COLUMBIA BASIN FISH & WILDLIFE COMPENSATION PROGRAM

British Columbia
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BC Fisheries

SLOCAN RIVER SUMMER TEMPERATURE IN 1997 &1998: IMPLICATIONS FOR RAINBOW TROUT DISTRIBUTION AND PRODUCTION

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FOR
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Executive Summary

The Slocan River is one of the larger rivers in the West Kootenays. In the 1960s, it supported an excellent recreational fishery for large rainbow trout. This fishery declined drastically in the mid-1970s and trout numbers have remained low since then, in spite of experimental stocking programs and closure of the river to angling since 1994.

The Columbia Basin Fish and Wildlife Compensation Program monitored summer temperatures in the Slocan drainage in 1997 (5 stations) and 1998 (9 stations) to determine whether temperature might be a factor relating to low abundance of trout in the drainage. Data from the two years provide examples of both cooler than average (1997) and warmer years (1998) because discharge was unusually high in 1997 and low in 1998.

Results showed that the Slocan River is warmer than most other rivers of the region. Temperatures in the mainstem river reached 21.5 ^{o}C in 1997 and 24.4 ^{o}C in 1998. The period of warm temperatures (daily maximum > 20 ^{o}C) lasted three to four weeks in 1997, and about 8 weeks in 1998. These temperatures occur in almost all of the mainstem; slightly cooler sections are found immediately downstream of the confluence with Lemon Creek, and perhaps downstream of Winlaw and Hird Creeks. Little Slocan River below Koch Creek is about 2 ^{o}C cooler than the mainstem.

Literature review indicates that mainstem temperatures are well above optimum rearing conditions for rainbow trout juveniles. This may be a primary cause of low trout densities, through avoidance (movement of trout out of warm areas) and/or low growth and survival of juveniles. Distributions of trout in the Slocan River during snorkel surveys in 1998 and 1985, and electrofishing surveys in 1986 were examined and appear to be consistent with a temperature effect on trout distribution in the Slocan River.

Comparison of recent data to historical temperature measurements suggests that the river had relatively high temperatures prior to 1976, although there may have been slight increases since then. However, conclusions are weakened by the low number of historical measurements.

Anecdotal accounts of historical trends in rainbow trout abundance suggest that high numbers of large trout, prior to the mid-1970s, were a temporary phenomenon related to the period of eutrophication in Kootenay Lake. These fish probably were not year-round residents of the Slocan River, but rather migrated into the Slocan in the fall and spring from Kootenay River.

It is recommended that remaining supplies of cool water from tributaries and groundwater be protected from further water licensing, as these are likely providing thermal refugia critical for trout survival in late summer and winter. Any barriers to upstream migration of juveniles from the mainstem into cooler tributaries should be removed. In-stream habitat enhancement structures for juvenile trout should be located in cooler areas to allow the best opportunities for growth and survival. Additional monitoring to identify other areas of cool water refuge is required to refine the description of available rearing habitat in the Slocan drainage.

Acknowledgments

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1.0 INTRODUCTION

The Slocan River is one of the larger rivers in the West Kootenay. Rainbow trout (*Oncorhynchus mykiss*) and bull trout (*Salvelinus confluentus*) are present in the system, as well as mountain whitefish (*Prosopium williamsoni*), longnose sucker (*Catostomus catostomus*), northern squawfish (*Ptychocheilus oregonesis*), umatilla dace (*Rhinichthys umatilla*) and sculpin (*Cottus spp*.) (Zimmer et al. 1998). The river has been closed to trout angling since 1994, however, densities of catchable trout have increased only marginally since the closure (Oliver 1999).

There is significant interest from local residents, stakeholder groups, and agencies in improving the production and abundance of rainbow trout in the river. The first step in this process is to attempt to understand the factors which currently limit trout production and distribution.

Freshwater fish are poikilothermous; their body temperature is set by the temperature of the water in which they live. Temperature is the main factor determining the metabolic rate (i.e., cost of living), which in turn influences a variety of dependent physiological variables ranging from growth rate to swimming performance to reproduction (Reid et al. 1997). Consequently, temperature can be the most important factor determining distribution of trout (Barton and Taylor 1982). Since the mainstem of the Slocan River begins as the outflow of Slocan Lake, its summer temperatures have the potential to be warmer than most other streams in the region. Nevertheless, prior to 1997, there were no temperature data for the river other than a few spot-check temperatures recorded by Environment Canada between 1949 and 1976.

The Columbia Basin Fish and Wildlife Compensation Program (CBFWCP) began monitoring summer temperatures in the Slocan River in 1997 (Arndt 1998). This was continued in 1998 with extra stations to provide information about the effects of Lemon Creek and Koch Creek on the main river and the Little Slocan River. The data from the two years provide examples of both cooler than average (1997) and warmer (1998) years because river discharge was unusually high in 1997 and low in 1998.

This report describes the results of the 1998 monitoring, and compares them to 1997 and some earlier data. Potential implications of the temperature regime for trout distribution and production are discussed, and recommendations for further assessment and enhancement are presented.

2.0 METHODS

Nine temperature recorders (Ryan Instuments, Redmond, WA and Onset Computer Corp. Pocasset, MA) were installed in the Slocan River and tributaries (Fig. 1, Table 1) in late June and early July 1998. Three of the stations were the same as in 1997 (Table 1), and 6 were new:

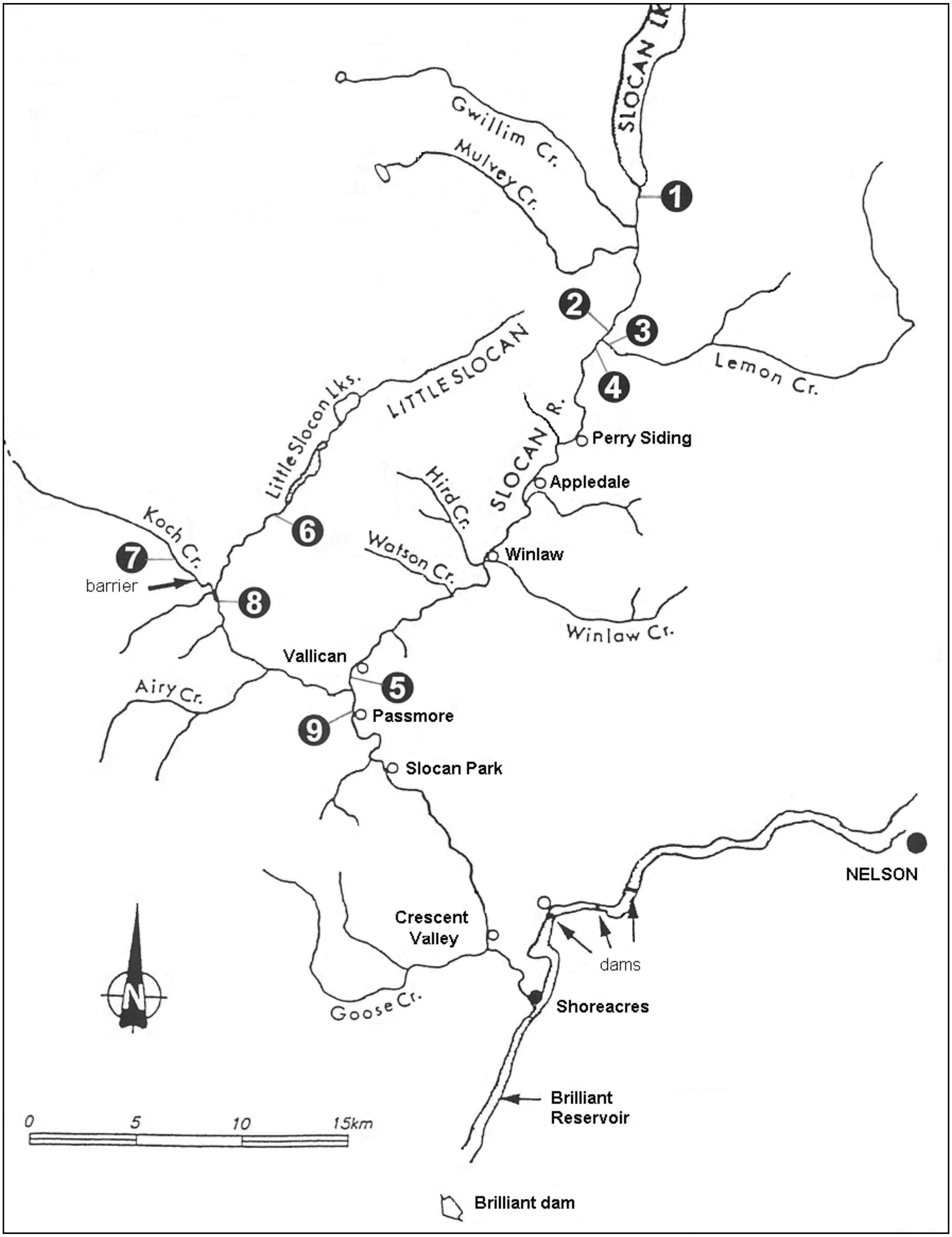


Figure 1. Slocan River temperature sampling stations for summer 1998. Map adapted from Griffith (1986a).

- Station 1 was added to assess the amount of warming that occurred in the marshy area between the outlet of Slocan Lake and the confluence with Lemon Creek.
- Station 4 was added to determine the degree to which Lemon Creek cooled the mainstem Slocan River below their confluence.
- Stations 6, 7, and 8 were added to provide information on temperatures in the upper reaches of Little Slocan River and the effect of Koch Creek.
- Station 9 was added to assess the degree to which the Little Slocan River cooled the mainstem Slocan River below their confluence.

Temperature loggers were also put in at the mouth of the Little Slocan River, and the Slocan River at Crescent Valley (1997 Stations 4 and 5), but the data were lost during downloading and calibration.

Recorders were set to log once per hour. Downloaded data were adjusted if necessary based on a calibration thermometer (Fisher Scientific). The 24 readings per day were used to calculate a mean, maximum, and minimum temperature for each day.

Table 1. Temperature recording stations in the Slocan River for summer 1998. Locations are plotted in Figure 1.

Stn	Location	Description
1	mainstem at Slocan Lake outlet	~30 m downstream of bridge in Slocan City on east side
2	mainstem upstream of Lemon Creek confluence (**1997 Station 1**)	~20 m upstream of Lemon Ck mouth on east side
3	Lemon Creek mouth (**1997 Station 2**)	just upstream of railway crossing on north side
4	mainstem downstream of Lemon Creek confluence	~200 m downstream of confluence on east side
5	mainstem upstream of Little Slocan River confluence (**1997 Station 3**)	near former bridge crossing on east side
6	Little Slocan River upstream of Koch Creek	under bridge 2.5 km downstream of Lower Little Slocan Lk
7	Koch Creek	~30 m downstream of FSR bridge crossing
8	Little Slocan River below Koch Creek confluence	~400 m downstream of Koch Ck confluence on east side
9	mainstem downstream of Little Slocan River confluence	~50 m upstream of Passmore bridge on west side

3.0 RESULTS

3.1 1998 Temperature Regime

Daily maximum, mean, and minimum temperatures for each station are provided in Appendices 1 to 9. At station 8 (Little Slocan River below Koch Creek confluence) the temperature logger was stranded as water levels receded so data are only available to August 28.

3.1.1 *Temperatures in the mainstem Slocan River*

Temperatures were very similar at four of the five mainstem locations (stations 1, 2, 5, 9) and were quite warm (Fig. 2). At these stations, daily maximum temperatures exceeded 22 ^{o}C, and daily mean temperatures exceeded 20 ^{o}C, for most of the period between late July and early September (Fig. 2).

The outflow of Slocan Lake was the warmest station; maximum temperature reached 24.6 ^{o}C, and the daily mean 23 ^{o}C (Fig. 2). This warm water from Slocan Lake sets the stage for the river temperature profile. Occasional rapid decreases (e.g. July 30) may be related to periods of cooler air temperatures or wind-induced seiches which temporarily displace warmer thermocline water at the outflow.

The only mainstem location at which temperatures were noticeably lower was downstream of the confluence with Lemon Creek (Station 4). Temperatures tended to be about 2 ^{o}C lower in this reach. Daily maximum temperature rarely exceeded 22 ^{o}C, and daily mean temperature was usually less than 20 ^{o}C (Fig. 2).

3.1.2 *Lemon Creek and its influence on the mainstem*

Lemon Creek is a cold tributary with temperatures 6-8 ^{o}C lower than the Slocan River above its confluence (Fig. 3). This cooler water had a significant effect on mainstem temperatures below the confluence, lowering the daily maxima and means by 2-3 ^{o}C (Fig. 3). This reach below Lemon Creek confluence was the only mainstem location at which daily mean temperature rarely exceeded 20 ^{o}C in 1998. The location of the temperature logger (200 m downstream of confluence) should have been adequate to allow mixing of the water below the confluence. Rate of warming downstream of this point was not determined, although temperatures are similar to upstream of Lemon Creek confluence by the time they reached the Little Slocan River confluence (station 5).

Re-routing of lower Lemon Creek, circa 1948, is believed to have caused partial damming of the mainstem between Slocan Lake (Station 1) and the Lemon Creek confluence (station 2)[1]. Temperatures did not increase in this reach in spite of the wide, marshy character (Fig. 4). For most of the summer, the lower station tended to be the same or slightly cooler than the water leaving Slocan Lake.

[1] It is reported that the mouth of the creek was moved downstream from its original location; this caused materials transported downstream in the creek to be pushed up against a rock bluff, causing raising of the water level and marsh conditions upstream (Bob Barkley, local resident, personal communication).

