted in the higher overwintering mortality rates in the mainstem Fraser upstream of Nahatlatch in 1996/97 than in 1998/99.

One of the first causes of overwintering mortality that must be examined are those caused by radio tags and/or the act of radio-tagging. To examine this, a study designed to determine the overwintering mortality of Sustut River steelhead used Robertson Creek hatchery steelhead for a control. The Robertson Creek steelhead were radio-tagged at the hatchery and held to observe the number of mortalities that resulted in an effort to establish a baseline mortality rate that could be expected from radio-tagging alone. Unfortunately the mortality rate for the hatchery reared, radio-tagged Robertson steelhead (approximately 30%) was much higher than the overwintering mortality (11%) for Sustut steelhead in the wild (Mark Beere, MELP Smithers, pers. comm.). Although this study failed to provide a baseline level of mortality caused by radio-tagging, autopsies performed on Robertson steelhead provided information about the role of radio tags in causing death. In some cases, the radio tags were applied with too much pressure resulting in a ruptured gastrointestinal tract. This also occurred in a study that used sockeye salmon to determine if radio-tagged and marked sockeye would die in different locations than sockeye that were only marked. Post mortems revealed that 21% of males and 47% of female sockeye had ruptured stomachs (Schubert and Scarborough 1996). However, since sockeye use all of their reserves for spawning, their gastrointestinal tracks at the time of radio tagging would likely be very fragile. In other steelhead mortality cases, the size of the radio tag put pressure on surrounding tissues causing them to become necrotic (Mark Beere, MELP Smithers, pers. comm.). This happened quite frequently in females with developing eggs. As the eggs developed they consumed a larger portion of space within the body cavity. This caused the gastrointestinal tract to be pinched between the developing eggs and the radio tag. This suggests that females may be somewhat more susceptible to radio tag induced mortality. These findings also suggest that mortalities caused by radio tags can be delayed and that a steelhead may carry a radio tag for a considerable amount of time before it dies. This may be the reason that interior Fraser steelhead radio-tagged close to their natal stream in late spring appeared to have a lower mortality rate than steelhead radio-tagged the previous fall. This may also be the reason that steelhead radio-tagged in the spring appeared to kelt at a higher rate than steelhead radio-tagged the previous fall. These steelhead have simply carried their radio tags for a shorter period of time and could complete spawning before complications from radio tagging caused death. Regardless of the cause however, all radio-tagged steelhead should have suffered from radio tag induced mortalities at a similar rate allowing comparisons of mortality rates for steelhead overwintering in different locations to be made, as long as these steelhead have carried their radio tags for a similar amount of time.

The second major cause of overwintering mortalities for interior Fraser steelhead would have been from natural causes and it is presumed that all steelhead would have been affected by these causes regardless of whether or not they were radio-tagged. In a Skeena study designed to determine the overwintering mortality of Sustut River steelhead, predation was found to be one of the major causes. Although predation is likely a cause of overwintering mortality for some interior Fraser steelhead it is probably responsible for a fairly small proportion. If predation was a major cause of overwintering mortality than it is unclear why predation levels would have been so much higher in the Fraser than the Thompson or Chilcotin Rivers. It is also likely that predation would have followed a pattern, with certain areas within a watershed having had much higher mortality rates then others. This type of pattern was not apparent in the Fraser, Thompson or Chilcotin Rivers. Another source of natural overwintering mortality for interior Fraser steelhead may involve their physiology. Some may simply not have enough energy reserves to sustain them through the winter and allow them to resume their upstream migration in the spring. This may explain some of the yearly variation in overwintering mortality rates as well as the variation seen in overwintering mortalities from different locations. Different environmental conditions on both a yearly basis and in different locations may cause different levels of stress for overwintering steelhead. An extreme example of this is the Fraser Canyon in the 1996/97 season, where 64% (14 out of 22) of the radio-tagged steelhead known to be in the canyon during the overwintering period disappeared. As previously mentioned, out of the 8 radio-tagged steelhead that did migrate upstream of the Nahatlatch/Fraser confluence, only 3 entered monitored tributaries and it is very unlikely that any of the remaining 5 spawned successfully. This may suggest that overwintering in and then migrating out of the Fraser Canyon the following spring caused those steelhead to use up a large enough portion of their energy reserves that they could no longer spawn.

