Continuous Water Temperature Monitoring in the Nicola River, B.C., 1994: Implications of High Measured Temperatures for Anadromous Salmonids

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CONTINUOUS WATER TEMPERATURE MONITORING IN THE NICOLA RIVER, B.C., 1994: IMPLICATIONS OF HIGH MEASURED TEMPERATURES FOR ANADROMOUS SALMONIDS

by

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ABSTRACT

During the summer of 1994 the Department of Fisheries and Oceans (DFO) established a program to obtain continuous water temperature data from six locations in the Nicola River watershed. The Nicola River drains part of British Columbia's Interior Plateau. The system supports populations of coho and chinook salmon which spawn during the summer and early fall months, and rear for a year or more in relatively small streams prior to seaward migrations. Data indicate that the Nicola River watershed experiences high water temperatures during July and August (up to 29°C on one occasion) which will impact fish populations, especially cold water species such as salmonids. Temperature data also provides an indication of conditions which can be expected in other Central Interior Plateau fish-bearing rivers including systems such as the Deadman and Bonaparte Rivers. Strategies for mitigating water temperatures in the Nicola River are recommended, and should be considered for implementation in other river systems which have experienced similar impacts from land uses.

RÉSUMÉ

Pendant l'été 1994, le ministère des Pêches et des Océans (MPO) a mis sur pied un programme visant à recueillir en continu des données sur la température de l'eau en six points du bassin de la rivière Nicola. Ce cours d'eau draine une partie du plateau intérieur de la Colombie-Britannique. Son réseau abrite des populations de coho et de quinnat qui frayent en été et au début de l'automne, et grossissent pendant un an ou plus dans des rivières assez petites avant d'entreprendre leur migration vers la mer. Les données indiquent que le bassin de la Nicola connaît des températures élevées en juillet et août (jusqu'à 29° C à une occasion), ce qui peut nuire aux populations de poissons, surtout aux espèces d'eaux froides comme les salmonidés. Les données sur la température donnent aussi une indication des conditions qui sont prévisibles dans d'autres rivières à saumon du plateau du centre de l'intérieur, notamment la Deadman et la Bonaparte. Nous recommandons des stratégies pour atténuer le réchauffement de l'eau de la Nicola, et ces stratégies pourraient être appliquées à d'autres systèmes hydrographiques où les modes d'utilisation des terres ont eu des effets comparables.

1.0 INTRODUCTION

The Thompson River drains the Interior Plateau of British Columbia, and typically has warm summer water temperatures in comparison with most other Fraser River tributaries. Seasonal water temperatures reflect climate conditions of the Interior Plateau, which normally experiences hot, dry summers. July and August maximum daily air temperatures are usually above 30°C and can exceed 40°C. Precipitation is also low, ranging between 250-500 mm annually (Hope et al. 1991a and 1991b; Pitt and Hooper 1994). Results of a 1993 Fraser River basin temperature monitoring program (Lauzier et al. 1995) indicated that the Thompson River may exert a significant warming effect on the Fraser mainstem (Foreman et al. *in press*). This prompted interest in examining temperature conditions of salmon-bearing tributaries in the Thompson River system.

Watercourses in the Thompson River watershed are particularly susceptible to high water temperatures during the summer months due to regional climate conditions, and land uses which are prevalent throughout the Interior Plateau. Land clearing for logging, cattle ranching, crop production, transportation routes, and urban development has resulted in considerable losses of riparian vegetation. The resulting lack of shading from trees and shrubs permits the sun to exert a direct warming influence on watercourses (Hall and Lantz 1969; Platts 1981). The destabilization of streambanks which accompanies losses of riparian vegetation further contributes to the problem because channels become wider. Streams consequently become shallower, and therefore more susceptible to warming. Water withdrawals for irrigation and other uses impose further temperature stresses on these aquatic systems by reducing flows and thereby contributing to more extreme daily water temperature fluctuations.

Water temperature is recognized as an extremely important variable which can affect the distribution, growth, behavior, metabolism, disease resistance, and ultimately, the survival and productivity of juvenile and adult salmonids (Brett 1971; Pauly 1980; Fagerlund et al. 1995). During warm summers with low flows, high water temperature becomes a potential environmental barrier to the upstream spawning migration of anadromous fish in the Fraser River. Pearse and Larkin (1992) identified temperature induced stress as a contributing factor to pre-spawning mortalities in the Fraser River watershed. Water temperatures in the Thompson River system are therefore of concern not only to salmon stocks of the Thompson sub-basin, but also with regard to all Fraser River stocks. During very hot, dry summers, temperatures in the Thompson River influence Fraser River mainstem temperatures, resulting in increases of several degrees Celsius (Foreman et al. *in press*). Despite the importance of water temperature for fish, only limited data documenting temperatures during spawning migrations and juvenile residency are available.

The Nicola River is a tributary to the Thompson River and supports populations of chinook, coho, and pink salmon, steelhead, and a variety of freshwater fish species. Land use activities and practices in the Nicola Valley are comparable with many other Thompson tributaries, which collectively provide significant salmon spawning and rearing habitat. Previous studies suggest that high water temperatures in the Nicola and Coldwater Rivers are a constraint for salmon production (Kosakoski and Hamilton 1982), and that local variations in water temperature are a major factor influencing salmonid distribution (Levings et al. 1985).

The present study was undertaken to learn more about Nicola water temperatures at six key locations, during summer months when both returning spawners and rearing juveniles would be impacted by high temperatures. Information about upstream/downstream temperature patterns, diurnal water temperature fluctuations, and the duration of temperatures which exceed critical thresholds for salmonids was of particular interest. This report summarizes results of the temperature monitoring program conducted in 1994 in the Nicola River watershed, discusses the implications of thermal conditions for salmonids, and recommends remediation actions.

2.0 STUDY AREA AND METHODS

2.1 Nicola Watershed

The Nicola watershed is located within the southern part of the Interior Plateau (Thompson Plateau) in southern British Columbia (Figures 1A and 1B). The Nicola River drains 914 km^2 of the 7280 km^2 Thompson River watershed, and is over 200 km in length. The river has approximately a dozen tributaries which provide important salmon habitats. Originating west of Kelowna, the Nicola flows north and west to Douglas Lake, and then northwest to Nicola Lake. From the outlet of Nicola Lake, which is regulated by a storage dam, the river flows sinuously southwest to its confluence with the Coldwater River near Merritt, and then northeast to Spences Bridge where it discharges into the Thompson River. The Coldwater River has cold water origins as the name implies, and begins high up in the Cascade mountains as glacial meltwater. This important Nicola River tributary also supports coho, chinook, and steelhead stocks.

The terrain reflects the regional climate and can be characterized by two distinct biogeoclimatic zones. The Ponderosa Pine/Bunch Grass zone occupies the floors and lower slopes of the Nicola River Valley. In summer this zone is extremely dry and warm. At lower elevations precipitation is insufficient to support forest growth and stands of trees were historically limited to riparian areas. Significant agricultural development including both crop production and cattle ranching is located in this zone. Riparian areas and expanses of flat land (fluvial/lacustrine terraces) have been extensively modified for agricultural use.

The Interior Douglas Fir zone occupies the mid to upper elevations of the watershed. Annual precipitation is 300-750 mm and summer temperatures are lower than in the lower elevation zone. This area is utilized for both forestry and agriculture, largely cattle grazing. In Spius Creek and the Coldwater River, logging activities are mostly confined to the headwaters. Disruptions of flow regimes and increases in siltation associated with logging have been noted in both systems (Rood and Hamilton 1995).

Water withdrawals from the watershed place heavy demands on a system with already low summer flows. Hydrology information for both the Nicola and Coldwater Rivers is summarized by Rood and Hamilton (1995). For the Nicola River they report a mean annual flow of 22.7 m^3/s, a mean August flow of 15.9 m^3/s, and a mean 7-day low summer flow of 9.5 m^3/s. The licensed August water demand is reported to be 8.6 m^3/s, which is 54% of the mean August flows. The mean annual flow of the Coldwater is 7.2 m^3/s, the mean August flow is 1.92 m^3/s, and the mean 7-day summer low flow is 1.06 m^3/s. The licensed August withdrawal is reported as 0.69 m^3/s, approximately 36% of mean August flows.

2.2 Equipment

The Nicola watershed temperature study used equipment and methods consistent with the Fraser River watershed temperature monitoring program of 1993 and 1994 (Lauzier et al. 1995). A total of six Starlogger 128 Kb data loggers (model 6004B) were used to record temperatures at sites identified below. Prior to installation each data logger was programmed using Starlog software, with a unique scheme defining when and what to record. Site names corresponded to the initials of the system (NIR or COR) plus the number of kilometers upstream from the confluence. All data loggers were programmed to record the average temperature every one hour, based on a 5 second scan rate. Two temperature probes (Thermistor temperature probes - model 6507A RED) were used per data logger, with one probe serving as a backup. Probes on 10 m leads were wired through a 1/2" conduit, and then checked using a calibrated total immersion thermometer. In addition, one air temperature probe was attached to a channel on the termination strip of the data logger at the Canford Bridge site (NIR56), and positioned outside the metal case and in the shade of surrounding rocks.

2.3 Installation

Data loggers were locked inside protective aluminum boxes and hidden on the stream bank with rocks and debris. Probes were positioned in well mixed, moving water with at least 5-7 meters of the probe lead in the water. Shallow sections of the river were avoided.

Equipment was installed between June 28 and July 5, 1994 and removed on October 28, 1994. The sites spanned the system from upstream of Nicola Lake to the confluence of the Nicola River with the Thompson River. Unfortunately equipment located at site NIR115, upstream of Nicola Lake, malfunctioned and only spot surface temperatures were collected upstream from Nicola Lake.

2.4 Site Selection

Monitoring sites were selected according to access and a number of significant or key features in the watershed (Figure 1A and 1B). In addition to specified Nicola River tributaries, Nicola Lake, the Merritt townsite, and the lower canyon (near Spences Bridge) were identified as distinct spatial features and considered in determining site locations. Temperature monitoring sites were located upstream and downstream of these features in well mixed water. Continuous temperature monitoring sites included:

- **NIR115 (Above Nicola Lake)**: located in the Nicola River approximately 2 km upstream of Nicola Lake. Equipment at this station malfunctioned and no data were collected.
- **NIR96 (Nicola Dam)**: located in the Nicola River approximately 100 m downstream of Nicola Lake Dam.
- **COR4 (Lower Coldwater)**: located in the Coldwater River at the southeast corner of Merritt. The Coldwater River supports areas of important coho, chinook, and steelhead habitat.

- **NIR56 (Canford Bridge)**: located in the Nicola River downstream of Merritt, and Guichon Creek, but upstream of Spius Creek. An air temperature probe was also installed here. Chinook spawning grounds are located between Merritt and Spius Creek. Considerable riparian vegetation losses have been noted in the urban center of Merritt.
- **NIR48 (Nicola/Spius)**: located in the Nicola River approximately 0.7 km downstream of the confluence with Spius Creek. Spius Creek also supports areas of significant coho, chinook, and steelhead spawning and rearing habitat.
- **NIR4 (Lower Nicola)**: located in the Nicola River approximately 4 km upstream from the confluence with the Thompson River.

In addition, spot surface temperatures were measured with a mercury thermometer for the following tributaries:

- **Quilchena Creek**: near where Quilchena discharges into Nicola Lake.
- **Clapperton Creek**: near confluence with the Nicola River just below Nicola Lake, downstream of NIR96 and upstream of COR4.
- **Guichon Creek**: near confluence with the Nicola River upstream of NIR56 and downstream of COR4.
- **Skuhun Creek**: near confluence with the Nicola River upstream of NIR4 and downstream of NIR48.

2.5 Site Visits

Data loggers were checked weekly to ensure that equipment was operating properly. Data were downloaded approximately every 4 weeks. If necessary data loggers or probes were repositioned and new positions were noted in the field book. Field notes included the date and time of visit, calibrated thermometer readings taken at the thermistor probe, and the temperature reading being recorded by each thermistor probe at the time of the visit.

2.6 Temperature Data, Edits and Adjustments

Temperature data were adjusted using the calibration thermometer readings and corresponding thermistor readings. Analysis of variance was used to select the thermistor probe for the subsequent analysis of temperature data results. Data for both thermistor probes were graphed and examined for errors before final probe (data) selection. Null values in the data set represent de-watered probes.

3.0 RESULTS AND DISCUSSION

3.1 Data Quality

Data quality was assessed according to differences between hourly temperature readings of thermistor probes at each site. Consistency between probe readings was notably high for all sites. Differences between readings occurred infrequently and were always <0.4°C. Average differences between probes for all readings per site ranged from 0.066°C (NIR56-Canford Bridge) to -0.0005°C (NIR4-Lower Nicola). Data set selection was based on comparison of probe readings with hand held thermometer readings acquired during downloading. Similarly, average differences between probe temperatures and acquired hand held readings were low, ranging from 0.18°C (NIR56-Canford Bridge) to -0.03°C (COR4-Coldwater).