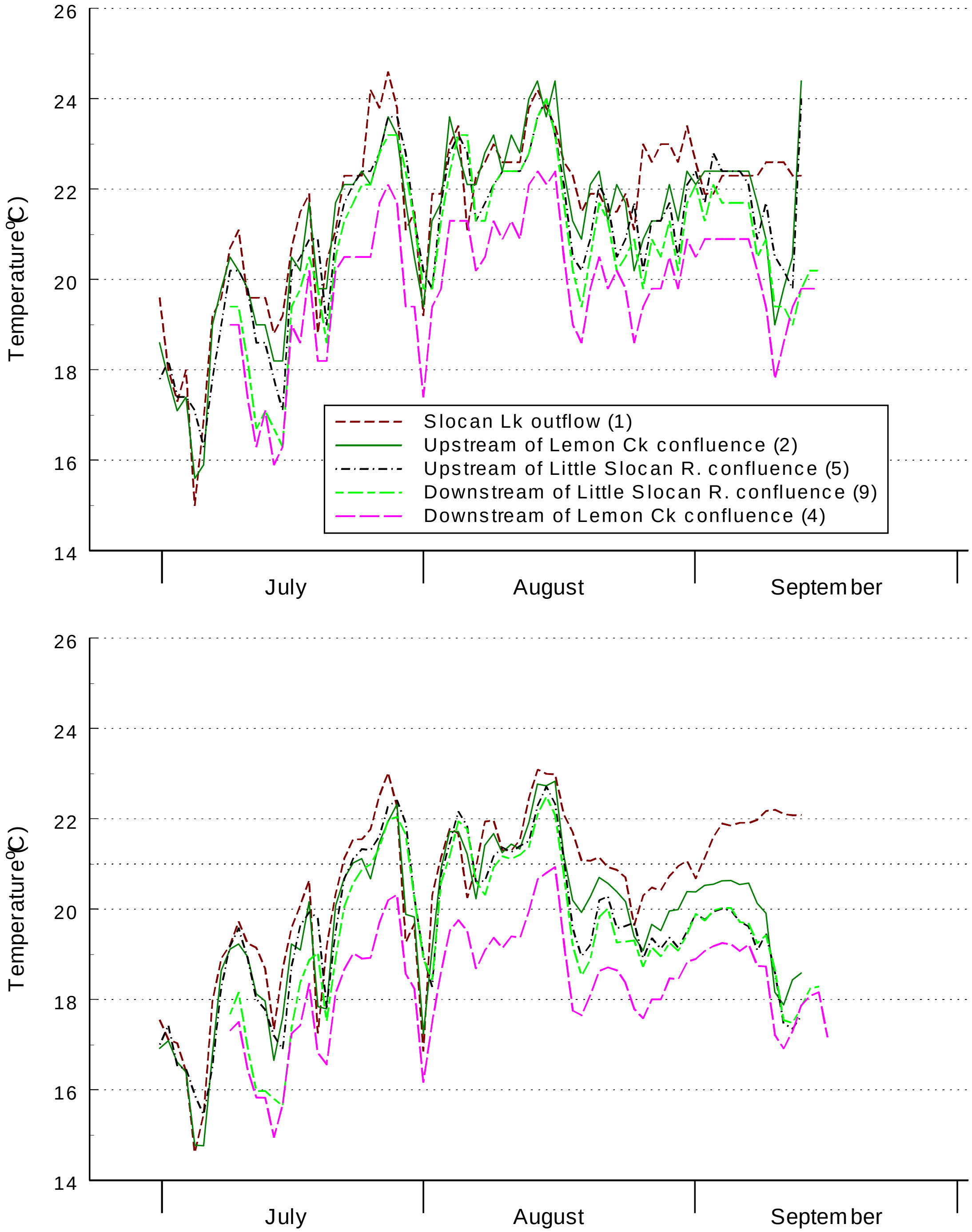


Figure 2. Daily maximum (top) and mean (bottom) temperatures for five mainstem locations in the Slocan River in 1998. Station numbers are in parentheses.

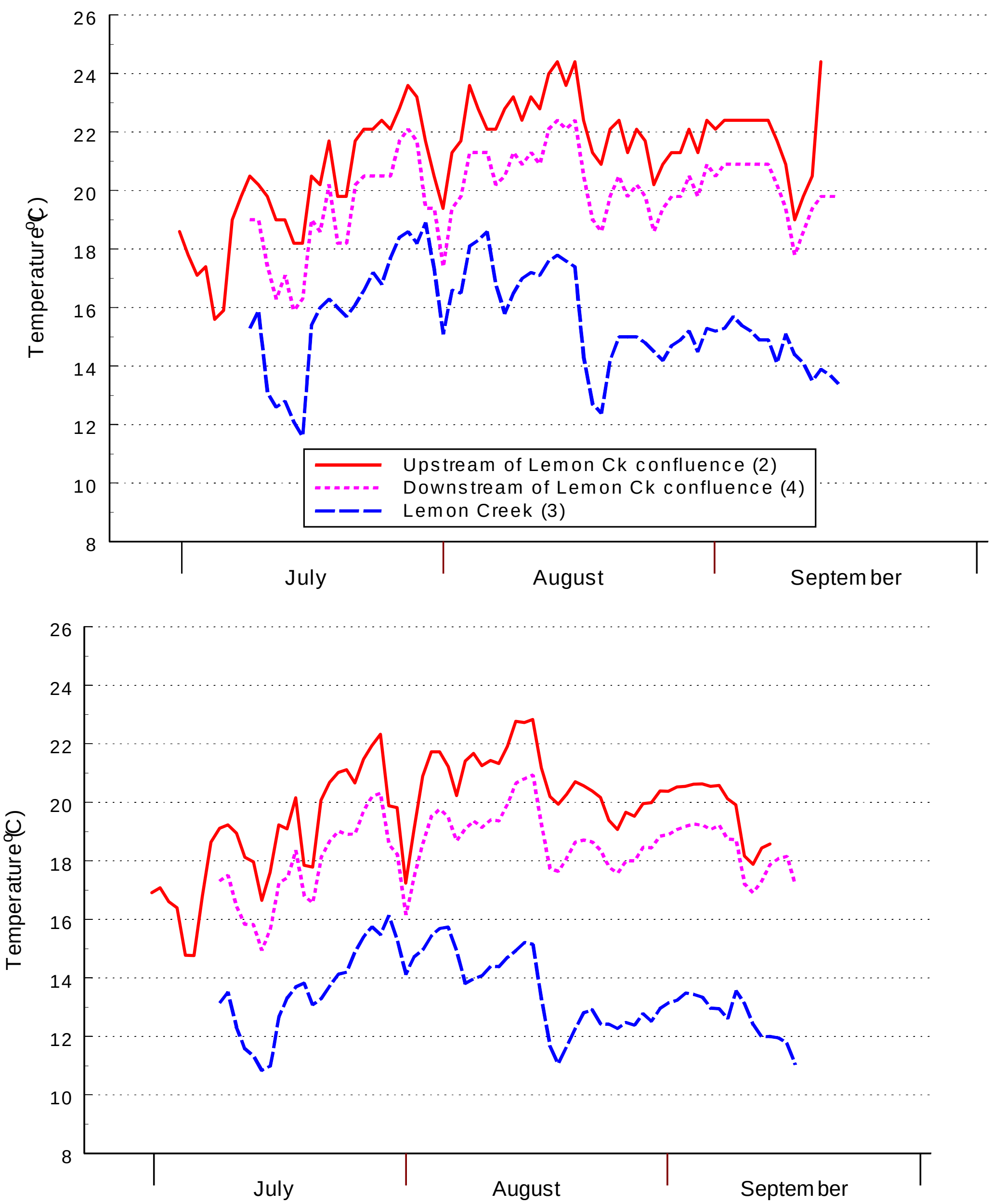


Figure 3. Influence of Lemon Creek on daily maximum (top) and mean (bottom) temperatures in the Slocan River in 1998. Station numbers are in parentheses.

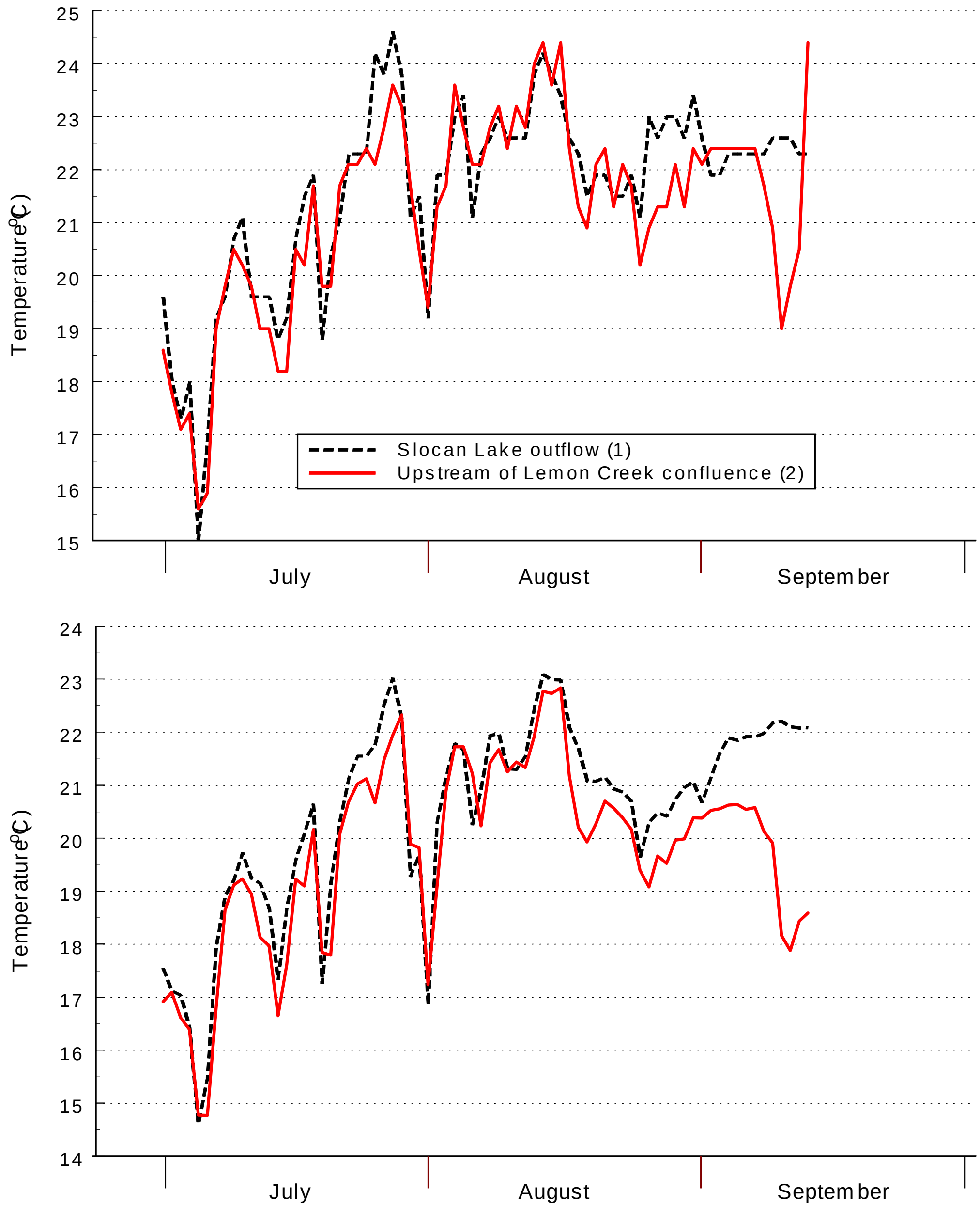


Figure 4. Daily maximum (top) and mean (bottom) temperatures in Slocan River at the outlet of Slocan Lake and immediately upstream of the confluence with Lemon Creek in 1998. Station numbers are in parentheses.

3.1.3 *Little Slocan River and its influence on the mainstem*

Little Slocan River is similar to the mainstem in that it has lakes at the head of the drainage. Maximum temperatures above the confluence with Koch Creek reached 24.5 ^{o}C, and mean temperatures were between 20 and 23 ^{o}C from late July to early August (Fig. 5). Daily maximum temperatures up to 23 ^{o}C were also recorded for this reach in 1992 (G. Oliver, unpublished data).

Koch Creek is a cold tributary with a temperature regime very similar to that of Lemon Creek. It had a significant effect on the temperatures of the Little Slocan River below its confluence, lowering daily maxima by about 2 degrees and daily mean temperatures by 2-4 degrees in 1998 (Fig. 5). Temperature data for the mouth of the Little Slocan are not available for 1998, but in 1997, they were 2-4 degrees lower than the mainstem Slocan River above its confluence (Arndt 1998). This suggests that the temperature regime in the Little Slocan below Koch Creek is similar to the mainstem reach downstream of Lemon Creek confluence.

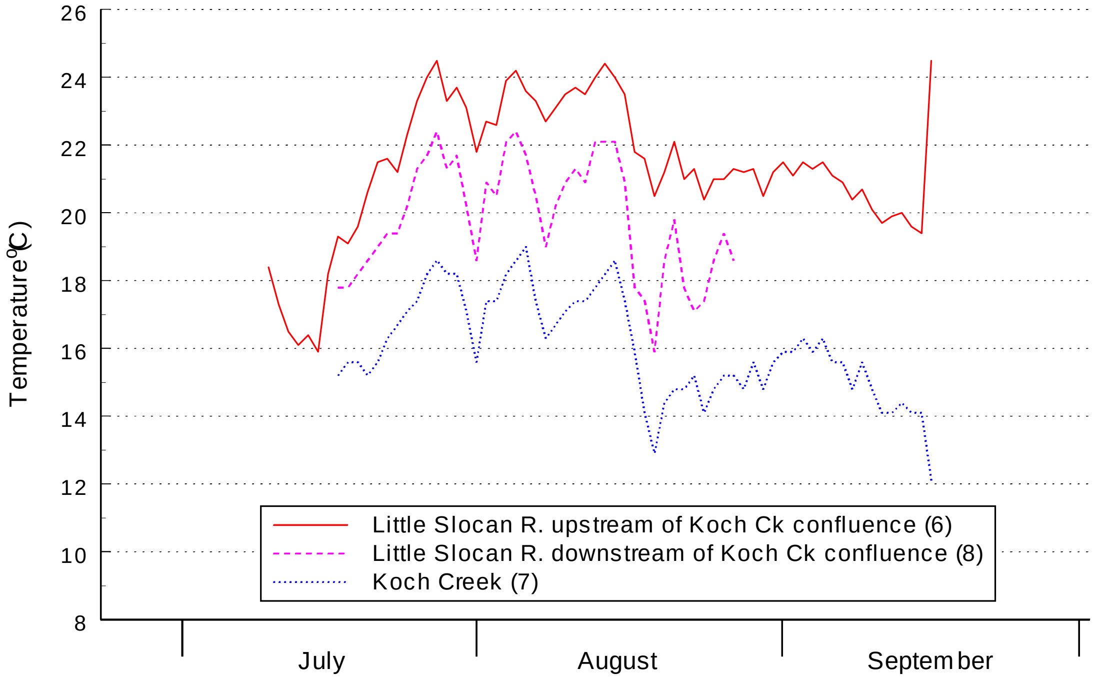
Temperatures upstream and downstream of the Little Slocan confluence were almost identical (Fig. 2), indicating that the Little Slocan River had a negligible effect on the mainstem because of the small difference in temperature and the large volume of water in the mainstem. There may be a small localized effect in the pool at the confluence.

