Smolt Productivity of Off-channel Habitat in the Chilliwack River Watershed

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ABSTRACT

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Various off-channel habitats along the Chilliwack-Vedder River were monitored during smolt migration in spring. Seven sites including four restored and three natural off-channel habitats were monitored using complete capture weirs located just upstream from their confluences with their parent streams. In 1997, salmonids were enumerated as migrants from these habitats. Their size and weight were sampled and possible factors affecting smolt migration were examined. Numbers of smolts captured of the two target species, coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*), ranged from 284 to 7176 and from 1 to 132, respectively in 1997. Coho smolt abundance from individual sites varied from <2 smolts • 100 m^{-2} to >50 smolts • 100 m^{-2}. The factors that led to the variability in coho smolt production are complex and unclear. A comparison of observed and predicted coho smolt yield indicated that average biostandard estimates overestimated the numbers of smolts emigrating from the habitats in this study. However, when the model accounted for differences in smolt yield between large and small ponds, observed numbers of coho smolts could exceed predictions. Numbers of coho smolts leaving off-channel sites in this study were comparable to those observed in other studies of coho smolt production. Subsequent monitoring in 1998 indicated that newly constructed off-channel habitat for coho require at least one year to achieve “capacity.” We also detected no differences in coho smolt production from natural versus restored habitats. It is suggested that the major benefits of off-channel restoration to the populations of coho salmon using these habitats will come as a result of the increase in the quantity of available off-channel habitat, not from any increase in the quality of that habitat. Juvenile steelhead also utilized off-channel areas, but in low densities (<1 smolt • 100 m^{-2}). Continued monitoring of these off-channel sites over the next two years is recommended, and results will be used to make decisions regarding future restoration efforts in the Chilliwack-Vedder River watershed and elsewhere.

ACKNOWLEDGEMENTS

The authors wish to thank Don Buxton who designed and installed the traps, and supervised the sampling program. This project was not possible without Don’s contribution. We also wish to thank the field crew, which included John Kupp, Erik Korinth, and Greg Inse. Staff at the Chilliwack River Hatchery provided workshop and other facilities, and assisted with sampling. Robert Brown assisted in the design of the traps and planning the program. Sherri Rendek entered the data. We also thank Pat Slaney and Bruce Usher who provided much appreciated advice for the project.

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INTRODUCTION

Off-channel habitats play an important role in maintaining the ecological integrity in coastal British Columbia rivers. They provide critical habitat through various salmonid life stages. Anadromous coho (*Oncorhynchus kisutch*; Sandercock 1991), chum (*O. keta*; Bonnel 1991), sockeye salmon (*O. nerka*; Burgner 1991), and resident salmonids (Brown and Mackay 1995) often select off-channel habitat to spawn. Resident species and anadromous species, with extended freshwater residency periods, rear in hydrologically stable off-channel areas (Peterson 1982a; Nickelson et al. 1992; Richards et al. 1992). This type of habitat provides a safe refuge against the high winter discharges in the main channel (Bustard and Narver 1975b). As a result, off-channel habitat can increase the overwintering survival rate of juvenile salmonids (Bustard and Narver 1975b; Narver 1978). Bustard and Narver (1975a) found that in Carnation Creek, B.C., overwintering survival rate of young coho was about twice as high in a series of unused beaver ponds compared to the survival rate found in the entire mainstem system. The major factor limiting salmonid densities in some streams may be the amount of adequate overwintering habitat (Bustard and Narver 1975a; Nickelson et al. 1992). In watersheds subjected to degradation of fish habitat in the mainstem, the magnitude of off-channel function importance greatly increases (Hartman and Scrivener 1990).

Coho salmon and steelhead trout (*O. mykiss*) are vulnerable to freshwater habitat deterioration because of their extended freshwater residency. In British Columbia, freshwater residency for coho is primarily one year, but can be up to four years in cold waters (Sandercock 1991). Steelhead rear in freshwater for two to five years (Ward and Slaney 1988). Juvenile coho overwinter in off-channel habitats (Swales and Levings 1989; Brown and Hartman 1988; Peterson 1982a; Peterson 1989b). Natural off-channel habitats include beaver ponds, wetlands, protected alcoves, side channels, and tributaries. Coho often migrate into off-channel ponds as fry and use the habitat as a rearing ground in the summer (Swales and Levings 1989). Juvenile steelhead have also been found in off-channel habitats (Swales and Levings 1989). Seelbach (1993) recorded steelhead using small tributaries with characteristics similar to off-channel habitat. Steelhead move into slower flowing waters in the winter (Bustard and Narver 1975a), and suitable off-channel habitat provides an environment with decreased velocity. However, steelhead have been reported to use off-channel to a much lesser degree than coho (Swales and Levings 1989).

Both juvenile steelhead and coho inhabit the Chilliwack River and its tributaries. The Chilliwack River originates in the northern Cascade Mountains in Washington State. It flows north to the Chilliwack Lake on the Canadian side of the border. The river then flows in a westward direction and eventually is renamed the Vedder River after passing by Vedder Crossing. The Vedder River flows into the Sumas River, which empties into the Fraser River. Anthropogenic disturbances in the Chilliwack River watershed, such as logging and dyking, have interfered with salmonid habitat, including natural off-channel habitats.

Logging in the Chilliwack River watershed began in the late 1800s. More than 20% of the watershed has been logged (Hay 1992; B.C. MOF 1995). Past studies have suggested that logging activities may have a negative impact on salmonid habitat. Slaney et al. (1996) partially attributed recent declines in coho and steelhead stocks in British Columbia to forestry-related habitat alteration, particularly past practices of logging adjacent to streambanks and natural off-channel habitats. Historical logging to streambanks has reduced the amount of large woody debris (LWD) in streams, and because coho use woody debris for cover, the population density of coho is reduced as described in Slaney and Martin (1997). Another consequence of logging activities has been an increase in suspended sediment production from roads and channels (Hay 1992). This increased sediment input may infill prime salmonid off-channel habitat (Cederholm et al. 1980; Hogan 1986; Tripp 1994). Much of the increase in suspended sediment is attributed to forest logging roads and their drainage systems (Hay 1992).

There is an estimated 600 km of logging roads in the Chilliwack watershed (B.C. MOF 1995). Rough estimates of sediment production from road washouts and failures during the November 1989 storm in the Chilliwack River were reported to be between 25 000 m^3 and 75 000 m^3 of bedload material (Hay 1992). Logging roads are also responsible for accelerated mass erosion (landslides). It has been difficult to distinguish between the sediment input caused by natural landslides and that caused by logging activities. In the Chilliwack River watershed, glacial deposits of clay have resulted in a landscape that is prone to natural landslides (Ron Henry, pers. comm.). Off-channel habitat has also been reduced as a result of the Chilliwack Lake Road. This road has cut off access to pre-existing off-channel habitats located along the Chilliwack River, such as Anderson Creek. Culverts hinder or prevent passage of fry and other juvenile fish (parr) to off-channel habitats (Whyte et al. 1997).

Off-channel habitat in the Chilliwack River watershed has also decreased as a result of dyking. Dyking began on the Chilliwack River in 1892 (B.C. MOF 1995). The river originally flowed north to the Fraser River. But, in 1894, floods diverted the river in a westward direction down Vedder Creek. At this location, the Chilliwack River was renamed the Vedder River. The Vedder River is now approximately 84% dyked. Therefore, off-channel habitat has been destroyed in the majority of the lower floodplain of the Chilliwack River watershed. Off-channel habitat in the lower reaches of the river are more crucial than in the upper reaches because juvenile coho migrate downstream from summer rearing habitat in search of adequate overwintering sites. Peterson (1982b) found that juvenile coho migrated as much as 32.6 km downstream. Historical draining and dyking of lower floodplains has decreased off-channel habitat in many agriculturally settled areas. For example, 6500 hectares, which included the Sumas Lake, have been drained for agricultural farmland in the Abbotsford region (Ron Henry, pers. comm.). Channelization of the Chilliwack River has probably also reduced its productive capacity. Approximately 6% of the Chilliwack River, between Chilliwack Lake and Vedder Crossing, has some form of bank stabilization. Future additional dyking in these areas were proposed by Hay (1992) as possible flood control options.

Off-channel habitat restoration efforts in the Chilliwack River watershed have been on-going for the past 15 years especially by the Resource Restoration Division of the Department of Fisheries and Oceans (DFO) (Sheng et al. 1990; Bonnel 1991), and more recently, through Watershed Restoration Program (WRP) proponents such as the Steelhead Society of B.C. and DFO with support from BC Environment. In 1995, DFO initiated the Anderson Creek Pond Off-channel Project on the Chilliwack River (Zaldokas 1996). Anderson Creek was inaccessible to anadromous salmon as a result of a poorly designed road bridge at Anderson Creek's confluence with the Chilliwack River. This project created a pond in the previously cut-off channel, provided flow from nearby Anderson Creek to the pond, and re-established anadromous salmonid access to upper Anderson Creek.

Another off-channel restoration project was the development of the R-4 off-channel site located approximately 2 km upstream from the confluence of Slesse Creek and the Chilliwack River (Zaldokas 1996). This project was initiated in 1995 by the Steelhead Society Habitat Restoration Corporation (SSHRC). The work consisted of developing an infiltration gallery to capture groundwater to be directed into excavated old flood channels that were previously cut off by the construction of a logging road. Another off-channel restoration project was the Centennial Trail Spawning/Rearing Channel (Bulbeard) constructed in 1996 by DFO. The purpose of this project was to provide suitable pink salmon spawning grounds, and to provide adequate year-round habitat capable of supporting all species of salmonids found in this portion of the watershed.

One of the oldest off-channel projects is a channel along the Vedder River, named Peach channel. Peach was initiated approximately 15 years ago by DFO. In addition to these "restored" off-channel habitats, important "natural" off-channel habitat sites have been identified along the Chilliwack River. Centre Creek Bridge and 14-Mile are small channels located in the upper reaches of the Chilliwack River. Thurston is a natural off-channel pond located in the middle reach of the Chilliwack River.

This report examines the productivity of juvenile coho and steelhead in these restored and natural off-channel habitats located in the Chilliwack River watershed. Estimations exist of the level of juvenile salmonid productivity expected in the off-channel habitats. For example, Keeley et al. (1996) have calculated the average productivity level for off-channel habitats based on a literature review of past studies. In addition, Adams and Whyte (1990) have determined biostandard estimates of total productivity of specific salmonid species for off-channel habitats.

The objectives of this report were:

1. To compare the total productivity of the off-channel habitat sites located within the Chilliwack River watershed with the average productivity value calculated by Keeley et al. (1996), and with the biostandard estimates adapted from Adams and Whyte (1990).
2. To compare fish health indices (mean weight and mean condition factor) for juvenile coho and steelhead among the seven off-channel sites.
3. To determine whether smolt outmigration from the off-channel sites is related to water temperature, air temperature, or precipitation.

METHODS

Seven study sites were selected in the Chilliwack River watershed (Table 1, Fig. 1). Sampling began on April 1, 1997 and continued until June 30, 1997 or until outmigration ended.

Table 1. A description of off-channel study sites in the Chilliwack River watershed (1997).

Sites	Total surface area (m^2)	Restored or natural	Pond or channel	Groundwater or surfacewater
Anderson	15 000	Restored	Pond	Surfacewater
Bulbeard	17 500	Restored	Ponds	Surfacewater
Centre Creek Bridge	2 639	Natural	Channel	Surfacewater
14-Mile	4 882	Natural	Combined	Surfacewater
Peach	12 251	Restored	Channel	Groundwater
R4	6 955	Restored	Combined	Groundwater
Thurston	6 000	Natural	Pond	Surfacewater

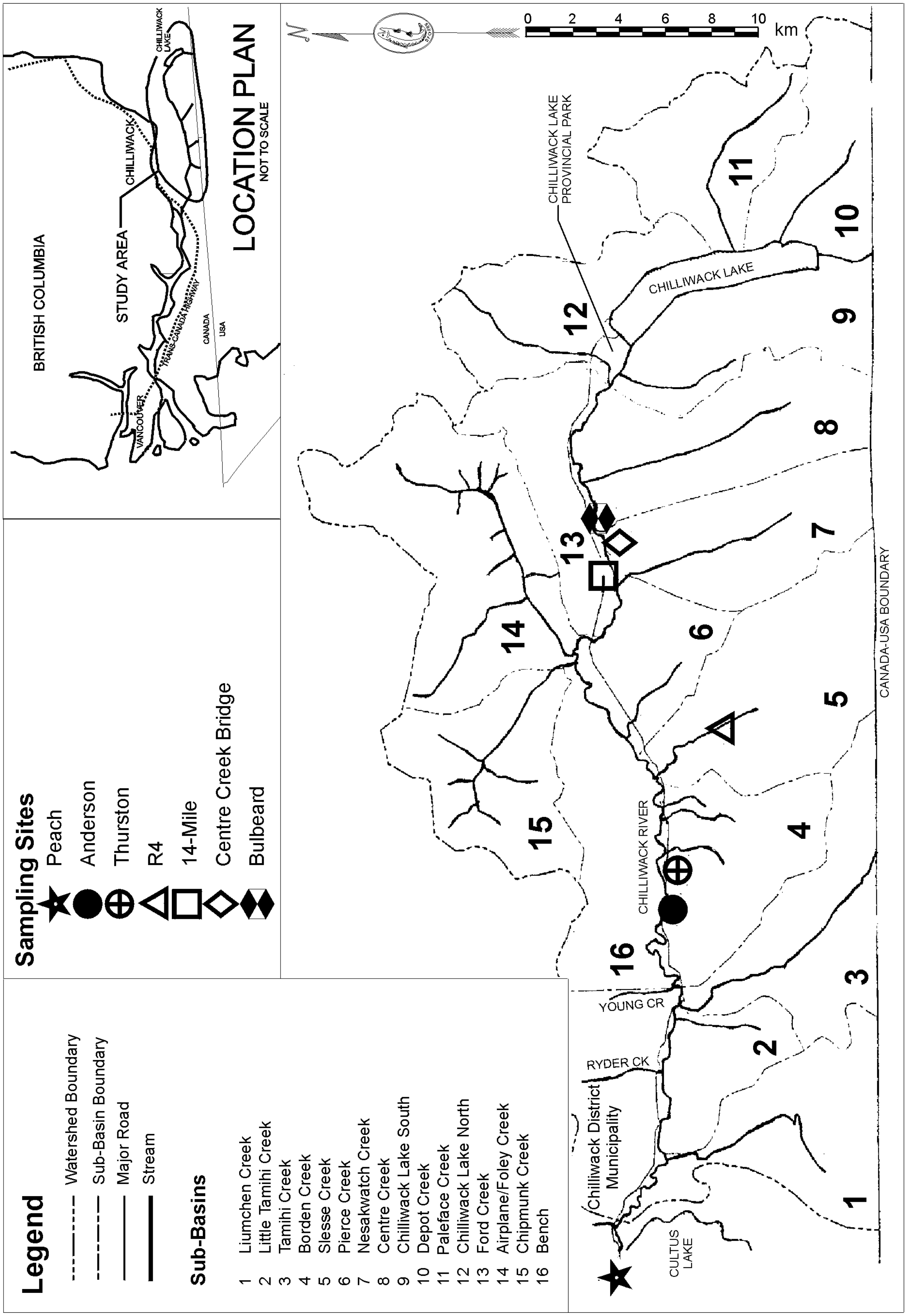

Figure 1. Location of off-channel sites in the Chilliwack River watershed (1997).

Downstream Trapping Sampling Protocol

Downstream traps were placed at the outlets of the off-channel sites. All fish were released downstream from the traps, to ensure being sampled only once. All fish from each trap were identified by species and counted daily. Length and weight measurements were taken on 10 coho per day or 15% of the previous day's total catch, whichever was greater. To ensure a random sample of measurements, fish were blindly netted from the total sample. Steelhead were categorized into silver smolts or parr, and were separately counted. All steelhead were weighed and measured, except those caught on the weekends. Although "silvered" steelhead smolts were easily distinguished from parr, separation of anadromous steelhead parr from the resident rainbow trout parr was impossible. Therefore, any parr greater than 250 mm was assumed to be a resident rainbow trout (P. A. Slaney, pers. comm.).