Spawning Migration and Run Timing

After completion of the relatively dormant overwintering phase, interior Fraser steelhead resume migrating upstream toward their spawning destinations. As mentioned previously, mobile and fixed telemetry data suggest that steelhead begin migrating towards their natal stream system in early March and subsequently enter their natal stream system in the third week of April. The exceptions to this are the Nahatlatch steelhead which appear to enter their natal stream approximately one week earlier in mid-April and Chilko steelhead which appear to enter the Chilko approximately two weeks later in early-May. The timing of entry into natal stream systems seems remarkably consistent and is not as affected by annual variations in water temperature or discharge as overwintering locations seem to be (Figures 19, 21, 22, 36, 53, 54, 55, 56 and 57). Spawning for most interior Fraser steelhead stocks also appears to occur at a consistent time of year, generally peaking in the third week of May (Webb *et al*. 2000a; Webb *et al*. 2000b). Once again Nahatlatch and Chilcotin steelhead seem to be slightly different in this regard (Hagen 2000; Hagen 2001b). Nahatlatch steelhead appear to spawn one or two weeks earlier in mid-May and Chilcotin steelhead appear to spawn approximately one week later near the end of May. This suggests that the timing of entry and spawning by interior Fraser steelhead may be governed in part by altitude and latitude.

Escapement Estimation using the Peterson Method

Relative abundance and population estimates for individual stocks were performed using the radio telemetry data from fall radio-tagged steelhead. As for any mark/re-capture study, 5 assumptions must be met in order insure the accurate and unbiased reporting of population estimates (Ricker 1975). The assumptions and the way they apply to the interior Fraser steelhead telemetry program are as follows:

1. Marked fish suffer the same mortalities as unmarked fish. In the case of radio telemetry it appears that radio-tagged steelhead suffer a mortality rate from the radio tags and/or radio tag application over and above natural causes of mortality. This would result in a positively biased estimate. There is no evidence that mortality rate from radio tagging varied between stocks.
2. Marked fish are equally vulnerable to re-capture. For the interior Fraser telemetry study, an electronic fish counter and a fishway/fish trap were used to enumerate steelhead. The assumption here is that radio-tagged steelhead behave essentially the same as non radio-tagged steelhead and will pass over the electronic counter and/or enter the fishway/fish trap at the same rate. Combining telemetry station data with electronic counter data on the Deadman River, McCubbing *et al*. (2000) found that fall radio-tagged steelhead that have survived up to the spawning period behave the same as non radio-tagged steelhead in terms of run timing.
3. Marked fish don't loose their marks. In the 1998/99 portion of this telemetry study there is an estimated regurgitation/expulsion rate for radio-tagged interior Fraser steelhead that appears consistent with other radio tagging studies of this type (Hooton and Lirette 1986). This effect also positively biases the estimate. There is no evidence to suggest that regurgitation/expulsion rate varied between stocks.
4. Marks are applied randomly over the entire run. This is probably the assumption that is most violated in this telemetry study in several respects. First, there appears to be strong evidence that anglers (which deployed a large proportion of radio tags in the lower Fraser) are not very effective at capturing Chilcotin steelhead. The Yale Fishwheel, which is effective at capturing Chilcotin steelhead, was not supplied with radio tags throughout the duration of interior Fraser steelhead run timing.
5. All marks are recognized and reported on recovery. For this study, marks were detected by telemetry stations operating 24 hours daily throughout the spawning period and/or by mobile tracking which was conducted on a regular basis throughout the spawning period. Aside from malfunctioned radio tags, there is virtually no chance that a radio-tagged steelhead could enter a monitored spawning tributary and not be detected. There is a chance however that a radio-tagged steelhead could enter an unmonitored tributary during the spawning period and not be detected although steelhead which were detected as kelts but not detected in a monitored spawning tributary are included in this mark/re-capture.

