Environmental datasets from the Stuart-Takla Fish Forestry Interaction Project: Baptiste watershed from 1995 to 2009

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ABSTRACT

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This report outlines the biological and physical data collected in the headwater streams of the Baptiste watershed as part of the Stuart-Takla Fish-Forestry Interaction Project. The goal of this research was to build a knowledge base on how forestry activities influence stream ecosystems in the interior of British Columbia. This report provides summaries of a subset of the studies conducted and data collected in the Baptiste watershed between 1995 and 2009. The key studies outlined within this report cover stream water temperature, groundwater temperature, aquatic macroinvertebrates, stream nutrients and water quality, stream periphyton, stream sediment, and canopy cover. The aim of this report is to provide context and information that allows researchers to use previously collected data and results to better understand the effects of forest harvest on headwater stream ecosystems.

RÉSUMÉ

Cunningham, D.S., Braun, D.C., Herunter, H., & Macdonald, J.S. 2024. Environmental datasets from the Stuart-Takla Fish-Forestry Interaction Project: Baptiste watershed from 1995 to 2009. Can. Tech. Rep. Fish. Aquat. Sci. 3585: v + 51 p.

Le présent rapport décrit les données biologiques et physiques recueillies dans les cours d'eau d'amont du bassin versant Baptiste dans le cadre du Projet D'Interaction Poisson-Foresterie Stuart-Takla. L'objectif de cette recherche était d'établir une base de connaissances sur la façon dont les activités forestières influencent les écosystèmes des cours d'eau de l'intérieur de la Colombie-Britannique. Ce rapport fournit des résumés d'un sous-ensemble d'études effectuées et de données recueillies dans le bassin versant de la Baptiste entre 1995 et 2009. Les principales études présentées dans ce rapport portent sur la température de l'eau des cours d'eau, la température des eaux souterraines, les macroinvertébrés aquatiques, les éléments nutritifs, le périphyton et les sédiments dans les cours d'eau, la qualité de l'eau des cours d'eau et la couverture de la canopée. Le but de ce rapport est de fournir un contexte et des informations qui permettent aux chercheurs d'utiliser les données précédemment recueillies et les résultats déjà obtenus pour mieux comprendre les effets de l'exploitation forestière sur les écosystèmes des cours d'eau d'amont.

INTRODUCTION

The objective of this report is to describe and summarize a large subset of the data collected in the Baptiste watershed as part of the Stuart-Takla Fish-Forestry Interaction Project (STFFIP). We aim to provide enough information so that the data can be used by researchers to better understand the effects of forest harvest on headwater streams. We begin by describing the characteristics of the Baptiste watershed and its headwater tributaries, as well as the study design used in the Baptiste headwater experiment. We then present a conceptual model that links forestry activities to different physical and biological indicators that were monitored in the Baptiste studies. Finally, we present the key studies and summarized data plots from the Baptiste headwater experiment. Data summaries are organized by response variable and experimental treatment (Table 1). Data are presented and the effects are described; the specific analyses used to test the effects of forest harvest and road crossings can be found in the associated primary papers referenced throughout this report.

The Stuart-Takla Fish-Forestry Interaction Project began in 1990 to build a knowledge base of the interactions between forest harvesting and aquatic habitat in the interior of British Columbia (BC) (Macdonald et al. 1992). At the time this project began, much of the knowledge on the relationship between forest harvesting in BC and productivity in aquatic habitats previously came from research in coastal ecosystems (Tschaplinski and Pike 2017). Differences in climate, hydrology, geology, vegetation, and aquatic species in interior BC required research into how aquatic ecosystems in the interior respond to forest harvesting (MacIsaac 2003).

The STFFIP was a DFO-led interdisciplinary project involving multiple researchers and agencies. Studies included the impacts of forest harvest practices on physical factors such as water temperature, sediment, flow, and water chemistry, and biological factors such as benthic invertebrate communities and Sockeye salmon (*Oncorhynchus nerka*) habitat use and fish production. The project was also intended to be long-term, with data collected over decades. This was all meant to elucidate the biological outcomes as a result of changes in physical factors that are associated with forest harvesting in the interior of BC (Macdonald and Herunter 1998) (Figure 1).

The STFFIP was separated into two study types, small stream studies and main creek studies. The focus of this report is on the small stream studies which consists of the data collected as part of the forest harvest experiment carried out in the Baptiste watershed between 1995 and 2009. The objective of the small stream studies was to understand the impacts of experimental forest harvest on headwater streams. The new Forest Practices Code of British Columbia Act was being implemented in 1995 and included variable retention riparian buffers on certain stream types. At this time the effect of these buffers on small interior stream ecosystems was unknown, and testing the efficacy of these variable retention buffers was a focus of the Baptiste studies (Macdonald et al. 2003a). The study design included both spatial and temporal controls (e.g., Before-After-Control-Impact - BACI design). Study streams were selected to have similar physical and biological characteristics and were monitored before and after forest harvest.

The most recent data collected by the STFFIP for the Baptiste watershed studies were in 2009 (water temperature), and the most recent analysis included data from 1995 to 2003 and was published in 2004 (Herunter et al. 2004). Published studies showed the impacts to stream temperature were immediate and persisted through the time period of the most recent analyses, while impacts to sediment, nutrients, and invertebrate communities were immediate yet showed evidence of recovery to pre-harvest conditions after two or three years.

This report aims to outline previous studies and provide existing data to allow this work to be revisited, analyzed, and carried forward. There is a need for long-term studies of forest harvest, and leveraging data from past research efforts is an opportunity to better understand long-term impacts and recovery of stream ecosystems from forest harvest. For example, future work could investigate the potential for long-term impacts and potential recovery of stream temperatures. At the time this report was written there had been no further forest harvest in any of the Baptiste headwater streams. This provides a unique opportunity to extend the original BACI study design to glean valuable information about the riparian treatments applied in the Baptiste watershed without the confounding effects of other forest harvest activities.

Table 1: Summary of the key studies conducted and datasets collected in the Baptiste watershed between 1995 and 2009. BACI is Before-After-Control-Impact, CI is Control-Impact. Coordinates of sampling stations can be found in Appendix A. Contact douglas.braun@dfo-mpo.gc.ca for data requests.

Section	Response Variable	Treatment	Study Design	Stream	Sample Years	Reference
1.0	Stream temperature	1.1 Riparian buffer	BACI	B1	1995-2009	Macdonald et al. 2003a; Macdonald et al. 2003b; Herunter et al. 2004
				B2	1995-2009	
				B3	1995-2009	
				B4	1995-2009	
				B5	1995-2009	
				B6	1995-2009	
	Stream temperature	1.2 Road crossing right-of-way	BACI	B3	1997-2003	Herunter et al. 2003
				B4	1997-2003	
				B5	1997-2003	
	Stream temperature	1.3 Downstream recovery	CI	B3	1997-2003	Moore et al. 2003; Story et al. 2003
				B4	1997-2003	
				B5	1997-2003	
2.0	Groundwater temperature	2.0 Riparian buffer	CI	B3	1996-2005	Macdonald et al. 2003a
				B4	1997-2007	
				B5	1996-2005	
3.0	Aquatic macroinvertebrates	3.0 Riparian buffer	BACI	B3	1996-1999	Herunter et al. 2004; Patterson et al. 2003
				B4	1996-1999	
				B5	1996-1999	
4.0	Nutrients and water quality	4.0 Riparian buffer	BACI	B3	1996-1999	Herunter et al. 2004
				B4	1996-1999	
				B5	1996-1999	
				B6	1996-1999	
5.0	Periphyton	5.0 Riparian buffer	CI	B3	1999	
				B4	1999	
				B5	1999	

Section	Response Variable	Treatment	Study Design	Stream	Sample Years	Reference
				BEAST	1999	
6.0	Stream sediment	6.1 Riparian buffer	BACI	B3	1996-2001	Beaudry 2003; Macdonald et al. 2003c
				B4	1996-2001	
				B5	1996-2001	
		6.2 Road crossing right-of-way	BACI	B3	1996-2001	Herunter et al. 2003
				B4	1996-2001	
				B5	1996-2001	
7.0	Canopy density	7.0 Riparian buffer	CI	B3	1997-2005, 2006, 2009	Macdonald et al. 2003b
				B4	1997-2005, 2009	
				B5	1997-2005, 2007, 2009	

Conceptual Model of Physical and Biological Effects

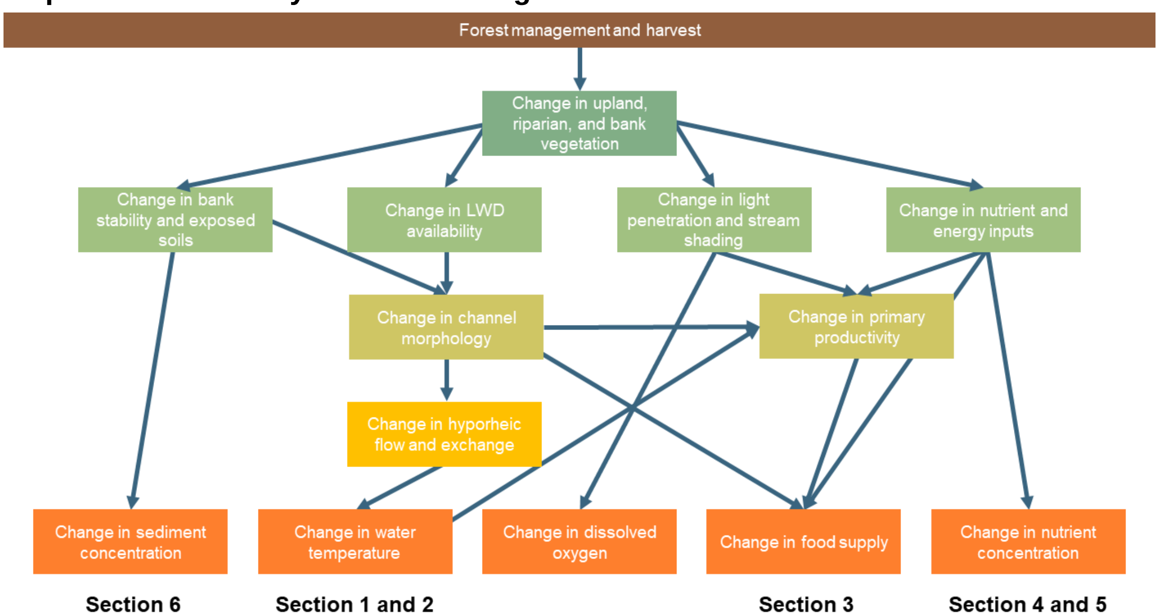

Figure 1: A conceptual model showing the potential impacts of forest harvesting on aquatic habitat studied in the Baptiste headwater experiment. The green and yellow boxes represent the potential stressors that result from forest harvesting, and orange boxes represent the endpoints of the effects on fish habitat. The section that addresses each endpoint is indicated by the back labels.

METHODS

Study Sites

The Stuart-Takla Fish-Forestry Interaction Project (STFFIP) Baptiste headwater experiment consisted of six headwater streams in the Hogem Range of the Omineca Mountains that form Baptiste Creek (Figure 2). This watershed is part of the Stuart-Takla drainage, which is the northernmost drainage of the Fraser basin. The study area is in the Sub-boreal Spruce biogeoclimatic zone. The area receives around 500 mm of precipitation each year, of which 160 to 280 mm falls as snow. The forests are dominated by hybrid white spruce (*Picea engelmannii* × *Picea glauca*), subalpine fir (*Abies Lasiocarpa*), and lodgepole pine (*Pinus contorta*) (Macdonald and Herunter 1998).