Data gaps occurred for the Coldwater (COR4) and Nicola/Spius (NIR48) sites, with each having approximately 7 days of missing data. In each case when field notes indicated de-watered probes corresponding data were identified according to extreme peaks and lows on graphs which were not consistent with characteristic data trends.

3.2 Statistical Analysis of Water Temperature Data

3.2.1 *Between-Site Comparisons*

Bonferroni (Dunn) T test was used to determine if any significant temperature differences occurred between sites. Variables used for comparison were daily maximum, minimum and mean temperatures. Values for these parameters are shown graphically for each site in Figure 2. Statistical comparisons between sites only addressed time periods when data were available for all sites (07/06/94-10/27/94). As noted above, both the Coldwater (COR4) and Nicola/Spius (NIR48) sites have missing data records due to dewatering, and no data were obtained for NIR115 (Above Nicola Lake) due to equipment malfunction.

Results of the Bonferroni T test suggest there were no significant differences ($P>0.05$) between sites in maximum and mean daily temperatures. However, data summaries do suggest that maximum temperatures are somewhat lower at the Nicola Dam site (NIR96) than at the other downstream sites. The maximum recorded water temperatures in the watershed were highest at sites downstream of the Nicola Dam site (see Table 4), and average monthly maximum temperatures were always lower at NIR96 (see Table 7). Conversely, minimum daily temperatures were significantly warmer ($P<0.05$) at the Nicola Dam (NIR96) site in comparison with all other sites.

Examination of hourly temperatures at the Nicola Dam (NIR96) site show very slight temperature fluctuations on a daily basis in comparison with the other sites (see Figure 3), which all experienced extreme temperature fluctuations and lower minimum temperatures.

These differences between the Nicola Dam site (NIR96) temperatures and the other sites reflect physical differences between a lake environment and a relatively small river. Nicola Lake acts as a heat absorber and temperature stabilizer. The large volume of lake water provides a large capacity to absorb heat, and surface water temperatures are relatively stable due to the large heat reserve contained in the lake. The Nicola Lake dam is located approximately 3 km downstream of deep lake waters and therefore only releases warm surface waters from the lake. Temperatures measured at NIR96 (100 m downstream from the dam) are directly determined by outflow from the surface waters of Nicola Lake.

At sites downstream from the lake, solar radiation contributes both directly and indirectly to the warming of surface waters during the daytime. In addition to direct heating of water, bottom substrate materials in shallow water can absorb significant quantities of solar radiation. Small tributaries and shallow sections of river may be heated during the day directly through solar radiation, and through the transfer of heat from air and substrate to water (Wetzel 1975). During the night when solar radiation is absent, heat is readily released to the atmosphere by moving (mixed) water with a relatively large surface area-to-volume ratio. Daily temperature fluctuations were expected and observed to be greater at downstream sites in comparison with the Nicola Dam site.

Results of the Bonferroni (Dunn) T test also showed that the Lower Nicola site (NIR4) had a significantly warmer ($P<0.05$) daily minimum temperatures in comparison with NIR48 (Nicola/Spius) and COR4 (Coldwater). NIR4's warmer minimum temperatures are likely linked to the greater heat retention characteristics associated with topography, differences in elevation, geographic orientation, as well as geomorphic characteristics which are unique to this downstream site. A lack of riparian vegetation was also noted at the Lower Nicola site, with streambanks consisting primarily of rock, rip-rap and boulder fill. The large boulders in the river at this location may absorb a lot of heat during the day, some of which would be transferred to the water at night (R. Lauzier, DFO, pers. comm.). It is also likely that the lower segment of the river, being somewhat barren and canyon-like, experiences greater solar heating. Although no air temperature data were collected at the Lower Nicola site, personnel attending the data loggers reported that this site was hotter than the others, and actually planned work so that they would avoid mid-day temperatures. The cooler source waters from the head waters of the Coldwater River and Spius Creek would also contribute to cooler early morning water temperatures at the Coldwater and Nicola/Spius monitoring sites.

Surface water temperatures for a number of Nicola tributaries were examined, however the number of measurements were too few to infer any statistical relationships with related downstream sites. Tabular comparisons indicate that all of the small tributaries except Quilchena Creek may be important cool water sources for the Nicola watershed (Table 1A to 1D), and more importantly, may provide cool water refuges for rearing salmonids when mainstem temperatures are high. The spot water temperature data collected at Quilchena Creek suggest that surface water temperatures are not much different from the Nicola and Coldwater River temperatures.

Table 1A. Surface water temperature (°C) of *Quilchena Creek, with comparisons to nearest sites and the Coldwater River.

DATE	TIME	QUILCHENA	Above Nicola Lake	Nicola Dam	Coldwater
8-Jul	10:30	17.70	16.30	18.46	16.03
15-Jul	13:20	22.00		20.64	21.40
22-Jul	13:25	23.80	22.50	23.29	22.83
29-Jul	10:15	18.20	18.40	21.21	
5-Aug	14:25	20.50	20.90	20.92	22.23
12-Aug	13:05	20.60		20.92	21.06
19-Aug	10:30	15.80		19.53	16.03
26-Aug	15:00	17.00		16.92	18.57
2-Sep	10:40	12.90	14.80	17.17	13.68
9-Sep		13.10			
16-Sep	13:15	15.80		16.43	16.52
3-Oct	13:45	12.00	11.00	10.16	10.21
11-Oct	13:30	9.00	9.00	9.15	8.80
17-Oct	13:50	8.00	9.00	7.01	8.01
24-Oct	12:55	7.00		6.07	6.48

*Quilchena Creek flows into Nicola Lake, upstream of the Nicola Dam and Coldwater sites, and downstream of the Above Nicola Lake site.

Table 1B. Surface water temperature (°C) of *Clapperton Creek, with comparisons to nearest sites and the Coldwater River.

DATE	TIME	UPPER CLAPPERTON	LOWER CLAPPERTON	Nicola Dam	Coldwater
8-Jul	11:00	12.80	16.50	18.45	17.02
15-Jul	12:55	14.70	17.00	20.64	21.64
22-Jul	13:00	17.00	20.50	23.29	22.83
29-Jul	10:30	15.60	16.10	21.49	
5-Aug	13:50	15.90	19.90	20.92	22.23
12-Aug	13:30	15.00	20.40	20.92	21.06
19-Aug	10:00	12.00	14.10	19.53	16.03
26-Aug	14:30	13.00	11.40	16.92	17.79
2-Sep	10:15	9.10	11.00	17.43	12.56
9-Sep		9.70	DRY		
3-Oct	13:30	6.00		9.95	8.60
11-Oct	13:05	6.00	6.00	9.15	7.43
17-Oct	12:40	6.00		7.01	7.43
24-Oct	12:35	6.00		6.07	6.48

*Clapperton Creek flows into the Nicola River downstream of the Nicola Dam site and upstream of the Coldwater confluence.

Table 1C. Surface water temperature (°C) of *Guichon Creek, with comparisons to nearest sites and the Coldwater River.

DATE	TIME	GUICHON	Canford Bridge	Coldwater
8-Jul	15:15	19.90	22.14	20.77
15-Jul	13:35	18.50	23.66	23.14
22-Jul	12:00	18.40	21.85	21.64
29-Jul	11:45	17.10	21.27	
5-Aug	10:50	16.90	19.59	17.28
12-Aug	9:35	14.10	17.23	16.03
19-Aug	11:05	14.90	17.74	16.77
2-Sep	12:20	13.40	15.52	15.07
9-Sep	10:35	12.60	13.66	12.56
3-Oct	12:35	8.00	10.01	8.60
11-Oct	12:05	6.00	7.45	6.29
17-Oct	11:10	6.00	6.88	6.11

*Guichon Creek flows into the Nicola River above the Canford Bridge site and downstream from the Coldwater confluence.

Table 1D. Surface water temperature (°C) of *Skuhun Creek, with comparisons to nearest sites and the Coldwater River.

DATE	TIME	SKUHUN	Lower Nicola	Coldwater
22-Jul	11:05	16.10	21.92	20.77
29-Jul	12:30	16.40	21.05	
5-Aug	12:00	16.60	21.63	19.11
12-Aug	10:40	13.30	18.83	17.28
19-Aug	12:15	13.60	18.83	17.79
2-Sep	13:10	12.20	16.27	16.52
3-Oct	11:40	8.00	9.39	7.24
11-Oct	11:05	6.00	7.42	5.37
17-Oct	10:20	5.00	6.28	5.55
24-Oct	11:00	5.00	5.00	5.00

*Skuhun Creek flows into the Nicola River above the Lower Nicola site and downstream from the Coldwater confluence.

3.2.2 *Comparison of Air and Water Temperatures and Trends*

Climate conditions in the Nicola watershed were assessed using both air temperatures collected by Environment Canada's weather station in Merritt and air temperature data collected at the Canford Bridge site (NIR56). Although a standard on-site louvered shelter was not used at NIR56, comparisons with Environment Canada temperatures for the Nicola Valley (Merritt STP) suggest the data contain no obvious errors (Figure 4A).

The maximum air temperature readings were generally higher at the Environment Canada weather station in Merritt, but the overall trends and characteristics were similar (Figures 4B and 4C). At the Canford Bridge site the location of the probe near the ground and the proximity of the site to water would account for slightly cooler temperatures and more moderate daily fluctuations.

Air temperature conditions are summarized in Table 2. Throughout the province temperatures in 1994 were unusually warm and this was especially apparent in the Nicola Valley, where maximum temperatures reached 42.5°C and average temperatures exceeded 25°C for almost 20 days.

Table 2. Summary of monthly air temperatures for the Nicola River at the Canford Bridge site (NIR56) and Merritt STP.

AIR NIR56	JULY	AUGUST	SEPTEMBER	OCTOBER
*N	632	744	720	664
MAX	33.49	29.73	18.87	15.58
MIN	14.16	12.15	5.95	0.38
AVG	21.42	17.77	13.27	5.95
MERRITT				
MAX	42.5	38.5	32.5	N/A
MIN	10.0	10.0	8.0	N/A
AVG	24.5	22.4	19.7	N/A

*N is number of hourly data records available per month at NIR56.

Hourly data were available for the Canford Bridge site (NIR56) but not for the Merritt STP site. Therefore, average hourly deviations from the daily mean were graphed for air at Canford Bridge (Figures 5A to 5D) and water temperatures were only compared to Canford Bridge air temperatures. Comparison of air temperatures with water temperatures show parallel trends, with peaks in air temperatures corresponding with similar water temperature peaks.

Graphs describing average hourly deviations from the daily mean for all sites (Figures 6A to 6E) show diurnal temperature patterns of day time heating and night time cooling as discussed above. For the Coldwater, Canford Bridge, and Nicola/Spius sites, the minimum and maximum temperatures were recorded at 8:00 and 17:00-18:00 respectively. Temperatures recorded at the Lower Nicola site (NIR4) reached minimums at 9:00 and maximums at 18:00, while the Nicola Dam site (NIR96) reached minimums at 10:00 and maximums at 19:00 (July and August).

Examination of data for average times of maximum and minimum temperatures show that downstream mainstem sites experience a lag time of 20 to 60 minutes in July and August relative to air temperatures at the Canford Bridge. Temperatures at the Nicola Dam (NIR96) reach maximums and minimums after the lower mainstem sites. The thermal stability inherent to a large water body such as Nicola Lake likely influences this comparative delay at the Nicola Dam. As solar radiation decreases towards the end of summer so do any noticeable between site trends.

3.3 Implications of Measured Temperatures for Pacific Salmonids

Inventory information indicates that chinook salmon spawn in the Nicola and Coldwater Rivers between mid-July and mid-September. Coho salmon begin returning to spawn to both systems in early fall. The juveniles of both species may rear in the Nicola River for a year or more prior to their seaward migration. Both species would therefore be impacted by high summer water temperatures as adults and/or juveniles. Data were therefore analyzed and interpreted in the context of temperatures which are preferred and lethal to both adult and juvenile life stages of anadromous Pacific salmonids.

Thermal tolerance (LT_{50}) is defined as the temperature which is tolerated by 50% of a test population for a sustained period of time, usually about 8 to 24 hours. LT_{50} is influenced by prior thermal history of the test fish, and numerous other stress-related factors. Acclimation temperature influences both the LT_{50} and the exposure time that results in death.