Based on these assumptions it was concluded that a mark/re-capture analysis on the 1996/97 data could not be performed. To begin with only 1 radio-tagged steelhead was detected in the Bonaparte and Deadman Rivers, which are the river systems with the most reliable escapement estimates and are the river systems best suited for calculating a marked to unmarked steelhead ratio. In the spring of 1997 however, the fish fence on the Deadman River could not be held due to high water. As a result the only reliable escapement estimate obtained was from the Bonaparte Fishway. At the fishway, 3 steelhead that had been radio-tagged in the fall of 1996 were captured but only one of those had retained its radio tag. Since it is unlikely that all of the steelhead radio-tagged in the fall of 1996 had a 66% regurgitation/expulsion rate the assumption that all stocks have a similar regurgitation/expulsion rate had been violated.

A mark/re-capture estimate was performed on the 1998/99 telemetry data despite some violation of the assumptions (Table 33).

Table 33. The Peterson mark/re-capture estimates of escapement and escapement estimates calculated by conventional means for interior Fraser steelhead in 1999.

Fate	Radio Tags Total without Fishwheel	Estimated Abundance using Peterson Method			Escapement Estimates from 1999
		mean	lower limit	upper limit	
Known					
Re-captured and Killed	1	121	67	242	na
Probable					
Spawned in Stein	1	121	67	242	na
Spawned in Nahatlatch	2	242	134	484	na
Spawned in Bridge/Seton	5	605	334	1210	427
Spawned in Chilcotin	3	363	201	726	744
Spawned in Nicola	17	2057	1137	4114	1200
Spawned in Bonaparte	3	363	201	726	450
Spawned in Deadman	7	847	468	1694	769
Spawned in Unmonitored Tributary	0	0	0	0	na
Regurgitated or Removed	3	363	201	726	na
Mortality	3	363	201	726	na
Unknown	21	2541	1404	5082	na
Total Thompson		3267			2419
Total Interior Fraser		4598			
Totals	66	7986	4412	15973	na

An electronic fish counter was used on the Deadman River and a fishway/trap was used on the Bonaparte River (Bennett 1999; McCubbing *et al*. 2000). A combined total of 10 fall radio-tagged steelhead entered these two river systems. The assumption that marks were applied randomly over the entire run was most violated. In an attempt to reduce biases caused by non random sampling, steelhead radio-tagged by the Yale Fishwheel were not used, since the fishwheel was only used to deploy radio tags early in the run timing. Unfortunately, this meant the majority of radio-tagged steelhead used for the mark/re-capture analysis were captured via angling and there is good evidence to suggest that anglers are not effective at capturing Chilcotin steelhead. This bias will likely result in the mark/re-capture method underestimating Chilcotin steelhead numbers. The results shown in Table 33 appear to agree with this statement.

Escapements estimated by the Peterson Method were generally higher than the escapements estimated or enumerated by conventional means as expected (Table 33). In general it appears that the Nicola is the dominant stock with escapements in the low thousands. This is likely followed by the Chilko stock, which appears to have an escapement in the high hundreds/low thousands. Bridge, Deadman and Bonaparte stocks appear to be similar in size with escapements in the mid- hundreds and Nahatlatch and Stein have the lowest escapements, ranging from the high tens to low hundreds.

Interestingly, the number of fall radio-tagged steelhead in each river system in 1996/97 season for the Nicola and Chilcotin stocks are very similar to the 1998/99 results without the fishwheel (Tables 22 and 24). In 1996/97 season however, there are virtually no representatives for the smaller stocks suggesting that the Nicola run was much more dominant in the 1996/97 season. Stocks such as the Nahatlatch, Stein and Deadman appear to have a later run timing and may have suffered a higher mortality in the Fraser Canyon in 1996/97. What is also striking is the number of radio-tagged steelhead with unknown fates. In the 1998/99 season, the Peterson Method estimated that the number of radio tags in the unknown fate category to represent approximately 2541 steelhead (Table 33). While this estimate is expected to be biased high, this is comparable and similar to the escapement estimate for the total Thompson River. Knowledge about what actually happened to these radio-tagged steelhead is required to determine the proportion of non radio-tagged tagged steelhead that suffered the same fate. If the majority of these missing radio tags were in steelhead that expelled/regurgitated the tag or died from radio tag induced causes, then the proportion of missing radio tags greatly overestimates the proportion of non radio-tagged steelhead in the population that failed to reach their spawning tributaries. If however the majority of missing radio-tagged steelhead did not expel their radio tag or die from radio tag induced causes then the question remains as to what proportion of these missing radio tags died from natural causes and what proportion were harvested and not reported. Despite these unknowns, 1 radio-tagged steelhead from the fall 1998 sample was reported harvested, representing an estimated 121 steelhead.