The six main Baptiste study streams are first order streams with mean reach gradients that range between 3 and 30% and are found at an average elevation of 980 m with west, northwest, and north aspects (Table 2). Reach gradients tended to decrease with elevation (Storey et al. 2003). Average daily water temperatures in the streams range from 0 to 13°C.The watershed is strongly influenced by underlying bedrock; the small amount of surface material in the watershed consists of basal till that is predominantly silty sand (Beaudry 2003). These small headwater streams are fishless upstream of a logging access road, with rainbow trout (*Oncorhynchus mykiss*) found in the lower portions of the streams (Patterson et al. 2003). Study stations were established in Baptiste East (BEAST) in 1999. Issues with data collection led to all eight study stations (BEAST 0-7) being discontinued by the end of 1999.

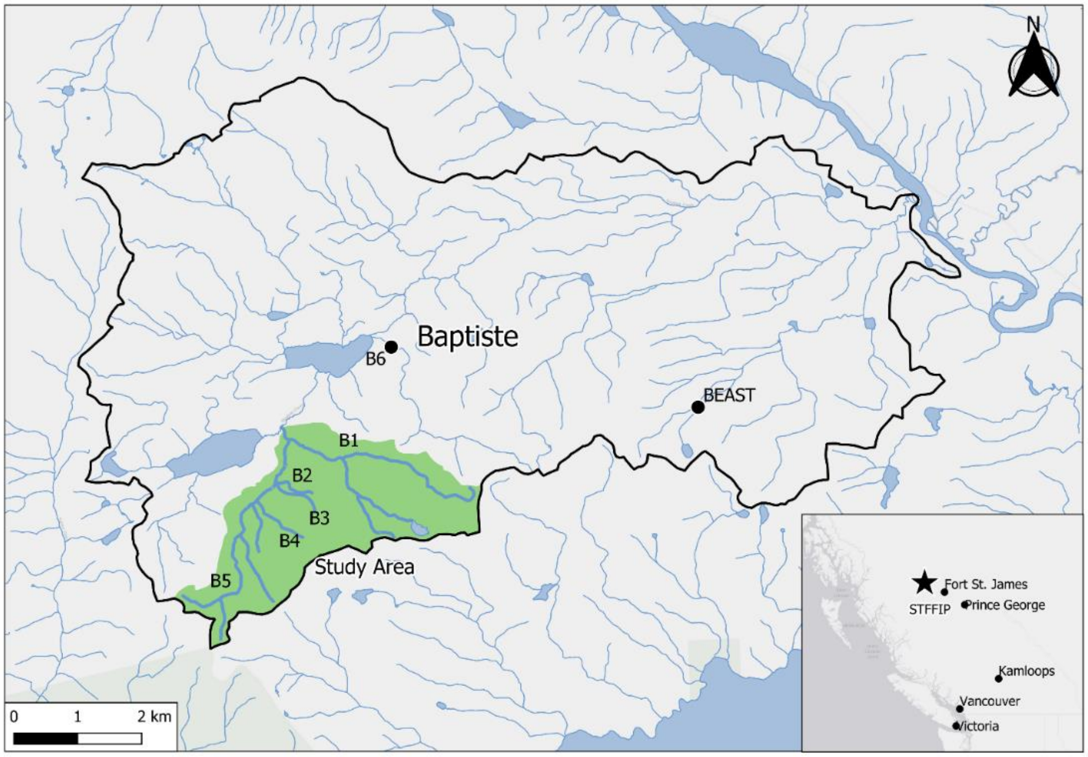

Figure 2: Map of the Baptiste component of the Stuart-Takla Fish-Forestry Interaction Project. The Baptiste watershed is outlined in black on the main map, with the study area highlighted in green. The locations of streams B1 – B6 and Baptiste East (discontinued) are labelled. The location of the Baptiste watershed within British Columbia is indicated by the star in the inset.

Table 2: Physical information on the main study creeks in the Baptiste watershed. Adapted from Macdonald et al. (2003b).

Stream	Bank-full width (m)	Watershed size (ha)	% Watershed harvested	Gradient (degrees)	Elevation (m)	Aspect	Riparian Treatment
B1	2.8	313	6	11	980	W	30 m high-retention
B2	1.0	18	89	12	980	NW	Patch-retention
B3	0.6	43	38	26	980	NW	20 m high-retention
B4	0.9	48	0	30	980	NW	Unharvested control stream
B5	1.4	150	40	7	980	N	20 m low-retention
B6	3.2	210	0	5	900	NW	Unharvested upstream control site

Study Design

Experimental Treatments

The small stream studies in the Baptiste watershed examined the impacts of vegetation clearing associated with forestry on stream response variables. Specifically the effects of: 1) different riparian vegetation retention and buffer widths, 2) road crossing right-of-way widths, and 3) undisturbed forested reaches on mitigating upstream impacts. Riparian vegetation buffer width treatments applied were 30 m and 20 m. Three retention treatments were applied: 1) High-retention was removal of only large merchantable timber with a diameter greater than 30 cm at breast height (DBH) within 20 m or 30 m of the streambank, 2) low-retention, was the removal of all merchantable timber with a diameter greater than 15 cm DBH for pine or 20 cm DBH for spruce/balsam, and 3) “patch-retention” was the combined treatment of high retention along the lower 60% of the stream and complete removal of all riparian vegetation in the upper 40% (Figure 3). The buffer width and retention treatments were applied together making 4 different combinations of buffer width and retention: 1) B1 30 m high-retention, 2) B2 20 m patch-retention, 3) B3 20 m high-retention, and 4) B5 20 m low-retention (Table 2). Between 6 and 89% of the treatment watersheds were harvested and control streams were not subject to harvest (Table 2).

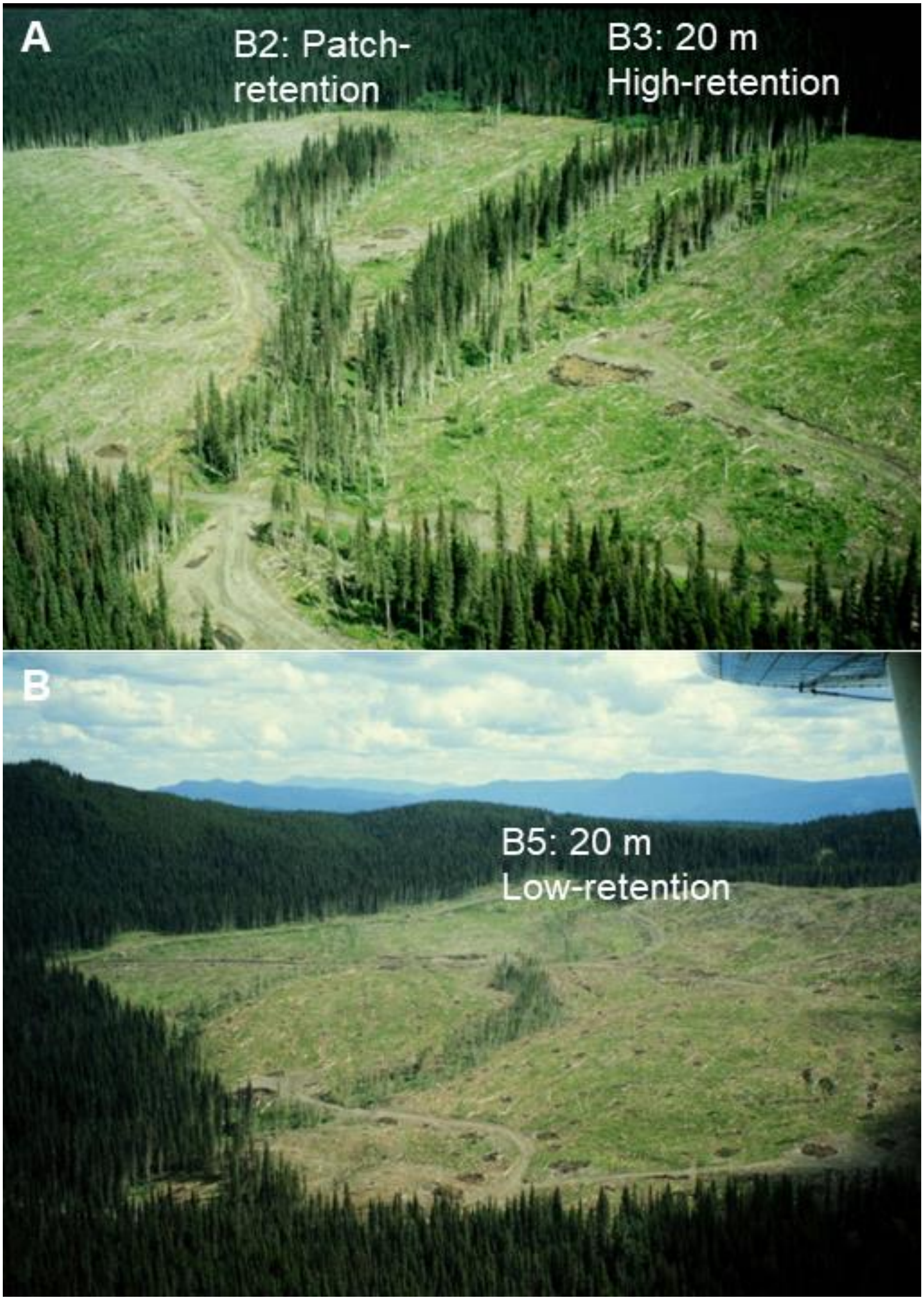

Figure 3: Photos of Baptiste study sites A) B2, B3, and B) B5 showing patch retention, 20 m high-retention and 20 m low-retention riparian buffer treatments, respectively.

Road right-of-ways are areas adjacent to a road that are cleared of all vegetation for road construction and maintenance. Right-of-way crossing treatments consisted of clearing 20 m, 30 m, and 50 m of the roadside vegetation. When the right-of-way intersected with streams it led to substantial reduction of riparian vegetation upstream and downstream of the road crossing and culvert.

Sample locations greater than 150 m downstream of harvested areas and road crossings were used to examine if and how temperature, periphyton, and aquatic macroinvertebrates recovered as the stream flowed through undisturbed forests with intact riparian areas.

Spatial-Temporal Replication of Treatments and Controls

A Before-After- Control-Impact (BACI) design was used as the general study design for the Baptiste headwater experiments. Sampling began in July of 1995, 18 months before the forest plots were harvested in the winter of 1996. Control sites were established upstream of harvested areas and road crossings as well as in adjacent streams that were free from any forest harvest activity and road building. Most studies followed the BACI design; however there were some studies that began after the forest harvest in 1996 where only a control impact (CI) design was possible (Table 1).

PROJECT SUMMARIES

1.0 Stream Temperature

Water temperature was monitored as a primary response variable to impacts of forest harvest. The first temperature loggers were installed in July of 1995 to collect pre-impact data (streams B1-B6) for two clearcuts that were harvested in the winter of 1996-1997. In addition to the two clearcuts, a new road was constructed in the winter of 1996, and monitoring these impacts resulted in three main studies that examined: 1) the effects of different riparian buffer widths and composition; 2) the effects of road crossing right-of-way widths; and 3) the downstream recovery of stream temperatures as water passed though stream reaches with undisturbed riparian areas. Stream temperature was the most extensively sampled variable with a total of 25 unique monitoring locations. While most stations had been removed by 2005, data collection continued for 8 out of the 25 stations until 2009, most of these stations were located in the downstream section of the harvested areas or below road crossings (Table 3 and Figure 4). At each station, stream temperatures were recorded hourly using Vemco Minilogs, and readings have an accuracy of ±0.2ºC. Stream temperature readings below 0ºC were assumed to be 0ºC and adjusted accordingly.