Temperatures which are preferred or directly lethal to salmonids are normally determined in laboratory bioassays, and direct translation to a natural system fails to account for the complexity of habitat variables such as poor water quality, predation, and other potential stressors which may affect fish (Servizi and Martens 1991). Potentially fatal temperatures may therefore be lower in an uncontrolled environment (i.e. the natural environment) as opposed to laboratory conditions where data defining lethal tolerances have been obtained. The critical temperatures referred to in this report are based on documented research and available expert opinions, outlined in Levy (1992), see also Brett 1952; Vernon 1958; Bell 1973; Smirnov 1975; Reiser and Bjornn 1979; Armour 1991; Heard 1991.

The lower end of the thermal tolerance range for the juvenile stages of anadromous salmonids was taken to be 21°C and the upper end of the range was 25°C (Table 3) meaning that 50% mortality of salmon populations would be expected somewhere in this temperature range. Data were analyzed to determine the frequency and duration of exceedances of these critical thresholds. A third critical temperature of 16°C, which defines the upper limit of preferred spawning migration temperature (Vernon 1958; Smirnov 1975; Reiser and Bjornn 1979; Wilson et al. 1987) was also used to interpret and assess the data. As reported by Snyder and Blahm (1968), returning spawners become more susceptible to disease as water temperatures exceed this 16°C threshold. Preferred temperatures are also much lower than tolerance limits, and the levels of both preferred and tolerable temperature for adults are usually lower than for juveniles (McCauley and Huggins 1979).

Table 3. Temperature Preferences and Tolerances - species *Oncorhynchus.*

>25°C	UPPER RANGE of LT_{50}
>21°C	LOWER RANGE of LT_{50}
>16°C	CESSATION of SPAWNING INCREASE in DISEASE
5-15°C	PREFERENCE for SPAWNING MIGRATION
4-14°C	PREFERENCE for SPAWNING

3.4 Overviews of Temperature Data

Daily maximum, minimum, and mean water temperatures are displayed in Figure 2, and show both the diurnal fluctuations and seasonal trends observed at each monitoring site. Significant temperature thresholds for anadromous salmon are delimited on the graphs at 25°C, 21°C and 16°C.

3.4.1 *Weekly Overviews*

Temperature data were summarized using 7-day increments for maximum, minimum, and mean daily temperatures at each site (Appendix 1). Results for each site were compared and ranked according to the hottest (1) and coolest (17) weeks (see lower right hand corner of the site summary tables in Appendix 1).

3.4.1.1 *The Hottest Weeks - Mid-Summer*

Water temperatures at all sites reached the upper end of the thermal tolerance range for anadromous Pacific salmonids (25°C). Weeks 3, 4, and 5 (mid-July to early August) were the hottest, and average water temperatures exceeded 21°C at all sites for each of these weeks, except for the Coldwater site in week 3, and the Nicola/Spius site in weeks 3 and 5. Maximum summer water temperatures were recorded at all sites on July 24, 1994 (Table 4). At the Coldwater River and Canford Bridge sites, maximum recorded temperatures reached 29°C during the last week of July, well above the lethal tolerance range for Pacific salmonids.

3.4.1.2 Cooling Trends - Late Summer/Early Fall

By week 8 (08/19/94-08/25/94) there was a gradual cooling trend in the system with average temperatures declining to a range of 17°C to 18.5°C. However, maximum temperatures were still in the lethal range at all sites, and significant reductions in maximum temperatures did not occur until weeks 13-14 (09/23/94-10/06/94), (Appendix 1). During week 12 (09/16/94-09/22/94) maximum water temperatures were still between 18.7°C and 21.5°C depending upon the site, although durations of these high temperatures were notably less than in earlier weeks.

3.5 Water Temperatures and Life Cycle Events of Nicola River Salmonids

During the first week of July through mid-September, recorded maximum water temperatures at all sites exceeded the threshold of temperatures preferred by adult salmon during their spawning migration (16°C), and reached lethal thresholds as described above. It is during this time-frame that chinook salmon migrate into the Nicola system for spawning in late September to October.

Minimum recorded temperatures were usually below the lower limit of the lethal tolerance range of anadromous salmon but exceeded 21°C at the Nicola Dam site continuously between July 20th and July 30th, and briefly exceeded 21°C at both the Canford Bridge (NIR56) and Lower Nicola (NIR4) sites during the same week.

Minimum water temperatures exceeded the upper limit of preference for spawning migration (16°C) during the study period between early July and approximately the second week of August. At the Nicola Dam site (NIR96) water temperatures continuously exceeded 16°C between early July and early September.

Average temperatures for July and August always exceeded the preferred temperature ranges for both rearing and migrating fish (>11.5°C-15°C, and >16°C respectively) at all sites. Preferred temperatures have been shown to correspond with physiological optimum temperatures, at which metabolic rate, metabolic scope, sustained swimming speed, and growth rate are optimized (Brett 1971). When optimum temperatures are exceeded a number of factors may combine to reduce chances of survival. For example, increased water temperatures increase the metabolic rates of all cold-blooded aquatic organisms, which raises their food requirements and hence increases the probability of predation on juvenile salmonids. Increased metabolic rate also leads to depletion of the limited onboard energy reserves of adult salmon which do not feed during their spawning migration.

Spot surface water temperature data collected at Clapperton, Guichon and Skuhun Creeks identified these systems as cool water contributors to the Nicola mainstem, with reported temperatures always cooler than temperatures recorded at nearby mainstem sites. Field studies in the Nicola have shown that juvenile salmon will make use of cool water inputs as refugia (Levings et al. 1985), and their importance in providing local refuge habitat is clearly significant to fish populations. Observations suggest that during periods of warm temperatures these cold water seepage sites, off-channel ponds, and inputs from cool creeks influence fish distribution patterns. During sampling of the Nicola River in 1985, of the mid-Nicola sites, salmonids were found only within a 10-foot radius of the outflow of Clapperton Creek into the Nicola (O. Langer, DFO, pers. comm.). Populations are undoubtedly limited by the availability of these cool water habitats. Kills of juvenile salmonids are difficult to detect and likely go unnoticed, however the personnel tending the Nicola data loggers did note a number of dead juvenile rainbow trout in the Coldwater River during the period of high water temperatures. Although there were no means of determining cause of death, conditions suggest that temperature may have been a factor.

In a recent study Berman and Quinn (1991) examined patterns of behavioral thermoregulation, habitat preference, and movements of fish during spawning migrations. Adult spring chinook salmon were tagged with temperature-sensitive radio transmitters and released back to the natural environment. During a four month tracking period it was discovered that tagged fish maintained an internal body temperature 2-5°C less than ambient river temperature by utilizing cooler thermal refuges. Such refuges must be abundant and available to fish if they are to be able to mitigate high ambient water temperatures. Temperatures at spawning grounds must also be in an appropriate range in order for spawning to be successful. In the Nicola watershed movements of migrating adult chinook were likely affected by warm temperatures. Typical chinook runs usually start arriving in mid-July, however in 1994 it was observed that the majority of mainstem Nicola chinook held in the Thompson River until mid-August or later (N. Todd, Diversified Ova Tech, pers. comm.).

While no kills of larger fish were reported on the Nicola or Coldwater Rivers, it is generally accepted that high water temperatures result in higher levels of pre-spawning mortality in anadromous salmon as a result of increased energy requirements for migration, and increased susceptibility to pathogens and parasites (Wedemeyer 1970; Williams 1973; Groberg et al. 1978; Gilhousen 1980; Gilhousen 1990). Migrating Nicola salmon in 1994 not only encountered unfavourable water conditions in the Nicola, but experienced higher than normal water temperature conditions in the Fraser and Thompson Rivers (Foreman et al. *in press*). Prolonged exposure to warmer temperatures during 1994 spawning migrations may have accelerated deterioration of salmonid health before arrival into even warmer Nicola waters.

3.5.1 *Implications of Daily Temperature Fluctuations*

Thomas et al. (1986) suggested that although temperature fluctuations may chronically stress fish, more harm may come from temporary (1-2 hour) high temperatures above lethal limits than from long-term fluctuating temperatures. In terms of susceptibility to disease, Fagerlund et al. (1995) remarked that sudden changes in water temperature may be a temporary phenomenon but can be devastating in terms of fish survival. In the Nicola system the majority of sites experienced both extreme daily fluctuations and coinciding peak temperatures, which frequently exceeded levels that are acutely lethal.

Graphs displaying average daily temperature fluctuations at all sites are provided in Figures 6A to 6E. Examination of temperature data showed a maximum daily fluctuation of 11°C (Aug-18), which occurred in the Coldwater River. For July, the hottest month and the period when daily fluctuations were greatest, average daily temperature fluctuations per site were: 1.8°C (Nicola Dam-NIR96), 5.1°C (Lower Nicola-NIR4), 7.3°C (Canford Bridge-NIR56), 7.3°C (Nicola/Spius-NIR48) and 7.8°C (Coldwater-COR4). Table 7 summarizes average maximum and minimum temperatures per site per month and puts daily fluctuations into a seasonal context. Average maximum and minimum temperatures provide a conservative estimate of typical fluctuations and related rates of change.

Research and field observations also imply that salmon survival sharply declines if sub-lethal temperatures are encountered for prolonged periods. Dean (1973) confirmed the importance of the time-temperature relationship in experiments. His studies revealed that a combination of gradual increase to a sub-lethal situation with a subsequent gradual decrease could be strikingly lethal. It has been suggested that in the Fraser system, mortality of migrating sockeye salmon can be significant when temperatures of >19°C are experienced over an extended period (I.V. Williams, DFO, pers. comm.). While temperature would not likely be the direct cause of death, subsequent stress responses would affect the ability of the fish to withstand infection and disease (Fagerlund et al. 1995). Holt et al. (1975) indicated that the progress of fatal infections in fish were accelerated at higher temperatures and retarded at lower temperatures. Although information about the condition of 1994 Nicola salmon was not available, conditions prevailed that could have put this population at significant risk - a combination of sustained high but non-acutely lethal temperatures, with frequent exceedances of acutely-lethal temperatures.

Table 7. Average maximum and minimum temperatures (°C) per month per site for the Nicola watershed, 1994.

		Nicola Dam NIR96	Coldwater COR4	Canford Bridge NIR56	Nicola/Spius NIR48	Lower Nicola NIR4
JULY	Avg. Max	21.4	23.1	24.8	22.9	23.0
	Avg. Min	19.6	15.3	17.5	15.6	18.0
AUGUST	Avg. Max	20.5	22.8	22.3	21.6	21.5
	Avg. Min	18.9	14.5	15.7	15.2	17.1
SEPTEMBER	Avg. Max	17.6	19.5	18.1	17.8	17.8
	Avg. Min	16.2	11.9	12.8	12.5	14.1
OCTOBER	Avg. Max	9.1	9.7	9.9	9.4	9.2
	Avg. Min	8.1	5.8	7.0	6.4	7.2

3.5.2 Fish Presence and Timing of Life Cycle Events

Life cycle information for salmonids in the Nicola and Coldwater Rivers indicate that both juveniles and adult spawners of some salmonid species are likely vulnerable to high water temperatures. Information available from DFO Stream Information Catalogues (SISS) pertaining to the presence of juveniles, and spawning seasons, has been summarized:

Coho salmon ***(Oncorhynchus kisutch)***

According to SISS catalogues coho salmon spawn throughout the Nicola River with the heaviest spawning between Spius Creek and Merritt. Spawning occurs between late September and early November, when water temperatures are declining (Figure 7A). While adult spawners may not be impacted by high water temperatures due to timing, resident juvenile populations would be particularly susceptible to high summer water temperatures. Juvenile coho rear in small freshwater streams for at least one year prior to their seaward migration. The habitat available to them for rearing is believed to be limited by temperature conditions, as an August field sampling program in the Nicola has shown them to be clustered in areas which are influenced by cool water inputs (Levings et al. 1985).

Coho also spawn in the Coldwater River between late October and late November, so spawners return after water temperatures have declined to the sub-lethal range (Figure 7B). Rearing juveniles are likely impacted by water temperatures during summer months. Results of an August field survey showed that coho fry were mostly restricted to areas with inputs of cool ground water, as on the Nicola River.

Pink salmon ***(Oncorhynchus gorbuscha)***

Pink salmon spawn in the lower 25 km of the mainstem Nicola, generally between Spius Creek and Spences Bridge. Spawning occurs on odd years from early September to mid October, when water temperatures are declining. Pinks have a fixed two-year life span, with the young migrating to sea immediately after emergence. Due to their life-cycle and the timing of spawning, pink salmon are less likely than other salmonids to be impacted by high summer water temperatures.