Kelting Behaviour

The run timing of kelts at Hope in 1997 and 1999 shows a positively skewed distribution with some steelhead exiting the Fraser as early as mid-May and sharp peak exodus in mid-June (Figures 27 and 62). Originally it was considered that the early part of the kelt run timing was made up of Nahatlatch steelhead, which appear to spawn slightly earlier than other interior Fraser stocks. Although this may be partly true in 1997 when there were 8 Nahatlatch kelts, there was only 1 Nahatlatch kelt in 1999. It was then considered that males and females may kelt at slightly different times, as males appear to have much longer spawning residency times than females. In 1996 however, out of the 38 kelts detected by the Hope telemetry station, only 6 (16%) were males and they appeared to be evenly distributed throughout the kelt run timing. Similarly in 1999, out of the 60 kelts detected by the Hope telemetry station, 7 (12%) were males.

Kelt run timing curves at Hope from 1997 and 1999 suggest that the timing of the completion of spawning is similar for both years. This is consistent with spawning timing investigations in known spawning tributaries, which have consistently shown spawning periods extending from late-April to early-June (Hagen 2000; Hagen 2001b). As mentioned previously, steelhead also entered their natal streams in 1997 and 1999 over a similar time period, despite the different environmental conditions between years.

From a statistical point of view the kelting rate of interior Fraser steelhead appears to be quite consistent from year to year, season to season and between individual stocks. Only the sample of steelhead, radio-tagged in the fall of 1998 showed a significantly higher kelting rate for Thompson steelhead than Chilcotin steelhead. Higher stress on migrating and spawning steelhead should result in depleted energy reserves and a lower kelting rate. Chilcotin steelhead, which migrate considerably further than Thompson steelhead, likely allocate more of their resources toward upstream migration and as a result fewer Chilcotin steelhead survive spawning. The inability to show statistically significant differences between the other samples of Chilcotin and Thompson steelhead may be due to small sample sizes.

There was a low kelting rate for steelhead last detected in unrecognized spawning tributaries in 1997 and 1999. Although it is possible that some of these steelhead may have spawned in unmonitored tributaries, it is very unlikely. It is possible that some of these steelhead simply died and drifted downstream past the Hope telemetry station. Although this may be possible for steelhead in the lower Fraser Canyon, it is hard to imagine a steelhead from the interior drifting that far without being washed up in a back-eddy. It is likely that most of these steelhead were alive when they were detected as kelts. It is possible that some of these steelhead's energy reserves were so depleted they could no longer continue there upstream migration and instead, attempted spawning wherever possible and then used the last of their energy reserves for kelting. This may be why the kelting rate for steelhead last detected in unrecognized spawning tributaries was higher in 1997 than in 1999. The environmental conditions in the 1996/97 season (along with the additional stress of radio tagging) may have overwhelmed some steelhead, causing them to return to the ocean without successfully spawning in an attempt to spawn the following year.

Acknowledgements

A project of this magnitude requires the special talents, skills and generosity of a great number of people. The authors would like to thank the following individuals and/or organisations for their contributions and support:

Organisation: Ian McGregor (WLAP Kamloops) for initiating the project;
Robert Bison (WLAP Kamloops) for general co-ordination and administration of the project;
Stephen Maricle (WLAP Kamloops) for general co-ordination of projects and deployment of radio tags;
and
Rob Dolighan (WLAP Williams Lake) for co-ordination of telemetry work upstream of the Bridge River rapids.