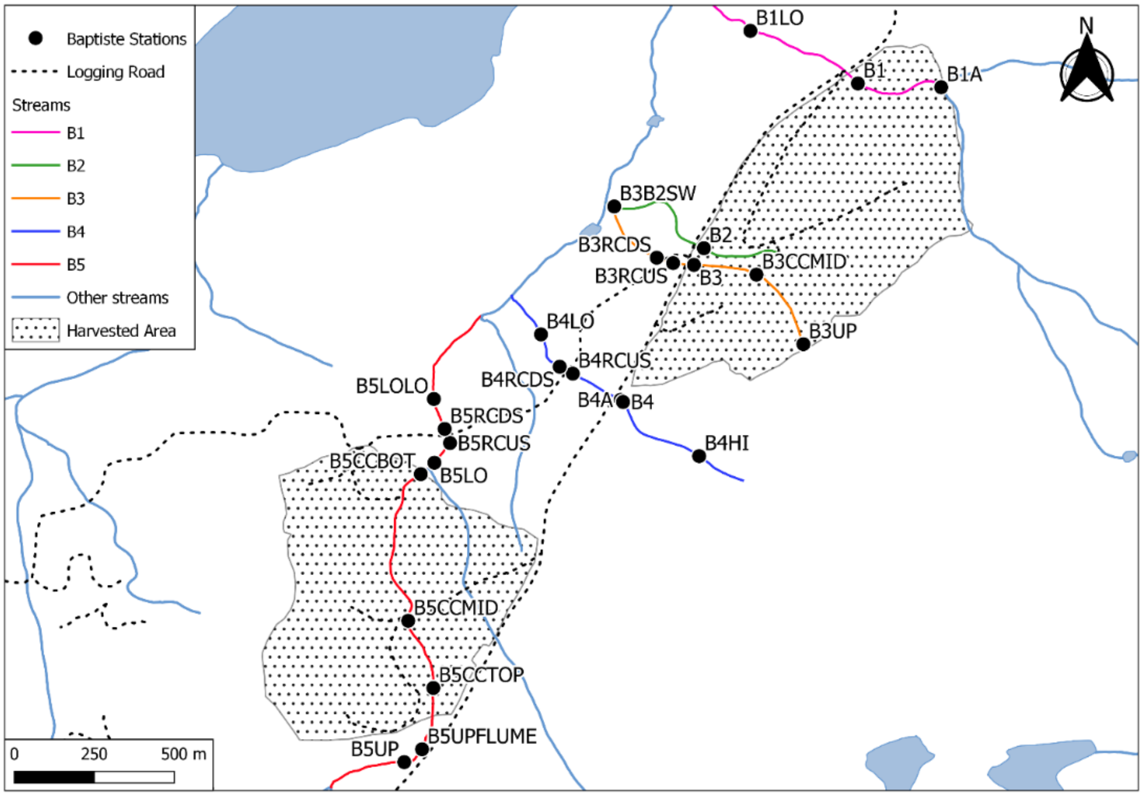

Figure 4: Map of the main study area of the Baptiste watershed. Focal streams B1-B5 are colour coded, and each temperature monitoring station is marked with a black point. Streams B6 and BEAST are not shown.

1.1 Riparian Buffer Width and Retention

Several studies (Herunter et al. 2004; Macdonald et al. 2003a; Macdonald et al. 2003b) examined how different riparian buffer treatments influence stream temperature (Table 3). The different treatments consist of different stream buffer widths (30 m and 20 m: high-retention, 20 m: low-retention, and 20 m: patch-retention). High-retention riparian buffers and spatial controls are described by Herunter et al. (2004) and Macdonald et al. (2003c). The pre-impact monitoring also offers temporal controls. Loggers provided hourly temperature readings beginning as early as July 1995 and continuing as late as September 2009. Temperature data were recorded for 18 months before harvesting occurred in the winter of 1996. Inconsistencies in the data due to logger failure and dewatering resulted in the removal of data from upstream of the cutblocks on B1, B2, and a portion of B3.

Stream temperatures increased in all treatment sites after harvests occurred. The patch-retention treatment had the largest increase in maximum stream temperatures, followed by the low-retention and high-retention, however the temperature moderating impact of the high-retention treatment diminished with time as several major windthrow events exposed the stream to more sunlight. The upstream control sites and control streams did not experience any notable changes in temperature during this period (Figure 5 and Figure 6). The treatment sites had greater diurnal temperature ranges than the control sites. The treatment sites experienced higher temperatures in the spring and summer, and slightly lower temperatures in the fall and winter (Figure 7-10). Maximum mean weekly temperatures increased by at least 4ºC in each of the treatment streams in the first seven years after harvesting.

Table 3: Water temperature logger stations for riparian buffer treatment, sampling dates and associated riparian buffer treatment.

Stream	Station	Installation Date	Removal Date	Treatment
B1	B1	1995-07-28	2009-09-17	30 m high-retention
	B1AN	1995-07-28	2003-05-24	Upstream control
	B1AS	1995-07-28	2003-05-24	Upstream control
	B1LO	1996-07-13	2005-09-26	30 m high-retention
B2	B2	1995-07-28	2009-09-17	20 m patch-retention
B3	B3	1995-07-28	2009-09-17	20 m high-retention
	B3B2	1996-07-13	2004-10-05	20 m high-retention
	B3B2SW	2004-10-05	2005-09-06	20 m high-retention
	B3CCMID	1999-06-06	2001-09-27	20 m high-retention
	B3UP	1996-09-28	2002-08-09	Upstream control
B4	B4	1995-07-28	2009-09-17	Unharvested control
	B4A	2005-09-26	2009-09-17	Unharvested control
	B4Hi	2004-05-20	2005-09-26	Unharvested control
	B4LO	1997-06-15	2005-09-06	Unharvested control
B5	B5CCBOT	1999-06-05	2002-08-09	20 m low-retention
	B5CCMID	1999-06-06	2001-09-27	20 m low-retention
	B5CCTOP	1999-07-11	2001-06-12	20 m low-retention
	B5LO	1995-07-28	2009-09-17	20 m low-retention
	B5LOLO	1997-06-15	2005-08-10	20 m low-retention
	B5UP	1995-07-28	2009-09-17	Upstream control
	B5UPFLUME	1999-07-11	2002-08-09	Upstream control
B6	B6	1995-07-28	2009-09-17	Unharvested control
BEAST	BEASTST4	1999-01-08	1999-12-08	NA

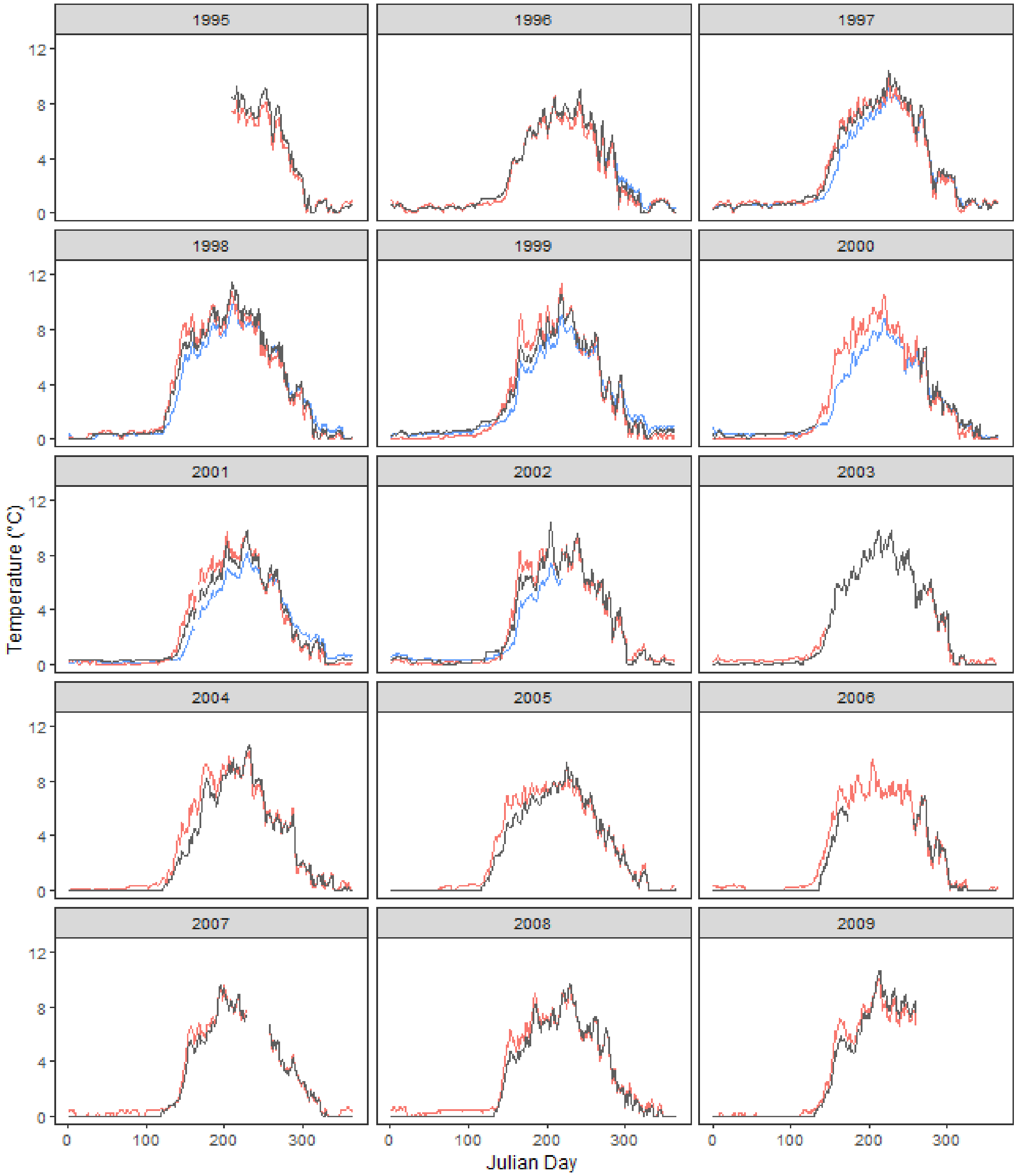

Figure 5: Mean daily stream temperatures for B3, the 20 m high-retention treatment stream. The blue line is for temperature at the upstream control station, the red line is for temperature at the downstream treatment station, and the grey line is for temperature at B4, the unharvested control stream.