3.2 Comparison of 1997 and 1998

Summer water temperatures in a given year are affected by both air temperature and discharge, because a larger volume of water is less influenced by the air temperatures. August is usually the most critical month due to the combination of low discharge and high air temperature. In 1997, mean air temperature was similar to the long term average (Table 2), but discharge was higher than average (Table 3; Fig. 6); 1998, in contrast, was a year of warmer air temperatures (Table 2) and low discharge (Table 3; Fig. 6). The range of discharge levels bracketed by the two years represents about half (49%) of discharge variation between 1950 and 1998. Discharge lower than the 1998 levels, or higher than the 1997 levels, occurred about once every 4 years (28% and 23%, respectively).

Table 2. Monthly mean temperature (^{o}C) at Castlegar Airport for 1966-1996 compared to 1992, 1997, and 1998 (Environment Canada, Kelowna).

Year	July	August	September
1966-1996 average	19.9	19.7	14.5
1992	19.6	19.4	13.1
1997	19.3	19.7	15.1
1998	22.6	21.5	18.3



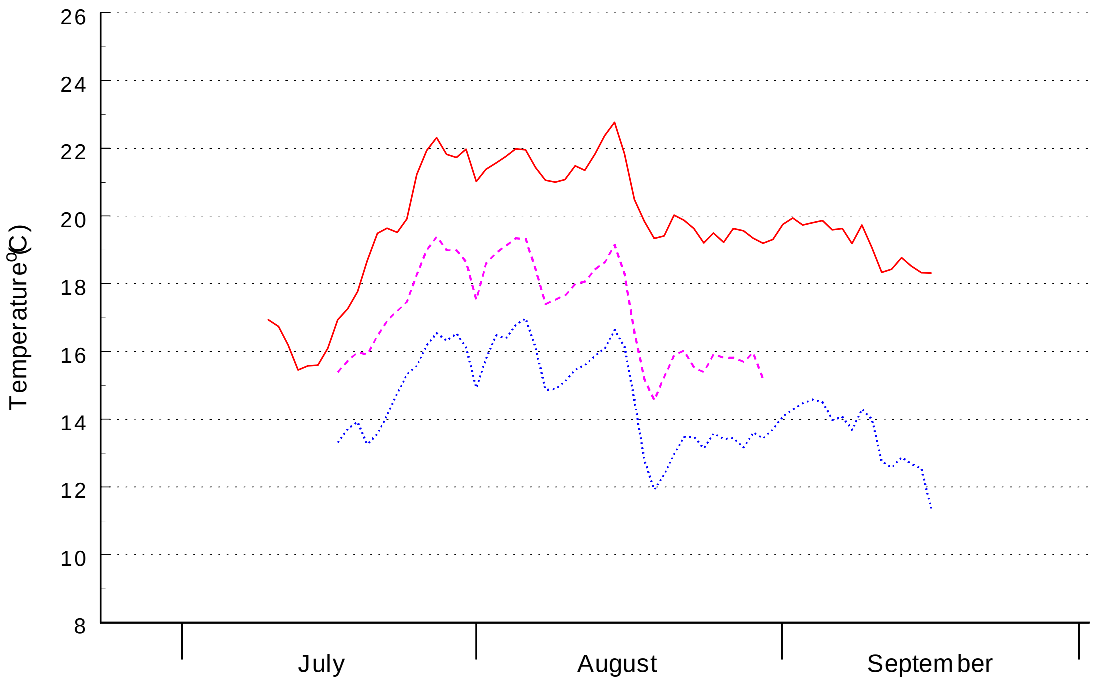


Figure 5. Daily maximum (top) and mean (bottom) temperatures in Koch Creek and in the Little Slocan River upstream and downstream of the confluence with Koch Creek in 1998. Station numbers are in parentheses.

Table 3. Mean daily discharge (m^3/s) in the Slocan River at Crescent Valley for 1950-1996 compared to 1992, 1997, and 1998 (Environment Canada, Water Survey of Canada, Nelson). The lowest mean August discharge observed since 1950 was 37.4 m^3/s, and the highest 162 m^3/s.

Year	**July**	**August**	**September**

1950-1996 average	191.2	75.3	46.9
1992	98.9	43.5	29.1
1997	275	96.1	71.5
1998	121	52.7	27.8

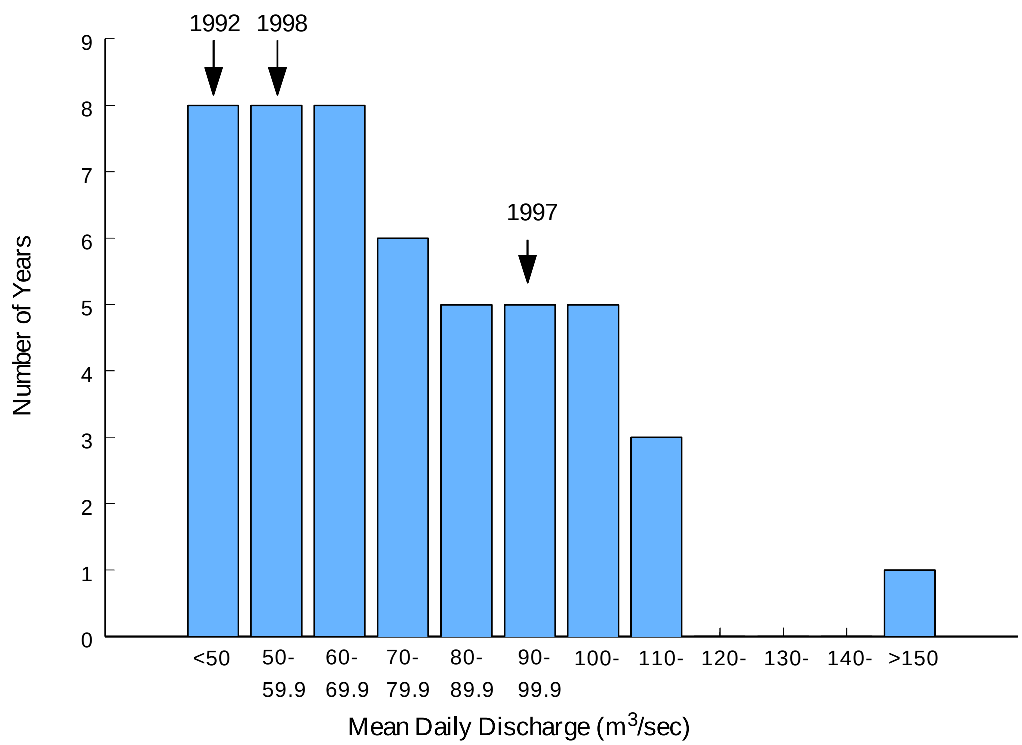


Figure 6. Frequency distribution of average daily discharge in August for 1950-1998 in the Slocan River at Crescent Valley (Water Survey of Canada).

Three stations were monitored in both 1997 and 1998 (stations 2, 3, 5; Fig. 1). Lower discharge and warmer air temperatures in 1998 resulted in: (a) warmer temperatures overall, and (b) a longer period of warm temperatures (Table 4). Above the confluence with Lemon Creek, 1998 mean and maxima tended to be about 4 degrees higher than 1997 in July, and 2 degrees higher than 1997 in August (Fig. 7). Similar differences were observed upstream of the Little Slocan River confluence, where 1998 temperatures were about 4 degrees higher in July and 1-2 degrees higher in August and early September (Fig. 8). Temperatures in Lemon Creek in 1998 were higher mainly in July (Fig. 9).

Table 4. Summer temperature comparisons for three sites in the Slocan River drainage in 1997[1] and 1998[2].

Station	Year	Observed Maximum (°C)	Maximum Daily Mean (°C)	Number of Days Daily maximum > 20 °C	Number of Days Daily Mean > 20 °C

2 (above Lemon Ck confluence)	1997	21.5	20.2	20	2
	1998	24.4	22.8	56	39
3 (Lemon Ck)	1997	17.5	15.1	0	0
	1998	18.9	16.1	0	0
5 (above Little Slocan confluence)	1997	21.3	20.4	23	3
	1998	24.0	22.7	58	27

[1] July 2 - Sept. 30
[2] July 1 - Sept. 15

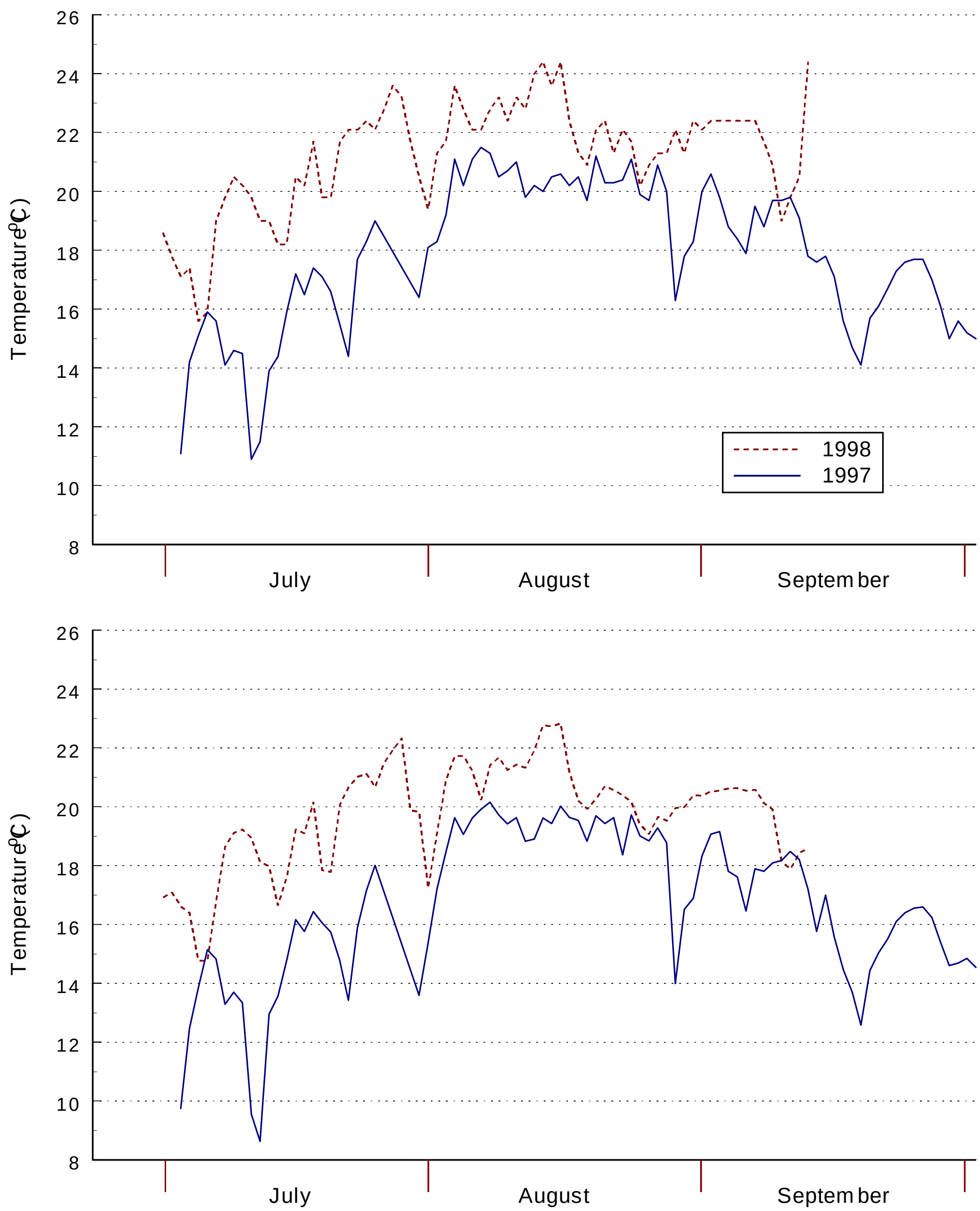


Figure 7. Daily maximum (top) and mean (bottom) temperatures in the Slocan River upstream of the Lemon Creek confluence (station 2) in 1997 and 1998.

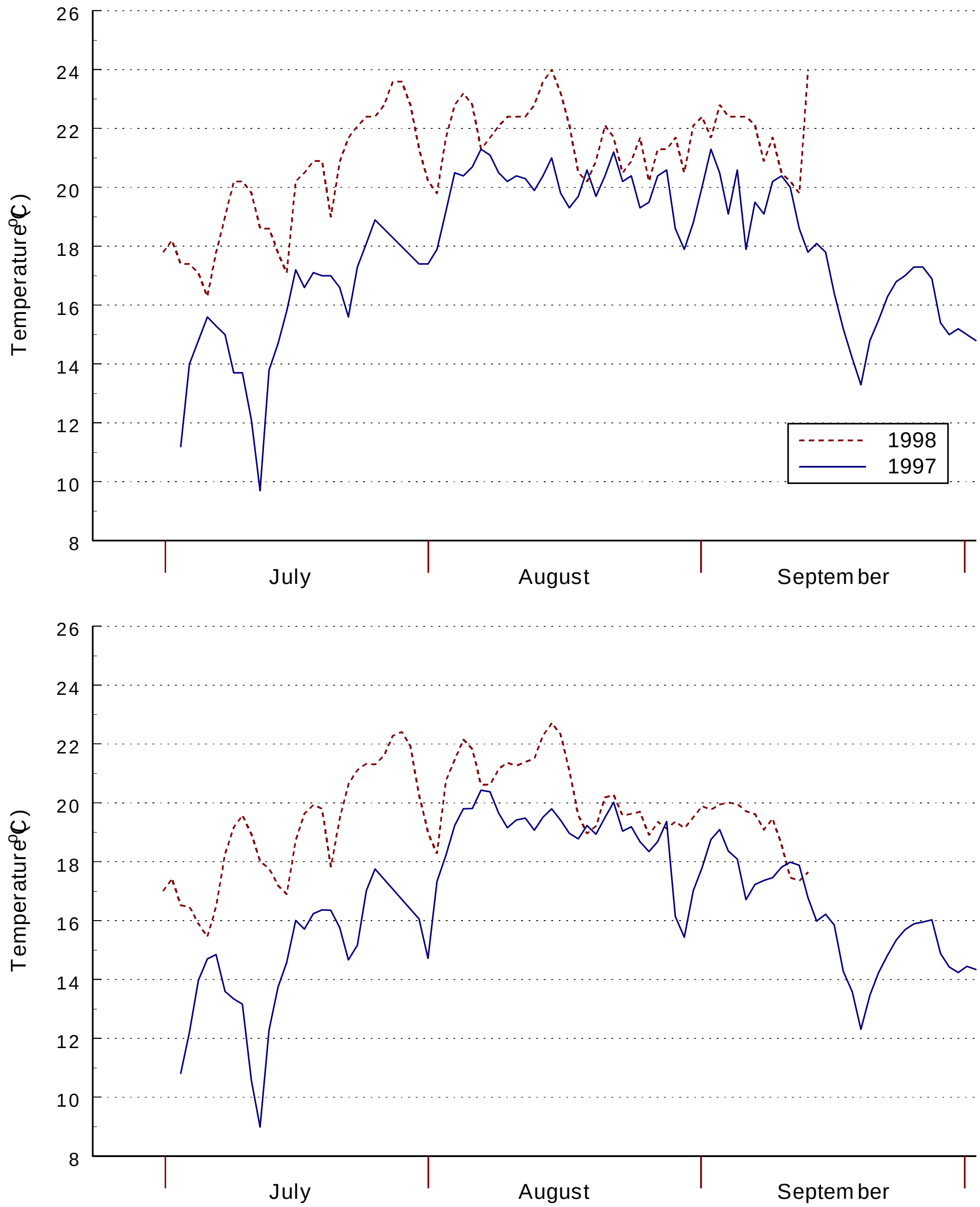


Figure 8. Daily maximum (top) and mean (bottom) temperatures in the Slocan River upstream of the confluence with the Little Slocan River (station 5) in 1997 and 1998.