Chinook salmon ***(Oncorhynchus tshawytscha)***

Chinook salmon spawn throughout the Nicola system, with the majority of spawning between Spius Creek and Merritt. Several hundred chinook have been observed downstream from Douglas Lake, and chinook have also been observed spawning upstream of Douglas Lake. Spawning occurs between mid-July and mid-September, making this species extremely vulnerable to the high summer water temperatures in the Nicola system (Figure 7C to 7E). Furthermore, water temperature data collected immediately upstream of Nicola Lake in the summer of 1995 during June to mid-July showed water at this reach to be hotter in comparison with all sites monitored in the 1994 study (Walthers and Nener, *in prep.*). Based on 1995 data, trends at NIR115 seem comparable to NIR56, which experienced very unfavourable temperature conditions in 1994. Regardless, chinook attempting to spawn upstream of Nicola Lake are likely strongly impacted by high water temperatures. Extensive land clearing has occurred on cattle ranches in this upper part of the watershed, and has resulted in extensive losses of riparian vegetation.

Chinook runs vary widely in terms of how long juveniles remain in their natal streams following emergence, prior to seaward migration. Some juveniles make use of cold water refuges in the Nicola River mainstem, while others pass down into the Thompson River. Sebastian (1982) suggested that as fish increase in size they move into deep water habitats found in larger systems downstream. Results of downstream trapping on the Nicola River in 1981 suggested that 80% of juvenile chinook outmigrated by mid-September (Sebastian 1982).

Chinook salmon are noted as returning to the Coldwater River in June, with spawning occurring between July and mid-September. Returning spawners would therefore confront the highest water temperatures of the year (Figure 7D).

Results of field studies show that juvenile chinook salmon generally start leaving the Coldwater system by March or April (Scott and Olmsted 1985). Some are believed to rear in the Nicola and some in the Thompson River.

Figures 7A to 7E display recommended temperature ranges (Reiser and Bjornn 1979) at significant sites for chinook and coho during juvenile rearing, adult migration and spawning. Graphs are relative to 1994 water temperatures and describe life-cycle ranges and associated temperature preferences for salmon in the Nicola system.

3.6 Factors Contributing to High Water Temperatures, and Opportunities for Mitigation

High water temperatures in the Nicola watershed are partly a result of inherent regional and system factors, including a characteristically warm summer climate. Nicola Lake has been viewed as a major determinant of high downstream water temperatures because warm surface waters comprise the bulk of the lake outflow. While release of deeper, cooler waters from the lake would provide lower baseline water temperatures in the area downstream of the lake, results of temperature monitoring suggest that all else being equal, significant warming would occur as water moves downstream. Regardless, cooler water temperatures immediately downstream of the lake could greatly benefit cold water salmonid populations.

Preliminary results of temperature monitoring in 1995 showed that the Nicola River upstream of Nicola Lake was the warmest site in comparison with all the other sites (Walthers and Nener, *in prep.*) during June to mid-July, so if Nicola Lake did not exist water in lower reaches might be even warmer. The upper Nicola River has suffered extensive losses of riparian vegetation due to ranching activities, which likely contributes to the higher water temperatures measured.

Land uses have likely significantly altered and aggravated a naturally elevated thermal regime. Numerous studies have demonstrated relationships between loss of riparian vegetation and increased water temperatures (Holtby 1988). Strips of riparian vegetation along watercourses have a significant role in keeping waters cool by providing shade from direct solar radiation, therefore preventing direct warming influences on water and sediments. Increased water temperatures result from an increase in the amount of solar radiation reaching the stream when riparian vegetation is lost.

The effects of devegetated streambanks on summer water temperature can greatly exceed the modeled impacts from global warming. One study from Oregon State (Hall and Lantz 1969) examined effects of clear-cutting an entire 71 ha watershed which provided spawning and rearing habitat for coho. Before logging, the maximum summer water temperature was 16°C, and the diurnal temperature fluctuation was measured to be 1.5°C. After logging, the maximum water temperature was 30°C and diurnal fluctuations reached 16°C.

Studies in the Slim Creek watershed of B.C., located 80 km east of Prince George, showed an average water temperature increase of 1-3°C relative to upstream unlogged sites (Brownlee et al. 1988). The same study found diurnal temperature fluctuations to be at least twice as large at downstream sites which lacked riparian vegetation in comparison with upstream shaded reaches. Water temperatures downstream of logged areas fluctuated over 8°C in one 24 hour period, compared with 2°C at the upstream control site. The average water temperature increase reported by Brownlee is in the range of that predicted to accompany global warming in B.C., as discussed in Levy (1992). In comparison with the Nicola River these other study streams are relatively small (low flows approximately $0.2m^3$/sec) however the findings are applicable to larger streams. During the warmest months the Nicola River experiences very low flows, which, combined with extensive losses of riparian vegetation, makes it very susceptible to warming influences.

While riparian losses have not been quantified along the Nicola River it is clear that losses are substantial and have occurred in association with land uses such as farming, ranching, transportation corridors, and urban development. Berry and Kahl (1982) reports that streambanks and vegetation are frequently altered and irrigation diversions are common on the Nicola River between the Coldwater River and Spius Creek confluences. This is the main chinook spawning area on the Nicola River. Preliminary results of a study recently commissioned by DFO-FRAP (Rescan, *in prep.*) indicate that bank erosion and slumping, substrate mobility, and channel instability are common in the Nicola and Coldwater River study areas (Dam outlet to confluence with Thompson, and Kingsvale to confluence with Nicola River, respectively).

Riparian losses can be approximated from information on other near-by rivers with very similar land use patterns. A study recently completed by Beeson and Doyle (1995) identified the presence/absence of riparian vegetation along bends in reaches of the Bonaparte, Deadman, and Salmon Rivers, and Chase Creek, all of which are tributaries to the Thompson River. The reaches studied ranged from 18 km to 36 km in length. The percent length of the reaches which were devegetated ranged from 46% to 63%. It is reasonable to assume that loss of riparian vegetation along the Nicola River and it's tributaries is in this range.

Temperature problems on the Nicola River are likely further compounded by the removal of large volumes of water for irrigation and other uses. Based upon information documenting licensed withdrawals on the Nicola, it has been estimated that approximately 50% of the summer flow volume is removed from the Nicola River system (Rood and Hamilton 1995).

4.0 CONCLUSIONS AND RECOMMENDATIONS

Results of the 1994 temperature monitoring program indicate that water temperatures in the Nicola River likely limit salmon production in this system. Previous examinations of escapement data suggest that populations of anadromous salmon are only 10-30% of historic levels (Sebastion 1982) and more recent escapement data do not suggest significant improvements since then. There are likely many factors contributing to the decline of Nicola River salmon populations, including increased fishing pressure, damage to fish habitat, and degradation of water quality. The high water temperatures observed throughout the Nicola mainstem in 1994 also likely contribute to the resulting effective loss of habitat available to rearing salmon and migrating spawners. Juvenile coho and many chinook runs normally rear for one or more years in or near their natal streams following emergence and would therefore be significantly influenced by available habitats with appropriate thermal regimes. Water temperature is a critical habitat component that may profoundly affect the future of Nicola River salmon stocks.

4.1 Protection of Cool Water Refugia

In the Nicola River appropriate habitat with a favourable thermal regime during summer months is clearly restricted to areas with cool inputs of surface or ground water. Rearing juveniles are suspected to be confined to areas where cool water inputs from springs and small groundwater-fed streams provide thermal refuges during hot summer months. These cool water inputs must be identified, mapped, and protected. Without safeguarding these areas further declines in salmon populations can be expected.

4.2 Restoration of Riparian Vegetation

It is recommended that efforts be directed towards restoring riparian areas along the river and its tributaries. Land clearing for logging, ranching, crop production, and urban development has resulted in removal of a significant proportion of shade from the Nicola and Coldwater Rivers, and numerous tributaries. Small tributary streams are particularly susceptible to warming, as small volumes of water will warm more quickly than large volumes under the same conditions. Tributaries lacking shade can be viewed as an effective heat absorbing network which contributes further warming to the Nicola mainstem, and in turn to the Thompson River.

Restoration of riparian vegetation would improve summer water temperature conditions, and would also address a number of other problems. Loss of riparian vegetation has resulted in erosion in many areas of the Nicola watershed, causing problems for both landowners and fish. Re-establishing riparian vegetation would return the extensive root systems which helps to hold soils together and resist erosive forces which accompany high water flows. The large organic debris (tree trunks and branches) which would eventually be contributed to the watercourse would help to further stabilize stream and river banks, and enhance fish habitat by providing narrower and deeper channels and habitat complexing. Riparian vegetation would also absorb some of the excess nutrients which are currently reaching the Nicola River and some tributaries from farms, ranches, and urban areas. Miles (1995) recommends that riparian corridors be established along the length of the Salmon River (Shuswap) for similar reasons. He suggests a riparian corridor on each bank with a width of at least three times the channel width. His recommendation is based on channel morphology relationships which indicate that the average radius of a meander bed is about 2.5 times the river width. Providing a corridor with total width of 6 to 7 times the channel width would therefore allow the river to migrate in a natural manner without disturbing adjacent property.

Recognizing the difficulty of persuading property owners to establish any riparian vegetation at all, we suggest beginning with a 15 m wide strip, and planting species capable of attaining good height, and extensive root systems. Species such as cottonwood, willows, and red osier dogwood appear to thrive in this area, and would provide the required habitat features over time. Where the channel is actively eroding, a wider riparian corridor should be established so that vegetation can develop sufficiently to stabilize the river channel. As recommended by Miles (1995) the performance of re-established riparian corridors should be monitored in a manner which would allow corridor width recommendations to be revised as required for different river settings.

Pilot projects to restore riparian vegetation have already been initiated along the Nicola River, and other tributaries of the Thompson River. To date results have been encouraging when work is done properly, with bands of willows quickly becoming re-established after stream banks are stabilized and grazing animals are excluded. Willows and red osier dogwood, which grow quickly and establish extensive root systems, should be interplanted with species such as alder and cottonwood which attain greater heights to provide shading.

4.3 Addressing Education and Financial Constraints to Change

Government agencies need to implement mechanisms for encouraging landowners to undertake this work, such as providing tax incentives. A strategic approach to educating private landowners about the importance of riparian areas is needed. It is clear that small, incremental losses have resulted in extensive and serious impacts to water quality and fish habitat, which threaten the future of salmonid populations in some areas of the Thompson River sub-basin. An effective education program for private land owners would be an important step towards protecting the existing riparian vegetation. Some level of enforcement should also be directed towards this issue.

4.4 Minimizing Water Withdrawals

The withdrawal of a significant proportion of instream flows during the hot and dry summer months contributes to temperature problems in the Nicola River and other Thompson River tributaries. Greater instream flows need to be secured during summer months for the Nicola River and its' cool tributaries. Water withdrawals should be metered to ensure that they do not exceed permitted volumes.

4.5 Other Options

Other suggestions for mitigating high water temperatures on the Nicola River have focused upon altering the dam which controls the outfall from Nicola Lake, so that it would release cooler, deeper water. Results of the present study suggest that while this may provide cooler water immediately downstream from the dam, the significant warming effects of direct solar radiation would reduce or eliminate this benefit further downstream, given present flow releases. Using a deep water syphon to develop a deep cold water discharge would require approximately 4 km of piping, which would be extremely costly (R. Grace, MELP, pers. comm.). The benefits of this type of work would have to be considered in comparison with the benefits which could be achieved by spending the same sum of money on other remediation efforts such as riparian restoration. The Nicola River upstream from the lake experiences higher water temperatures than the surface lake waters, and has suffered significant riparian losses as recently as in the past decade (O. Langer, DFO, pers. comm.). The upper Nicola used to provide important salmon spawning and rearing areas, and temperature problems here can only be addressed by revegetating riparian zones and securing greater instream flows.

4.6 Extrapolating to the Thompson Watershed

Water temperature problems on the Nicola are likely symptomatic of issues on other Thompson River tributaries with similar land uses. Riparian vegetation has been eliminated throughout many areas of the Thompson watershed and formerly significant salmon-producing systems have been significantly degraded. Restoration of these critical habitat components will be a very important step towards sustaining salmon populations. Failure to do so cannot help but detract from all other efforts made to enhance salmon stocks originating from the Thompson River drainage system and will make the salmon runs of the Thompson River system even more vulnerable to the effects of global warming.