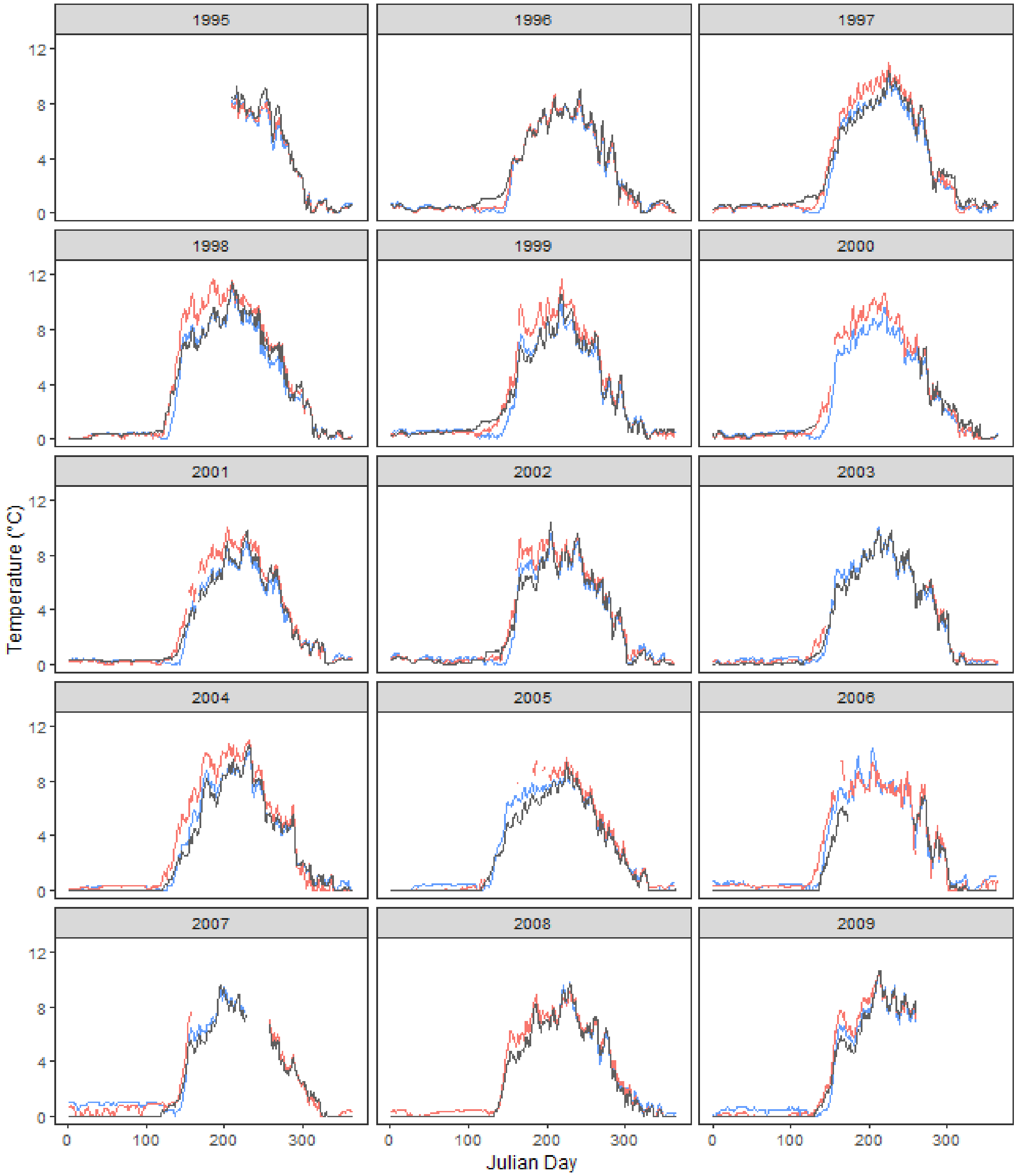

Figure 6: Mean daily stream temperatures for B5, the 20 m low-retention treatment stream. The blue line is for temperature at the upstream control station, the red line is for temperature at the downstream treatment station, and the grey line is for temperature at B4, the unharvested control stream.

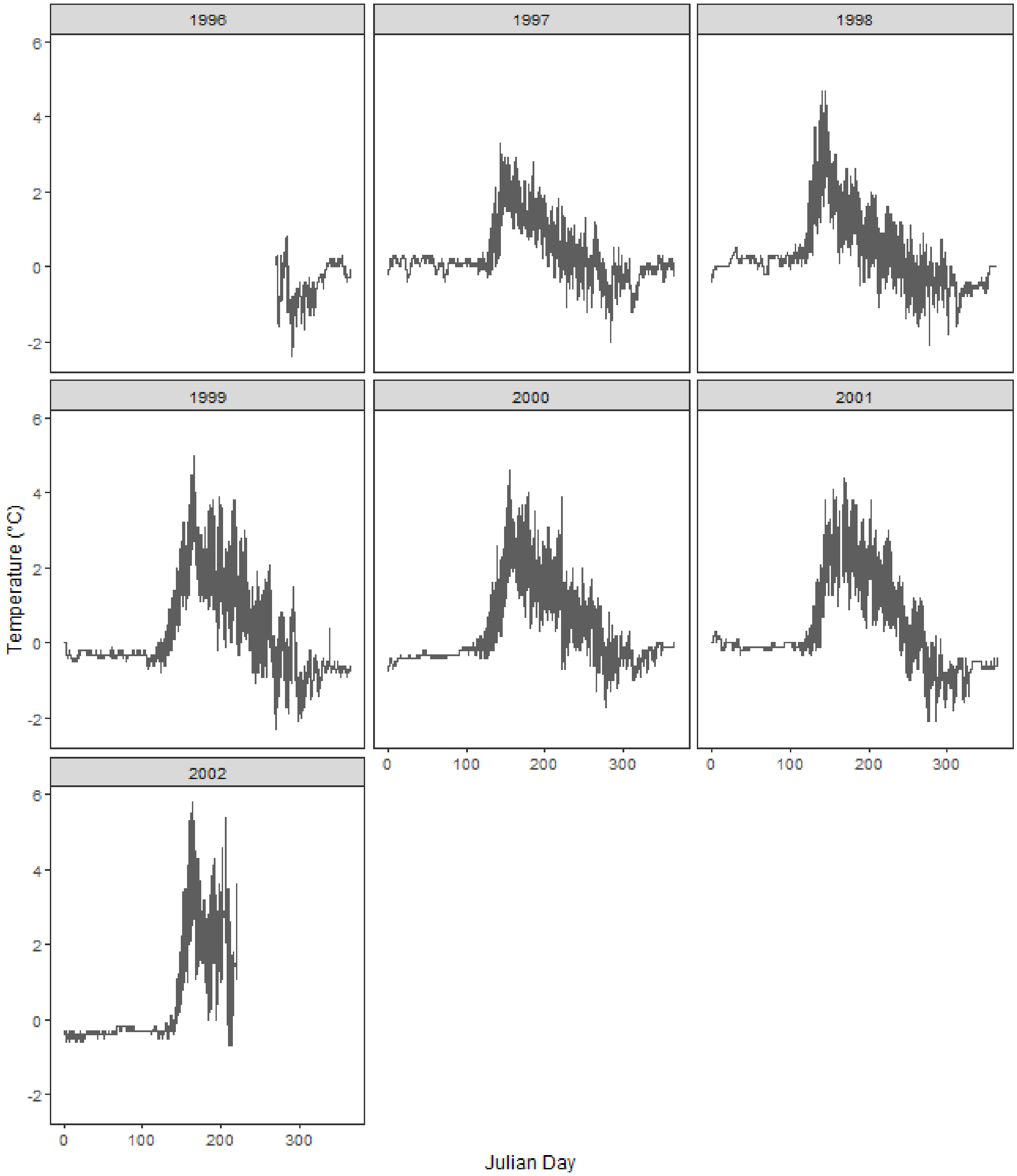

Figure 7: Hourly stream temperature difference at the downstream treatment station relative to the upstream control station in B3 (B3 minus B3UP), the 20 m high-retention treatment stream.

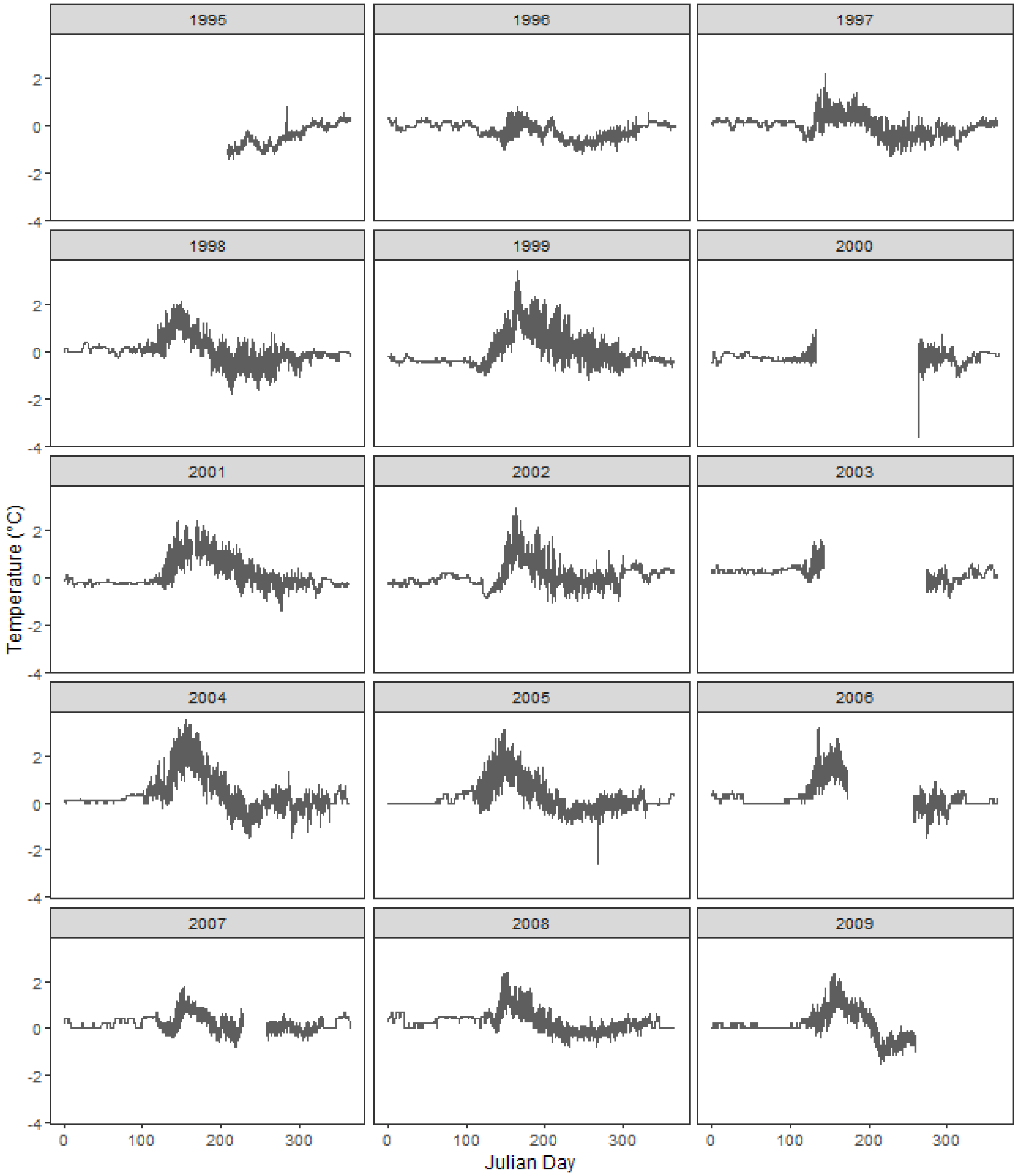

Figure 8: Hourly stream temperature difference at the downstream treatment station in B4, the unharvested control stream, relative to B3, the 20 m high-retention treatment stream.