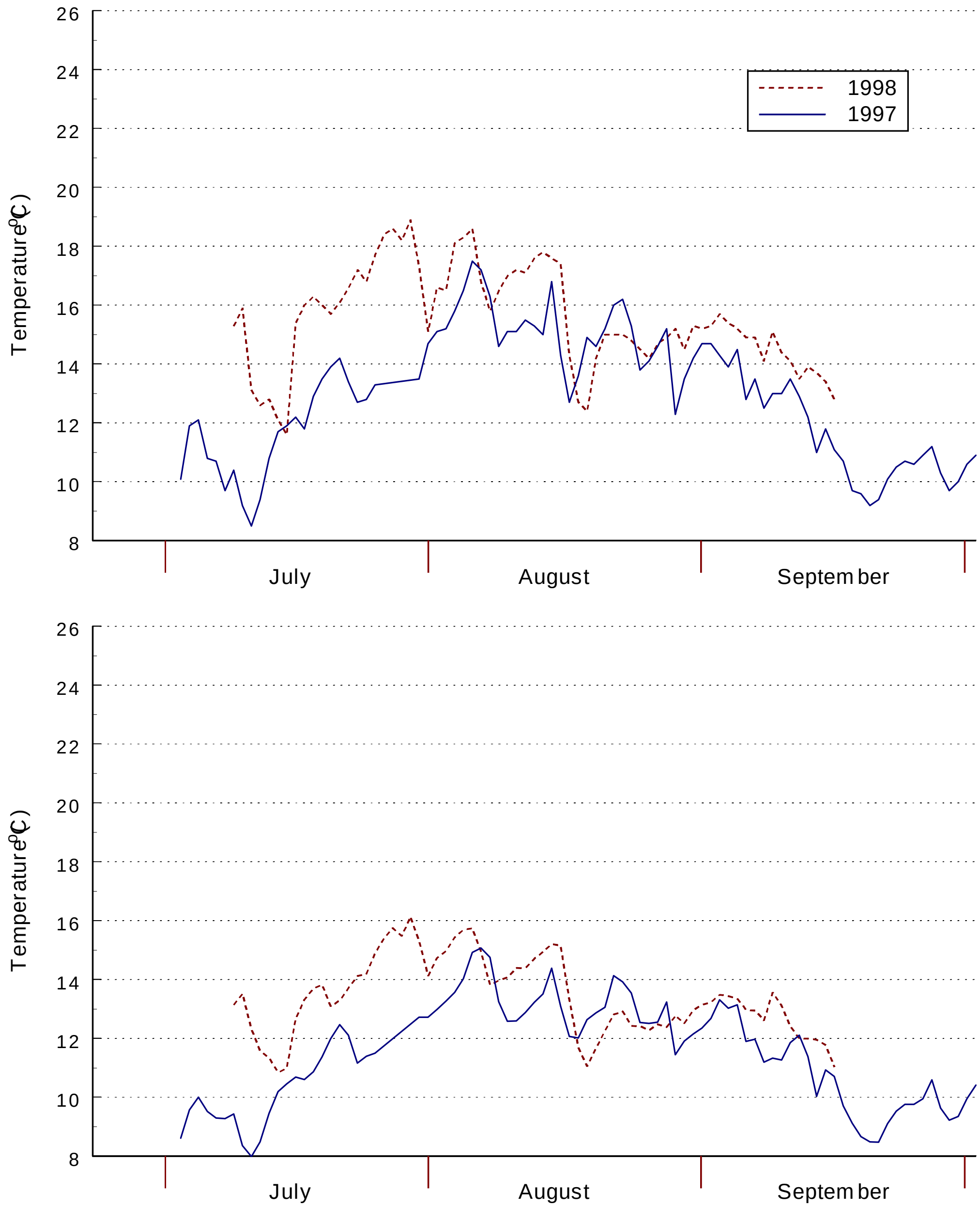


Figure 9. Daily maximum (top) and mean (bottom) temperatures in Lemon Creek (station 3) in 1997 and 1998.

4.0 DISCUSSION

4.1 Temperature Implications for Rainbow Trout Distribution

4.1.1 *Slocan River temperatures in relation to other trout studies*

Most fish species can tolerate a wide range of temperatures, but each typically has a narrow range at which growth and survival are maximized (Linton et al. 1997). In laboratory experiments, the upper lethal temperature for rainbow trout has been reported as 24-28 ^{o}C (McCauley and Pond 1971) or 26 ^{o}C (Kaya 1978), and the optimum for growth and food utilization as 15 ^{o}C (Cho and Kaushik 1990; cited in Linton et al. 1997). Juvenile rainbow trout may select temperatures as high as 17-20 ^{o}C in a hatchery environment where food and oxygen are not limiting (McCauley and Pond 1971), but Avault (1996) gives 7-13 ^{o}C as a desirable range for rearing, and maximum temperatures of 16-18 ^{o}C as satisfactory.

Laboratory experiments with juvenile rainbow trout have shown that, when temperatures are already near the upper tolerance limits, an increase of even 2 ^{o}C can have marked effects on growth through decreased appetite and changes in metabolic costs associated with feeding and digestion (Linton et al. 1997, 1998; Reid et al. 1997). For example, Linton et al. (1997) found a decrease in food consumption of 30%, and a decrease in growth rate of about 40%, for fish held at a mean temperature of 22 ^{o}C compared to those at 20 ^{o}C. In another experiment (Linton et al. 1998), growth was reduced by >50% with an increase from 23 to 25 ^{o}C. These studies show that, even under conditions of excess and easily digestible food (commercial pellets fed to satiation once or twice daily), costs of feeding and digestion rapidly exceed benefits when temperatures are much greater than 20 ^{o}C.

Under natural conditions, food is less abundant and the energetic costs of feeding and digestion can be substantially higher because fish must maintain feeding positions for a longer period of time, and process natural items with lower digestibility than commercial foods. Consequently, optimum rearing temperatures in natural environments are likely to be lower than those reported for hatchery fish. Wurtsbaugh and Davis (1977a) in a study combining lab and field experiments, found temperatures >16 ^{o}C would cause reduced growth rates of juvenile rainbow trout in streams, because increased costs of maintenance metabolism could not be offset by a limited food supply. At average temperatures of 22.5 ^{o}C, growth rates were barely above zero even at the highest consumption rate estimated for wild fish in their study.

Avoidance of warm temperatures is commonly observed in streams. For example, Kaya et al. (1977) observed many juvenile and larger trout congregating near the mouth of a cool tributary creek and within its lower reaches during mid-summer in the Firehole River, Yellowstone National Park. An identical response has also been observed for brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) in the Little Southwest Miramichi River in New Brunswick during periods when river temperatures reached 23 - 26 ^{o}C (Cunjak et al. 1993). Matthews and Berg (1977) found that rainbow trout in a California stream avoided high temperature areas in August, seeking refuge in cooler seeps that averaged 18.3 ^{o}C. Similarly, in the Bow River, Alberta, rainbow trout move upstream to cooler reaches during the hottest part of the summer (A. Locke, Alberta Environmental Protection, pers. comm.)

High temperatures may have a more pronounced effect on growth and distribution of young-of-the-year fish than adult fish because relative maintenance requirements decrease with increased fish size (Wurtsbaugh and Davis 1977b), and winter survival is likely dependent on reaching a minimum size at the end of the first growing season (Close and Anderson 1992). Arndt (1984) found an absence of young-of-the-year brook trout and brown trout (Salmo trutta) in warmer sections of an Ontario stream, even though larger trout were present, and young-of-the-year fish were present upstream and downstream of these sections.

In the Slocan River, daily mean temperatures in 1998 were between 20 and 23 ^{o}C in most of the mainstem reaches for most of the summer (Fig. 10). The studies discussed above suggest that these reaches are marginal with respect to rainbow trout temperature tolerances. It would be expected that juvenile, and to a lesser extent, adult trout would avoid most areas of the mainstem during part of July and August of most years. In 1998, the warm period (daily mean >20 ^{o}C) lasted 30 - 40 days (Table 4), however, one in four years would be expected to have a more severe warming period based on discharge frequency (see section 3.2).

If it is correct that temperature is a major factor influencing distribution and abundance of rainbow trout in the Slocan River, there are several implications:

- survival of juveniles is likely to be low in most reaches of the mainstem in warmer years; in years of high discharge and cooler temperatures there may be higher juvenile survival
- densities of trout in the warmer sections of the stream are likely to remain low with or without a harvest fishery, particularly *if low densities are a result of avoidance of high temperature (as opposed to low survival in warmer zones)*
- maintaining closure of cooler sections (e.g. Little Slocan River) is unlikely to result in significant increases of trout in warmer sections *if trout are avoiding unsuitable temperatures*
- a catch-and-release fishery during the warmer periods (late July - August) could have a higher risk of incidental mortalities because trout are stressed by temperatures near their upper limits.

Adults may be more able to tolerate high temperature than juveniles because of lower maintenance metabolism. If this is the case, it is possible that an increase in juvenile survival in cooler reaches would result in better recruitment and higher densities of larger trout in the warmer sections (see 5.0 Summary and Recommendations).

Figure 10. Temperature zones in the Slocan River and location of 1998 snorkel surveys. Temperature zones are provisional, based on available temperature and tributary discharge data. Other localized areas of cooler water may be present.

4.1.2 *Evidence for a temperature effect on trout distribution in Slocan River*

Although the literature suggests that trout production in the Slocan River should be limited by temperature, this should also be tested on the Slocan River itself, since there is some evidence of stock specific differences in temperature-growth relationships (Wangila and Dick 1988). Specific experiments to test for a temperature effect on trout distribution in the Slocan River have not been done, but there are some data which can be examined to see if they fit predictions of the above section.

A problem with the interpretation of the density and size distribution data at different reaches is that we do not know to what extent the observed distributions represent fish movement/habitat selection, versus survival at the different reaches. However, it seems unreasonable to consider each stream reach (from the Oliver 1999 snorkel survey) as distinct population units because: (a) large movements of 0+ fish after emergence are typical for *Oncorhynchus* species (Keith et al. 1998; Arndt 1998, unpublished data from Murphy Creek), and (b) a radio telemetry study (Baxter and Roome 1998) documented fairly extensive migrations of adult trout, with some fish which were tagged in the mainstem Slocan River later moving downstream into Brilliant reservoir and upstream into Slocan Lake. Hughes (1998) recommends that age structure be considered on the basis of whole rivers, with fish movement being given the same consideration as recruitment, growth, and mortality.

<u>1998 snorkel surveys</u>

In 1998, snorkel fish counts were conducted in five reaches of the Slocan River (Fig. 10). One reach (Lemon Creek) was located in the coolest portion of the mainstem starting at the confluence with Lemon Creek. This reach was the only one with daily temperatures that seldom exceeded 20 ^{o}C in 1998 (Fig. 2). Another reach (Winlaw) was located in a predominantly warm section, but which has some cool water input from Winlaw Creek on the east side and Hird Creek on the west. Although the discharge from these creeks is considerably less than Lemon Creek (Appendix C, Zimmer et al. 1998), they probably still provide significant local inputs of cooler water. The last three reaches (Passmore, Slocan Park, Crescent Valley) are located in the warmer downstream sections. Passmore and Slocan Park reaches do not have any known significant inputs of cooler water. In the Crescent Valley reach, there is one fairly large tributary, Goose Creek, which may have a localized cooling effect although its temperature is not as cool as the other creeks (Griffith 1986b, Appendix I), and the large volume of mainstem flow at that point is likely to overcome the effect quickly.

If avoidance of high temperature is a factor influencing trout distribution, it would be expected that densities of trout, especially juveniles, would be highest in the Lemon Creek reach, followed by the Winlaw reach, and lowest in the three downstream reaches. Results of the 1998 survey fit expectations in terms of overall densities for juvenile and larger trout (Table 5). The *percentage* of juveniles, however, was not consistently lower at the downstream sites.

Table 5. Number of rainbow trout per km during snorkel counts at 5 sites in the Slocan River in early September 1998 (data from Oliver 1999).

Reach	All Fish	Juveniles ≤ 9 cm	Fish ≥ 10 cm	% Juvenile
Lemon	422.7	94.2	328.5	22
Winlaw	205.7	89.3	116.4	43
Passmore	88.6	20.0	68.6	23
Slocan Park	56.8	20.3	36.5	36
Crescent Valley	114.9	15.0	99.9	13

A second way of testing for a temperature effect is to compare counts of juvenile trout on either side of the mainstem in the reach immediately below the Lemon Creek confluence. At this point there is a significant thermal gradient across the stream, with the east shoreline being cooled by water from Lemon Creek, and the west shoreline receiving warmer mainstem flows until mixing is complete at some point downstream. A greater number of juveniles is expected on the east side of the river.