Field assistance: Nick Basok and volunteer lower Fraser anglers, Rob Basok, Sean Bennett, John Hagen, Don Ignace, Jannice Joe, Mark Fetterly and Rodger Kanno (J.O. Thomas and Associates), Richard Alexander, Jerry Dewit, Mandy Dewit, Bill Koski, Maurice Lirette, Don McCubbing, Dean Miller, Brian Mitchell, Jim Mitchell, Dave Ritchie, Marvin Rosenau, Matt Stabler, Ray St. Pierre, Alf Stephanson, Shannon Stotyn, Gene Tisdale, Derek Thompson, Dean Watts, Stacy Webb, Tom Wilkinson and Andrew Young.

Fishers: Alan Baker, John Malatestinic (and the crew of the Argent I), Chief Ken Malloway, Barry Manuck and the Fraser River Fishermen's Society, Captain Barry Marcotte of the Sun Mariner and the remaining Nitinat chum test fishers, Jon Mikkelsen (UBC Mechanical Engineering), Mark Petrunia, Joe Seymour and Yale First Nations.

Pilots and Flight Charter Services: Tom Arduini (Arduini Helicopters Ltd.), Peter Fraser, Doug Mitchell and Doug Smallman (Cariboo Chilcotin Helicopters, Kamloops and Lillooet), Dan Nelson (Spring Aviation), Parson Aviation (Merritt) and Valley Helicopters (Hope and Merritt).

Assistance with telemetry equipment: Mark Beere, Brad Fanos, Bryan Hebden, Nisga'a Tribal Council, John Noakes (Simply Solar) and Warren Williams.

Access to private property: Nancy Arcand (GVRD Parks), Tony Baliff, Tony and Deb Dalbello, Ron and Karen Engelbrecht, Wes and Ralph Gilmore, Captain Edwin Reid and Chief Byron Spinks (Lytton Band).

REFERENCES

Alexander, R.F., K.K. English and W.R. Koski. 1996. Distribution, timing and numbers of steelhead returning to the Skeena watershed in 1995. Report by LGL Limited, Sidney, BC, for Fisheries Branch, BC Ministry of Environment, Lands and Parks, Victoria, BC

Anderson, W.G., R.S. McKinley and M. Colavecchia. 1997. The use of clove oil as an anesthetic for rainbow trout and its effects on swimming performance. North American Journal of Fisheries Management 17:301-307.

Andrews, T.R. and H.M. McSheffrey. 1976. Commercial Interception of Steelhead Trout Stocks in British Columbia. Marine Resources Branch. pp. 13

Anonymous. 1997. 1996 Nitinat (Area 21) gill net test fishery/by-catch study. DFO South Coast Division, Nanaimo. Unpublished.

Antifeau, T. 1976. Thompson River Steelhead Survey. Fish and Wildlife Branch (Kamloops, BC) pp. 30.

Barnhart, R. A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) - steelhead. U.S. Fish Wildl. Serv. Biol. Rep. 82.

Baxter, J. S. and J. Hagen. 1997. Summary of field work carried out at Homfray Channel fish farm to examine the long-term effects of clove oil on rainbow trout in saltwater. Ministry of Environment and Lands, Kamloops, BC.

Behnke, R.J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6.

BC Ministry of Environment. 1992. State of the Environment for the lower Fraser River basin. SOE report No. 92-1. 79 p.

Beacham, T.D., S. Pollard and K.D. Le. 1999. Population Structure and Stock Identification of Steelhead in Southern British Columbia, Washington, and the Columbia River Based on Microsatellite DNA Variation. Transactions of the American Fisheries Society 128:1068-1084.

Beere, M.C. 1991. Steelhead Migration Behaviour & Timing as Evaluated from Radio Tagging at the Skeena River Test Fishery, 1989. Ministry of Environment Recreational Fisheries Branch, Smithers, BC.

Bennett, S. 1999a. Summary of the 1999 Bonaparte River Fishway Operation and Enumeration of Anadromous and Non-anadromous *Oncorhynchus mykiss*. Ministry of Environment and Lands, Kamloops, BC.