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FIGURES

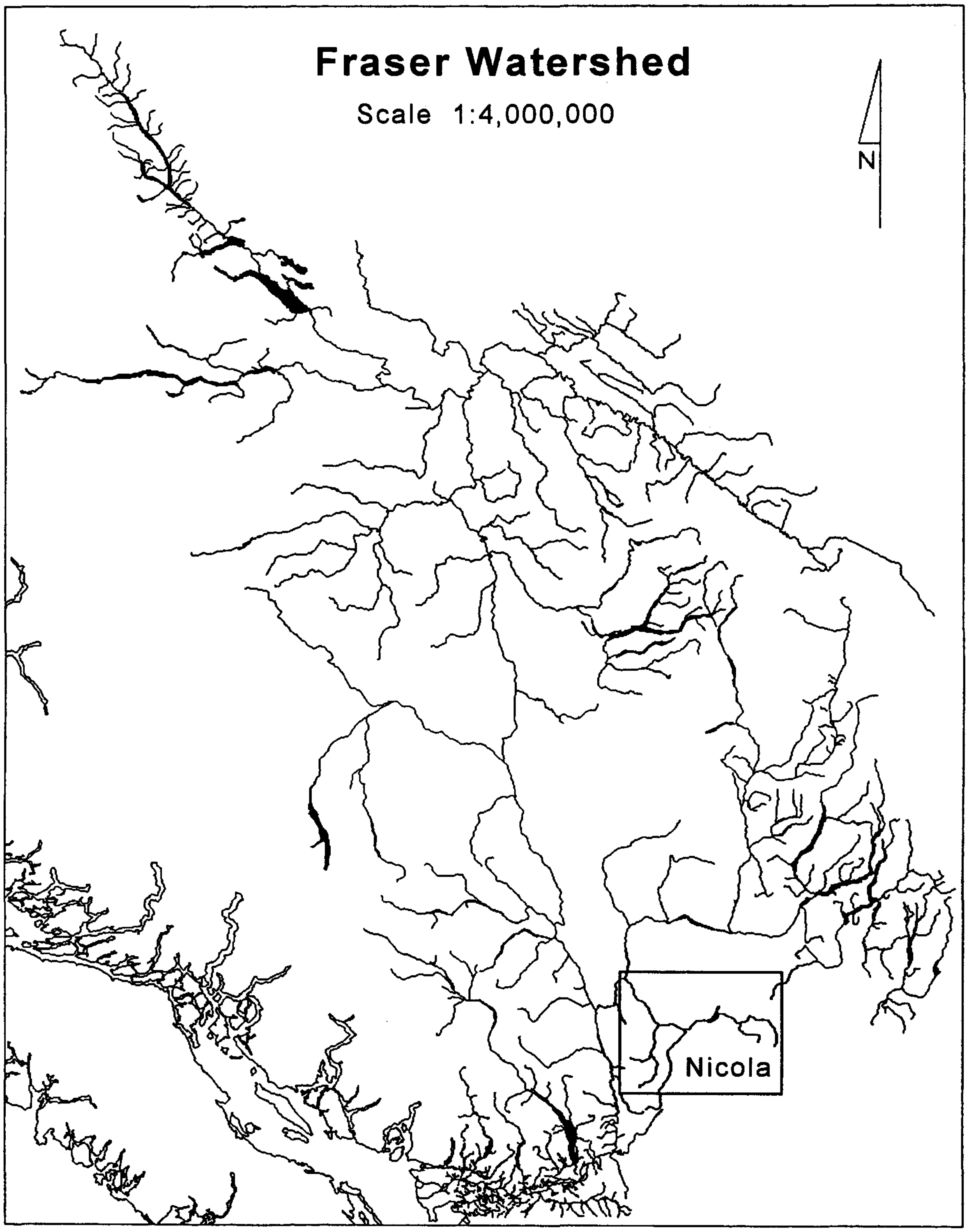

Fig. 1A. Fraser River Basin, British Columbia.

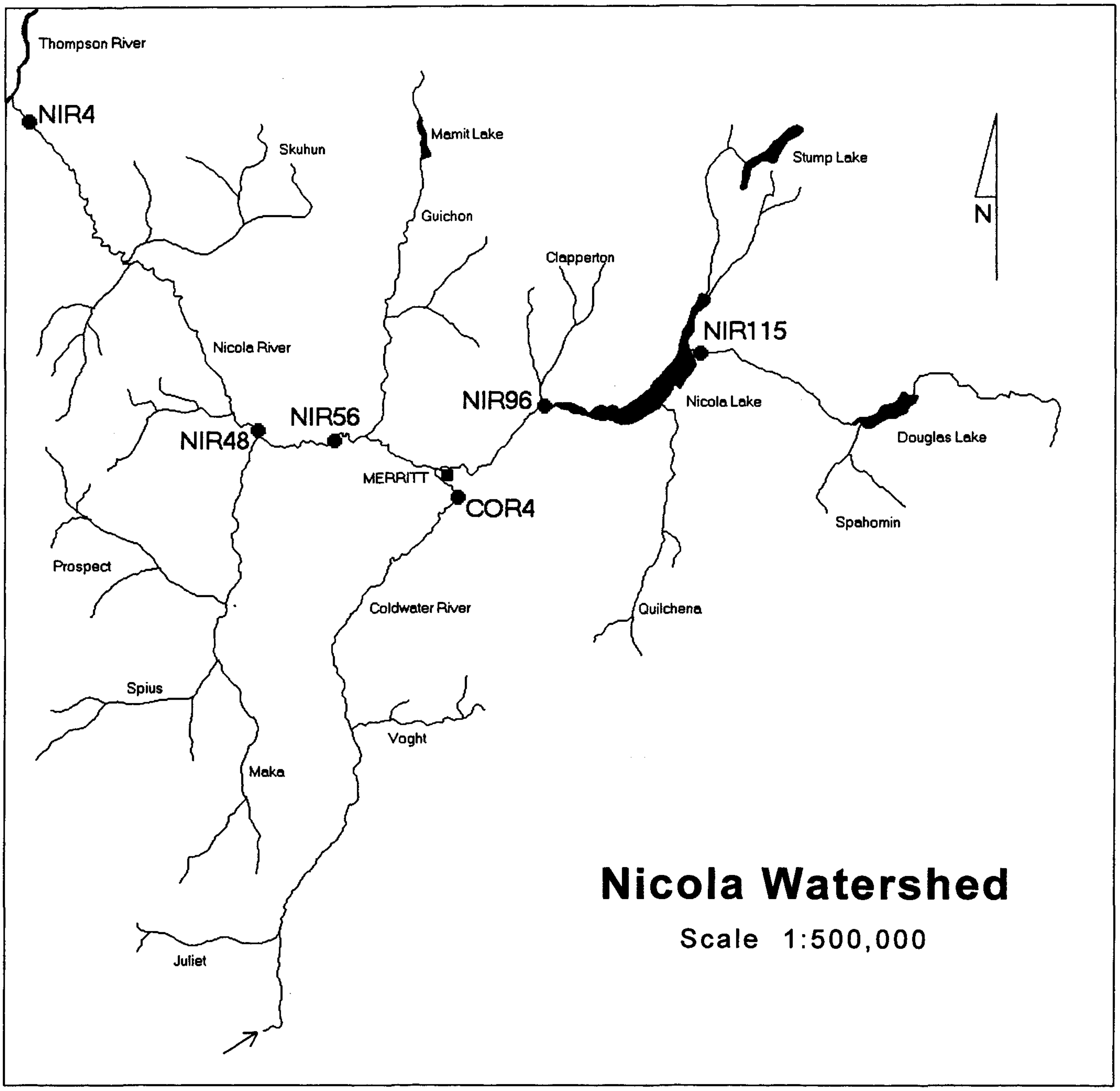

Fig. 1B. Location of temperature monitoring sites, 1994.

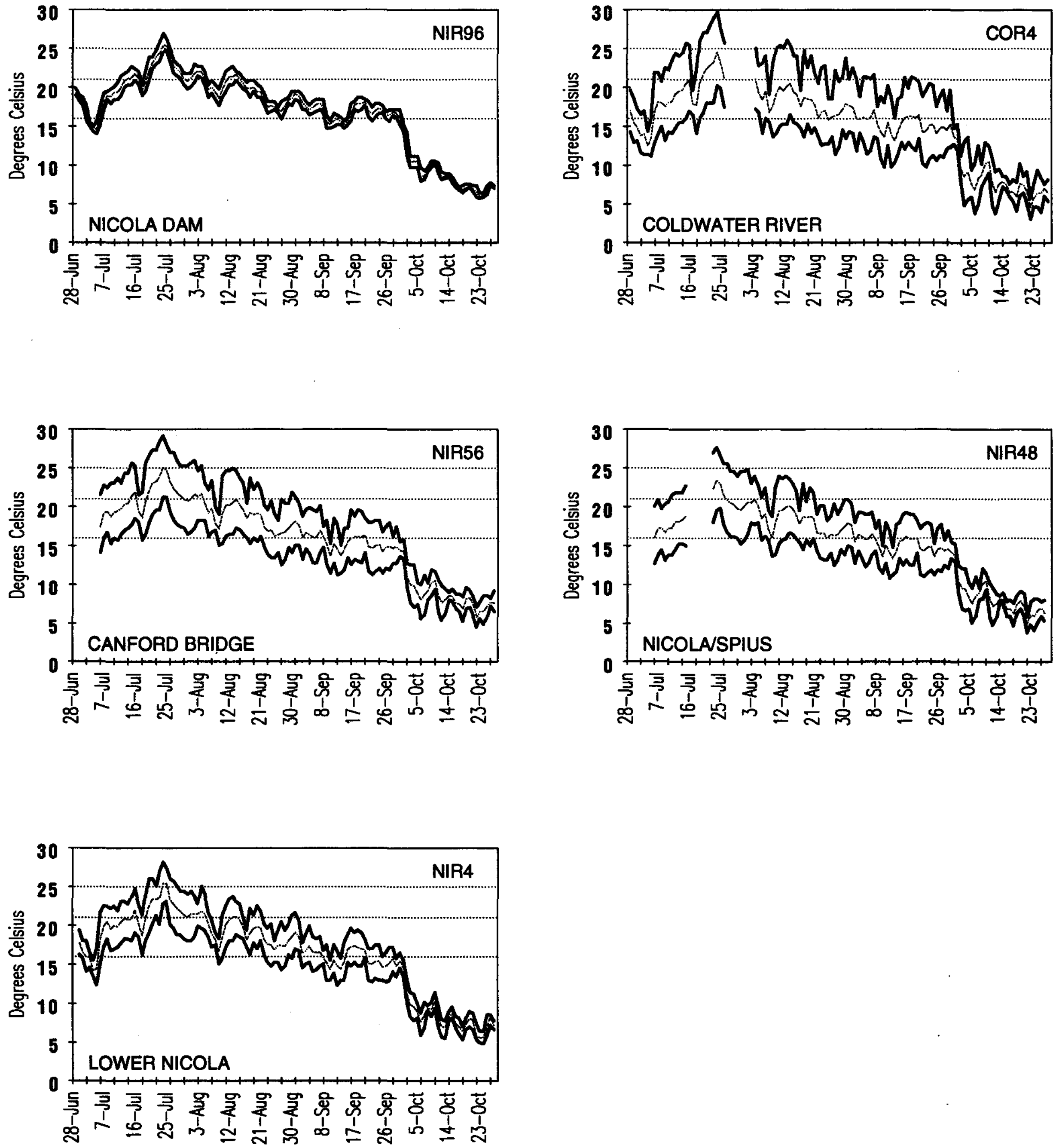

Fig. 2. Daily maximum, minimum and mean water temperatures for all Nicola watershed sites, 1994. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit of LT_{50}, respectively.