Results support expectations. Using the shore and nearshore lanes, average count of juvenile trout on the Lemon Creek side was 105.5 compared to 23 for the west side of the river (data from Oliver 1999). Also, it was noted that on the Lemon Creek side, highest numbers of juveniles were found primarily in the upstream portion of the reach (close to Lemon Creek inflows), except for an area of spring seepage farther downstream, which also had high numbers in its vicinity (C. Legebokow observations during snorkel survey, pers. comm.).

Fish assessments prior to 1998

Data from surveys in August 1985 and 1986 also appear to be consistent with a temperature effect on juvenile distribution. Griffith (1986a, p.16) noted that the most significant factor in the August 1985 snorkel surveys was the "observation of considerably [his emphasis] higher numbers of small fish in mainstem areas near (particularly downstream of) the confluences of larger tributaries." He also noted that physical habitat conditions were basically the same above and below the Little Slocan confluence and concluded that differences in trout densities must be related to some tributary influence rather than habitat suitability in the mainstem (p.6). Similar results were obtained in an August 1986 electrofishing survey (Griffith 1986b), which found no rainbow trout fry in two sections of the mainstem located in warmer reaches even though they were chosen for their high quality spawning/rearing habitat[2]; the only mainstem site with trout was located about 0.5 km downstream of Winlaw and Hird Creeks. The 1986 study also recorded high densities of trout fry in the lowermost 30 m of Winlaw Creek, below the first culvert barrier.

[2] One site was immediately downstream of Slocan Lake outlet where rainbow trout have been observed spawning, and the other was in the lower river upstream of Goose Creek. Neither is near a cooler tributary.

4.2 Historical Changes in Temperature Regime

A pertinent consideration is whether or not the temperature regime in the Slocan has changed substantially over the last few decades, and in particular since the 1960s and early 1970s, when angling in the river reached its peak (see section 4.3). Factors which may have contributed to warmer temperatures in the Slocan River include:

- decreased volume of mainstem flow due to water withdrawals (agricultural and domestic) from the river and its tributaries
- decreased volume of flow from cooler tributaries due to altered run-off patterns resulting from logging in the Slocan valley and tributary drainages
- re-routing of lower Lemon Creek
- loss of shade along the river due to agriculture and construction of dwellings

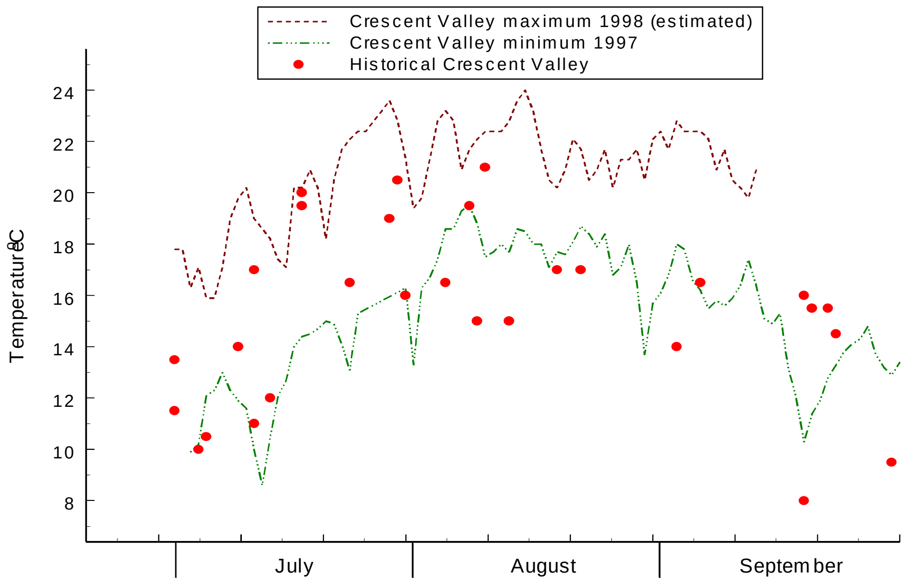
The cumulative effect of water withdrawals for domestic and agricultural use is difficult to measure, however, these uses have undoubtedly increased as settlement has increased in the valley. Furthermore, peak demands for these uses occur during the hottest, driest parts of the summer, and thus they are likely to aggravate conditions during already warm periods.

More severe freshets and lower base flows are sometimes associated with tree removal in a drainage basin. Perhaps the most important effect of these in the Slocan River is the reduced summer flows in cooler tributaries such as Lemon Creek (see Figure 11 in Oliver and Cope 1997). These tributaries have an important role in cooling the mainstem and may be providing critical thermal refugia during particularly warm periods.

Re-routing of lower Lemon Creek, circa 1948, is believed to have caused a partial damming of the Slocan River at the confluence with Lemon Creek (B. Barkley, local resident, pers. comm.), creating the wide marshy section of river for approximately 5 km upstream of the confluence[3]. It was expected that there might be substantial warming of the water temperature in this reach, but 1998 results showed this was not the case. The lack of warming in this section may be due to: (a) the fact that water leaving Slocan Lake is already near the air temperature, and (b) cool water inputs from Gwillim and Mulvey Creeks. It is possible that, if the historical channel was narrower, the input of these two creeks would have had a noticeable cooling effect; August discharge from Gwillim Creek is only slightly less than Lemon Creek (Appendix C, Zimmer et al. 1998).

A few historical temperature records exist for Slocan City and Crescent Valley; measurements were taken infrequently and time of day was not recorded. These data are plotted in Figure 11 with maximum daytime[4] temperature in 1998 and minimum daytime temperature in 1997 for comparison. The graphs give some indication that historical temperatures were lower in August and September, but it is difficult to make reliable conclusions based on the limited data. Temperatures ≥ 20 ^{o}C were recorded three times at Crescent Valley (1958, 1960, and

[3] According to B. Barkley, Lemon Creek outflow was moved by CPR; this caused material transported downstream in the creek to be pushed against a rock bluff, resulting in raising of the water level and marsh conditions upstream.
[4] Calculated from recordings between 0900 and 1600 since historical measurements were taken during the day.



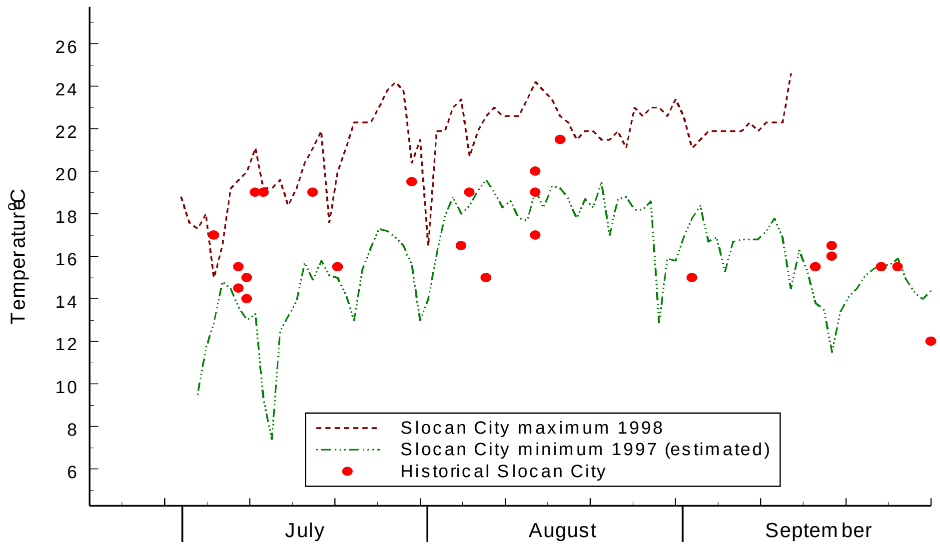


Figure 11. Historical temperature recordings at Slocan City (1950-1967) and Crescent Valley (1951-1975) in comparison to daytime maximum temperatures in 1998 and daytime minimums in 1997. Crescent Valley 1998 was estimated using 1998 data from upstream of the Little Slocan confluence, since these two stations had very similar temperatures in 1997. Slocan City minimums in 1997 were estimated using the 1997 data from above Lemon Creek confluence since these two stations were very similar in 1998. (Historical data are from Water Survey of Canada.)

1965) indicating that temperatures were fairly high during some of the years when the fishery was at its peak.

4.3 Historical Trends in Rainbow Trout Abundance

The Slocan River and surrounding area has undergone major environmental impacts over the last century, which have substantially altered both fish habitat and fish access to the drainage. Prior to 1935, the river supported large runs of both Pacific salmon and Dolly Varden (see Zimmer et al. 1998). Construction of Grand Coulee dam in Washington (1935) blocked migration of Pacific salmon, and construction of Brilliant dam (1942) ended movement of Dolly Varden from the Columbia River into Kootenay and Slocan Rivers (D. MacDonald, Appendix F in Zimmer et al. 1998). Later impacts included the building of additional dams and canal in the Kootenay River upstream of the Slocan confluence, eutrophication of Kootenay Lake due to the Cominco fertilizer plant in Kimberley (started 1953)[5], and later oligotrophication of Kootenay Lake (1970s) due to pollution abatement and closure of the fertilizer plant, and construction of Duncan and Libby dams (1967 and 1972 respectively). Cottonwood Trout Hatchery at Nelson was closed in 1965 after operating for 20-30 years (J. Hammond, MELP Regional Fisheries Biologist, Nelson, pers. comm.). While these major changes were taking place in the drainage upstream and downstream of the Slocan River, significant changes were also taking place with respect to land uses in the Slocan valley itself. Most of the lower valley has been converted from forest to agricultural land and settlements, and most of the tributary drainages have been logged.

Although there were no formal fisheries assessments until the 1980s, anecdotal information going back to the 1940s gives fairly strong evidence that the Slocan River did not support a large population of <u>resident</u> rainbow trout historically. High numbers of large rainbow trout were a temporary phenomenon, and these fish were not residents of the Slocan River, but rather, <u>migrants</u> from the Kootenay River.

According to some residents, the mainstem of the Slocan River was not a destination for many anglers prior to the construction of Brilliant dam (J. Braun, F. Salekin, C. Salekin, pers. comm.). Most anglers preferred the Columbia and Kootenay Rivers (F. Salekin); angling in the Slocan drainage occurred mainly in the Little Slocan River and its tributaries, and in Lemon Creek, rather than in the mainstem (F. Salekin, D. Edgar, pers. comm.). Resident fish at that time were small (always ≤18 inches), had large spots and a pronounced stripe with deep orange colouration on the cheek, and had large heads in proportion to the body size (J. Braun). Following construction of Brilliant dam in 1942, there may have been some increase in the abundance and growth of rainbow trout during the early years of high productivity in the reservoir (Zimmer et al. 1998), however, accounts indicate that the era of best angling in the Slocan River occurred later, beginning in the mid-1950s (J. Braun) and extending into the 1960s and early 1970s (Bob Podovelnikoff, F. Salekin, S. Willford, pers. comm.). This period coincides with the period of peak phosphorous inputs and high productivity in Kootenay Lake. At this time, fish of 5-6 pounds (2.2-3.6 kg) were common, and there was excellent fishing in the Kootenay River below and between the dams (J. Braun, B. Podovelnikoff, pers. comm.), as well as in the west arm of Kootenay Lake near Nelson (T. Burns 1996).

[5] According to Ashley et al. (1997), production at the fertilizer plant tripled by late 1964. Peak losses of phosphate occurred in the mid to late 1960s prior to pollution abatement measures in 1972, decreases in fertilizer production in the 1970s, and closure in 1977.

Fish caught in the Slocan River at that time were believed to be migrants from the Kootenay River (J. Braun, F. Salekin, pers. comm.). Movements up the Slocan occurred in the spring and fall (J. Braun, B. Podovelnikoff, pers. comm.) Best angling, according to one individual, was during the last 2 weeks of September and first week of October (B. Podovelnikoff, pers. comm.), although J. Braun recalls larger fish moving into the river about the time grasshoppers became abundant. During this period there are also reports of a kokanee run up the Slocan River (B. Lindsay, MELP Fisheries Biologist, pers. comm), and it is possible that the trout were following the kokanee to feed on eggs and moribund adults in the fall, and making pre-spawning movements in the spring.

These migrant rainbow trout were dramatically different in appearance from the resident trout, not only in size[6] but also in colouration and shape (very silvery with just a hint of pink on cheek and side; small heads in proportion to body) (J. Braun, pers. comm.). Their large size, and small heads in proportion to body size, indicate that these fish had very high growth rates, likely as a result of the high nutrient transport from Kootenay Lake during that period. Recruitment of trout may have been from stocking programs in the Kootenay River reservoirs at that time and/or entrainment through the upstream dams. Rainbow trout numbers were very high in the west arm of Kootenay Lake at that time (T. Burns, 1996). In the mid 1970s, apparently coinciding with the onset of oligotophication in Kootenay Lake (Ashley et al. 1997), catches of rainbow trout dropped dramatically (Zimmer et al. 1998). Although a fishery still exists in Slocan Pool of the Kootenay River, the high numbers of large fish seen in the 1960s have not returned. Angling success in the west arm of Kootenay Lake (Grohman Narrows) also dropped abruptly after 1975 (T. Burns, 1996) In summary, there is strong evidence that the good fishing prior to the mid-1970s was a spin-off effect of nutrient conditions and fish populations in Kootenay Lake and River at that time, rather than production from the Slocan River itself. The fish were not year-round residents of Slocan River but rather moved in temporarily, either to feed or spawn.

If it is true that historical production of resident rainbow trout in the Slocan River was not high, it may be unrealistic to expect high productivity now. Nevertheless, there may still be opportunities to increase production somewhat by enhancing habitats in those sections of the Slocan River that are more suited to their temperature tolerances.

The fishery of the 1960s, based on migrant fish, is not likely to return unless nutrient conditions in Kootenay Lake and River return to the levels of that time. A return to the eutrophic conditions that existed in the 1960s and early 1970s is not likely to happen. However, fertilization of the lake since 1992 has caused significant increases in lake productivity (Ashley et al. 1997), and some of this productivity may be evidenced in the Kootenay River downstream.

4.4 Other Factors Influencing Trout Abundance

[6] Fish up to 10 lb weighed on grocery store scales (J. Braun)

The following is not intended to be a comprehensive review of all factors which might be influencing current abundance and distribution of rainbow trout in the Slocan River, but only an attempt to evaluate the available evidence supporting some factors which have been suggested in recent reports and meetings.