Stream temperature was taken near the trap using an on-set temperature data logger. The air temperature and precipitation were recorded daily at a climate station located at the Chilliwack River Hatchery.

Statistical Analysis of Juvenile Coho and Juvenile Steelhead Data

In the statistical analysis of steelhead, the steelhead were divided into three groups and analyzed separately:

1. Recorded steelhead smolts only.
2. Recorded steelhead smolts and parr (≤ 250 mm fork length [FL]).
3. Recorded parr ≤ 250 mm FL.

Total Productivity

Total productivity was calculated for each of the sites as number of fish per 100 m^2. The downstream trapping protocol assumed that every juvenile coho and juvenile steelhead from the off-channel habitat was trapped and counted. A visual comparison of total productivity was made between the sites and the biostandard estimates adapted from Adams and Whyte (1990), and with the average level of productivity calculated by Keeley et al. (1996). The observed values were also compared with the predicted level of productivity of salmonids in ponds, based on the logarithmic relation established by Keeley et al. (1996) [i.e., Log_{10} fish number = .051 log_{10} pond area (ha) + 3.47].

There were complications with the downstream trapping method used in this study. In extremely high flows, the water overflowed the sandbags. As a result, some fish may have bypassed the traps. In other cases, the traps became blocked with debris. These problems were most prevalent at Peach site. The number of fish not counted, as a consequence of malfunctioning traps, was estimated. This estimate was determined by calculating the average number of fish recorded two days before and two days after the trap malfunctioned. This value was added to the observed total productivity for comparison with the biostandard estimates adapted from Adams and Whyte (1990), and with the average level of productivity calculated by Keeley et al. (1996).

Mean Weight and Mean Condition Factor (CF)

The Fulton condition factor was used as an index of condition, or well-being. Condition factor was calculated using the following formula: $C = (W/L^3) \times 100\,000$, where W = weight (grams) and L = length (mm) (Murphy and Willis 1996). A single-factor analysis of variance (ANOVA) test was used to determine if there was a significant difference in the mean weight and/or mean condition factor between the study sites for juvenile coho or steelhead. The statistical software package SPSS was used to run a Fisher's least-significant-difference (LSD) test to determine if the sites significantly differed ($p < .05$).

Relationship Between Outmigration and Physical Variables

A linear regression test was used on each of the sites to determine if a relationship existed between outmigration and physical variables, including daily precipitation, water temperature, and air temperature.

RESULTS

Comparison of Estimated Productivity with Observed Productivity

In 1997, a variety of juvenile salmonid species comprised the output from each of the off-channel sites (Table 2). Peach had an exceptional number of chum fry (nearly 400 000). Cutthroat were significant at 14-Mile (42 individuals). Bulbeard, 14-Mile, R-4, and Thurston yielded more coho fry than Anderson, Centre Creek Bridge and Peach. The greatest number of juvenile coho were found at Anderson (Fig. 2), and Bulbeard had the least number of coho. Anderson had the highest recorded number of juvenile steelhead (Fig. 3), and the number of juvenile steelhead at Bulbeard and 14-Mile were negligible. Steelhead smolts were present at Anderson, Peach and R-4. Anderson had the greatest number of steelhead smolts and Centre Creek Bridge had the greatest number of steelhead parr as migrants.

Table 2. Number of individuals trapped, by species, at each off-channel site during spring, 1997 (f = fry, juv = juvenile, p = parr, s = smolt).

Sites	Coho-f	Coho-juv	Steelhead-p	Steelhead-s	Chum-f	Char	Cutthroat
14-Mile	10992	1736	7	1	0	2	42
Anderson	56	7176	75	132	13	0	2
Centre Creek Bridge	10	1351	145	2	11	0	12
Bulbeard	1484	284	1	1	780	0	0
Peach	5	2171	77	110	398519	0	2
R-4	3618	2106	72	52	0	4	0
Thurston	2152	818	114	2	11575	0	8

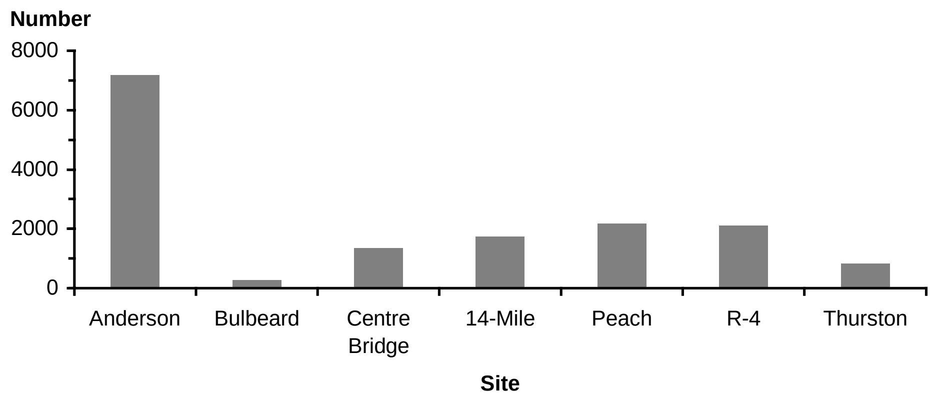

Figure 2. Total number of coho at each off-channel site in 1997.

(See text below for comparison in 1998.)

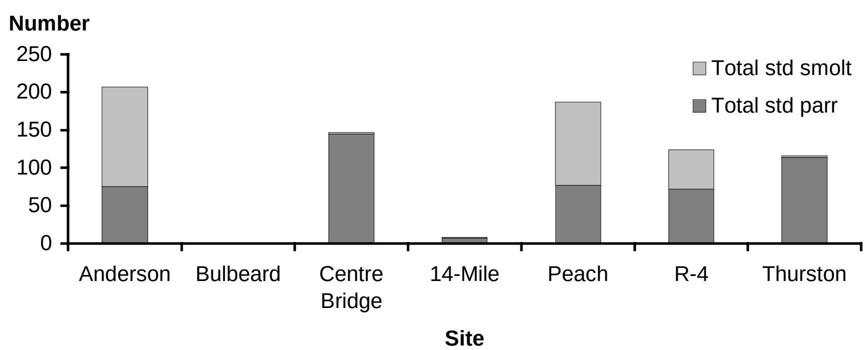

Figure 3. Total number of steelhead (parr and smolts) found at each site in 1997.

Outputs of coho smolts were also recorded in 1998 and are reported here because Bulbeard was a newly constructed site in 1997. Coho smolt counts in 1998 were 3089 at Anderson, 8752 at Upper Bulbeard, 4302 at Lower Bulbeard, 3567 at Lower R-4 (new site) and 588 at Upper R-4 (old site). Thus, by the second year (1998) after fry had colonized the Bulbeard channel – pond site in 1997, coho smolt output was much greater then all other sites.

The total productivity (number of fish per 100 m^2) of juvenile coho and steelhead were calculated for each site (Fig. 4, Appendix 1). Anderson and Centre Creek Bridge were the most productive sites for coho. The least productive site was Bulbeard.

The most productive site for steelhead was Centre Creek Bridge. This site had the highest productivity level of steelhead parr (5 per 100 m^2), but lacked any steelhead smolts (Appendix1). Steelhead smolts were found in significant numbers (1 fish per 100 m^2) at three sites: Anderson, Peach, and R-4.

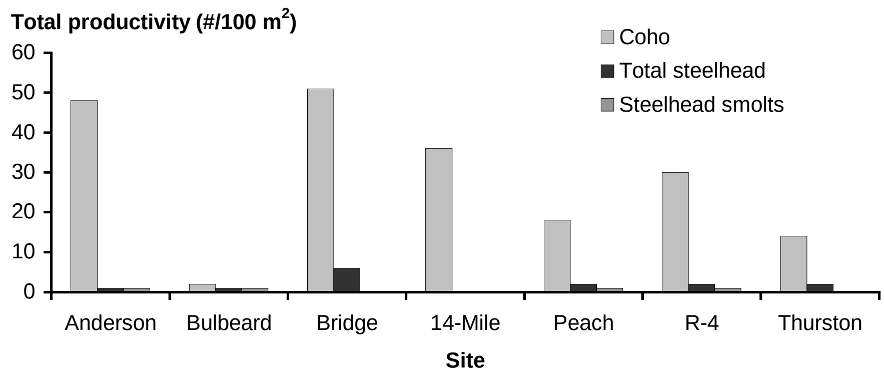

Figure 4. Total "productivity" (fish per 100 m^2) for each site (1997) ("Bridge" = Centre Ck. Bridge).

A comparison was made between the observed productivity at the Chilliwack off-channel sites with the biostandard estimates adapted from Adams and Whyte (1990), and with the average productivity calculated by Keeley et al. (1996) (Appendix 1). The observed values were consistently less than these estimated values in 1997. The level of productivity of juvenile coho at Centre Creek Bridge was closest to an estimated value (Fig. 5).

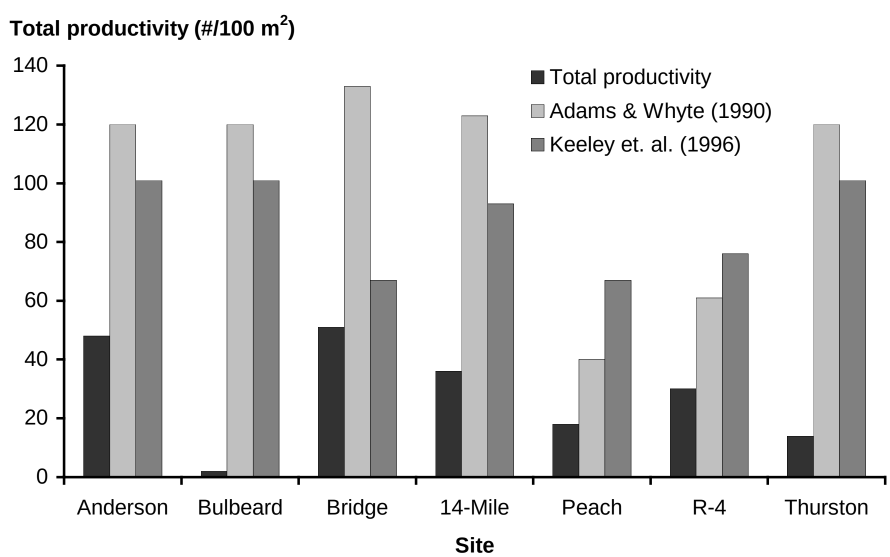

Figure 5. Comparison of observed total "productivity" from the Chilliwack off-channel sites with the biostandard estimates (Adams and Whyte 1990) and the average productivity (Keeley et al. 1996) (1997).

After calculating the number of fish that may have by-passed the traps as a result of trap malfunctions, it was determined that only a negligible number of fish would not have been counted. For example, at Peach the productivity would have increased from 18 fish to 19 fish per 100 m^2.

Anderson (highly productive) and Bulbeard (least productive) were the largest off-channel pond complexes (Fig. 6). Centre Creek Bridge (most productive) was a natural channel with the smallest surface area. The second smallest system, 14-Mile, was another natural off-channel system that recorded a high level of coho productivity (Fig. 4).

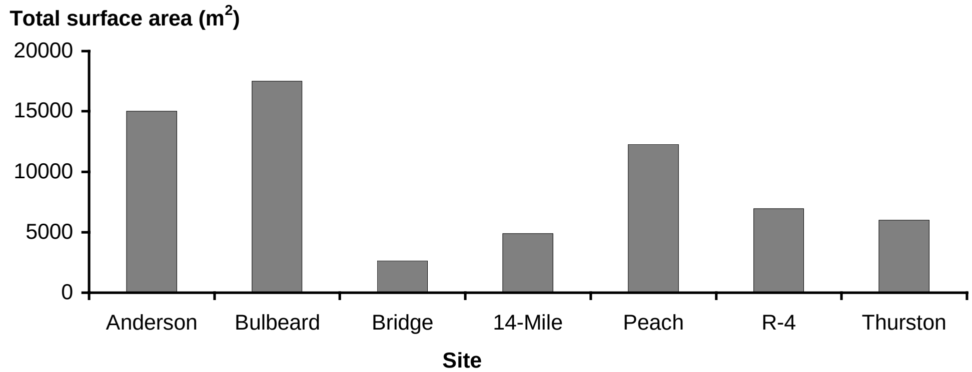

Figure 6. Total surface area for each of the off-channel study sites (1997).

Keeley et al. (1996) concluded that the productivity of a smaller pond is greater per unit area than that of a larger pond, and the estimated number of salmonids in a pond can be determined from a logarithmic line (Fig. 7). Observed total juvenile salmonid productivity was compared against values predicted by the logarithmic line from Keeley et al. (1996) [i.e., Log_{10} fish number = .051 $\log_{10}$ pond area (ha) + 3.47]. Anderson Pond far exceeded the predicted value, whereas Bulbeard was less productive than expected in 1997, but also greatly exceeded expected smolt output in 1998.

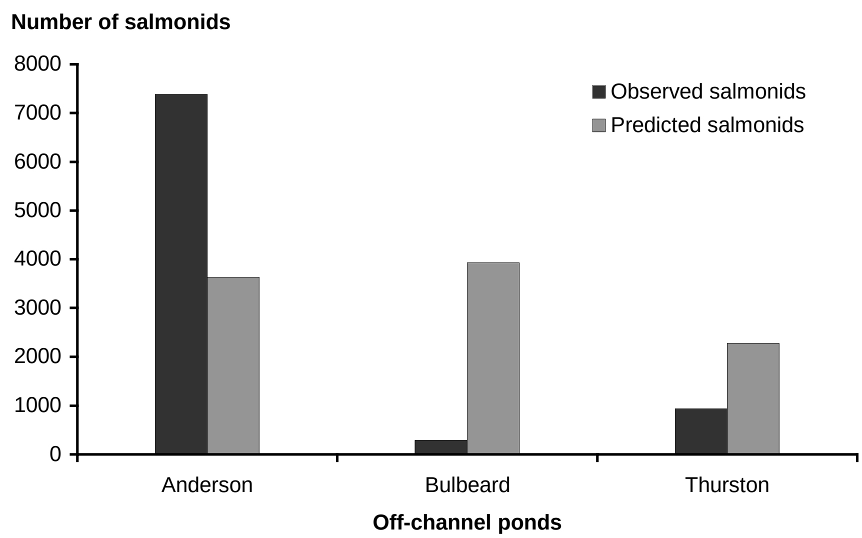

Figure 7. Comparison of observed and predicted number of juvenile salmonids per pond area in 1997 based on the logarithmic line proposed by Keeley et al. (1996).

(See text for 1998 comparison – coho outputs; note marked increase in Bulbeard in 1998.)

Mean Weight and Mean Condition Factor

Coho

Forty to 50% of juvenile coho were measured and weighed at each site (Table 3). The Bulbeard site had the highest mean weight (mean weight = 20.6, SE = ± 0.104). This value was significantly greater than the mean weight at any other site (Appendix 2) (Fig. 8). Peach (mean weight = 14.7, SE = ± 0.071) and Thurston (mean weight = 14.5, SE = ± 0.129) did not significantly differ from one another, and they had the next highest mean weight. The mean weight at R-4 (mean weight = 6.9, SE = ± 0.393) was significantly lower than at any other site (weight histograms for each site are located in Appendix 3).

Table 3. Percentage of juvenile coho measured from the total number caught in the downstream traps in 1997.