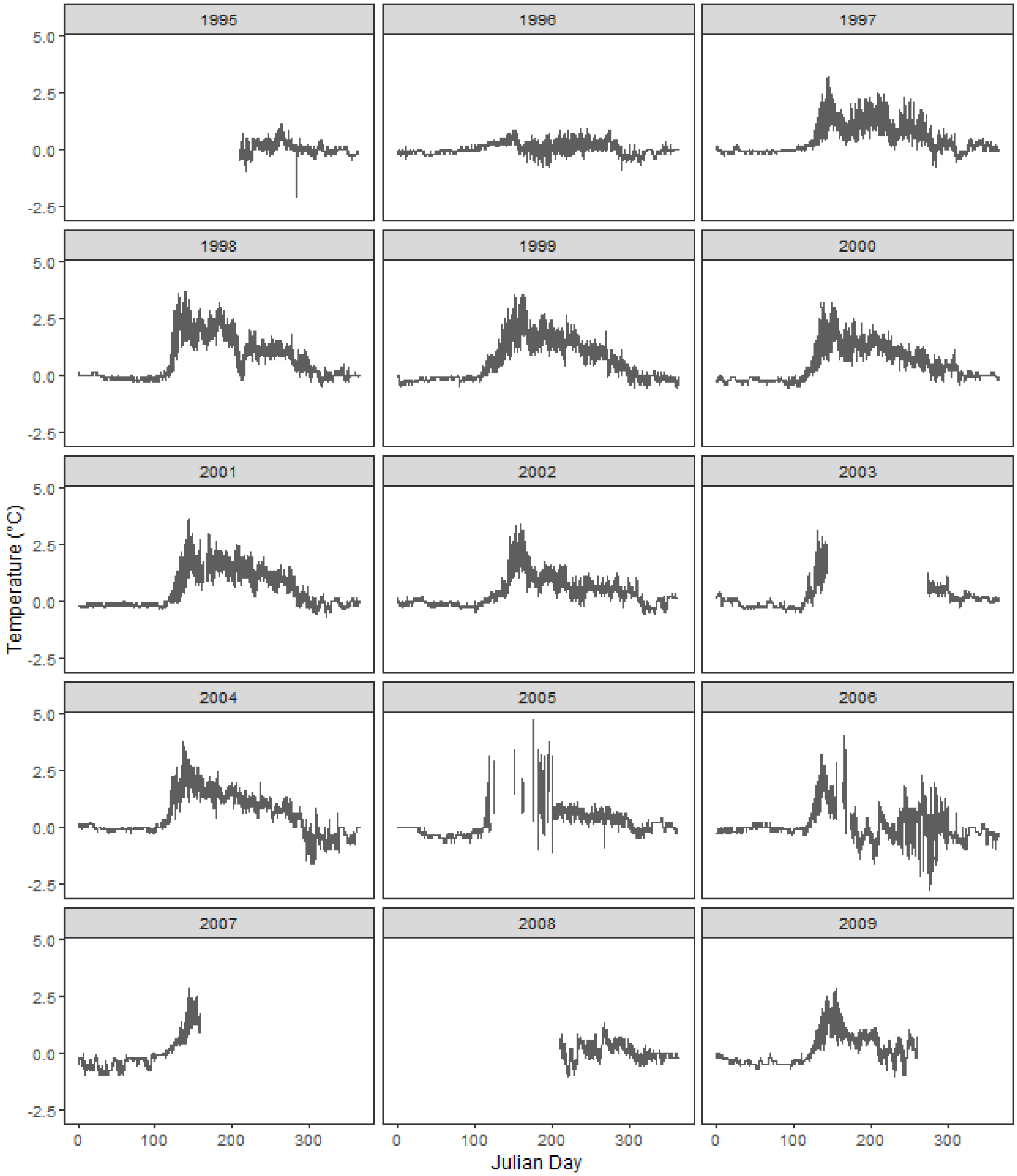

Figure 9: Hourly stream temperature difference at the downstream treatment station relative to the upstream control station in B5, the 20 m low-retention treatment stream.

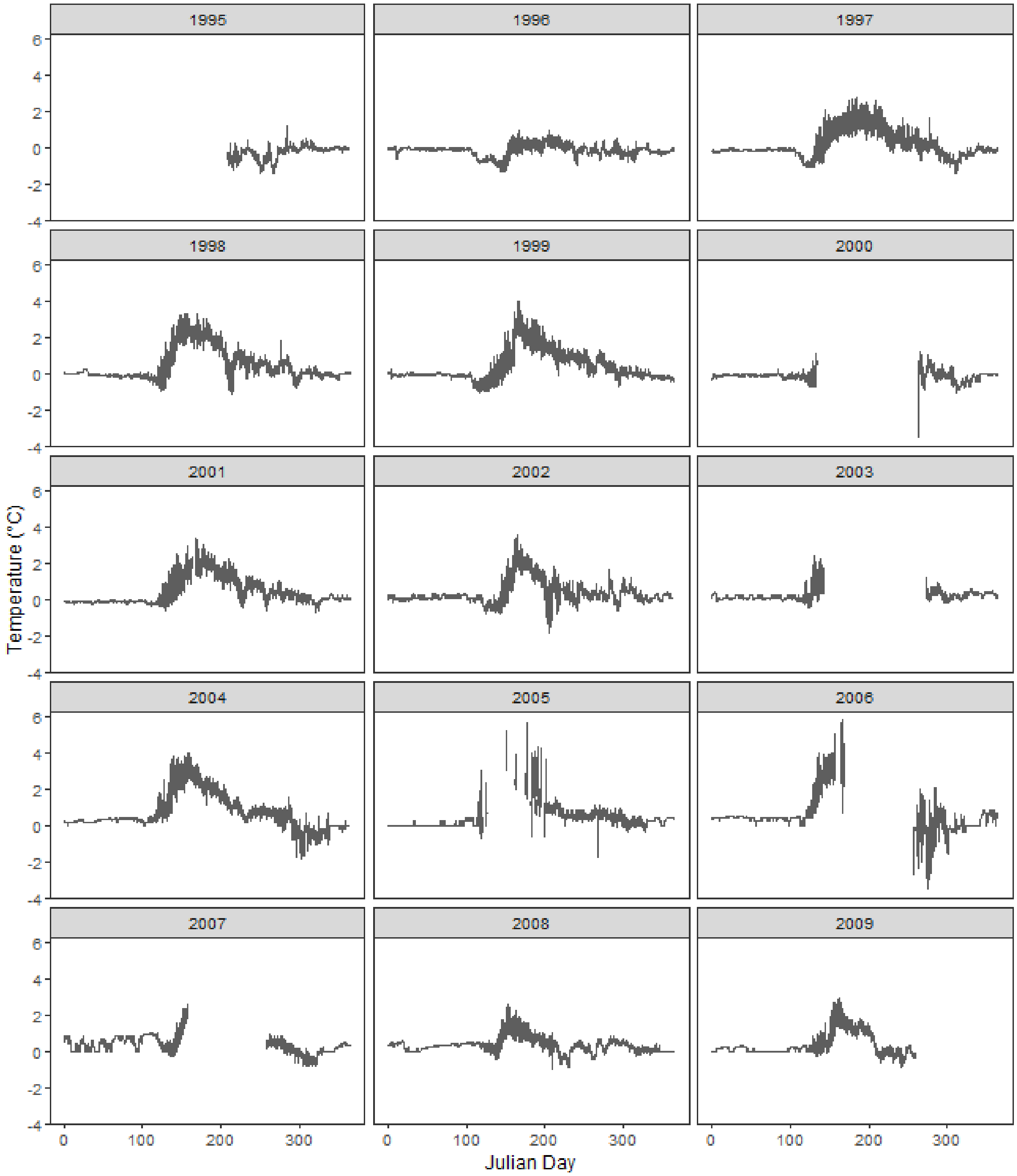

Figure 10: Hourly stream temperature difference at the downstream treatment station in B4, the unharvested control stream, relative to B5, the 20 m low-retention treatment stream.

1.2 Road Crossing Right-of-Way Width

The road crossing study explored how light penetration and channel morphology influenced stream temperature. For the road crossing study, temperature loggers were placed in the thalweg upstream and downstream of road crossings to monitor road right-of-way influences on stream temperature (Herunter et al. 2003). The streams in this study are B3, B4, and B5, which have 50 m, 20 m, and 30 m right-of-way widths (Table 4; Figure 11). For this study, B4 acts as an unharvested control, while B3 and B5 are downstream of cutblocks. Hourly temperature recordings were collected continuously between May 1997 and May 2003. Loggers were checked for accuracy using a calibrated mercury thermometer 4 times per year, and stream temperature readings below 0ºC were assumed to be 0ºC. Rainfall and air temperature were measured at the Middle River DFO camp (55.057617 W, -125.504167 N), and air temperature was also monitored at an adjacent station on Middle River (55.038817 W, -125.486567 N).

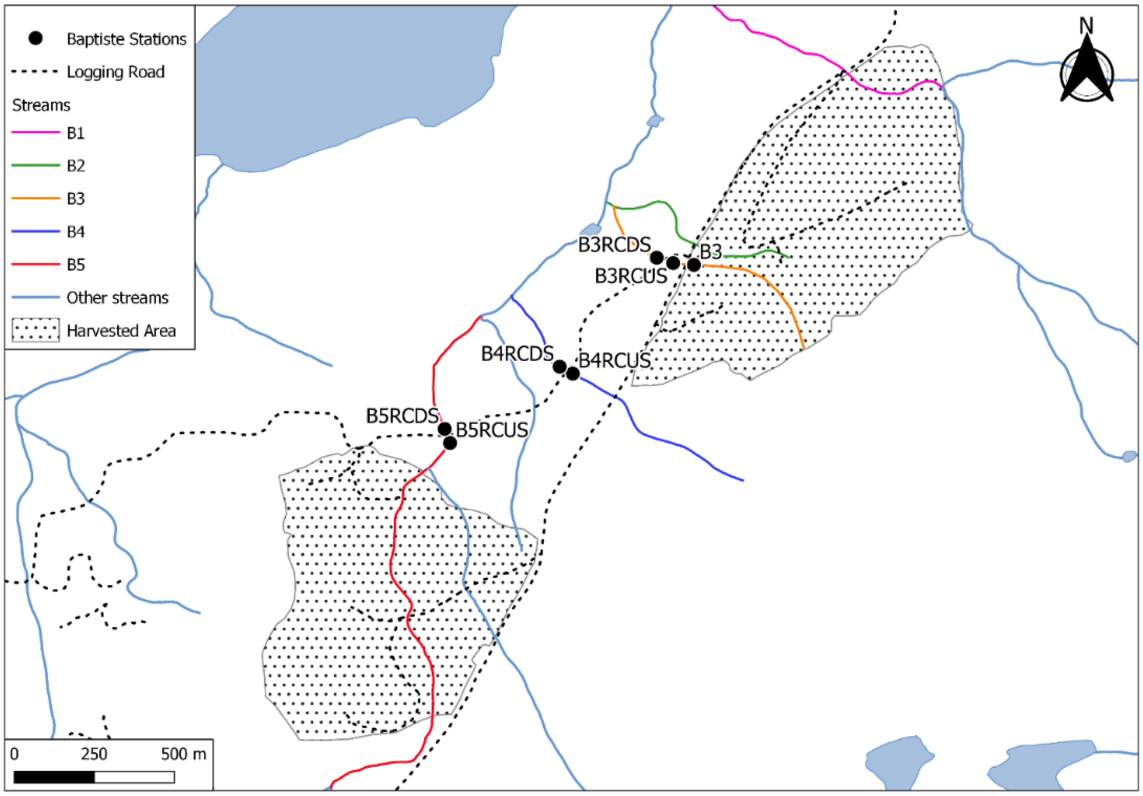

Figure 11: Map indicating the location of the road crossing station locations where temperature loggers were deployed in the Baptiste watershed.

The study found that stream temperatures increased as water passed through right-of-ways in the spring and summer and showed no change or a slight decrease in temperatures during the winter (Figure 12-17). In addition, the study found that larger right-of-ways had greater impacts on stream temperature. Temperature results from B3 which had three stations monitoring stream flow under two road crossings suggest that the temperature increases were cumulative. The main cause of increased downstream temperatures is thought to be increased solar radiation due to clearing of the riparian vegetation upstream and downstream of the right-of-ways.