Overfishing, prior to the 1994 closure, has often been suggested as a partial or main cause of the low numbers of resident trout (e.g. Oliver 1996; Baxter and Roome 1998; Zimmer et al. 1998). Local accounts do indicate that harvest rates were high during the period in the 1960s and early 1970s, however, rainbow trout densities have remained low after 5 years of angling closure so it seems unlikely that excessive harvest was the cause of the low numbers. Illegal angling during the closure has also been blamed, and while it is possible that this might be a factor affecting bull trout populations[7], there is little evidence of a large amount of poaching on the mainstem Slocan River in summer that would be sufficient to keep rainbow trout numbers at a low level. Conservation officers responsible for patrolling the Slocan Valley indicate that the level of poaching on the mainstem river is probably quite low, and say they get very few complaints of illegal angling[8]. During installation and monitoring of temperature loggers over two years, I have encountered one illegal angler.[9]

Incidental mortality of trout caught and released during the whitefish season (Feb.1 - Apr. 15 below Winlaw Creek) is unlikely to be a significant cause of low trout numbers because catch-and-release mortality rates are generally low during seasons when water temperatures are cold. Brobbel et al. (1996), for example, found that Atlantic salmon kelts caught at low temperatures in spring recovered more quickly and with lower mortality rates than bright salmon caught during summer at approximately 20 ^{o}C.

A lack of sufficient nutrients has also been suggested as a partial cause of the low trout numbers, because the stream has been deprived of the annual input of nutrients via Pacific salmon carcasses since the construction of Grand Coulee dam. However, more recent work in this regard (Oliver 1998) has shown that the productivity of the system remains fairly high, so that the low numbers of trout must be related to other factors (G. Oliver, pers. comm.). Numbers of trout in the reach below Lemon Creek exceeded 400 fish/km showing that the river is capable of supporting higher numbers of trout than are present in the lower reaches. Furthermore, snorkel surveys have shown that the lower river has a high biomass of other species (e.g. mountain whitefish, northern squawfish).

Lack of spawning habitat has been investigated as a potential factor. A radiotelemetry study by the Ministry of Environment, Lands, and Parks in 1997 located several major and minor spawning areas in the mainstem of the Slocan River, as well as suspected spawning

[7] According to Zimmer et al. (1998), some locals feel that there is still an illegal harvest of bull trout when they are concentrated below migration barriers on certain tributaries.
[8] For the period when A. Christie was responsible for the Slocan valley, the area was patrolled 2-3 times per month and only one charge and one warning was laid. The river was canoed several times, but only one angler was sighted. (notes from meeting on 5 March 1998)
[9] a woman with a fishing rod was seen in the upper reach where trout numbers were highest in the Oliver (1998) survey.

movements into the Little Slocan River. The conclusion was that, in general, spawning habitat does not appear to be a limiting factor in the Slocan River (Baxter and Roome 1998).

The ‘unbalanced’ size/age structure of the trout population which has been observed in all surveys since 1985 (Griffith 1986b; Oliver 1996; Oliver 1999) supports the view that there is low survival from the juvenile to sub-adult stages. Oliver (1999) suggests this as an apparent bottleneck that is preventing more rapid recovery of larger size-classes of trout. The limiting period probably occurs before the end of the second growing season, with most mortalities occurring during the first growing season and/or during the first winter. Griffith (1986b) recommended stocking of yearlings to augment natural recruitment, but stocking programs from 1989-1991 (Appendix G, Zimmer et al. 1998) did not result in an appreciable change in the age structure during the surveys in 1992 and 1993 (Oliver 1996). This suggests that stocked juveniles either emigrated or had very low survival.

There are two main possibilities that could account for low survival during the early stages: (1) lack of sufficient cover for juveniles, and (2) unsuitable temperatures that limit growth and survival. This report suggests that temperature could be a major causal factor for the observed distributions, however, Oliver (1999) has suggested that they may be related to differences in habitat complexity, and noted that the highest number of trout (and juveniles) in the 1998 survey were found in the Lemon Creek reach, which also had a very high level of habitat complexity in the form of large woody debris. There may be interaction between temperature, hiding cover, and nutrient conditions, because greater food availability allows growth to be maintained at higher temperatures, and the presence of good cover lowers energetic costs related to feeding and predator avoidance, as well as providing shade.

5.0 SUMMARY

1) Maximum summer temperatures in the Slocan River mainstem were higher in 1998 (>24 ^{o}C) than 1997 (>21 ^{o}C) because of lower discharge and warmer air temperatures. The period of warm (daily mean >20 ^{o}C) temperatures lasted 27-39 days in 1998, compared to 2-3 days in 1997.
2) Summer temperatures in most reaches of the Slocan River mainstem in 1998 were well above optimal rearing temperatures for juvenile rainbow trout. Warm temperatures may be a primary cause of low trout densities in these sections, either through avoidance and/or low survival of juveniles in these reaches.
3) Lemon Creek had a significant cooling effect on mainstem temperatures below the confluence. This reach also supported high densities of trout in a snorkel survey in early September 1998 (Oliver 1999).
4) Koch Creek temperatures were very similar to Lemon Creek, and the effect of Koch Creek on the Little Slocan River was similar to that of Lemon Creek on the mainstem. Cooler tributaries such as these may be providing important refuge areas for trout during late summer.

5) Temperatures in the Little Slocan are warm upstream of Koch Creek. Downstream of Koch Creek they are probably similar to the mainstem reach downstream of the Lemon Creek confluence.
6) Temperature did not increase in the marshy section of river between the outlet of Slocan Lake and Lemon Creek confluence. This may be reflecting the cooling effects of Gwillim and Mulvey Creeks. If this part of the stream had a narrower channel historically, these creeks may have lowered mainstem temperatures by a few degrees.
7) Comparison of historical temperature records to 1997 and 1998 gives some indication of an increase in August and September temperatures since 1976, however, conclusions are limited by the low number of historical measurements.
8) Anecdotal accounts of historical trends in rainbow trout abundance suggest that high numbers of large trout were a temporary phenomenon in the 1960s and early 1970s. These fish were not believed to be a resident population, but migrated into the Slocan River in fall and spring from Brilliant Reservoir. The peak period and collapse appear to coincide with periods of eutrophication and oligotrophication in Kootenay Lake. Migratory fish may have recruited from stocking programs in Kootenay River reservoirs and/or entrainment through upstream dams.
9) An 'unbalanced' size structure (low number of juveniles) has characterized all population surveys in the lower Slocan River since 1985. This suggests a 'bottleneck' of low juvenile survival. Possible causes could be a lack of sufficient cover (e.g. large woody debris), or unsuitable temperatures. Further monitoring would help to resolve the relative importance of these factors.
10) Low numbers of larger trout in most mainstem reaches during the summer could be a result of warm temperature avoidance, and/or low survival of juveniles. If the primary cause is temperature avoidance, numbers are likely to remain low. However, adults may be more able to tolerate higher temperatures than juveniles because of lower maintenance metabolism. If this is the case, it is possible that an increase in juvenile survival in cooler sections would result in better recruitment and higher numbers of larger trout in the warmer sections.

6.0 RECOMMENDATIONS

6.1 Assessment

- snorkel upstream and downstream of Lemon, Gwillim, and Mulvey Creek confluences during a period of high temperature (mid-late August) to further test temperature hypothesis (main spawning area is upstream of Lemon Creek near lake outlet so this would also test whether fry densities are related to spawning location); include habitat complexity in observations
- conduct a survey to locate additional areas of cooler water (other tributaries, spring seepage) and check for juveniles concentrated in these areas; map these locations for future protection

6.2 Enhancement

- instream habitat enhancement (cover for juveniles) should be located in cooler stream reaches (i.e. downstream of cool tributaries, areas of spring seepage); OR experimentally in paired sites (above and below cool inputs, or below and across the stream from cool inputs); monitoring of the use of these sites should be included as part of the enhancement project; monitoring should include both the number of fry present, movement patterns, and growth data if possible

- ensure that there are no barriers for movement of juveniles into cooler tributaries during the low water period of mid-late summer

- supplies of groundwater and surface flows in tributaries should be protected (i.e. restrict new water licenses) as these probably provide temporary refuge areas which are critical to summer survival of juvenile trout

- activities aimed at stabilization of the riparian zone (e.g. tree planting, cattle fencing) would have long term benefits by providing shade and narrowing of the river channel

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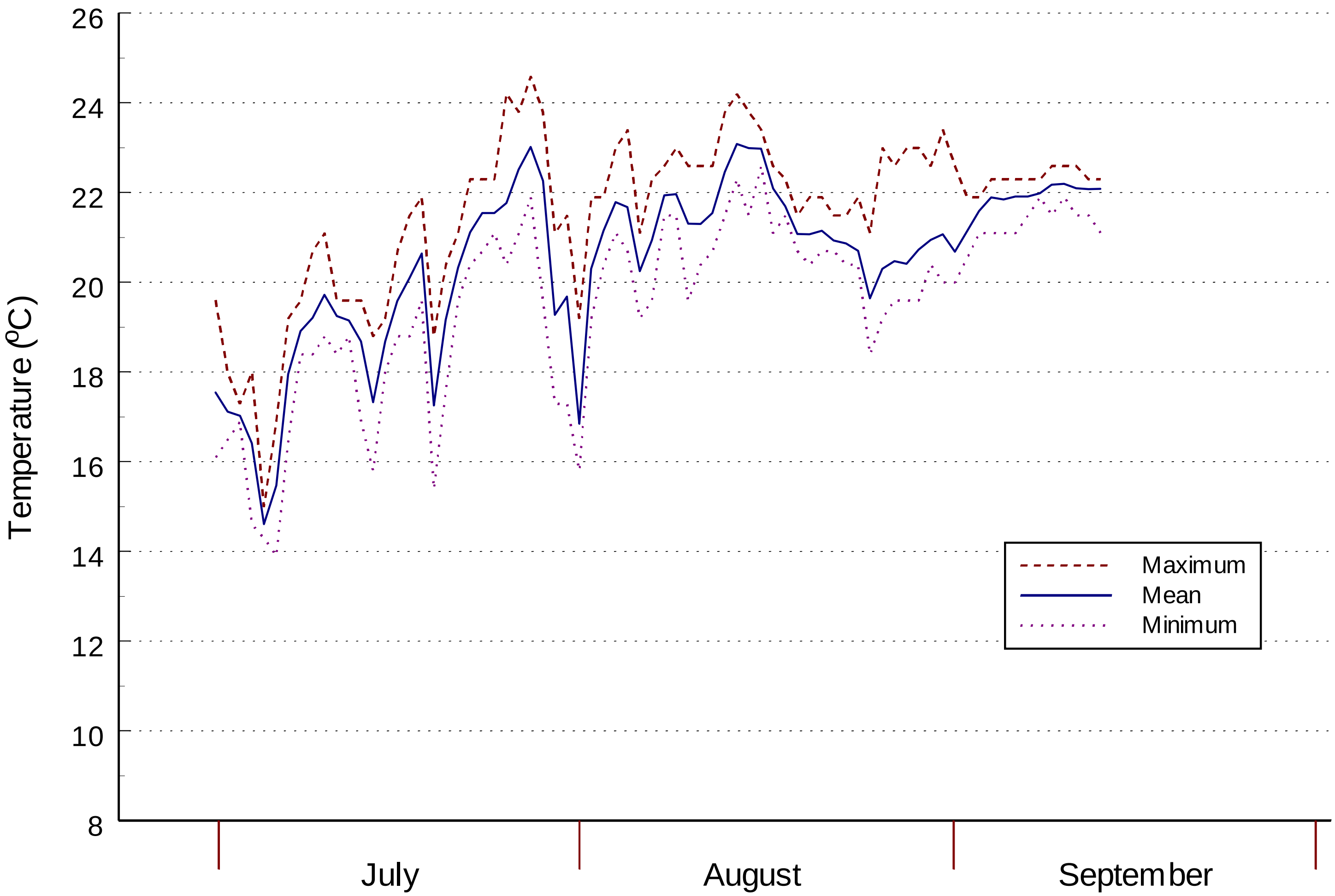
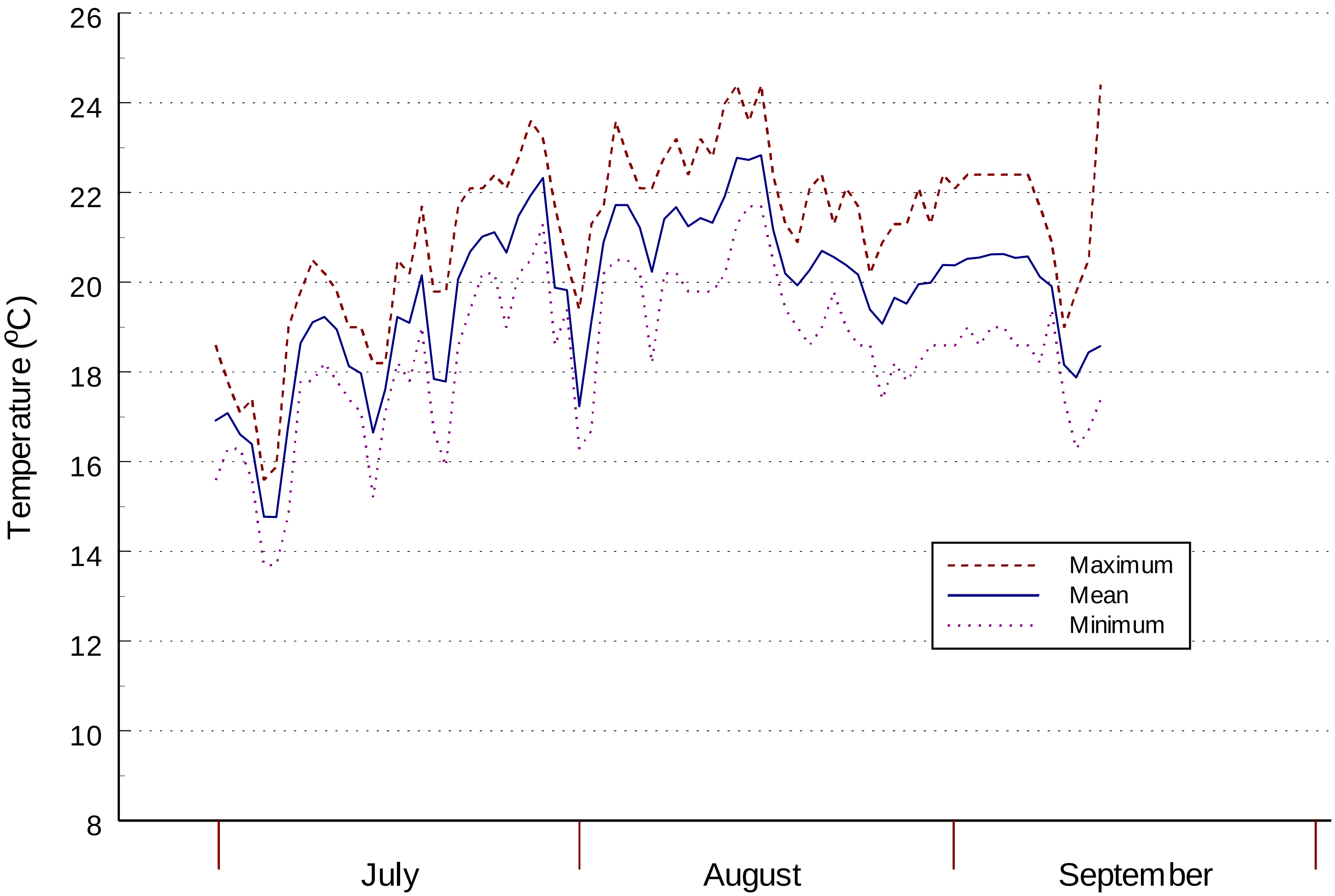
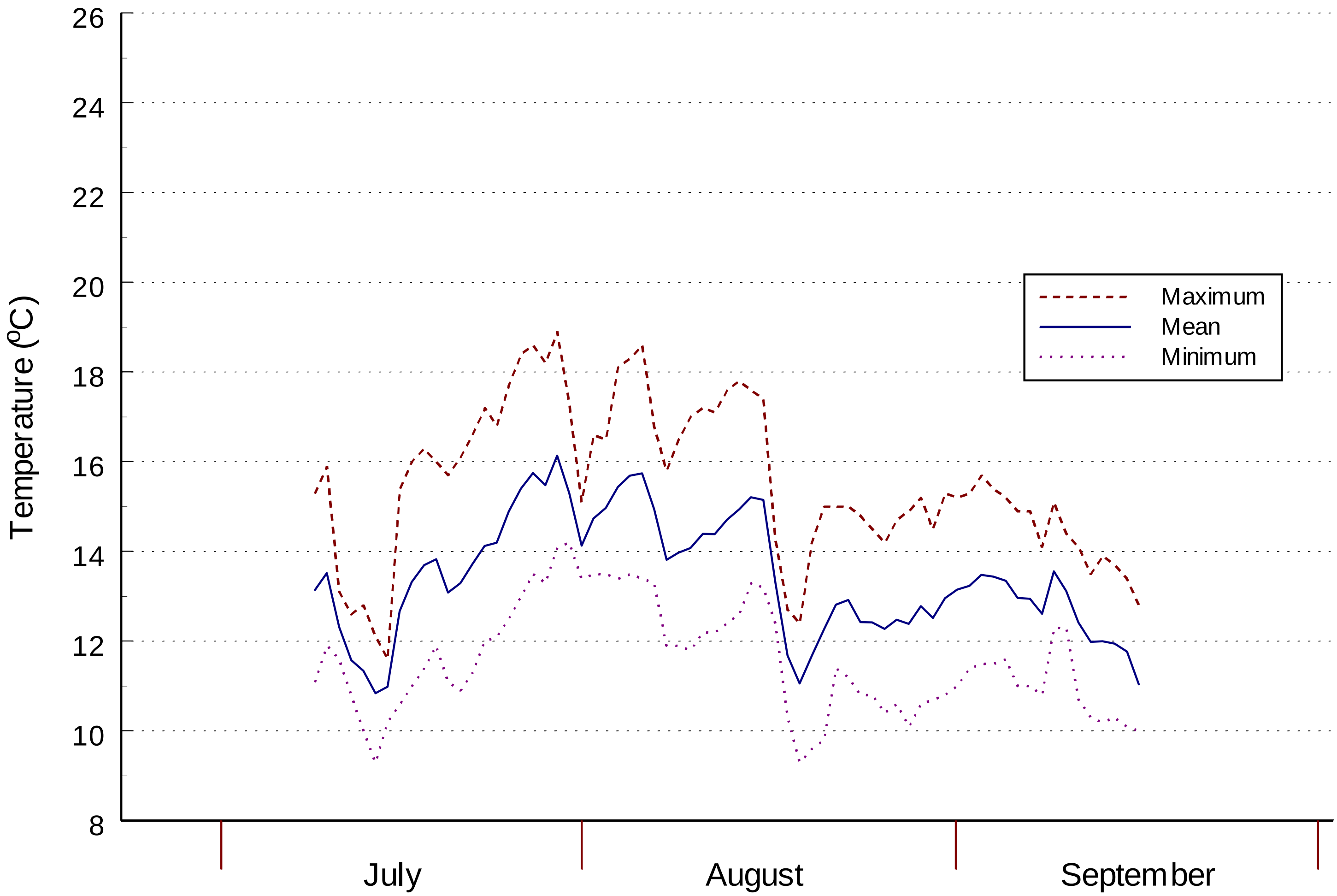
APPENDICES