Sites	Number measured	Number counted	Percent of sample measured
14-Mile	600	1736	35
Anderson	974	7176	14
Centre Creek Bridge	453	1351	34
Bulbeard	143	284	50
Peach	623	2171	29
R-4	625	2106	30
Thurston	310	818	38

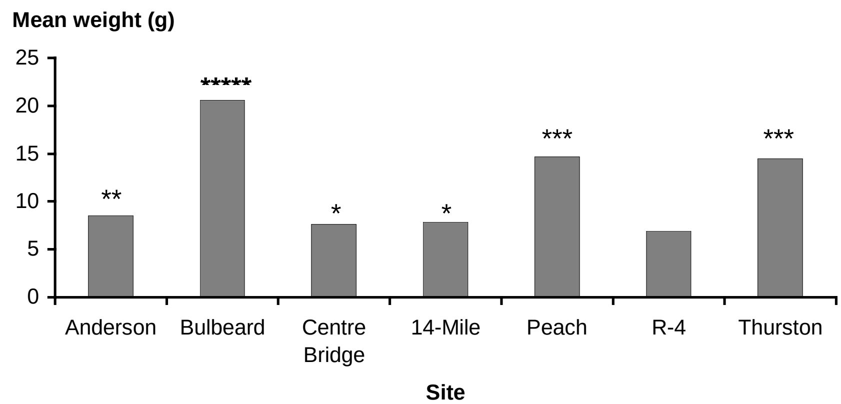

Figure 8. Coho mean weight per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

There was also significant difference in the mean condition factor among the study sites (Fig. 9). Thurston site had the greatest CF ratio (mean CF = 1.12, SE = ± 0.005). Bulbeard (mean CF = 1.12, SE = ± 0.003), 14-Mile (mean CF = 1.11, SE = ± 0.004), and R-4 (mean CF = 1.10, SE = ± 0.008) followed with the next highest CF values, but these sites did not differ significantly from one another. Anderson had the lowest CF value (mean CF = 1.02, SE = ± 0.006). This value was significantly lower than at the other sites. There was a suggested inverse relationship observed between the condition factor and the level of productivity at each site (Fig. 10), where R-4 appeared to be an outlier ($R^2 = 0.31$, $p = 0.2$). Coho condition factor histograms for each site are located in Appendix 4.

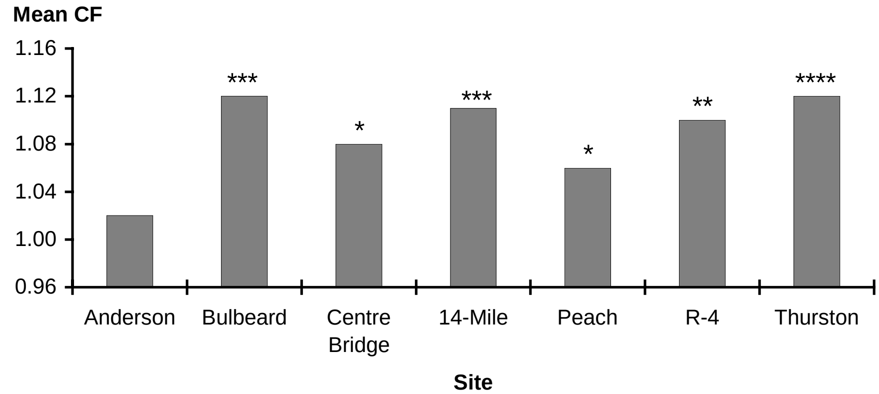

Figure 9. Coho mean condition factor per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

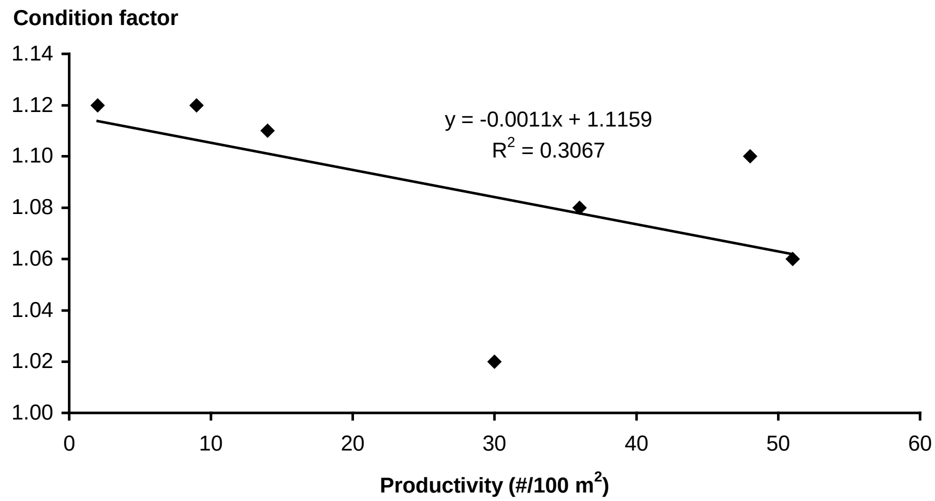

Figure 10. Decrease in coho mean condition factor with site productivity in 1997.

Steelhead

Total Steelhead

Mean weight of steelhead (parr plus smolts) was significantly different among the sites. The highest mean weight was at R-4 (mean weight = 41.2, SE = ± 1.542) (Appendix 2, Fig. 11). The lowest mean weights were found at Centre Creek Bridge (mean weight = 9.1, SE = ± 3.976) and Thurston (mean weight = 8.0, SE = ± 0.491). The mean weight at these two sites did not differ significantly from each other, but did differ from the other sites.

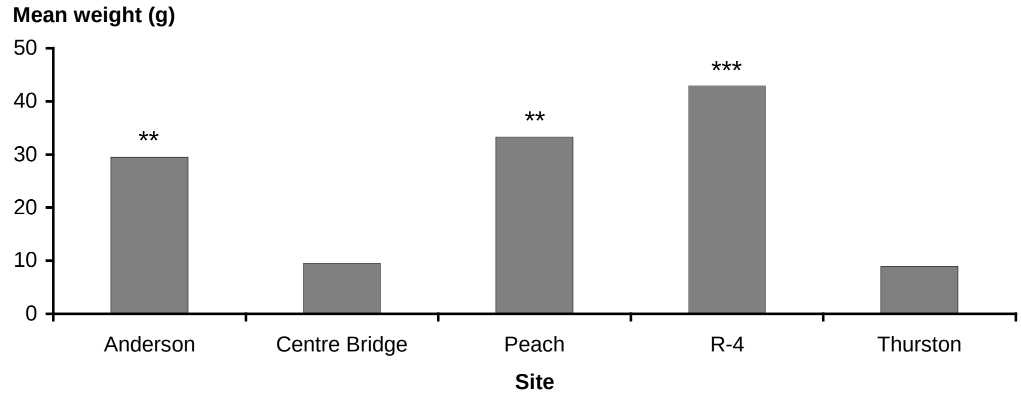

Figure 11. Steelhead mean weight per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

Mean condition factor of steelhead (parr plus smolts) differed significantly among the sites. The highest mean CF values were found at Thurston (mean CF = 1.16, SE = ± 0.008) and R-4 (mean CF = 1.13, SE = ± 0.006) (Appendix 2, Fig. 12). The lowest mean CF values were found at Peach (mean CF = 1.04, SE = ± 0.028) and Anderson (mean CF = 1.00, SE = ± 0.010).

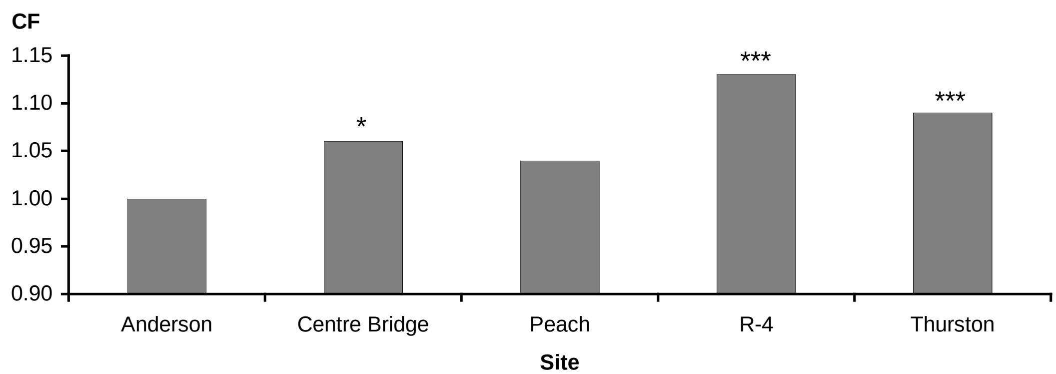

Figure 12. Steelhead mean condition factor per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

Steelhead Parr

Steelhead parr were present at five sites: Anderson, Centre Creek Bridge, Peach, R-4, and Thurston. A significant difference existed in parr mean weight among these sites (ANOVA, $p < .05$). R-4 (mean weight = 20.4, SE = ± 1.926) and Peach (mean weight = 17.4, SE = ± 0.635) had the highest mean weights. These averages did not significantly differ from each other, but differed from the other sites (Appendix 2, Fig. 13). The remaining three sites did not statistically differ in mean weight.

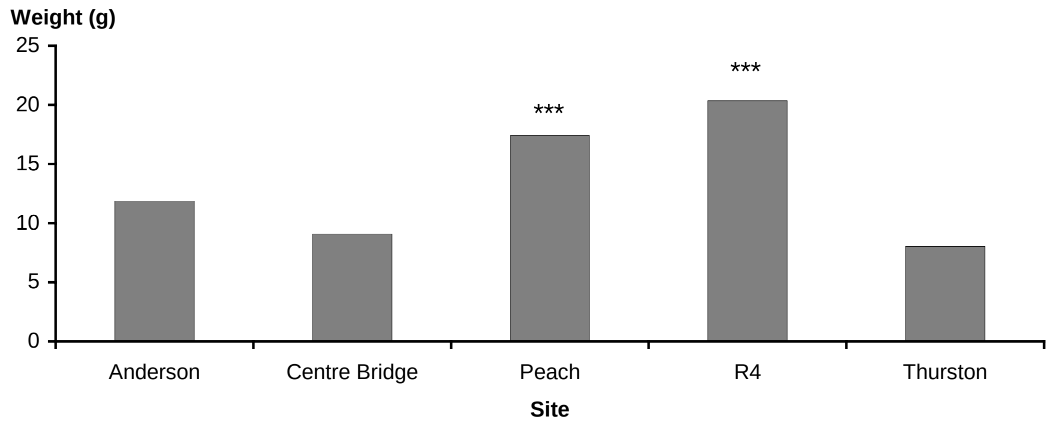

Figure 13. Steelhead parr mean weight per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

Mean condition factors were significantly different among the sites for parr (ANOVA, p <.05). Thurston (mean CF = 1.16, SE = ± 0.016) and R-4 (mean CF = 1.12, SE = ± 0.006) had the highest CF ratio (Appendix 2, Fig. 14). The mean weight at these sites were statistically similar. Anderson (mean CF = 1.06, SE = ± 0.032) and Peach (mean CF = 1.01, SE = ± 0.010) had the lowest mean CF.

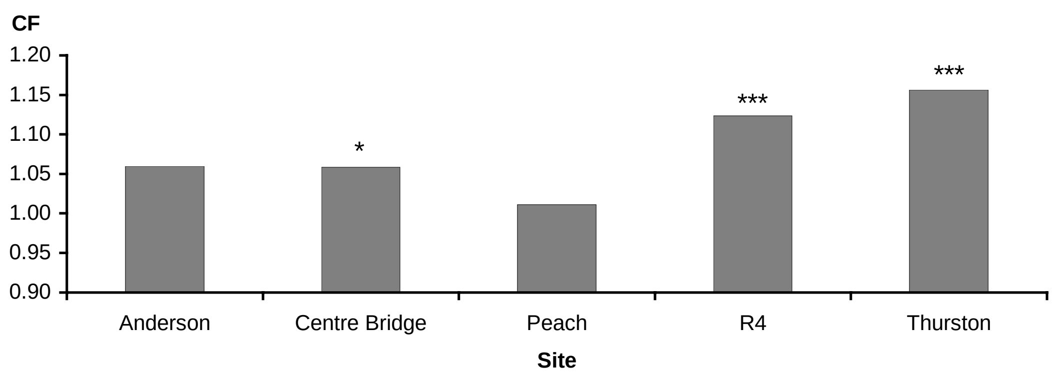

Figure 14. Coho mean condition factor per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

Steelhead Smolts

Significant numbers of steelhead smolts were found at only three sites: Anderson, Peach, and R-4. There was a statistically significant difference in smolt mean weight among these sites (ANOVA, p <.05). The mean weight of R-4 (mean weight = 62.8, SE = ± 1.3552) was significantly higher than that of the other sites (Appendix 2, Fig. 15). (Histograms of the frequency distribution of steelhead smolts weight (grams) per site are found in Appendix 5.)

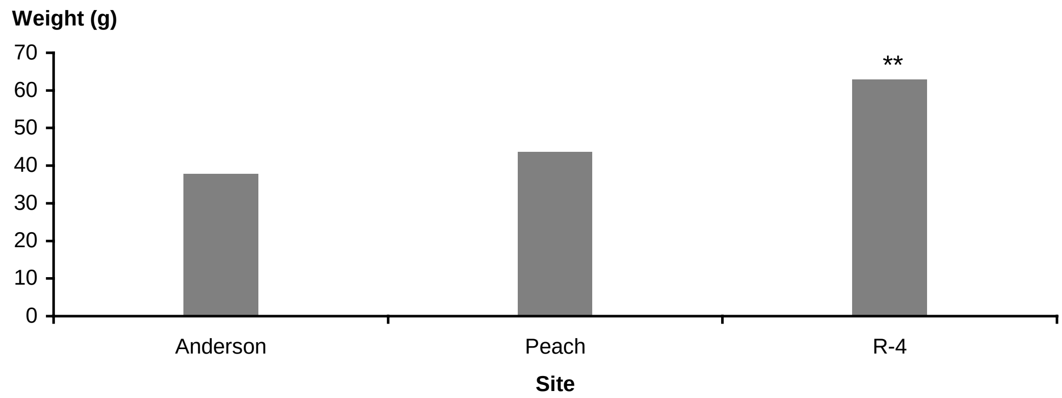

Figure 15. Steelhead smolt mean weight per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

An ANOVA also determined that a statistically significant difference existed in smolt mean CF among the three sites (F = 10.04, p-value <0.0001). All of the sites were significantly different from one another (Appendix 2, Fig. 16). R-4 had the highest CF ratio (mean CF = 1.14, SE = ± 0.008) (Fig. 30). Anderson had the lowest (mean CF = 0.97, SE = ± 0.056). Histograms of the steelhead smolts CF per sites are found in Appendix 6.

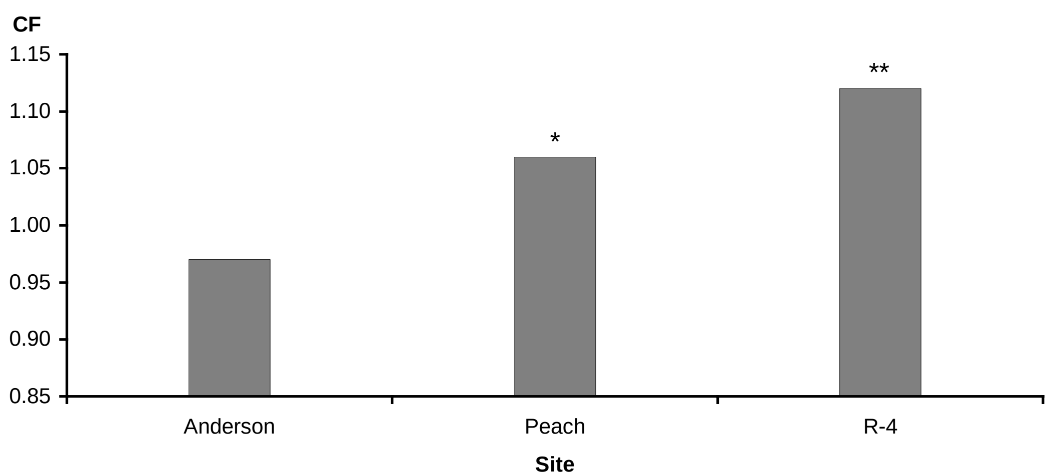

Figure 16. Steelhead smolt mean condition factor per site in 1997. Sites with the same number of asterisks (*) are statistically similar.

Steelhead Fork Length

The fork lengths for the majority of the steelhead were measured (Appendix 7). Smolts ranged in size from 90 to 290 mm (Table 4). The majority of smolts at Anderson and Peach were approximately 160 mm (Appendix 7-3, 7-4). R-4 had a high number of smolts at both 160 mm and 180 mm (Appendix 7-5). The frequency distribution of smolts began at approximately 140 mm for Anderson and R-4. Steelhead parr ranged in length from 60 to 290 mm. Parr over 250 mm was assumed to be a resident rainbow trout.

Table 4. Range of steelhead smolt and parr fork lengths per site (1997).