Table 4: Road crossings station information, sampling dates and associated right-of-way treatments.

Stream	Station	Installation Date	Removal Date	Treatment
B3	B3	1995-07-28	2009-09-17	Upstream control
	B3RCDS	1997-05-07	2003-05-24	50 m right-of-way
	B3RCUS	1997-05-07	2003-05-24	Upstream control
B4	B4RCDS	1997-05-07	2003-05-24	20 m right-of-way
	B4RCUS	1997-05-07	2003-05-24	Upstream control

Stream	Station	Installation Date	Removal Date	Treatment
B5	B5RCDS	1997-05-07	2003-05-24	30 m right-of-way
	B5RCUS	1997-05-07	2003-05-24	Upstream control

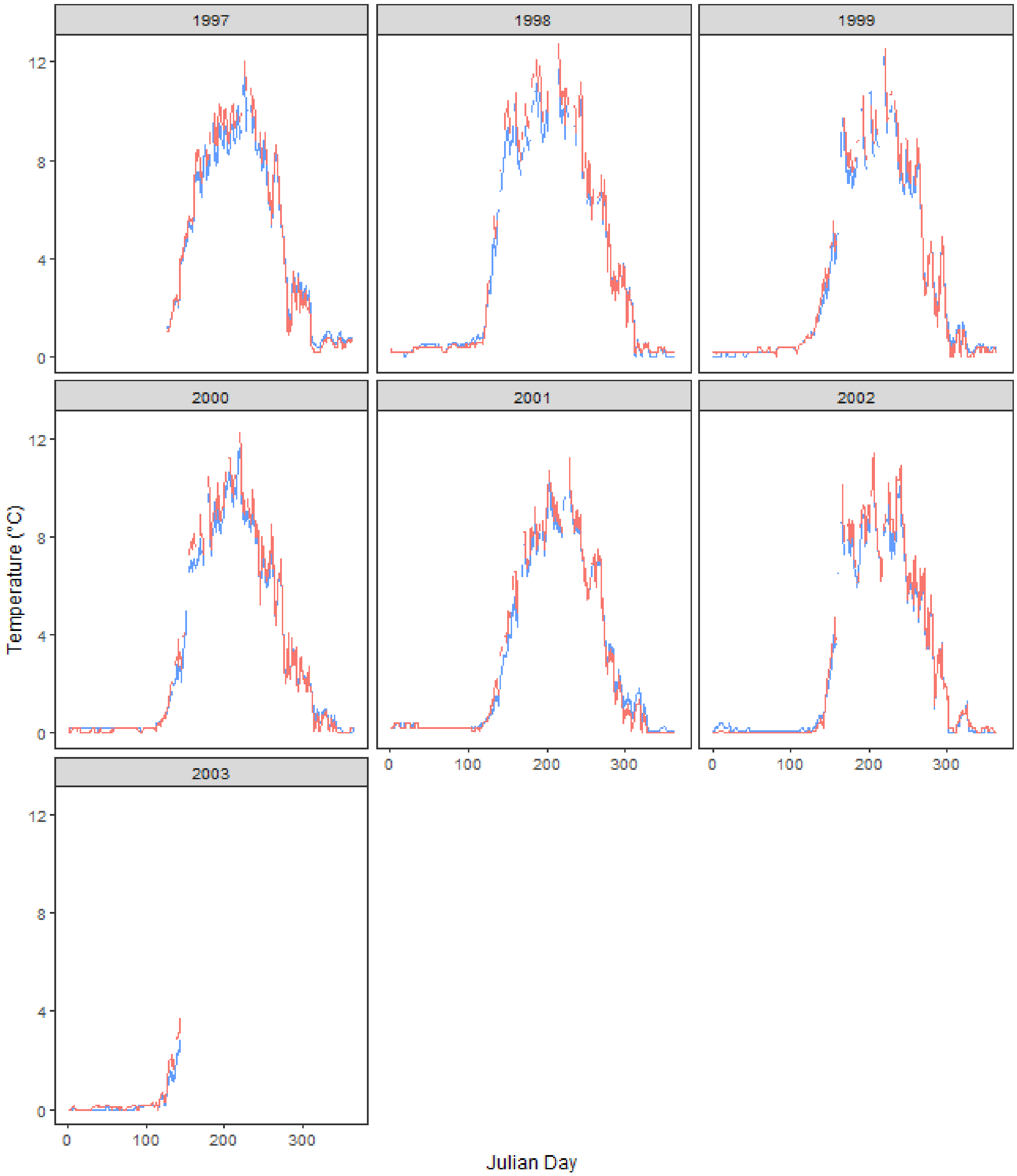

Figure 12: Mean daily stream temperature in B3, the 20 m high-retention buffer treatment stream. The red line is for temperature at B3RCDS below the road right-of-way, the blue line is for B3RCUS above the 50 m road right-of-way.

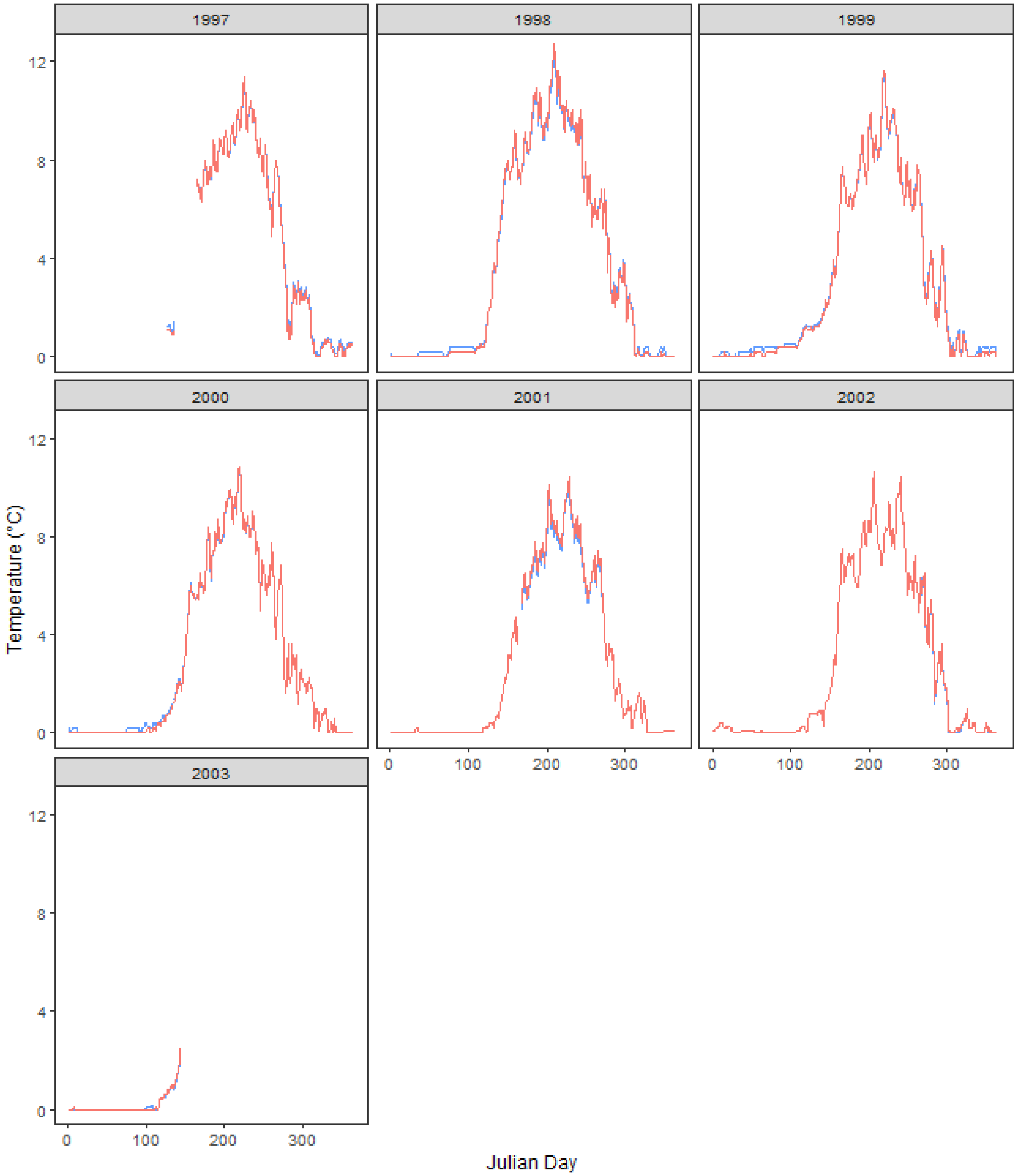

Figure 13: Mean daily stream temperature in B4, the unharvested control stream. The red line is for temperature at B4RCDS below the road right-of-way, the blue line is for B4RCUS above the 20 m road right-of-way.

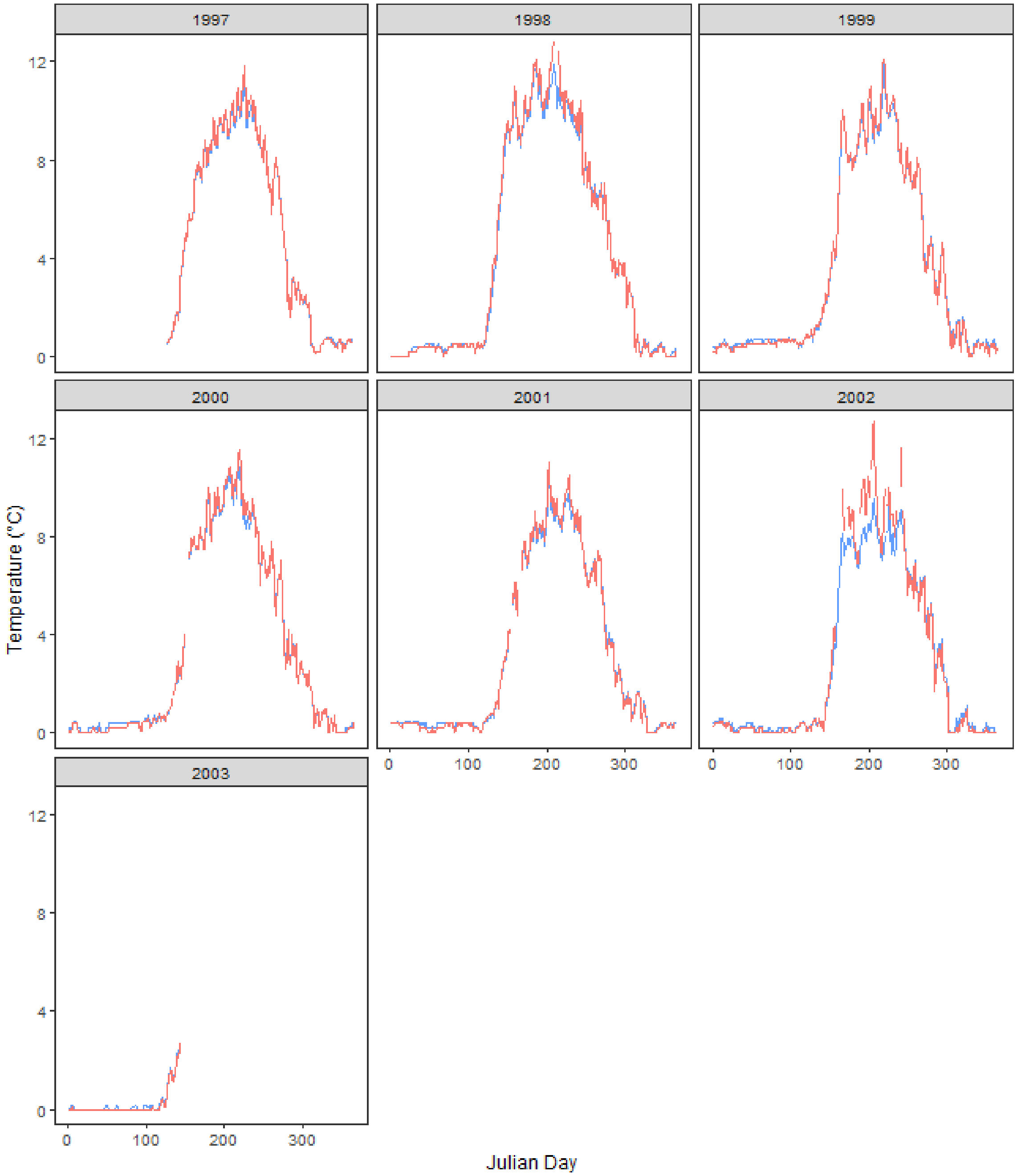

Figure 14: Mean daily stream temperature in B5, the 20 m low-retention buffer treatment stream. The red line is for temperature at B5RCDS below the road right-of-way, the blue line is for B5RCUS above the 30 m road right-of-way.