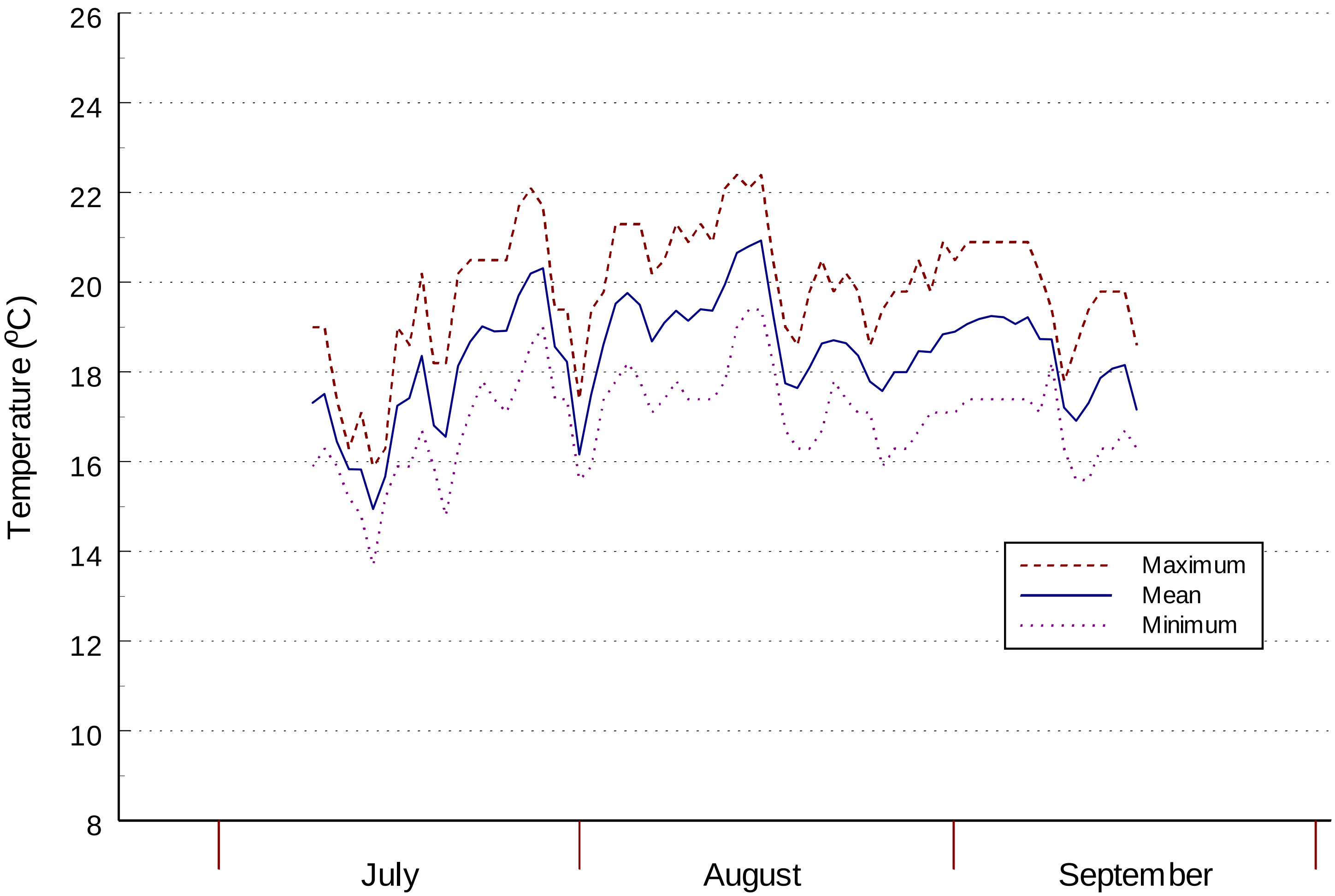
Appendix 1. Daily mean, maximum, and minimum temperatures in the Slocan River at the outflow of Slocan Lake (Station 1) in 1998.



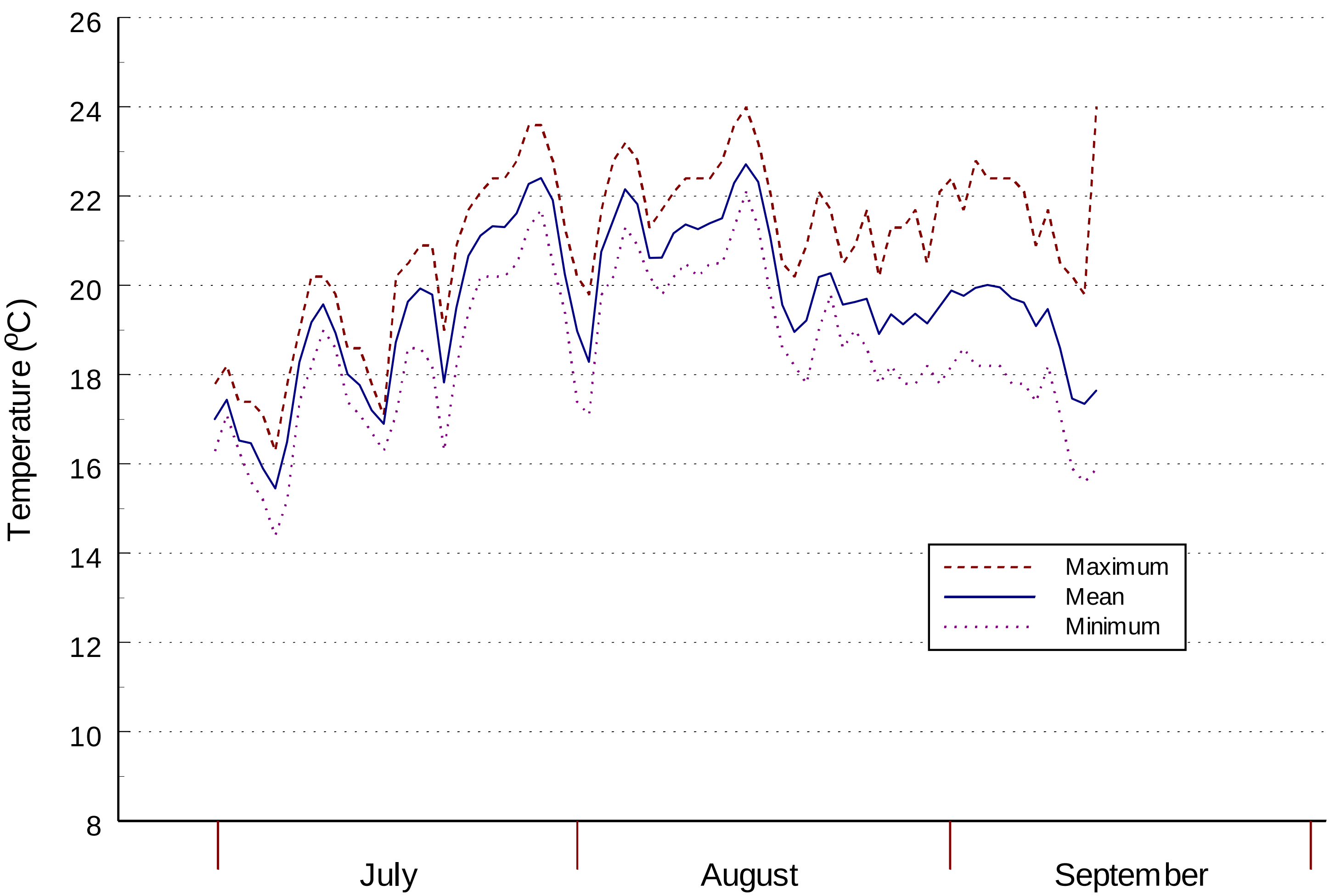
Appendix 2. Daily mean, maximum, and minimum temperatures in the Slocan River upstream of the confluence with Lemon Creek (Station 2) in 1998.