Site	Smolt Fork Length Range	Parr Fork Length Range
Anderson	90–200 mm	70–170 mm
Peach	100–210 mm	80–200 mm
R-4	100–290 mm	60–230 mm
Centre Creek Bridge	Not present	60–170 mm
Thurston	Not present	60–130 mm

Water Temperature and Relationship Between Outmigration and Physical Variables

The relationship between the number of recorded fish leaving off-channel habitats and physical variables (i.e., precipitation, water temperature, and air temperature) were examined for each site. This relationship was investigated for both juvenile coho and steelhead (Appendix 8, 9). In all cases, R^2 values were weak (range 0.08 to 0.28, most <.15) and thereby were not significant biologically over the duration measurement (data on file). Daily precipitation and daily air temperature for the Chilliwack River were also recorded (Appendix 10).

Daily water temperature differed significantly between the study sites ($p < .05$). Anderson and Thurston had the warmest mean temperatures and did not differ significantly between each other, but did differ among the other sites (Appendix 11, Table 5). R-4 and Bulbeard had the coolest mean temperatures.

Table 5. Results of Fischer's LSD test on the water temperature among the sites. There is no significant difference among sites with the same number of asterisks (*) (1997).

Site	Mean water temperature (°C)	LSD results
Anderson	8.9251	*
Thurston	8.5524	*
Peach	8.0304	**
Centre Creek Bridge	7.4519	***
14-Mile	7.4425	***
R-4	6.4851	****
Bulbeard	6.4270	****

DISCUSSION

Coho Productivity

Juvenile coho were present at all seven Chilliwack off-channel sites; however, the level of "productivity" was notably different among the study sites. Past studies have suggested that numerous factors influence juvenile coho productivity and their overwintering survival rate in off-channel habitats. Sheng et al. (1990) suggested that coho smolt production from new channels may increase with time as progeny from channel-produced spawners colonize the habitat. However, their data were incomplete and they postulated that climate, habitat parameters, and biotic conditions were also critical determinants. Off-channel habitat features such as density of woody debris, riparian vegetation, substrate type, food supply, pool depth, and water velocity were not measured in this study. However, these measurements may explain some of the variability in productivity levels found at the various off-channel sites along the Chilliwack River. Bustard and Narver (1975a) found that the availability of cover, water velocity, and depth determined the suitability of stream areas for overwintering juvenile fish. Juvenile coho have a strong preference for side-pools offering overhanging bank cover (Bustard and Narver 1975b). As the structural complexity (i.e., woody debris, emergent vegetation) increases in off-channel habitat, overwinter survival rate of juvenile coho increases (McMahon and Hartman 1989; Nickelson et al. 1991). The presence of deeper areas (3.5 m) tends to maximize survival for smolt emigration. Pond morphometry plays a significant role in the survival of juvenile coho (Peterson 1982a, Cederholm et al. 1988). They found that ponds that were shallower and lacked deep pools had a lower survival rate as a result of predation.

Chapman (1962) suggested that spatial needs and food supply were involved in regulating net production of coho. Centre Creek Bridge was the most productive site (based on number of fish per 100 m^2). It was also a flowing channel. This site may have had an abundant supply of food from the organic drift carried in by the incoming water supply. Coho often feed on organic drift (Mason and Chapman 1965). Anderson was also a highly productive site and may have fulfilled the spatial needs required by the juvenile coho, as it was one of the largest sites. Anderson was less productive (per surface area) than Centre Creek Bridge, yet it had over 7 times the number of juvenile coho owing to its large area. This suggests that having a suitable less productive large site may be more beneficial than spending resources on a more productive smaller site, unless several small sites can be developed.

The size of coho populations found in a pond may fluctuate considerably from year to year (Swales and Levings 1989; Brown and Hartman 1988). The population size may be a result of the magnitude, timing, and duration of the peak summer flows in the main river, which influences access to the off-channel habitat by juvenile coho (Swales and Levings 1989). As indicated by subsequent sampling in 1998, the average productivity, obtained from sampling the Chilliwack off-channel sites over a number of years, would be a more accurate value to compare to the average biostandards calculated by Keeley et al. (1996). In 1997, the observed productivity levels were consistently lower in the Chilliwack River off-channel sites compared to these estimates. This may also be a result of the low magnitude of winter flooding in 1997. Environment Canada recorded the maximum daily discharge at the outlet of Chilliwack Lake and at Vedder Crossing as being at a 1.15-year flood frequency level. The observed productivity values from the Chilliwack River were, however, similar to other studies. For example, Argue and Armstrong (1977) found that small tributaries on the Squamish River contained coho smolt densities of between 48 to 72 per 100 m^2. In comparison, the Chilliwack River's Anderson and Centre Creek Bridge sites contained juvenile coho densities of 48 and 51 per 100 m^2, respectively. In Chapman's (1965) investigation of three small streams in Oregon, he found that the yield of seaward emigrants ranged from 18 to 67 per 100 m^2. Foy and Decker (1997) found that the average coho density for Coquitlam River off-channel restoration projects combined was 34 smolts per 100 m^2. Zaldokas et al. (1997) recorded an average coho smolt yield of 24 fish per 100 m^2 in a restored off-channel pond and 82 fish per 100 m^2 from restored side channels in Shop Creek, B.C. An estimated 32 coho smolts per 100 m^2 were in the restored off-channel ponds along the Telkwa River (Bustard 1997).

Steelhead Productivity

The productivity of juvenile steelhead in the off-channel areas also varied greatly between sites. Swales and Levings (1989) reported that anywhere between 0.3% to 24.0% of the total catch from an off-channel pond was composed of steelhead. Hartman (1965) found that steelhead were able to inhabit a wider range of microhabitats than coho in the Chilliwack River. Adequate velocity and habitat diversity are the most likely requisites for habitat utilization by juvenile steelhead (Sheng et al. 1990). Steelhead are most often found in high velocity areas such as riffles, runs, or deep pools in the thalweg (Bisson et al. 1988; Ward and Slaney 1979). Bustard and Narver (1975a) reported that as the water temperature dropped, steelhead moved into the deeper pools. Juvenile steelhead preferred to hide in the rubble, or if they were older they moved into the same type of cover as the coho (i.e., woody debris, overhanging brush) but stayed closer to the bottom.

A significant number of steelhead smolts were found in the Peach, Anderson, and R-4 sites. Once again, off-channel habitat features such as density of woody debris, substrate type, food supply, pool depth, and water velocity may help explain the difference in productivity levels found at the off-channel sites of the Chilliwack River.

Although a significant number of steelhead were found in five of the Chilliwack off-channel sites, studies in the past have shown that steelhead were generally scarce in off-channel habitats, such as ponds (Swales and Levings 1989). Keeley et al. (1996) did not calculate an average productivity value for steelhead in off-channel habitats, and Adams and Whyte (1990) estimated a biostandard value for only side channels with surface intakes. A lack of estimates for steelhead productivity in off-channel habitats might be because steelhead have been found to be more adapted to the surface temperature regimes and relatively high water velocities found in the mainstem and tributary streams. The highest level of juvenile steelhead productivity was found at Centre Creek Bridge (surfacewater, high velocity channel). However, our results showed a significant number of steelhead in the ponds at Anderson and Thurston (low water velocity), and Peach and R-4 (both groundwater channels). Steelhead were absent from the 14-Mile and Bulbeard sites (mainly pond complexes). Although many studies note that steelhead were found in off-channel habitats, actual productivity values are lacking in the literature.

Coho Size and Condition Factor

There was a significant difference in mean weight and mean condition factor (CF) among the sites. The CF is an indication of the quality of the fish, with higher values suggesting healthier fish, although wild salmonids undergo a decrease in condition at smolting. Coho had a higher condition factor (CF) in sites which supported fewer numbers of coho. This suggests that a density-dependent relationship exists. Coho fry occupy and aggressively defend territory (Hoar 1951; Dill et al. 1981). The size of the territory defended greatly varies and depends on the number of dominating individuals present. If there are less dominating individuals, then there is a wider range of territory available for each fish. Coho often feed on the organic drift carried by the incoming water supply (Mason and Chapman 1965). The limiting space found in narrow and productive channels, such as Centre Creek Bridge, may influence the low CF values found at this site.

Hartman (1968) found that the growth rate in the Chilliwack River was relatively low. As a result, a portion of each year class remained in the river for two summers before migrating to sea. This depressed growth rate was a result of the higher flows and lower temperatures. Owing to these physical characteristics of the Chilliwack River, adequate off-channel overwintering habitat would be advantageous in the Chilliwack River watershed. Studies have shown that the growth of juvenile coho in off-channel ponds was faster than that of juvenile coho in the main channel. Swales and Levings (1989) reported that juvenile coho from an off-channel pond reached mean lengths of 62–79 mm at the end of the first growing season, compared with 53 mm in the main river. The mean weight of juvenile coho was highest (20–22 g) at the Bulbeard site, although recruitment was weak in 1997. The mean weight was also high at the next least productive sites, Peach (14.69 grams) and Thurston (14.47 grams). These are relatively large fish compared to the mean coho smolt size of 11.4 grams found in the Keogh River (Ward et al. 1990). This suggests that the least productive sites may support two year old juvenile coho, perhaps as a result of slow growth rates found at these sites.

Steelhead Size and Condition Factor

A significant difference in mean weight and mean CF existed among the sites. Peach and Anderson had the lowest CF value for juvenile steelhead. Optimal feeding sites for steelhead have preferred range of water velocities, access to a plentiful food supply, and escape cover nearby (Raleigh et al. 1984). The low CF values may be a result of inadequate feeding sites, relative to densities.

The majority of the smolts ranged in length between 140 to 190 mm, with some smolts measuring less than 140 mm (Appendix 7). These smolt measurements were consistent with those of Ward and Slaney (1988) and Peven et al. (1994). The highest frequency of smolts occurred at 160 to 170 mm. Ward and Slaney (1988) found that the mean length of steelhead at two years of age was 153 mm, and 177 mm at three years. This suggests that the majority of steelhead smolts measured in the off-channel sites were between two to three years of age. This compares favorably with Hartman's results from his 1968 study on the Chilliwack River. He found that 1.9% of the steelhead spent only one year in fresh water, 61.7% spent only two years, and 35.7% had spent three years in fresh water.

Of the three off-channel sites at which steelhead smolts were recorded, R-4 had the highest mean weight for the smolts (62.83 grams) and the longest most frequent length (180 mm). This may be a result of the slower growth rate found in habitats with colder temperatures (Hartman 1968). R-4 was significantly colder than the other two sites, Peach and Anderson. The steelhead might have remained in freshwater longer because if the juvenile steelhead does not reach a certain size by a specific time, it will stay in freshwater for the additional year (Peven et al. 1994). Hartman (1968) found that higher temperatures and stable flows increases the growth rates.

Coho Outmigration

Studies have determined that outmigration was strongly influenced by water temperature and precipitation (Swales and Levings 1989). In certain Chilliwack off-channel sites, significant relationships existed between juvenile coho outmigration and water and air temperature, but the R^2 was relatively low (i.e., $\cong$ 10%). No significant relationships existed between outmigration and daily precipitation. Yet, there may be a "lag time" between the heavy rains and outmigration. Investigation into the possibility of a lag time was not examined in this report. The precipitation levels and air temperature were measured only at the Chilliwack River Fish Hatchery, and the outmigration at the seven sites was compared with these data. Air and precipitation measurements should have been taken at each site, since these variables may fluctuate between sites, and these site-specific data should have been compared with outmigration from each site.

Smolts from the off-channel sites along the Chilliwack River were observed outmigrating in groups. Although the coho fry are extremely aggressive and territorial, coho smolts tend to aggregate in deep water, and then emigrate in schools (Hoar 1951). Coho smolt outmigration occurred in peaks between May 13 and June 10. Past studies have recorded coho smolts outmigrating in this same time frame. For example, Swales and Levings (1989) found that catches increased during May, and were highest in late May and early June (peaking on May 22) in the Coldwater River. On the Keogh River, Ward et al. (1990) recorded May 7 as being a peak migration time, and Argue and Armstrong (1977) noted May 11 in the Squamish River system.

Steelhead Outmigration and Physical Variables

Significant relationships existed between juvenile steelhead outmigration and physical variables such as air and water temperature. The peak outmigration time for steelhead smolts is in early May, similar to Ward et al. (1990) who found peak migrations occurring on May 7 and June 2. Argue and Armstrong (1977) recorded steelhead smolts outmigrating two weeks before coho smolts. Also, median migration dates were typically ranged from May 9 to May 18 in the Quinsam River (Lirette et al. 1985).

RECOMMENDATIONS

Downstream trapping of the off-channel habitats should continue over a period of several years. The population size utilizing an off-channel habitat tends to fluctuate from year to year. Long-term sampling would result in more accurate measurements of off-channel productivity to compare with the biostandard estimates. Ideally, to gain a better understanding of the coho populations utilizing off-channel habitats, detailed trapping should be used to distinguish between juvenile coho which have immigrated into the off-channel habitat as a refuge, from those that are present as a result of spawning in the off-channel habitat.

Access to additional off-channel habitats by anadromous salmonids, currently blocked off due to the Chilliwack Lake Road or other disturbances, should be identified and rectified. Methods for this are outlined in Whyte et al. (1997) and Lister and Finnigan (1997). Increasing the amount of accessible and suitable off-channel habitat may increase the survival of overwintering juvenile salmonids, and increase the productivity of the Chilliwack River.

Other restorative techniques, which may increase the suitability of salmonid habitat in the Chilliwack River, should be examined. These techniques include improving the upstream movement of adult fish and improving spawning habitat (Whyte et al. 1997). Since the Chilliwack River acquires 63% of its water flow from steep tributary creeks above Vedder Crossing (Hay 1992), unused logging roads should be deactivated and up-slope areas should be stabilized. In addition, any necessary improvements should be made to the riparian zone to stabilize channels and provide large wood inputs where determined to be beneficial and of low risk in the long term.

There was a wide range in the level of productivity of juvenile coho and steelhead among the off-channel sites along the Chilliwack River. Factors influencing off-channel site suitability and productivity is a complicated issue. Two sites which appear similar (i.e., in age and size) may vary considerably in productivity, such as the Anderson and Bulbeard sites. Numerous factors influence the net productivity at a site (e.g., pool depth, food availability, structural complexity, riparian vegetation, dissolved oxygen content, pond morphometry, velocity, substrate, spatial needs). These factors should be measured and monitored in order to further understand the key requirements in off-channel suitability, and to help determine what makes one site more productive than another.

CONCLUSION

The Chilliwack River watershed is a geologically sensitive and unstable system of high fisheries values. Natural instabilities, such as sediment input due to clay leaching, are compounded by the disturbances associated with logging, dyking, and roadways. In order to protect the salmonid stocks in the Chilliwack River, close monitoring of these anthropogenic disturbances should be undertaken routinely.

One way to protect and maintain existing salmonids is through restoration and development of off-channel habitat. Off-channel habitats in the Chilliwack River watershed have been proven to support juvenile salmonids, such as coho and steelhead.

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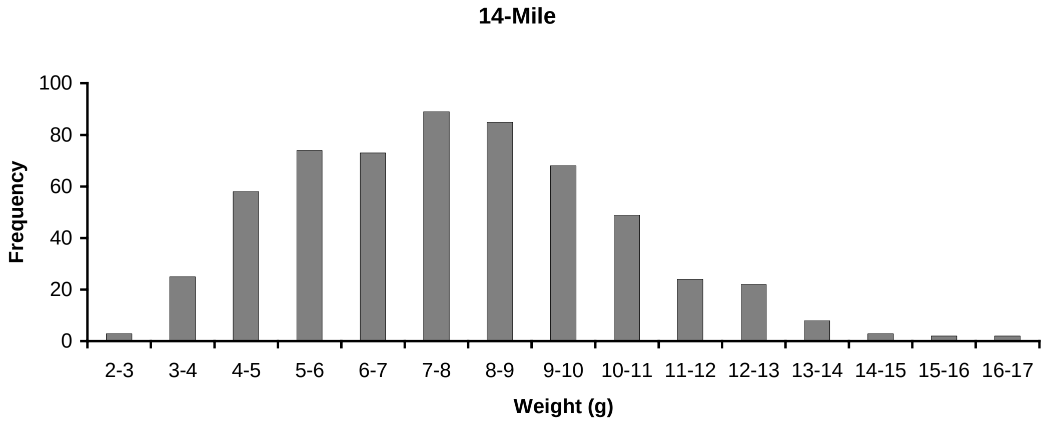
APPENDIX 1. Comparison of observed juvenile coho and steelhead productivity with estimates.