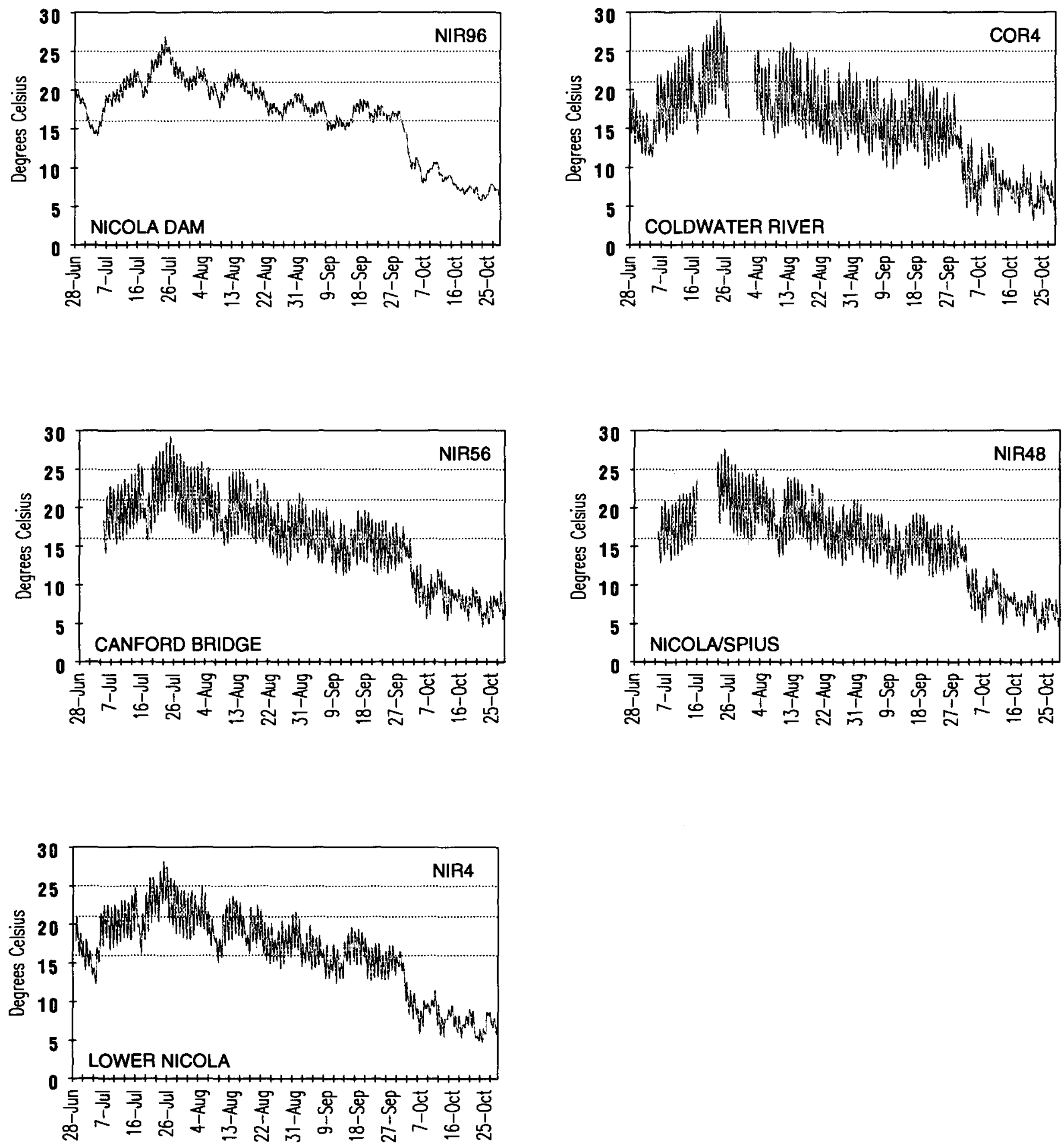

Fig. 3. Hourly water temperatures for all Nicola watershed sites, 1994. Lines at 16°C, 21°C and 25°C correspond with (a) maximum preferred spawning migration temperature, (b) lower limit of LT_{50}, and (c) upper limit of LT_{50}, respectively.

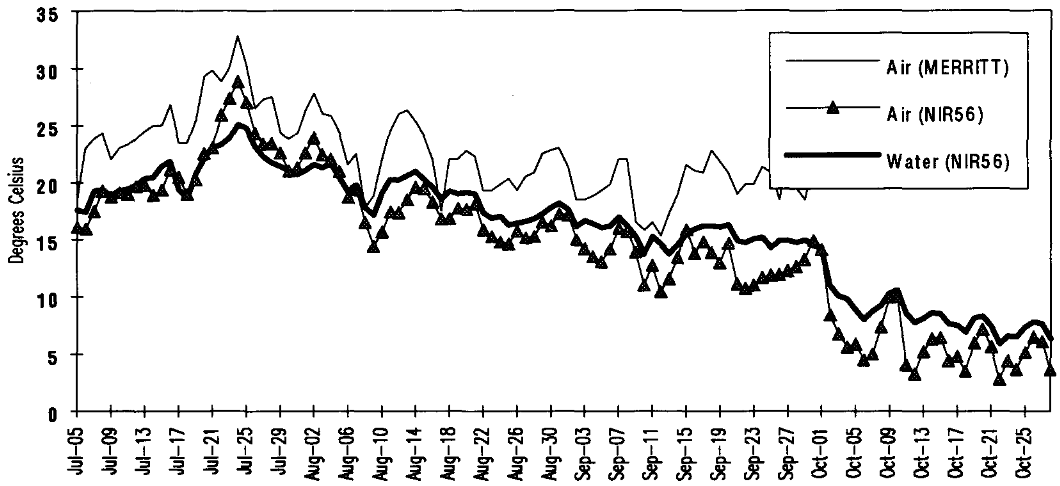

Fig. 4A. Nicola watershed daily average air temperatures at Merritt STP and both air and water temperatures for the Canford Bridge site on the Nicola River at NIR56, 1994.

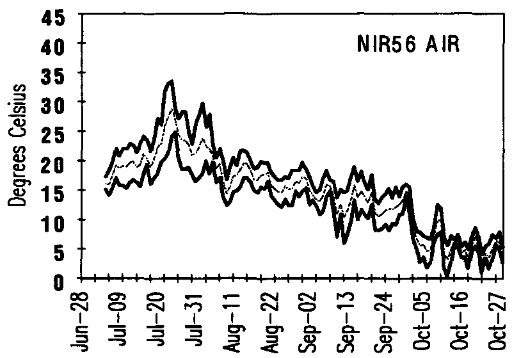

Fig. 4B. Daily maximum, minimum and mean air temperatures at NIR56 (Canford Bridge), 1994.

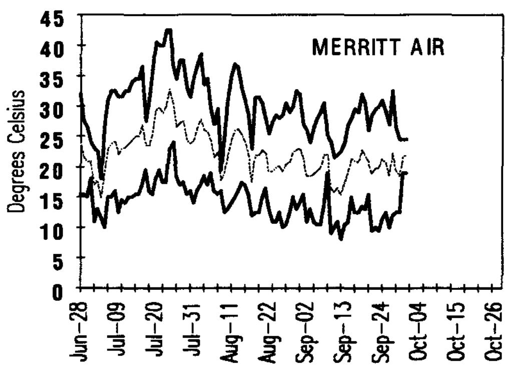

Fig. 4C. Daily maximum, minimum and mean air temperatures Merritt STP-1125079, 1994.

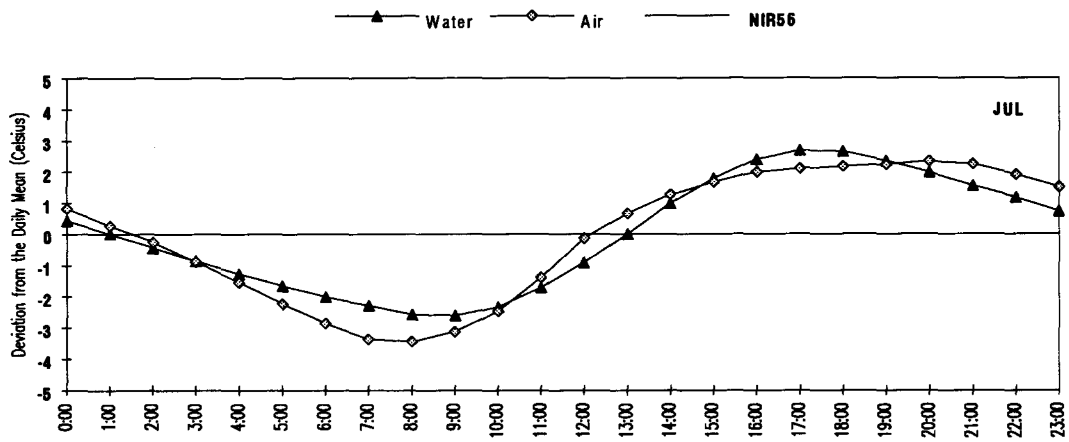

Fig. 5A. Average hourly deviations from the daily mean for air and water temperatures during July on the Nicola River at the Canford Bridge site (NIR56), 1994.

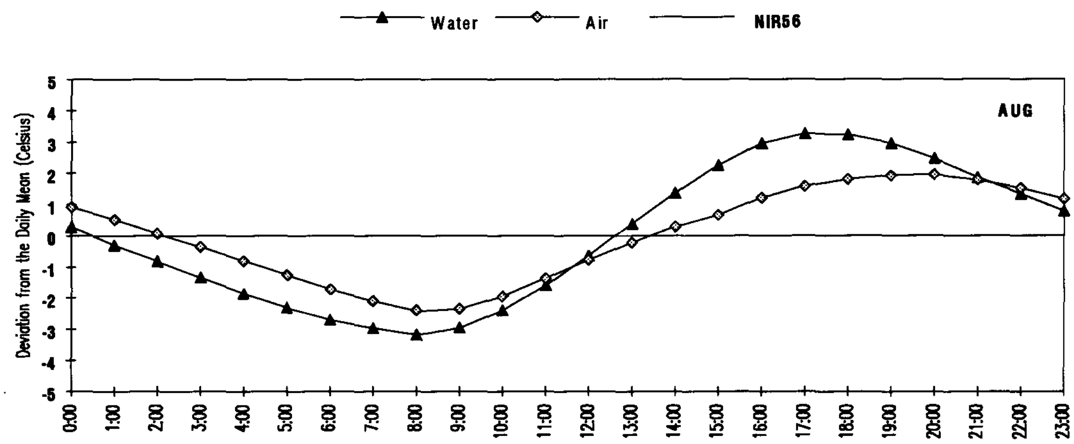

Fig. 5B. Average hourly deviations from the daily mean for air and water temperatures during August on the Nicola River at the Canford Bridge site (NIR56), 1994.

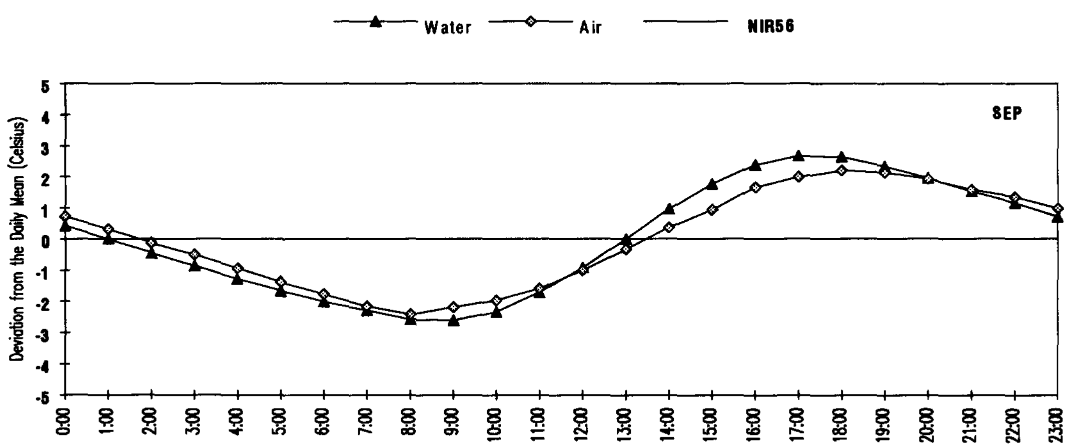

Fig. 5C. Average hourly deviations from the daily mean for air and water temperatures during September on the Nicola River at the Canford Bridge site (NIR56), 1994.

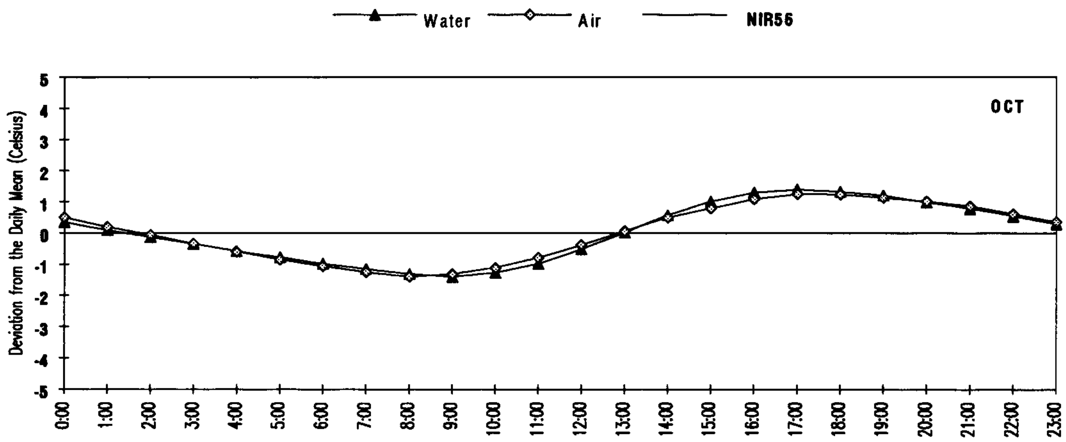

Fig. 5D. Average hourly deviations from the daily mean for air and water temperatures during October on the Nicola River at the Canford Bridge site NIR56, 1994.