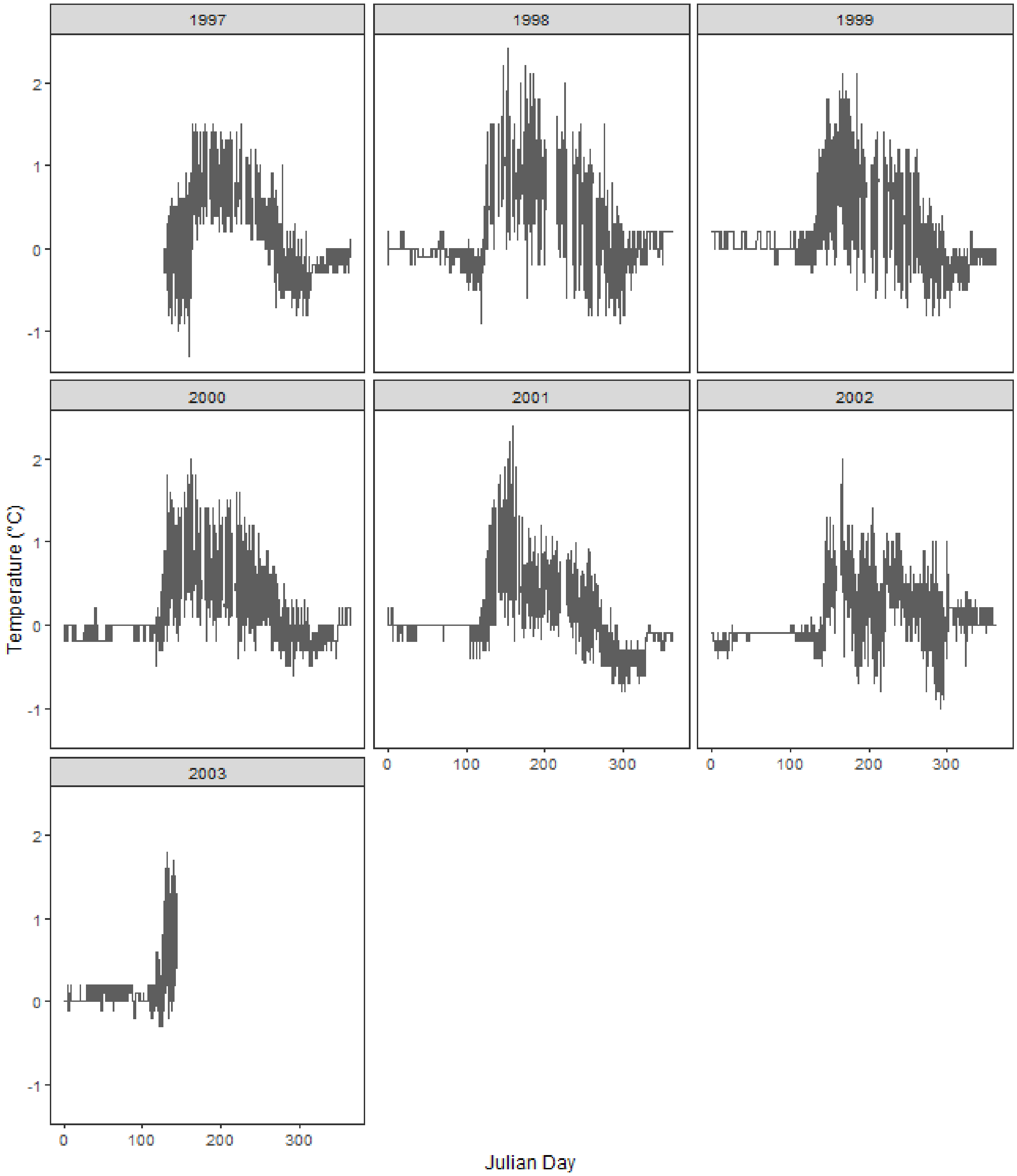

Figure 15: Hourly stream temperature difference at B3RCDS below the road right-of-way relative to station B3RCUS above the 50 m road right-of-way in B3, the 20 m high-retention treatment stream.

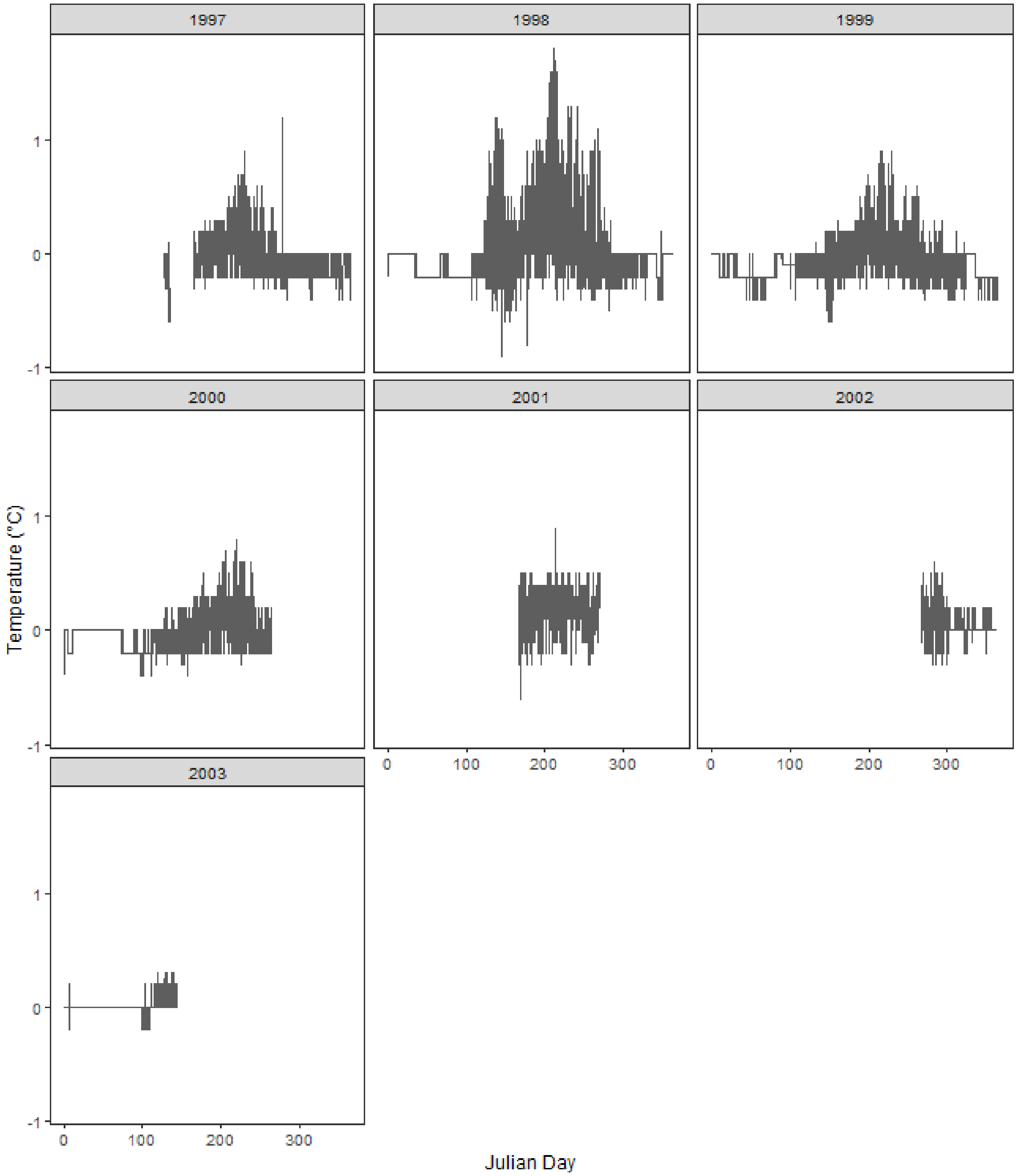

Figure 16: Hourly stream temperature difference at B4RCDS below the road right-of-way relative to station B4RCUS above the 20 m road right-of-way in B4, the unharvested control stream.