	Site						
Variables	**Anderson**	**Bulbeard**	**Centre Ck. Bridge**	**14-Mile**	**Peach**	**R-4**	**Thurston**
Restored or natural	Restored	Restored	Natural	Natural	Restored	Restored	Natural
Pond or channel	Pond	Ponds	Channel	Combined (76% P. & 24% Ch.)	Channel	Combined (73% Ch. & 27% P.)	Pond
Groundwater or surfacewater	Surfacewater	Surfacewater	Surfacewater	Surfacewater	Groundwater	Groundwater	Surfacewater
Total surface area (m^2)	15 000	17 500	2 639	4 882	12 251	6 955	6 000
Total coho (#)	7 176	284	1 351	1 736	2 171	2 106	818
Coho productivity (# /100 m^2)	48	2	51	36 9 (channel) 27 (pond)	9	30 22 (channel) 8 (pond)	14
Biostandards (# /100 m^2) – Adams and Whyte (1990)	120	120	133	123 32 (channel) 91 (pond)	40	61 29 (channel) 32 (pond)	120
Average (# /100 m^2) –- Keeley et al. (1996)	69 1	69	67	68 6 (channel) 52 (pond)	67	68 49 (channel) 19 (pond)	69
Total steelhead - parr and smolt (#)	207	2	147	8	207	123	116
Total steelhead productivity (# /100 m^2)	1	0	6	0	2	2	2
Biostandards (# /100 m^2) – Adams and Whyte (1990)	NA	NA	10	2.4 (channel) NA (pond)	NA	NA	NA
Average (# /100 m^2) – Keeley et al. (1996)	23	23	37	26 8.9 (channel) 17.5 (pond)	37	33 27 (channel) 6 (pond)	23
Steelhead smolts (#)	132	1	2	1	132	52	2
Steelhead smolt productivity (#/100 m^2)	1	0	0	0	1	1	0
Biostandards (# /100 m^2) – Adams and Whyte (1990)	NA	NA	10	2.4 (channel) NA (pond)	NA	NA	NA
Average (# /100 m^2) – Keeley et al. (1996)	NA	NA	NA	NA	NA	NA	NA
Steelhead parr (#)	75	1	145	7	75	71	114
Steelhead parr productivity (#/100 m^2)	1	0	5	0	1	1	2

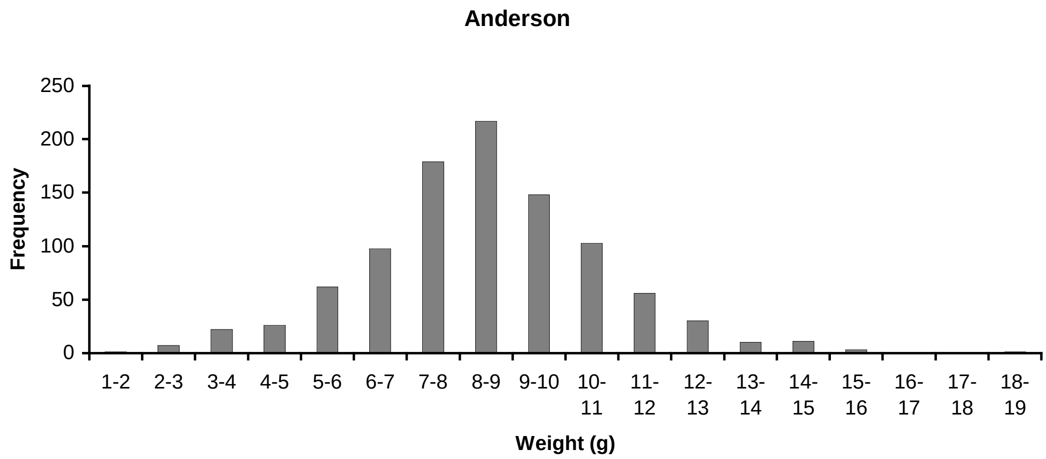
APPENDIX 2. Fischer's LSD test results on mean weight and mean condition factor for juvenile coho and juvenile steelhead among sites. Sites with the same number of asterisks (*) are not statistically different.

Species	Site	n	Mean weight (g)	Standard error (+/-)	LSD sig.	Site	Mean CF	Standard error (+/-)	LSD sig.
Coho (total)	Bulbeard	585	20.6	0.104	* * * * * *	Thurston	1.12	0.005	* * * *
	Peach	974	14.7	0.071	* * * *	Bulbeard	1.12	0.003	* * *
	Thurston	434	14.5	0.129	* * * *	14-Mile	1.11	0.004	* * *
	Anderson	133	8.5	0.608	* * *	R-4	1.10	0.008	* * *
	14-Mile	623	7.9	0.199	*	C.C. Bridge	1.08	0.006	* *
	C.C. Bridge	595	7.6	0.113	*	Peach	1.06	0.004	*
	R-4	286	6.9	0.393		Anderson	1.02	0.006	
Steelhead (total)	R-4	125	41.2	1.542	* * * *	Thurston	1.16	0.008	* * *
	Anderson	89	29.3	0.623	* *	R-4	1.13	0.006	* * *
	Peach	96	29.0	1.981	* *	C.C. Bridge	1.06	0.020	*
	C.C. Bridge	100	9.1	3.976		Peach	1.04	0.028	
	Thurston	78	8.0	0.491		Anderson	1.00	0.010	
Steelhead (parr)	R-4	40	20.4	1.926	* * *	Thurston	1.16	0.016	* * *
	Peach	89	17.4	0.635	* * *	R-4	1.12	0.006	* * *
	Anderson	48	11.9	2.204		Anderson	1.06	0.032	
	C.C. Bridge	51	9.1	3.266		C.C. Bridge	1.06	0.013	*
	Thurston	78	8.0	0.491		Peach	1.01	0.010	
Steelhead (smolt)	R-4	69	62.8	1.352	* *	R-4	1.14	0.008	* *
	Peach	74	43.5	5.739		Peach	1.06	0.015	*
	Anderson	48	37.3	6.087		Anderson	0.97	0.056	

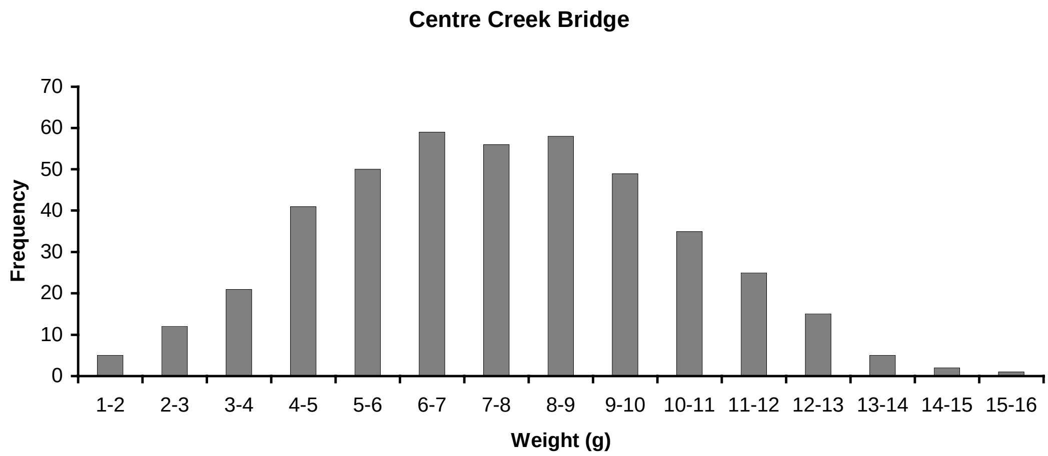
APPENDIX 3. Frequency distribution of juvenile coho weight.



A3-1. Frequency distribution of juvenile coho weight at 14-Mile.

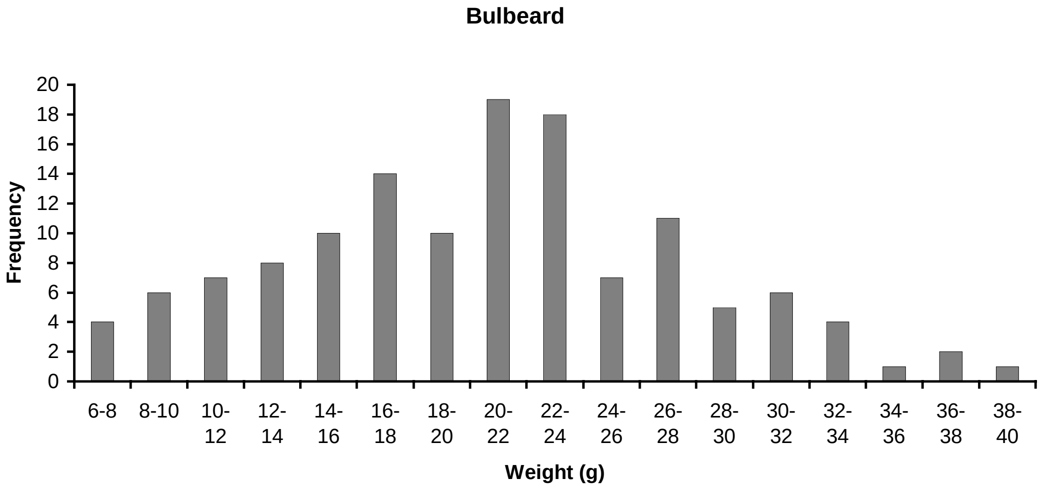


A3-2. Frequency distribution of juvenile coho weight at Anderson.

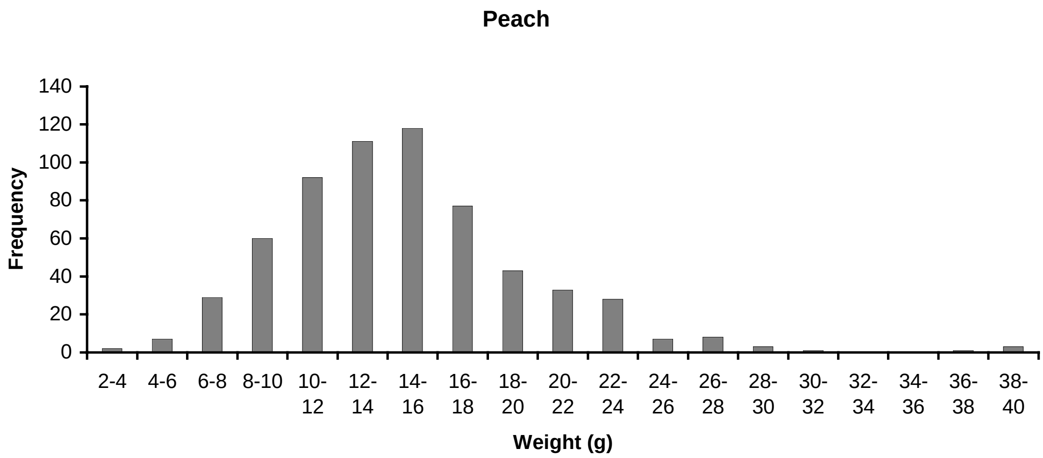


A3-3. Frequency distribution of juvenile coho weight at Centre Creek Bridge.

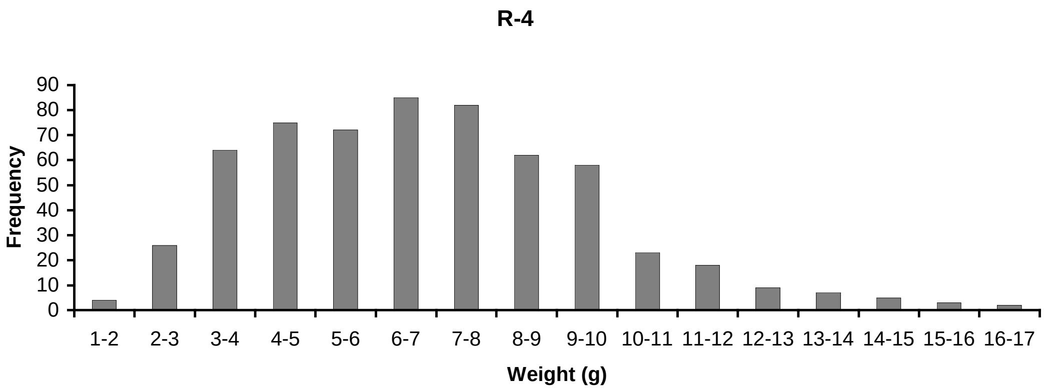
APPENDIX 3. Frequency distribution of juvenile coho weight (cont.)



A3-4. Frequency distribution of juvenile coho weight at Bulbeard.

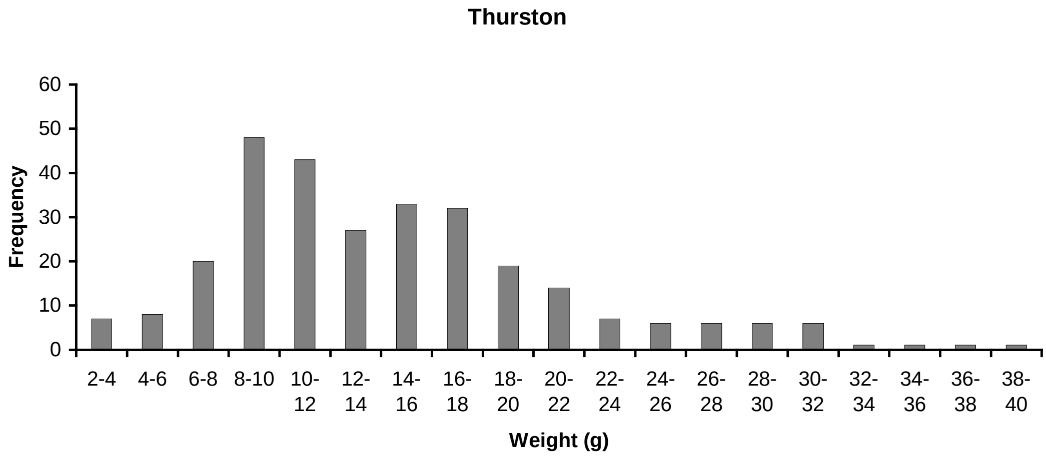


A3-5. Frequency distribution of juvenile coho weight at Peach.



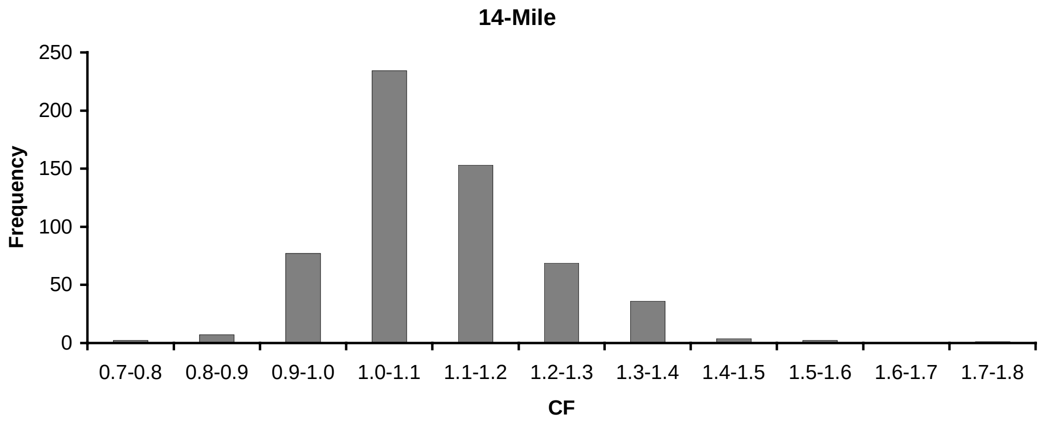
A3-6. Frequency distribution of juvenile coho weight at R-4.

APPENDIX 3. Frequency distribution of juvenile coho weight (cont.)