Bennett, S. 1999b. Summary of the 1998 Fraser River Tooth Net Fishing Results. BC Conservation Foundation, Kamloops. pp. 30. Unpublished.

Bison, R.B. 1991. The reproductive biology of steelhead trout *(0. mykiss)* in the Bonaparte River, 1991. Unpublished manuscript prepared for BC Environment, Lands and Parks, Fisheries Branch, Kamloops, BC 32p.

Bison, R.B. and J.R. Renn. 1997. Regression analysis of the Albion Chum Test Fishery in relation to interior Fraser River steelhead escapements. Ministry of Environment and Lands, Kamloops, BC. 17p.

Burgner, R. T., J. T. Light, L. Margolis, T. Okazaki, A. Tautz and S. Ito. 1992. Distribution and origins of steelhead trout *(Oncorhynchus mykiss)* in offshore waters of the North Pacific Ocean. Inter. N. Pacific Fish. Comm. Bull. No. 51. 92 p.

Hagen, J. 2000. The reproductive biology of steelhead *(Oncorhynchus mykiss)* in the Nahatlatch and Stein Rivers. Ministry of Environment and Lands, Kamloops, BC.

Hagen, J. 2001a. Adult steelhead (Oncorhynchus mykiss) habitat use and population size in the Bridge River, springtime 2000. Ministry of Environment and Lands, Kamloops, BC.

Hagen, J. 2001b. Habitat use by Steelhead (*Oncorhynchus mykiss*) in the Chilcotin River Watershed, 1996-1999, and implications for population monitoring. Ministry of Environment and Lands, Kamloops, BC.

Hamilton, K. 1985. A study of the variability of the return migration route of Fraser River sockeye salmon (Oncorhynchus nerka). Can. J. Zool. 63. 1630-1943.

Hebden, B.W. 1981. West Fraser steelhead program: summary report. Ministry of Environment and Lands, Kamloops, BC. pp. 27

Hemus, D. 1974. Dean River summer steelhead-observations on life history, population, and the fishery in 1973. Fish and Wildlife Branch (Victoria, BC) pp. 64.

Hooton, R.S. and M.G. Lirette. 1986. Telemetric Studies of Winter Steelhead, Gold River, 1982-83. Ministry of Environment (Nanaimo, BC) Fish. Rep. No. 86. pp. 24.

J. O. Thomas and Associates. 1997. Evaluation of selective salmon fisheries in the lower Fraser River. Report prepared for Fisheries and Oceans Canada, New Westminster, BC. Unpublished.

J. O. Thomas and Associates. 1998. 1997 Fraser selective salmon fisheries final report. Report prepared for Fisheries and Oceans Canada, New Westminster, BC. Unpublished.

Koski, W. R., R. F. Alexander and K. K. English. 1995. Distribution, timing and numbers of coho salmon and steelhead returning to the Skeena watershed in 1994. Report by LGL Limited, Sidney, BC, for Fisheries Branch, BC Ministry of Environment, Lands and Parks, Victoria, BC

Maricle, S.J.and I.A. McGregor. 1993. 1989 Bonaparte River Fishway Enumeration, Sampling and Radio Tracking of Adult Spawning Steelhead. Ministry of Environment and Lands, Kamloops, BC.

McCubbing, D.J.F., J.R. Renn, S. Maricle and R. Bison. 2000. Enumeration of Steelhead Trout Escapement to the Deadman River in British Columbia - a cautionary lesson of the potential impacts to stock recruitment and data collection using a fish fence. Ministry of Environment and Lands, Kamloops, BC.

McGregor, I.A. 1986. Freshwater Biology of Thompson River Steelhead (*Salmo gairdneri*). Masters Thesis. University of Victoria. pp. 151.

Nelson, T. C., R. G. Bison, and J. R. Renn. 1998. Fraser River steelhead telemetry program 1996-97. Report for Ministry of Environment, Lands and Parks, Kamloops, B.C. and BC Ministry of Fisheries, Victoria, B.C. by LGL Limited, Sidney, B.C. 145 p.