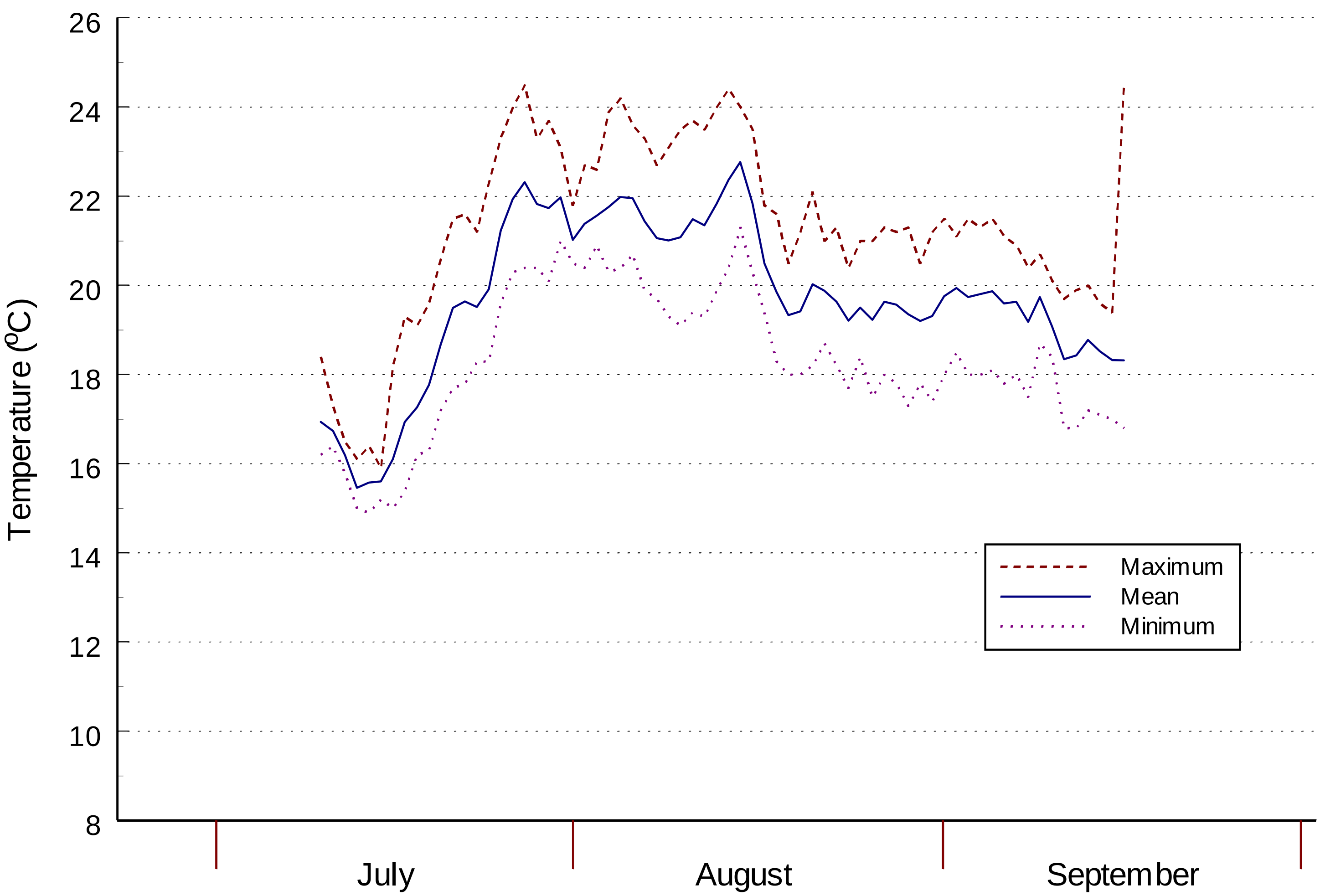
Appendix 3. Daily mean, maximum, and minimum temperatures in Lemon Creek at its mouth (Station 3) in 1998.



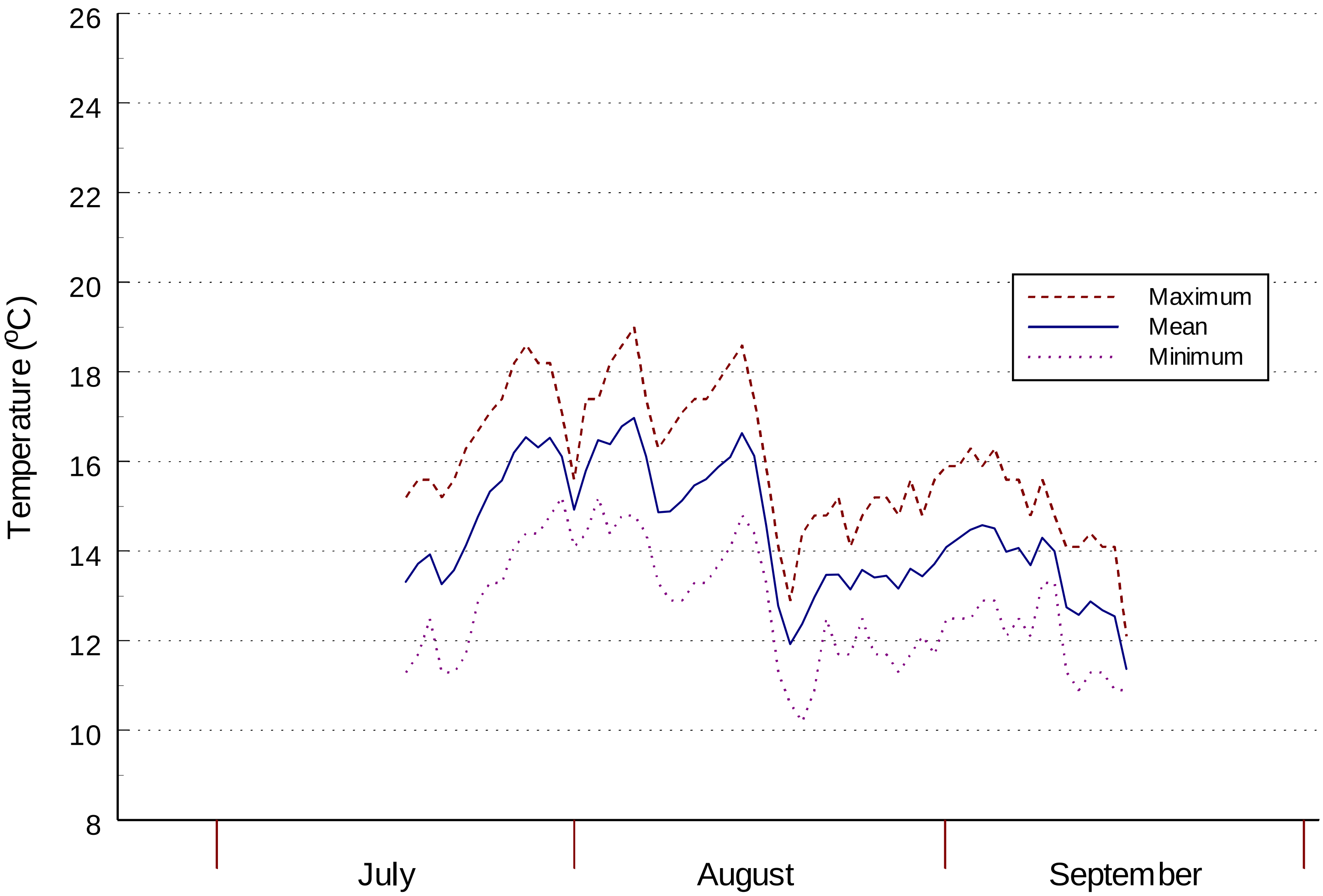
Appendix 4. Daily mean, maximum, and minimum temperatures 200 m downstream of the confluence of the Slocan River and Lemon Creek (Station 4) in 1998.



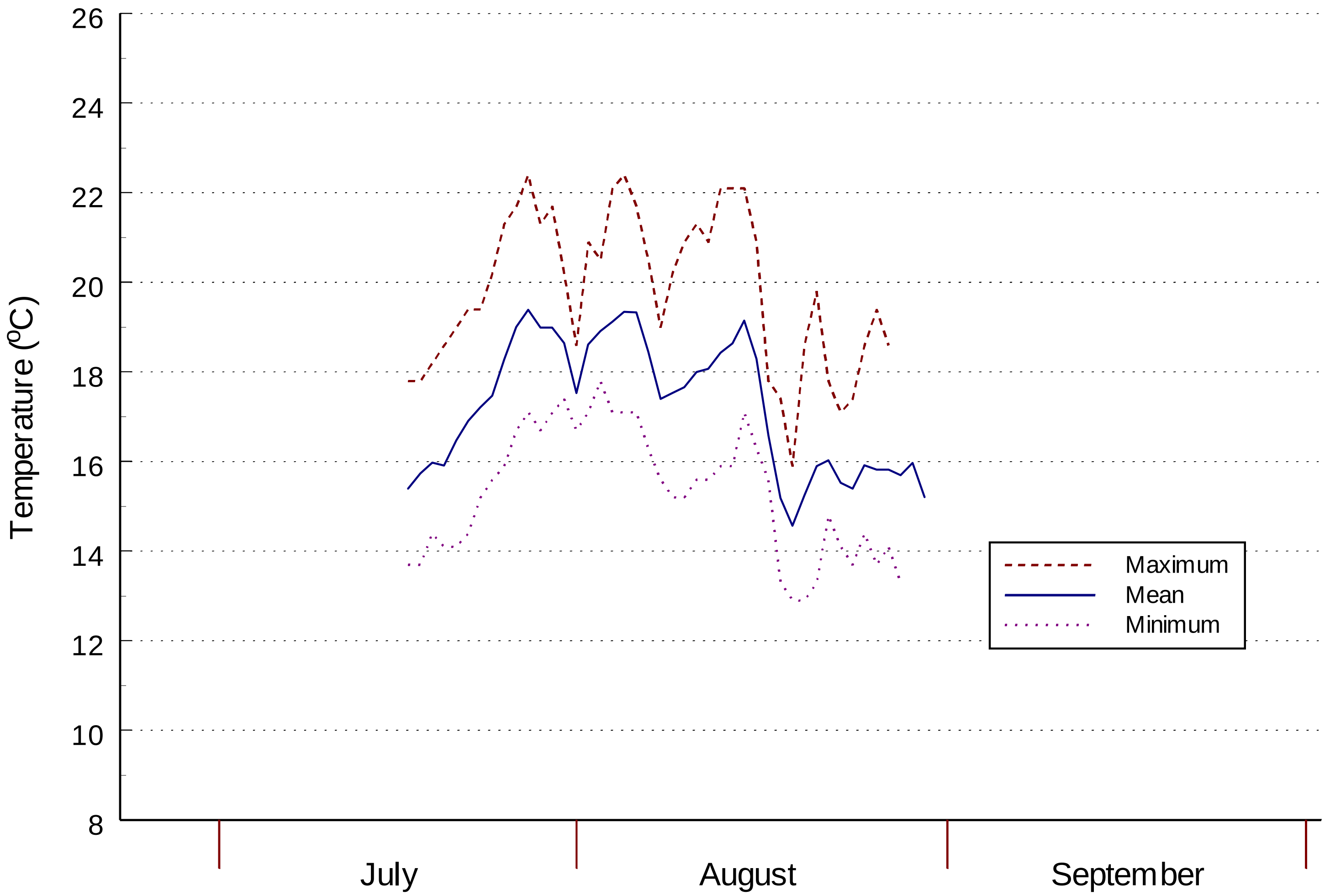
Appendix 5. Daily mean, maximum, and minimum temperatures in the Slocan River upstream of the confluence with the Little Slocan River (Station 5) in 1998.



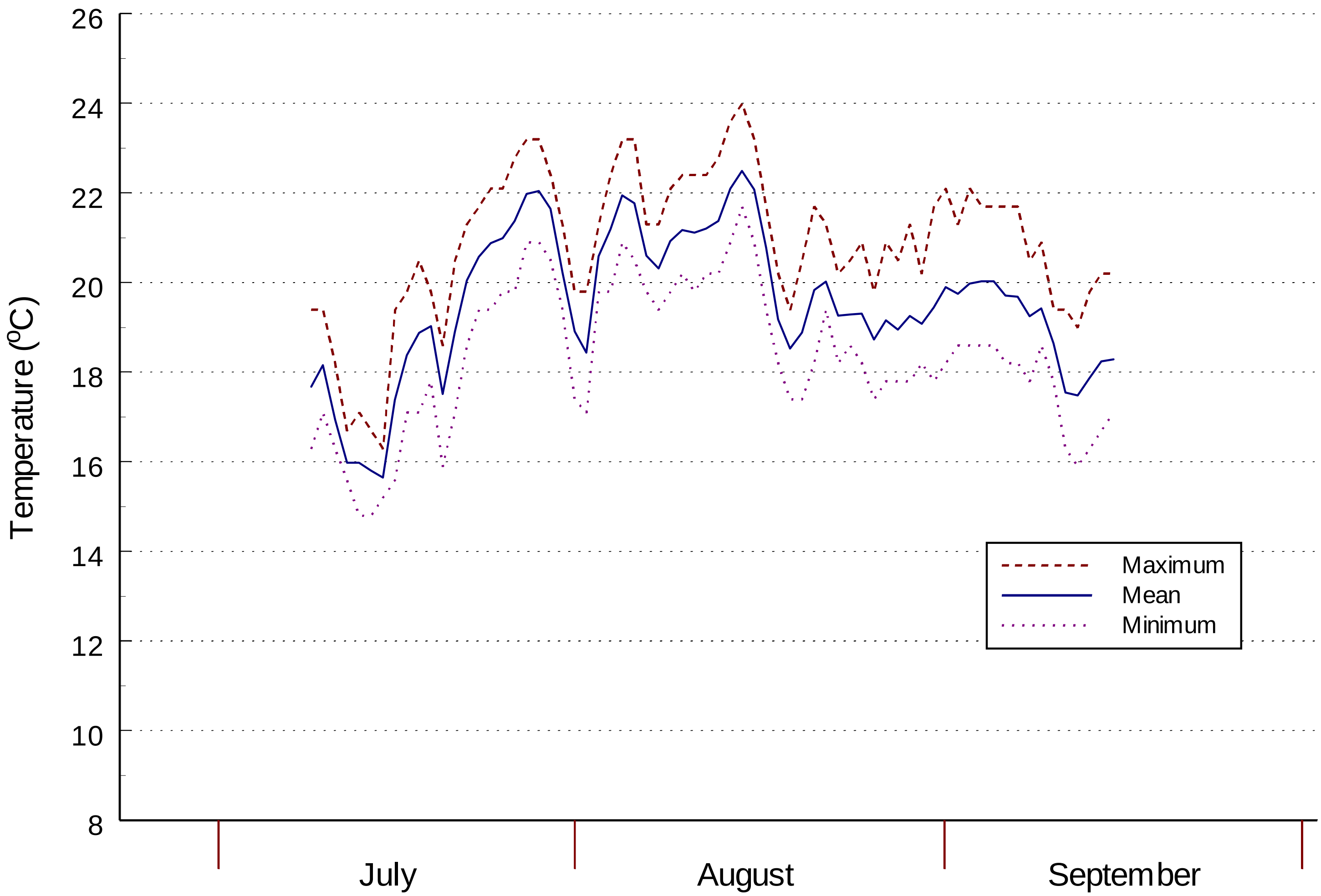
Appendix 6. Daily mean, maximum, and minimum temperatures in the Little Slocan River near the outflow of Little Slocan Lakes (Station 6) in 1998.



Appendix 7. Daily mean, maximum, and minimum temperatures in Koch Creek (Station 7) in 1998.



Appendix 8. Daily mean, maximum, and minimum temperatures in the Little Slocan River 400 m below the Koch Creek confluence (Station 8) in 1998.



Appendix 9. Daily mean, maximum, and minimum temperatures in the Slocan River downstream of the confluence with the Little Slocan River (Station 9) in 1998.