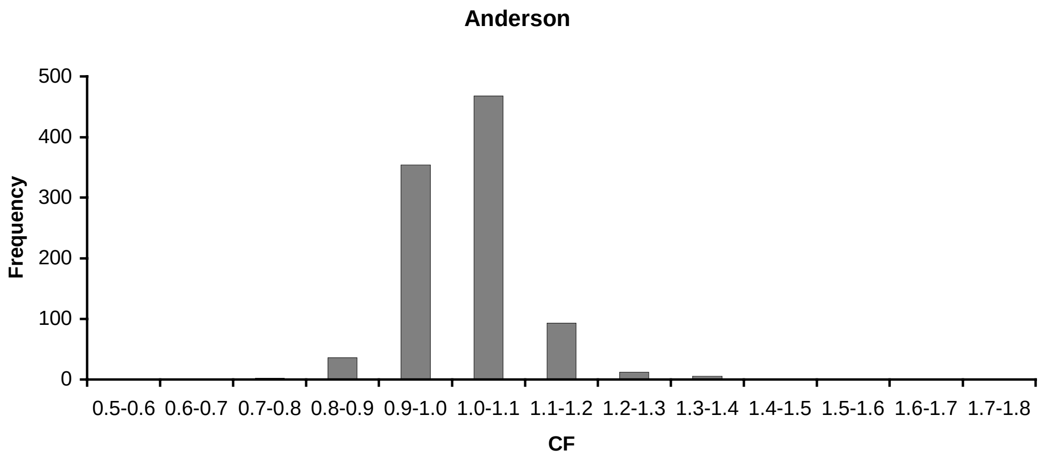


A3-7. Frequency distribution of juvenile coho weight at Thurston.

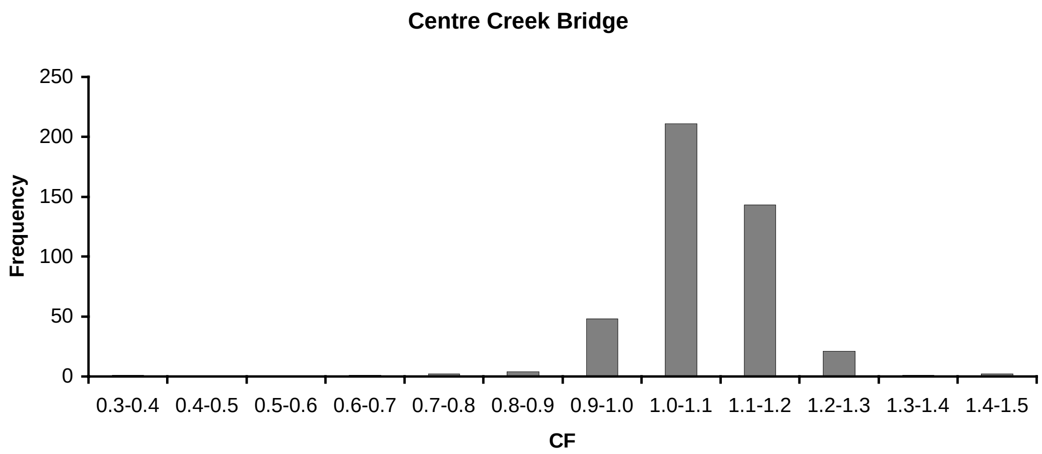
APPENDIX 4. Frequency distribution of juvenile coho condition factor (CF).



A4-1. Frequency distribution of juvenile coho CF at 14-Mile.

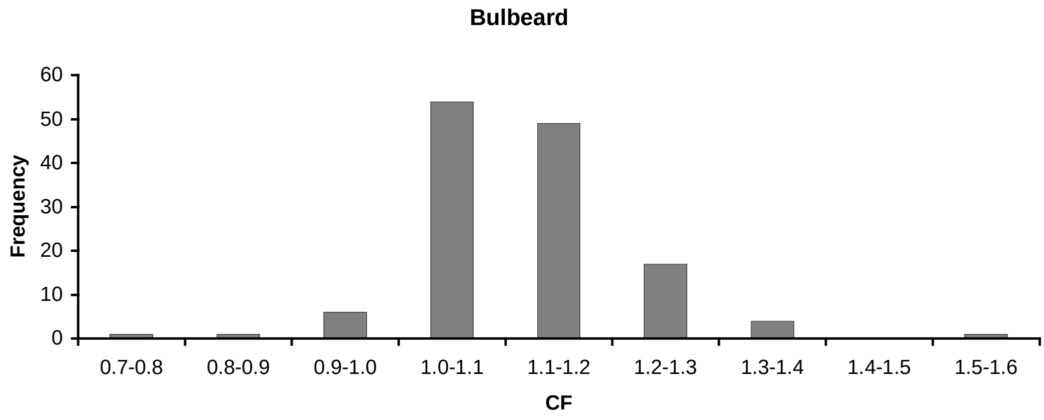


A4-2. Frequency distribution of juvenile coho CF at Anderson.

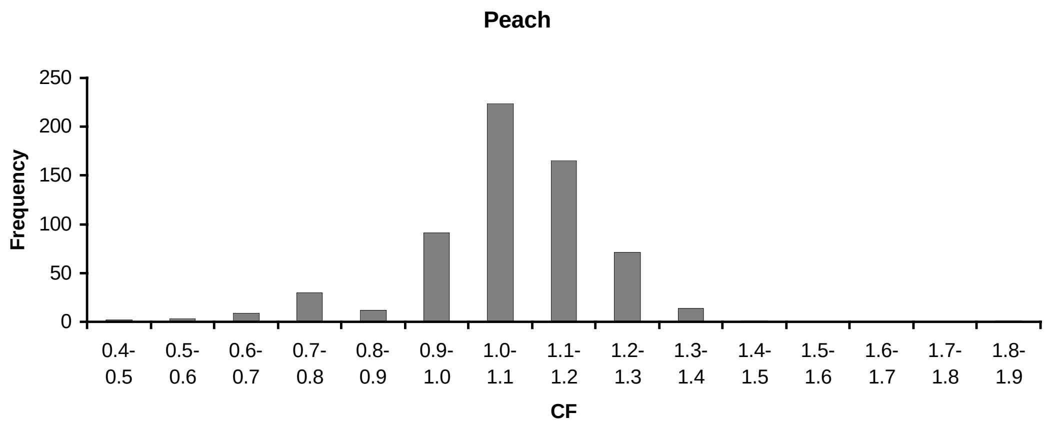


A4-3. Frequency distribution of juvenile coho CF at Centre Creek Bridge.

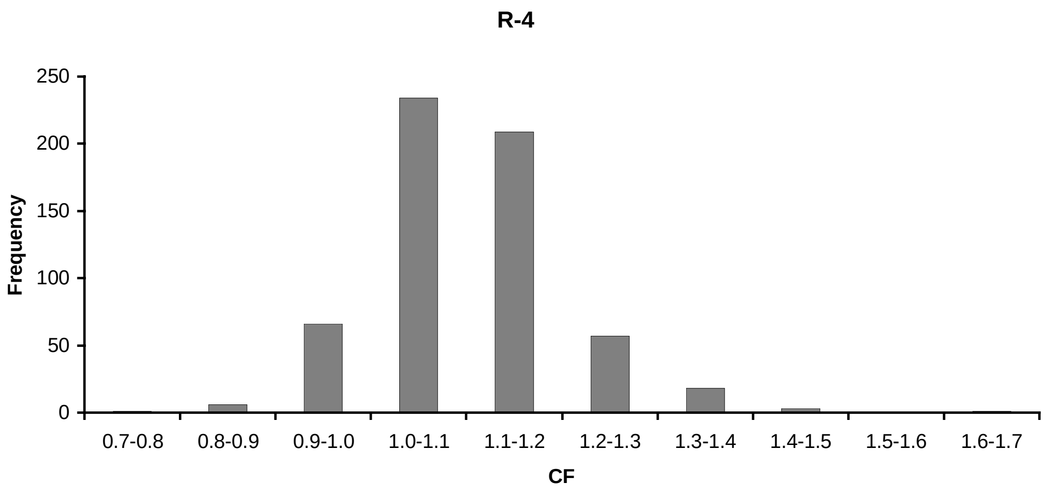
APPENDIX 4. Frequency distribution of juvenile coho condition factor (CF) (cont.).



A4-4. Frequency distribution of juvenile coho CF at Bulbeard.

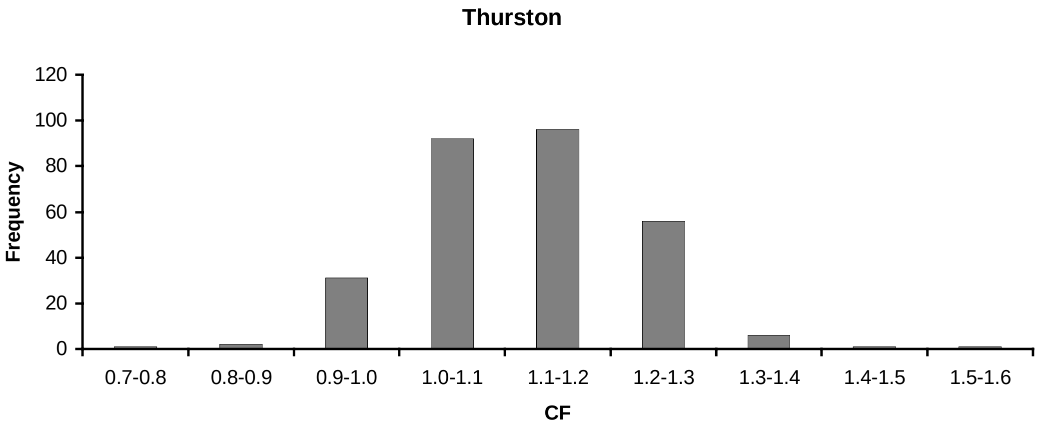


A4-5. Frequency distribution of juvenile coho CF at Peach.



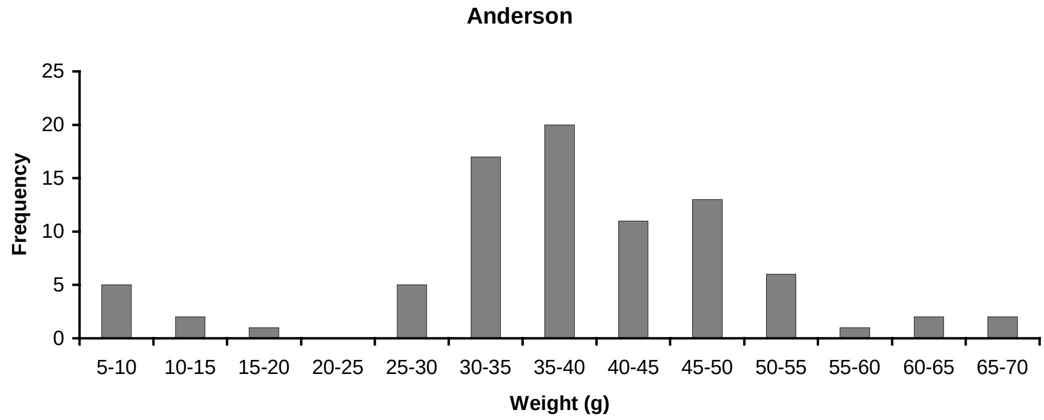
A4-6. Frequency distribution of juvenile coho CF at R-4.

APPENDIX 4. Frequency distribution of juvenile coho condition factor (CF) (cont.).

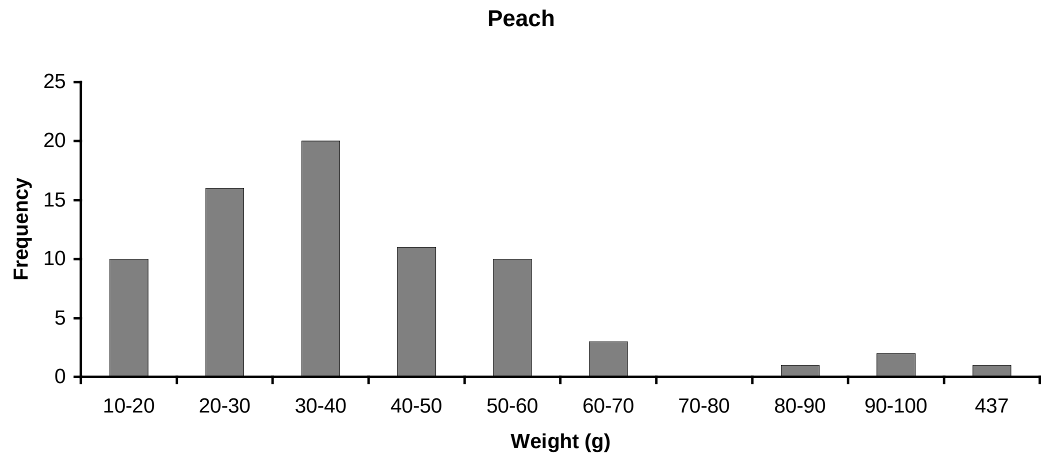


A4-7. Frequency distribution of juvenile coho CF at Thurston.

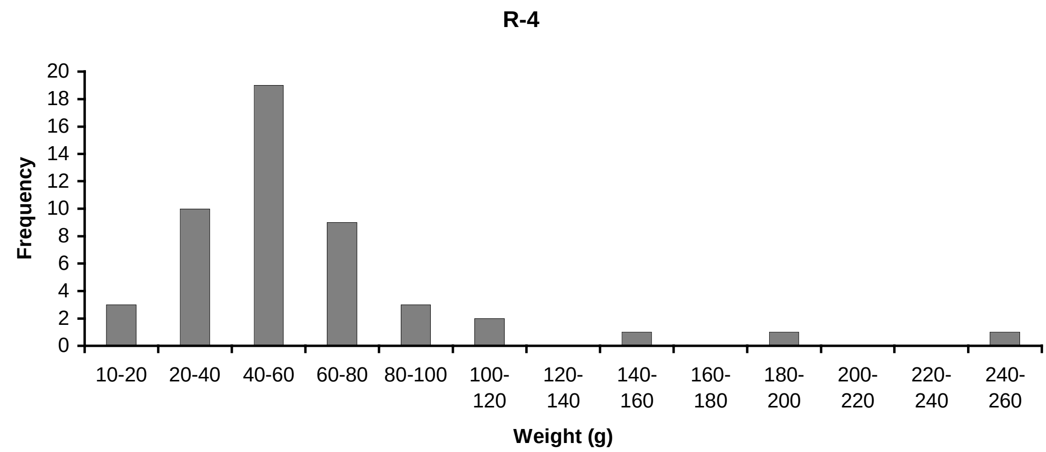
APPENDIX 5. Frequency distribution of steelhead smolts mean weight.



A5-1. Frequency distribution of steelhead smolts mean weight at Anderson.

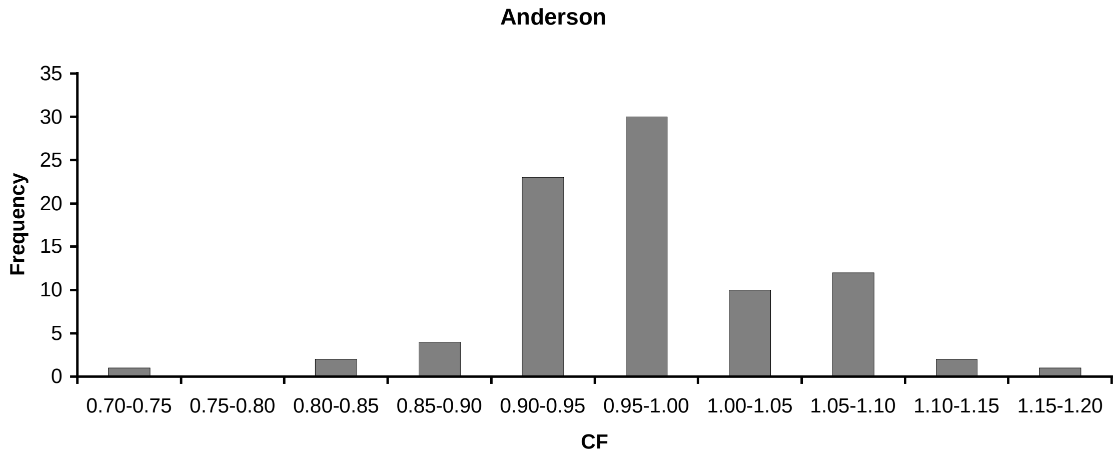


A5-2. Frequency distribution of steelhead smolts mean weight at Peach.