Nelson, T. C. and R. F. Alexander. 1995. Radio Biotelemetry of movements of sub-mature starry flounder (*Platichthys stellatus*) in the Fraser River Estuary during March and April 1994. Part II *In*: T. C. Nelson (editor). Studies of the starry flounder in the Fraser River, 1992-94. Report prepared for Fraser River Estuary Management Program, Water Quality/Waste Management Committee. Technical Report WQM 95-02. v + 71 p.

Nelson, T. C., R. Alexander, and C. D. Levings. 1994. Ultrasonic and radio biotelemetry assessment of the distribution and movement of starry flounder (*Platichthys stellatus*) in the Fraser River Estuary during late January to early April 1993. Report prepared for Fraser River Estuary Management Program, Water Quality/Waste Management Committee. Technical Report WQWM 93-07. v + 41 p.

Olmstead, W.R. and D.C. Moore. 1985. An Ecological Study of Steelhead Trout (*Salmo gairdneri*) Reproduction in the Deadman River. Ministry of Environment and Lands, Kamloops, BC. 42p.

Parkinson, E. 1984. Identification of steelhead stocks in the Commercial Net Fishery of the Southern BC Coast. Fisheries Management Report No. 81, pp. 16.

Pearlstone, P.S.M. 1976. Management Implications of Summer Habitat Characteristics of Juvenile Steelhead Trout (*Salmo gairdneri*) in the Big Qualicum River. Fisheries Management Report No. 67, pp. 13.

Renn, J.R. 1995. Summary of the 1995 Bonaparte River Fishway operation and enumeration of anadromous and non-anadromous *Oncorhynchus mykiss.* Ministry of Environment and Lands, Kamloops, BC.

Renn, J.R. 2001. Appendices for the migration characteristics and stock composition of interior Fraser steelhead as determined by radio telemetry, 1996-1999. Ministry of Environment and Lands, Kamloops, BC.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Environment Canada, Ottawa. pp. 382.

Ruggerone, G. T., T. P. Quinn, I. A. McGregor and T. D. Wilkinson. 1990. Horizontal and vertical movements of adult steelhead trout (*Oncorhynchus mykiss),* in the Dean and Fisher Channels, British Columbia. Can. J. Fish. Aquat. Sci. 47:1963-1969.

Schubert, N.D. and G.C. Scarborough. 1996. Radio Telemetry Observations of Sockeye Salmon (*Oncorhynchus nerka*) Spawners in Chilko River and Chilko Lake: Investigation of the Role of Stress in a Mark-Re-capture Study. Fisheries and Oceans Canada. New Westminster, BC.

Spence, C.R. 1978. Chilko - Chilcotin River Steelhead Survey. Fish and Wildlife Branch (Williams Lake, BC) pp. 57.

Spence, C.R. 1980. Radio telemetry investigation of the instream distribution and movement of adult Chilcotin River steelhead trout. Ministry of Environment (Williams Lake, BC) Tech Rep. No. F-80-2; pp. 49.

Spence, C.R. 1989. Rates of Movement and Timing of Migrations of Steelhead Trout to and Within the Skeena River, 1988. Ministry of Environment Recreational Fisheries Branch, Smithers, BC.

Webb, S., R. Bison, A. Caverly and J.R. Renn. 2000a. The Reproductive Biology of Steelhead (*Oncorhynchus mykiss*) in the Bridge and Seton Rivers as Determined by Radio Telemetry. Ministry of Environment and Lands, Kamloops, BC.

Webb, S., R. Bison and J.R. Renn. 2000b. The Reproductive Biology of Steelhead (*Oncorhynchus mykiss*) in the Nicola River as Determined by Radio Telemetry. Ministry of Environment and Lands, Kamloops, BC.

Whately, M.R. 1977. Kispiox River steelhead trout: the 1975 sport fishery and life history characteristics from angler catches. BC Fish and Wildlife Branch (Smithers, BC) Fish. Tech. Circ. No. 30, pp. 22. and appendices.

Zar, J.H. 1984. Biostatistical Analysis 2nd Edition. Prentice-Hall, Inc. New Jersey. pp. 718.