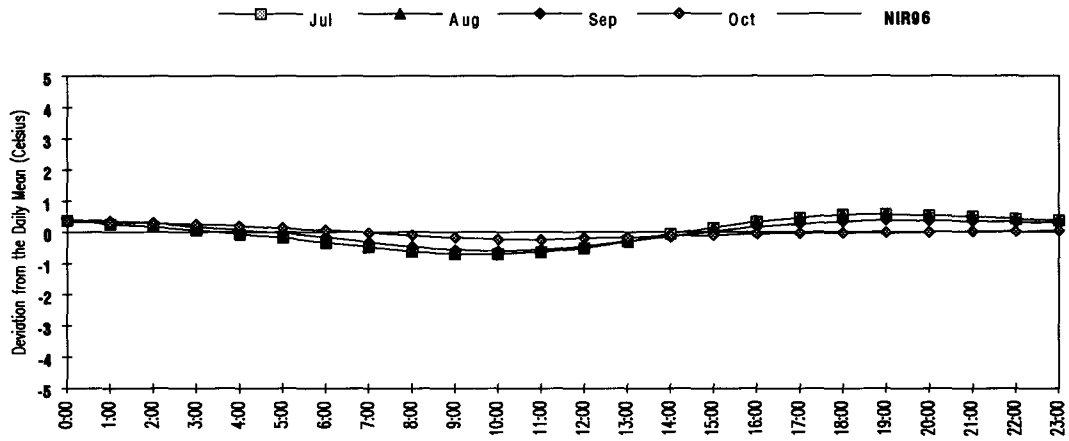

Fig. 6A. Average hourly deviations from the daily mean for water temperature per month at the Nicola Dam site (NIR96), 1994.

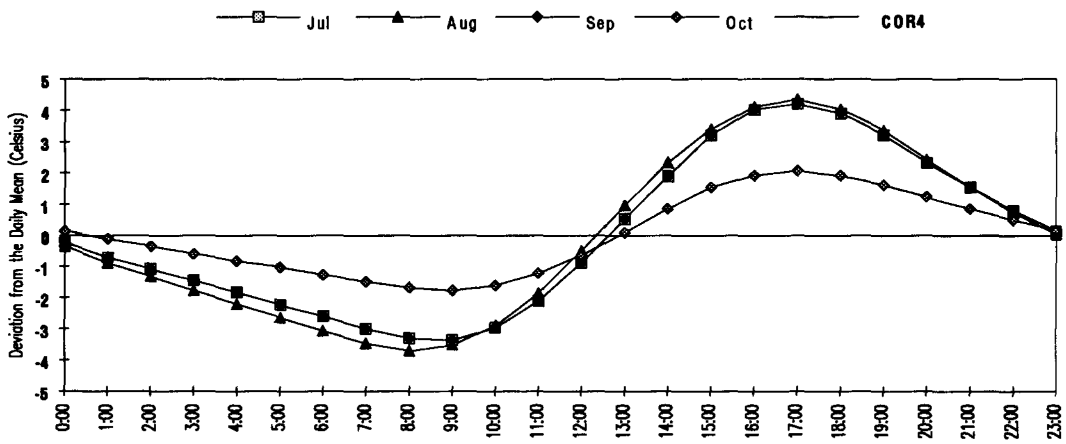

Fig. 6B. Average hourly deviations from the daily mean for water temperature per month at the Coldwater River site (COR4), 1994.

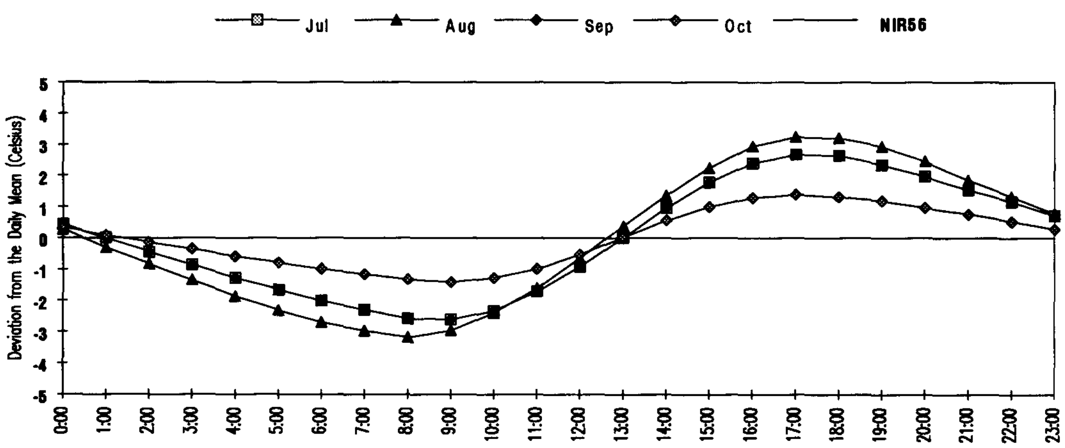

Fig. 6C. Average hourly deviations from the daily mean for water temperature per month at the Canford Bridge site (NIR56), 1994.

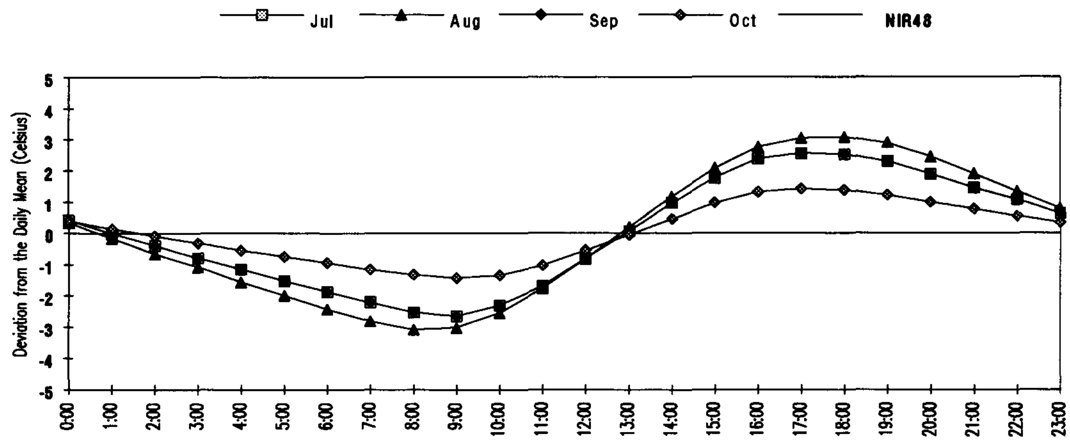

Fig. 6D. Average hourly deviations from the daily mean for water temperature per month at the Nicola/Spius site (NIR48), 1994.

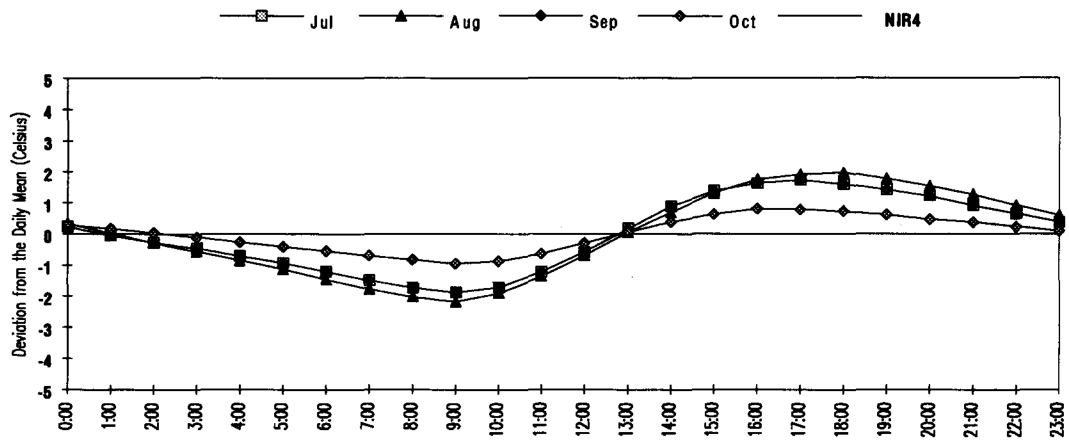

Fig. 6E. Average hourly deviations from the daily mean for water temperature per month at the Lower Nicola site (NIR4), 1994.

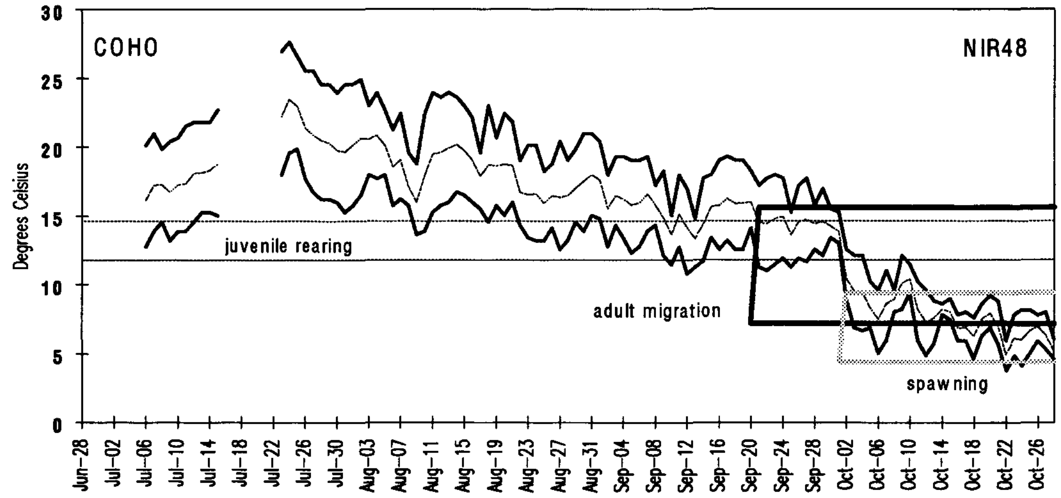

Fig. 7A. Daily maximum, minimum and mean water temperatures and recommended temperature ranges (Reiser and Bjornn 1979) during timing of the various life-cycle stages of Nicola coho stocks at the Nicola/Spius site (NIR48), 1994.

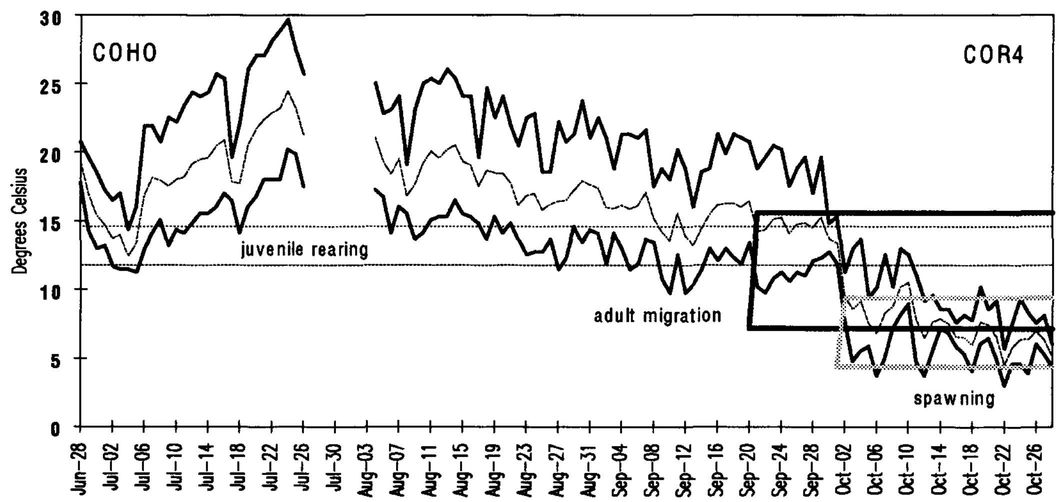

Fig. 7B. Daily maximum, minimum and mean water temperatures and recommended temperature ranges (Reiser and Bjornn 1979) during timing of the various life-cycle stages of Nicola coho stocks at the Coldwater River site (COR4), 1994.