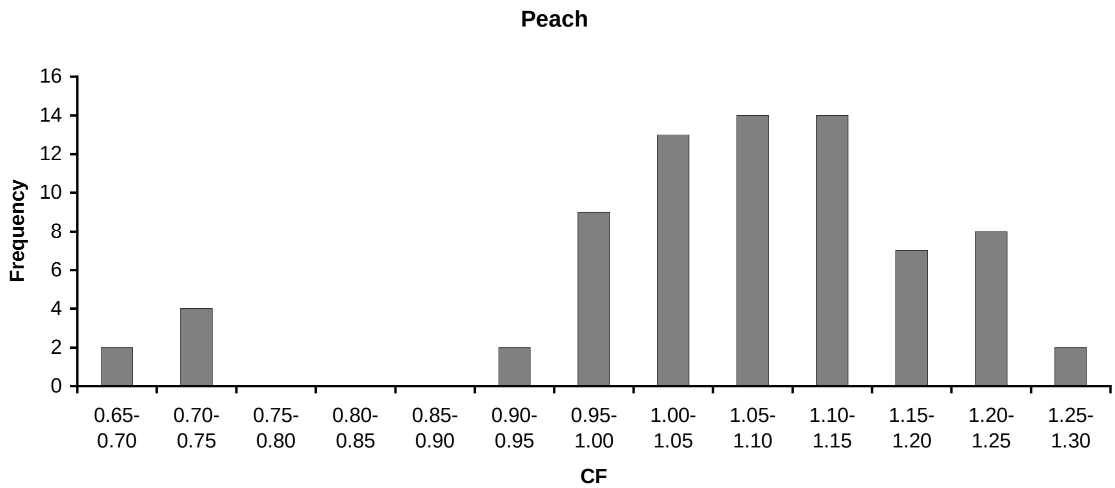


A5-3. Frequency distribution of steelhead smolts mean weight at R-4.

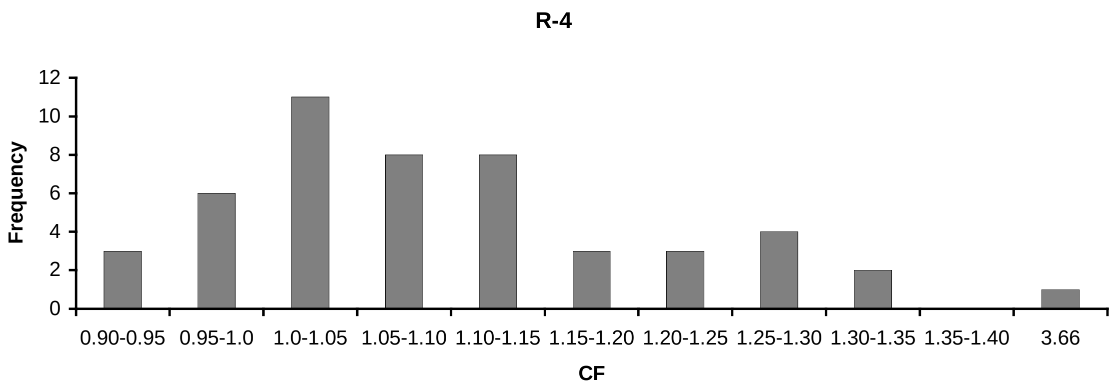
APPENDIX 6. Frequency distribution of steelhead smolts condition factor (CF).



A6-1. Frequency distribution of steelhead smolts CF at Anderson.

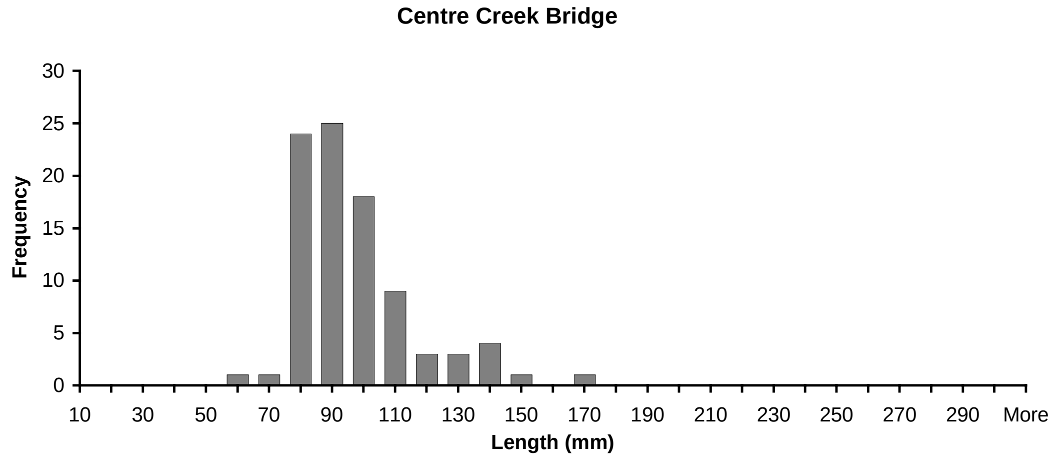


A6-2. Frequency distribution of steelhead smolts CF at Peach.

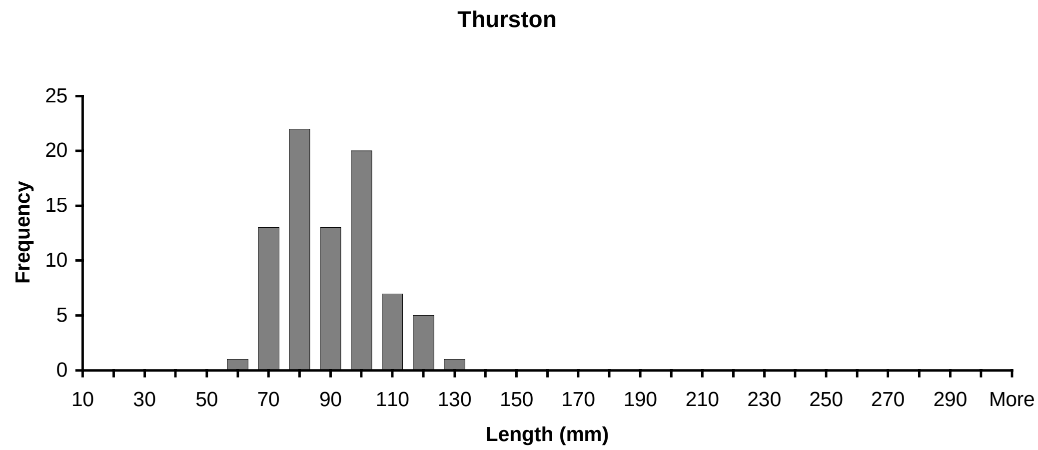


A6-3. Frequency distribution of steelhead smolts CF at R-4.

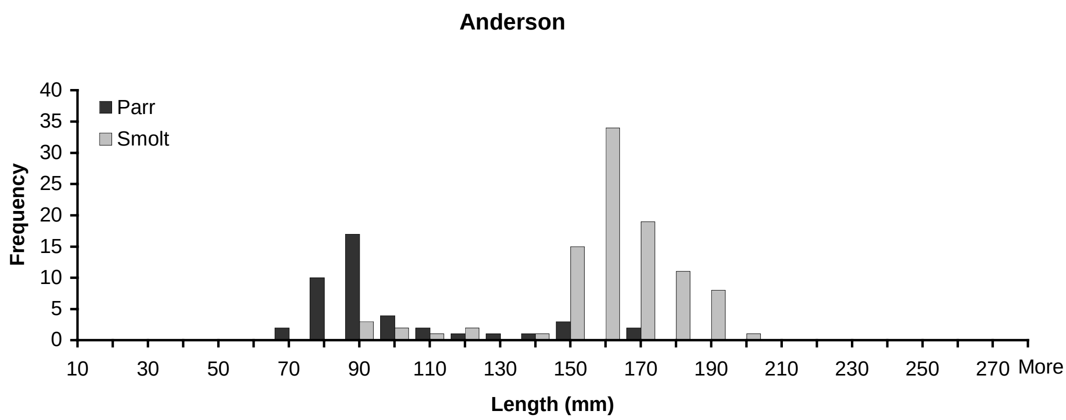
APPENDIX 7. Frequency distribution of juvenile steelhead parr fork length.



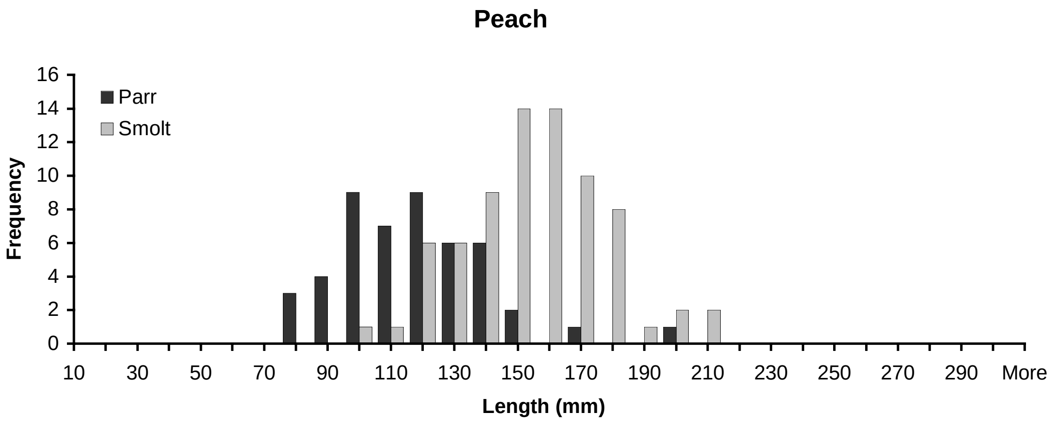
A7-1. Frequency distribution of juvenile steelhead parr fork length at Centre Creek Bridge.



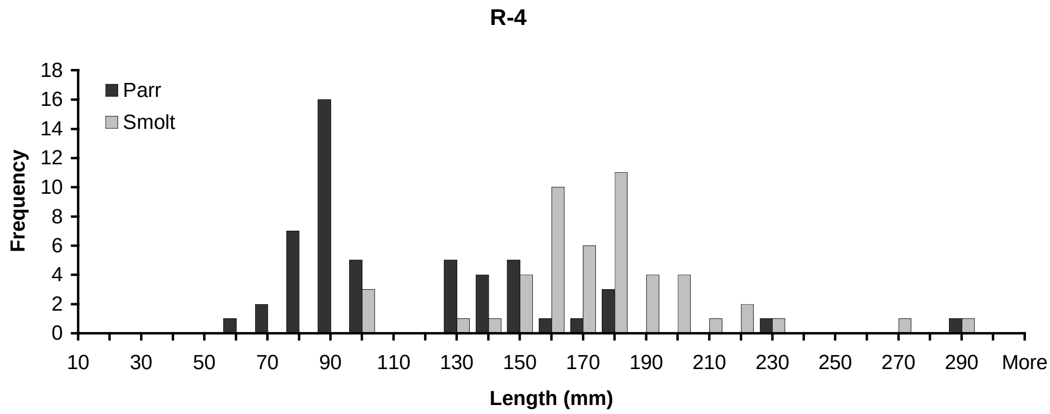
A7-2. Frequency distribution of juvenile steelhead parr fork length at Thurston.



A7-3. Frequency distribution of juvenile steelhead parr and smolts fork length at Anderson.

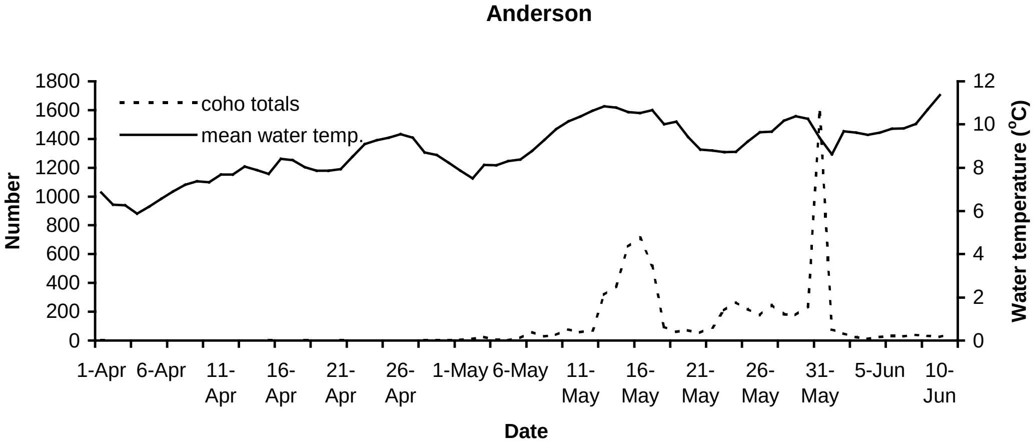


A7-4. Frequency distribution of juvenile steelhead parr and smolts fork length at Peach.

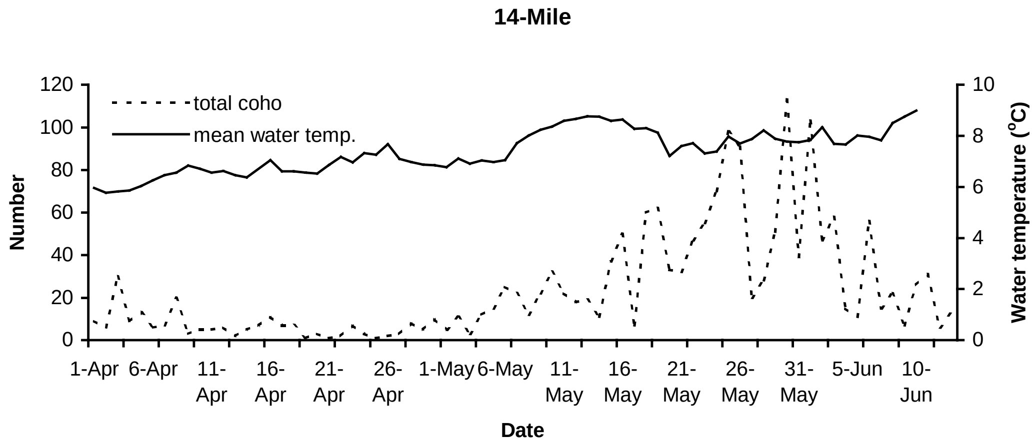


A7-5. Frequency distribution of juvenile steelhead parr and smolts fork length at R-4.

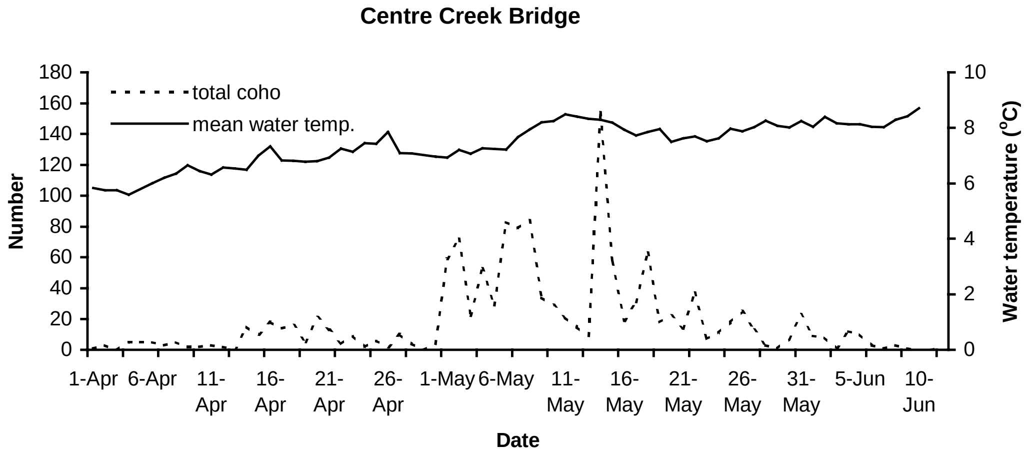
APPENDIX 8. Outmigration of juvenile coho with daily water temperature.



A8-1. Outmigration of juvenile coho with daily water temperature at Anderson.

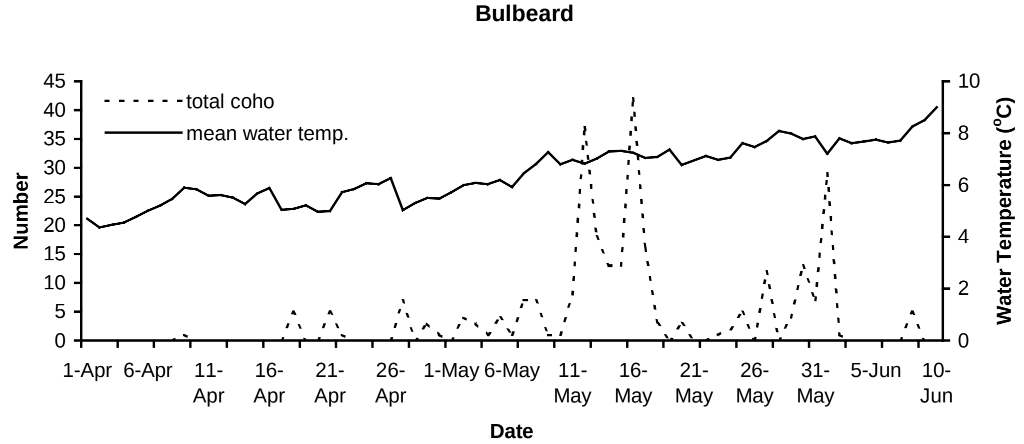


A8-2. Outmigration of juvenile coho with daily water temperature at 14-MIle.

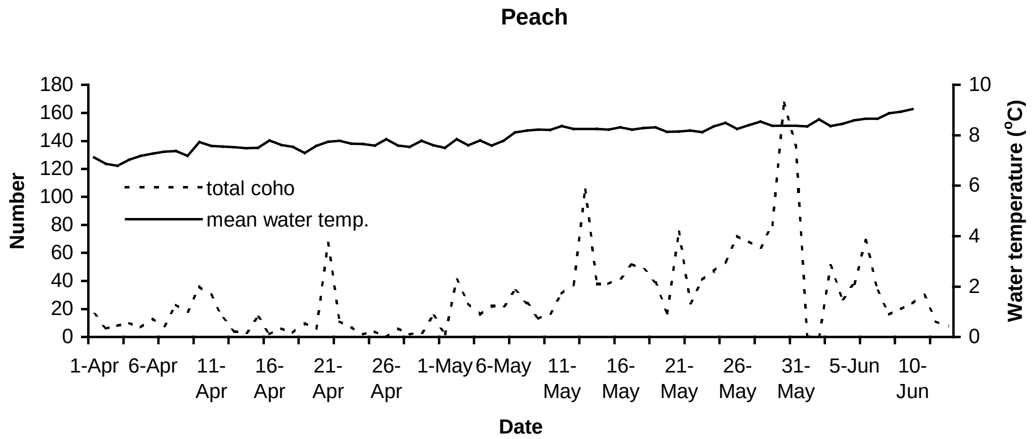


A8-3. Outmigration of juvenile coho with daily water temperature at Centre Creek Bridge.

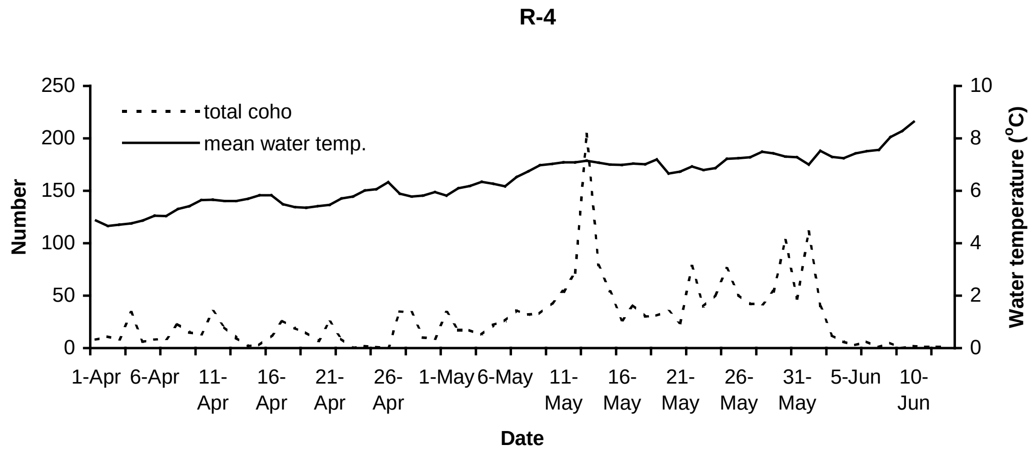
APPENDIX 8. Outmigration of juvenile coho with daily water temperature (cont.).



A8-4. Outmigration of juvenile coho with daily water temperature at Bulbeard.

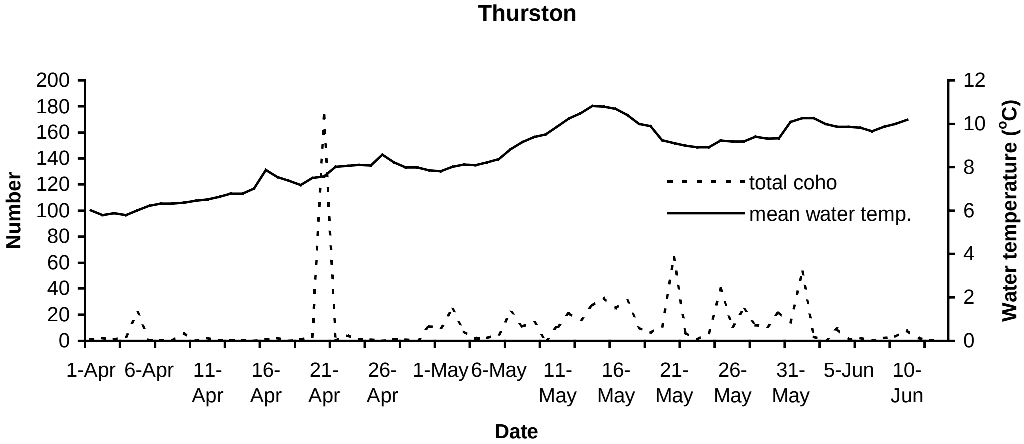


A8-5. Outmigration of juvenile coho with daily water temperature at Peach.



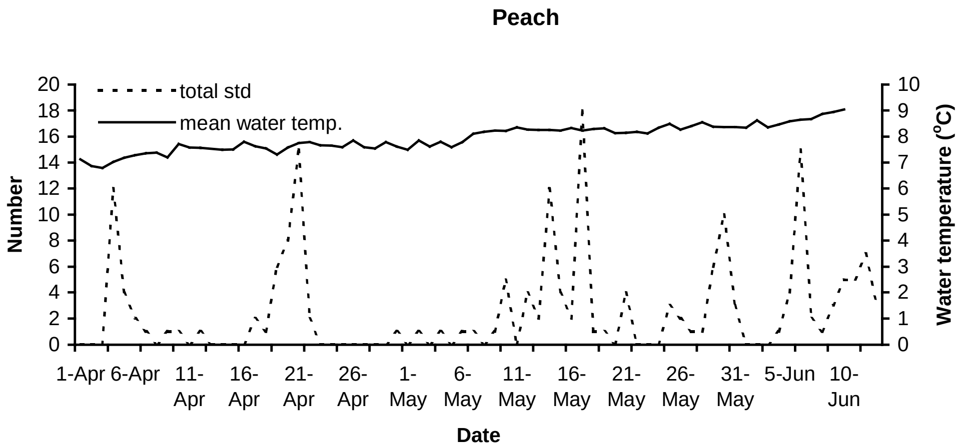
A8-6. Outmigration of juvenile coho with daily water temperature at R-4.

APPENDIX 8. Outmigration of juvenile coho with daily water temperature (cont.).

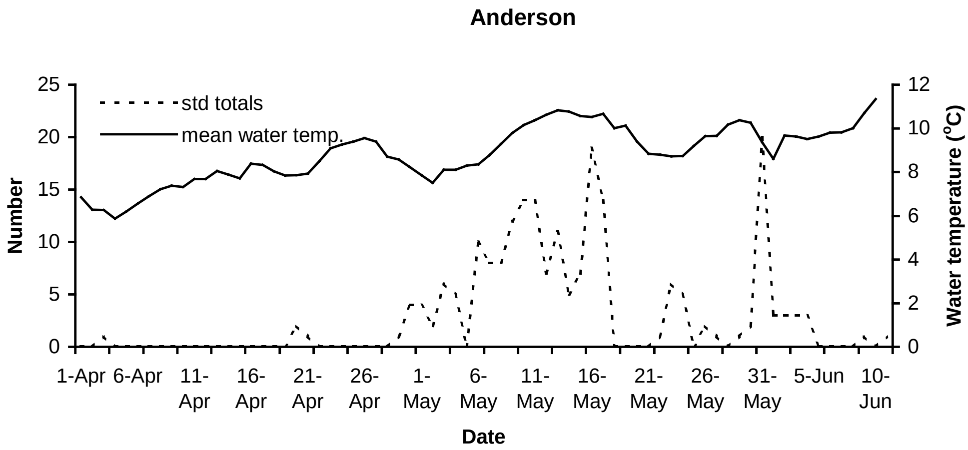


A8-7. Outmigration of juvenile coho with daily water temperature at Thurston.

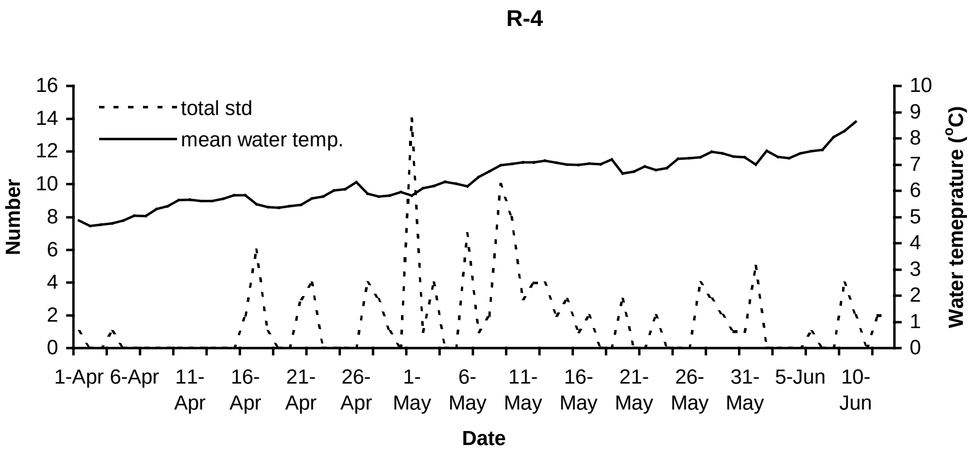
APPENDIX 9. Outmigration of juvenile steelhead with daily water temperature.



A9-1. Outmigration of juvenile steelhead with daily water temperature at Peach.

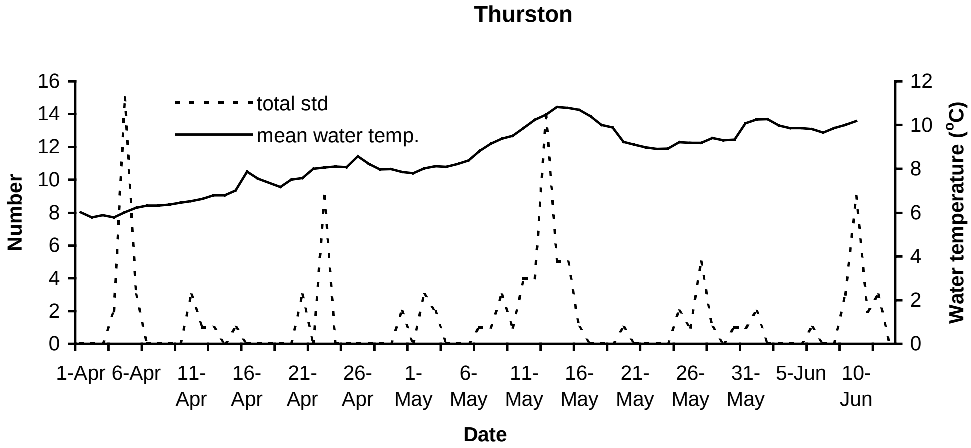


A9-2. Outmigration of juvenile steelhead with daily water temperature at Anderson.

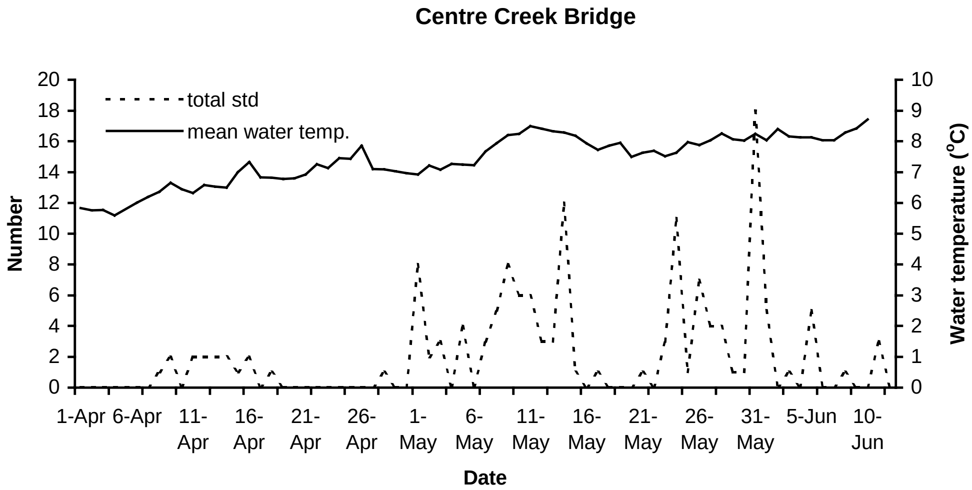


A9-3. Outmigration of juvenile steelhead with daily water temperature at R-4.

APPENDIX 9. Outmigration of juvenile steelhead with daily water temperature (cont.).

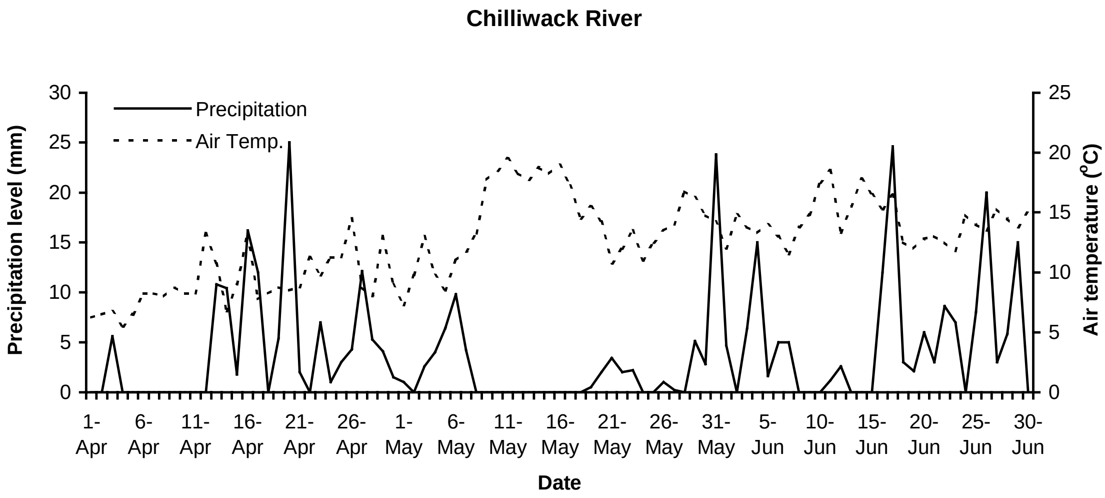


A9-4. Outmigration of juvenile steelhead with daily water temperature at Thurston.



A9-5. Outmigration of juvenile steelhead with daily water temperature at Centre Creek Bridge.

APPENDIX 10. Daily precipitation and daily air temperature for the Chilliwack River.



APPENDIX 11. The water temperature for each off-channel Chilliwack site, over time.