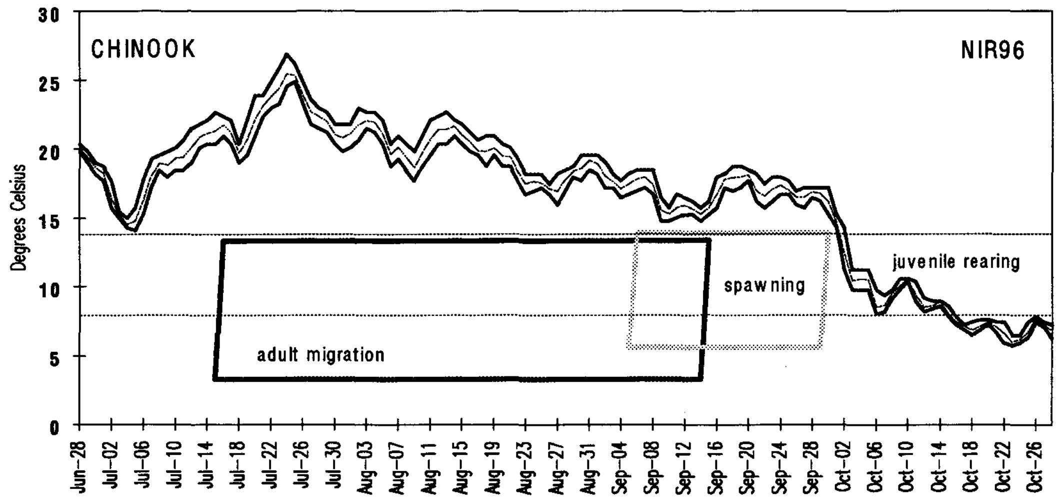

Fig. 7C. Daily maximum, minimum and mean water temperatures and recommended temperature ranges (Reiser and Bjornn 1979) during timing of the various life-cycle stages of Nicola chinook stocks at the Nicola Dam site (NIR96), 1994.

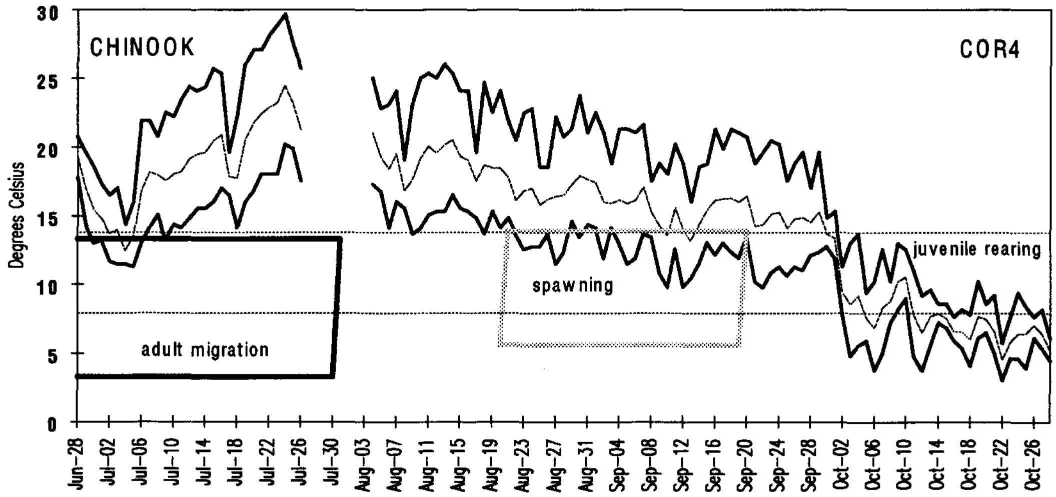

Fig. 7D. Daily maximum, minimum and mean water temperatures and recommended temperature ranges (Reiser and Bjornn 1979) during timing of the various life-cycle stages of Nicola chinook stocks at the Coldwater River site (COR4), 1994.

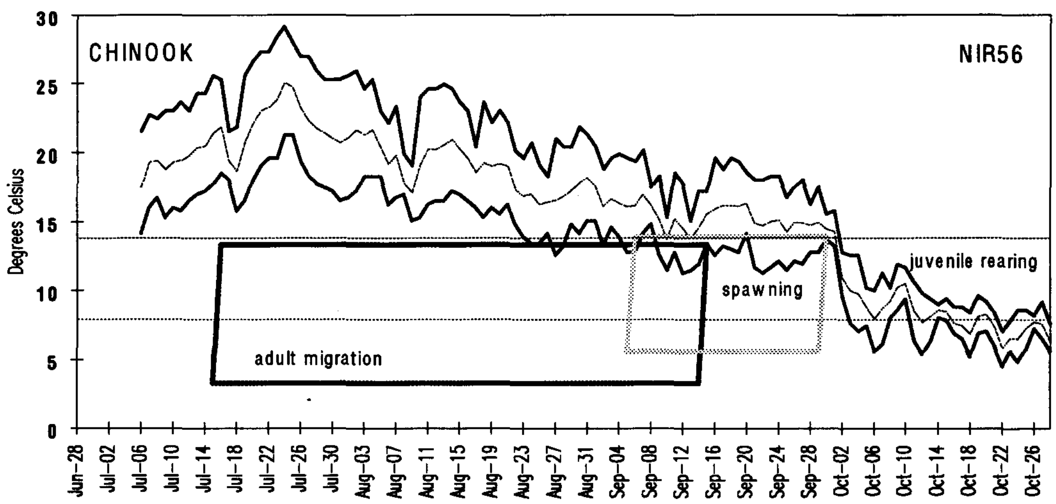

Fig. 7E. Daily maximum, minimum and mean water temperatures and recommended temperature ranges (Reiser and Bjornn 1979) during timing of the various life-cycle stages of Nicola chinook stocks at the Canford Bridge site (NIR56), 1994.

APPENDIX 1

Weekly Site Summaries

APPENDIX 1. Site summaries by week for the Nicola watershed, 1994. (N is number of available temperature records used in determining averages. Maximums and minimums are defined as the highest and lowest temperature peaks recorded during each week per site. Temperatures are in °C).

WEEK 1	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	56	57	168
AVG	16.20	14.78	18.25	16.61	16.46
MAX	19.25	21.93	22.74	20.95	22.52
MIN	14.05	11.26	14.11	12.74	12.33

AIR TEMPERATURE	MAX	32.50	WATERSHED	MAX	22.74	NIR56
(MERRITT)	MIN	10.00		MIN	11.26	COR4
	AVG	19.41		*(07/01/94 - 07/07/94)*		

9

WEEK 2	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	19.80	18.60	19.65	17.58	20.29
MAX	22.08	24.40	24.29	21.82	23.13
MIN	17.94	13.22	15.28	13.18	16.76

AIR TEMPERATURE	MAX	34.50	WATERSHED	MAX	24.40	COR4
(MERRITT)	MIN	12.50		MIN	13.18	NIR48
	AVG	23.70		*(07/08/94 - 07/14/94)*		

6

WEEK 3	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	43	168
AVG	21.40	20.25	21.03	18.99	21.24
MAX	23.91	27.10	27.31	23.63	26.05
MIN	18.99	14.13	15.76	15.01	16.27

AIR TEMPERATURE	MAX	40.50	WATERSHED	MAX	27.31	NIR56
(MERRITT)	MIN	15.50		MIN	14.13	COR4
	AVG	26.20		*(07/15/94 - 07/21/94)*		

3

WEEK 4	NIR96	COR4	NIR56	NIR48	NIR4
N	168	133	168	154	168
AVG	24.00	22.54	23.45	22.08	23.76
MAX	26.90	29.70	29.15	27.64	28.18
[illegible]	[illegible]	[illegible]	17.74	16.21	18.83

1

WEEK 5	NIR96	COR4	NIR56	NIR48	NIR4
N	168	37	168	168	168
AVG	21.52	21.42	21.23	20.26	21.50
MAX	22.98	25.05	25.93	24.90	25.04
MIN	19.80	17.27	16.49	15.25	18.04

AIR TEMPERATURE			WATERSHED			
(MERRITT)	MAX	38.50		MAX	25.93	NIR56
	MIN	14.00		MIN	15.25	NIR48
	AVG	25.47		*(07/29/94 - 08/04/94)*		

2

WEEK 6	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	19.89	18.72	19.10	18.31	19.17
MAX	22.08	25.38	24.61	23.94	24.07
MIN	17.68	13.68	15.04	13.63	15.06

AIR TEMPERATURE			WATERSHED			
(MERRITT)	MAX	35.00		MAX	25.38	COR4
	MIN	12.50		MIN	13.63	NIR48
	AVG	21.63		*(08/05/94 - 08/11/94)*		

5

WEEK 7	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	20.80	19.29	19.90	19.29	20.11
MAX	22.68	26.06	24.93	23.94	23.75
MIN	18.72	13.68	15.28	14.54	16.27

AIR TEMPERATURE	MAX	37.00	WATERSHED	MAX	26.06	COR4
(MERRITT)	MIN	12.00		MIN	13.68	COR4
	AVG	23.30		*(08/12/94 - 08/18/94)*		

4

WEEK 8	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	18.56	17.22	17.80	17.38	18.50
MAX	20.92	24.08	23.04	22.41	22.52
MIN	16.67	12.56	13.43	13.18	14.82

AIR TEMPERATURE	MAX	31.50	WATERSHED	MAX	24.08	COR4
(MERRITT)	MIN	11.00		MIN	13.18	NIR48
	AVG	20.83		*(08/19/94 - 08/25/94)*		

7

WEEK 9	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	18.11	17.07	17.23	17.04	18.11
MAX	19.53	23.76	21.85	20.95	21.63
MIN	15.94	11.47	12.55	12.52	14.35

AIR TEMPERATURE	MAX	32.50	WATERSHED	MAX	23.76	COR4
(MERRITT)	MIN	10.00		MIN	11.47	COR4
	AVG	21.46		*(08/26/94 - 09/01/94)*		

8

WEEK 10	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	17.60	16.07	16.35	16.02	16.60
MAX	18.99	21.64	20.14	19.29	19.92
MIN	16.43	11.47	12.77	12.30	14.12

WEEK 11	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	15.56	14.36	14.62	14.42	15.26
MAX	16.67	20.21	18.52	18.23	18.83
MIN	14.75	9.80	11.26	10.81	12.33

AIR TEMPERATURE *(MERRITT)* MAX 28.00 MIN 8.00 AVG 17.41

WATERSHED MAX 20.21 COR4 MIN 9.80 COR4

(09/09/94 - 09/15/94)

12

WEEK 12	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	17.42	15.70	15.74	15.51	16.58
MAX	18.72	21.34	19.59	19.29	19.64
MIN	15.70	9.80	11.26	11.02	12.77

AIR TEMPERATURE *(MERRITT)* MAX 32.00 MIN 9.50 AVG 20.86

WATERSHED MAX 21.34 COR4 MIN 9.80 COR4

(09/16/94 - 09/22/94)

11

WEEK 13	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	16.84	14.85	14.83	14.50	15.17
MAX	17.94	20.49	18.26	17.97	17.52
MIN	15.70	10.63	11.47	11.23	12.77

AIR TEMPERATURE	MAX	32.50	WATERSHED	MAX	20.49	COR4
(MERRITT)	MIN	9.50		MIN	10.63	COR4
	AVG	20.10		*(09/23/94 - 09/29/94)*		

13

WEEK 14	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	11.87	9.83	10.88	10.47	11.10
MAX	17.17	15.31	15.76	15.49	16.51
MIN	7.97	3.76	5.58	5.01	5.91

AIR TEMPERATURE	MAX	N/A	WATERSHED	MAX	17.17	NIR96
(MERRITT)	MIN	N/A		MIN	3.76	COR4
	AVG	N/A		*(09/30/94 - 10/06/94)*		

14

WEEK 15	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	9.32	8.56	9.01	8.71	8.61
MAX	10.57	13.00	11.90	12.08	11.46
MIN	8.16	3.76	5.40	4.83	5.54

AIR TEMPERATURE	MAX	N/A	WATERSHED	MAX	13.00	COR4
(MERRITT)	MIN	N/A		MIN	3.76	COR4
	AVG	N/A		*(10/07/94 - 10/13/94)*		

15

WEEK 16	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	7.51	7.10	7.92	7.37	7.63
MAX	8.95	10.21	9.61	9.18	9.59
MIN	6.44	4.11	5.22	4.65	5.36

AIR TEMPERATURE	MAX	N/A	WATERSHED	MAX	10.21	COR4
(MERRITT)	MIN	N/A		MIN	4.11	COR4
	AVG	N/A		*(10/14/94 - 10/20/94)*		

16

WEEK 17	NIR96	COR4	NIR56	NIR48	NIR4
N	168	168	168	168	168
AVG	6.75	6.19	7.00	6.30	6.79
MAX	7.77	9.40	9.21	8.78	8.79
MIN	5.70	3.05	4.50	3.76	4.82

AIR TEMPERATURE	MAX	N/A	WATERSHED	MAX	9.40	COR4
(MERRITT)	MIN	N/A		MIN	3.05	COR4
	AVG	N/A		*(10/21/94 - 10/27/94)*		

17