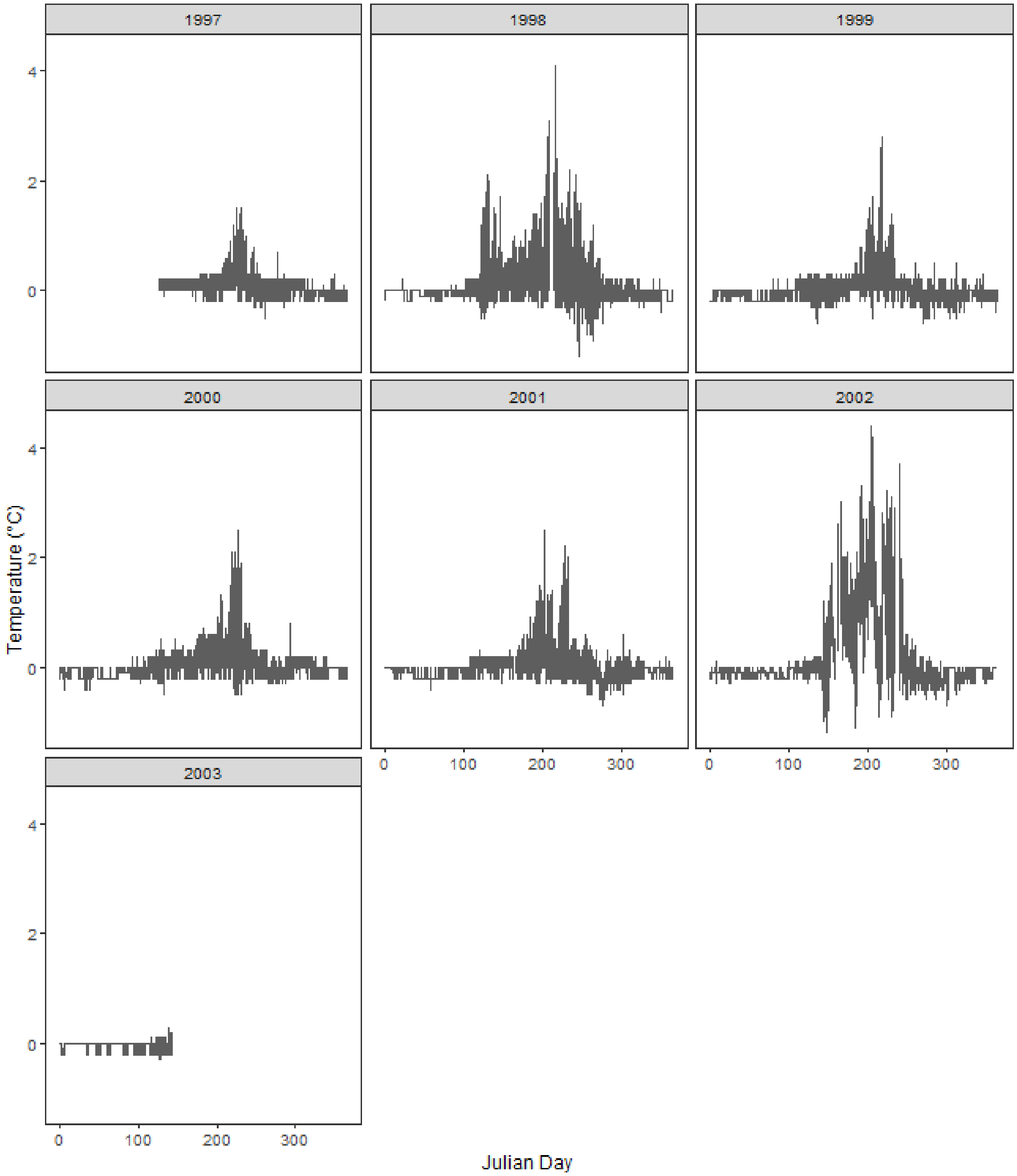

Figure 17: Hourly stream temperature difference at B5RCDS below the road right-of-way relative to station B5RCUS above the 30 m road right-of-way in B5, the 20 m low-retention treatment stream.

1.3 Downstream Thermal Recovery

Two thermal recovery studies explored what happens to stream temperatures as a stream flows from a clearcut back into an intact forest. In the first study (Moore et al. 2003), done in the summer of 1999, loggers were placed at the downstream edge of cutblocks and roads and stations measuring thermal recovery were placed 170 m downstream (Figure 18). Loggers were placed in three streams: an unharvested control stream (B4), and two streams with different riparian treatments in the upstream clearcuts, a high-retention 20 m buffer (B3), and a low-retention 20 m buffer (B5) (Figure 18; Table 5).

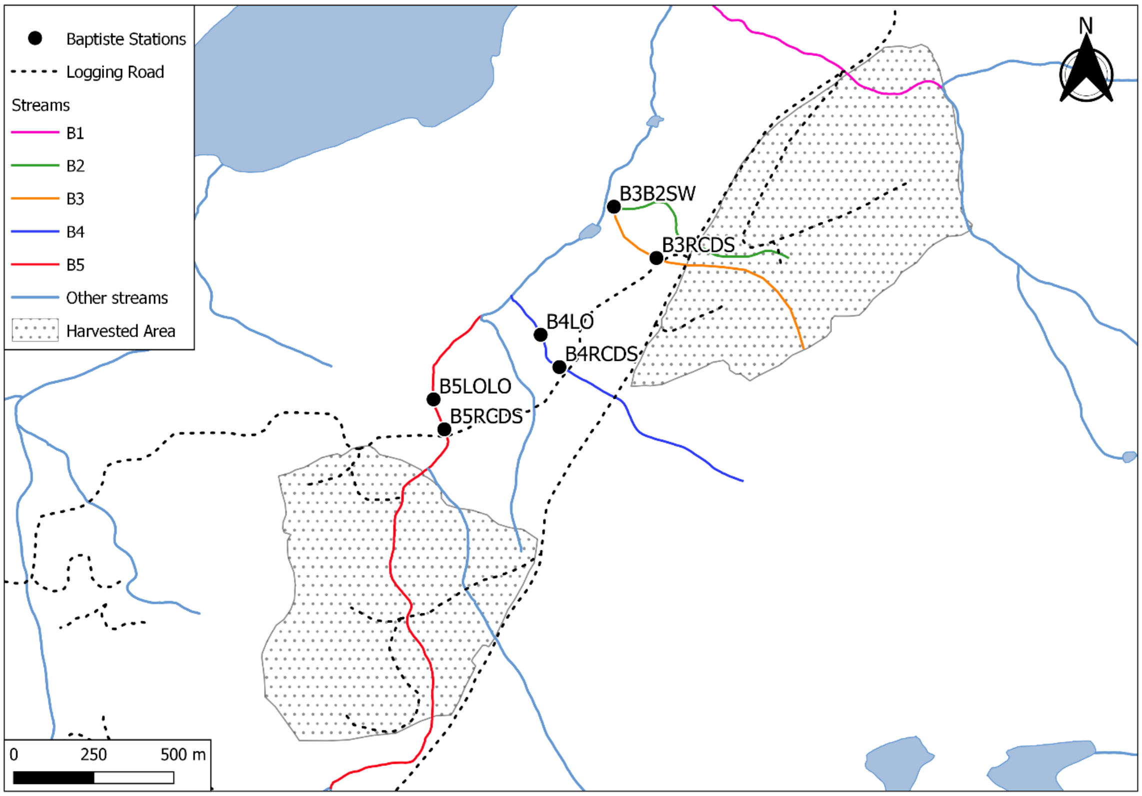

Figure 18: Map indicating the thermal recovery station locations where temperature loggers were deployed for the thermal recovery study in the Baptiste watershed.

This study found downstream cooling occurred in both B3 and B5 (Figure 19-24). The downstream stations on B3 and B5 recorded lower mean daily temperatures and maximum daily temperatures. The cooling was more pronounced on B5, which showed downstream differences in mean daily temperature of up to 3.7ºC, whereas downstream temperature differences observed in B3 were up to 2ºC. No cooling was observed in B4 (control stream), in fact downstream warming was often observed. The authors conducted a pilot groundwater study to explore how shallow groundwater inputs contributed to the cooling effect. The pilot study used constant-rate salt injections and electrical conductivity measurements to estimate groundwater inputs. The results of this study suggested that decreases in stream temperature occurred through groundwater inputs and advected stream water.

A second thermal recovery study (Story et al. 2003) was done in B3 and B5 in the summer of 2000 and served as a follow-up to Moore et al. (2003). The study measured different contributions of energy fluxes and calculated the energy balances. They estimated that groundwater inflow was responsible for 40% of the cooling effect, and a combination of bed heat conduction and hyporheic exchange were responsible for 60% of the cooling effect. The authors also found that downstream temperatures at B5 were similar to upstream temperatures during periods of higher streamflow and lower during periods of lower streamflow, suggesting that stream water in B5 is lost to infiltration and replaced by groundwater in periods of low flow. This study found evidence that different types of aquifers feed B3 and B5, resulting in differences in the temperature profiles of these catchments.

Table 5: Water temperature logger stations, sample periods and associated riparian buffer treatments for thermal recovery study.

Stream	Station	Installation Date	Removal Date	Treatment
B3	B3RCDS	1997-05-07	2003-05-24	Upstream impact
	B3B2	1996-07-13	2004-10-05	Downstream recovery
B4	B4RCDS	1997-05-07	2003-05-24	Upstream impact
	B4LO	1997-06-15	2005-09-06	Downstream recovery
B5	B5LOLO	1997-06-15	2005-08-10	Upstream impact
	B5RCDS	1997-05-07	2003-05-24	Downstream recovery

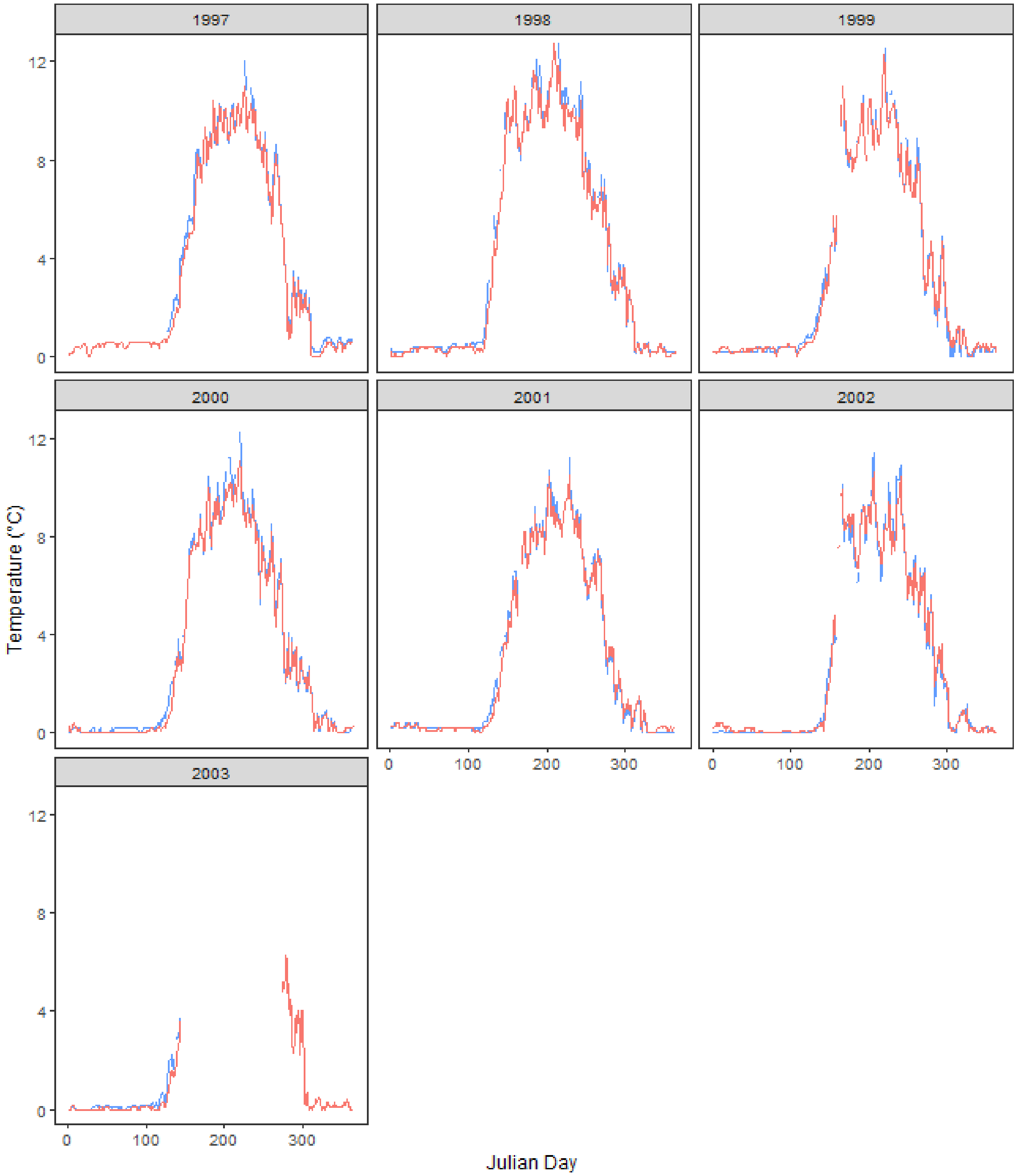

Figure 19: Mean daily stream temperature in B3, the 20 m high-retention treatment stream, measured for a thermal recovery study. Blue lines are for temperatures at B3RCDS placed downstream of the logging road at the bottom of the cutblock. Red lines are for temperatures at B3B2, 170 m downstream of the road in unharvested forest.

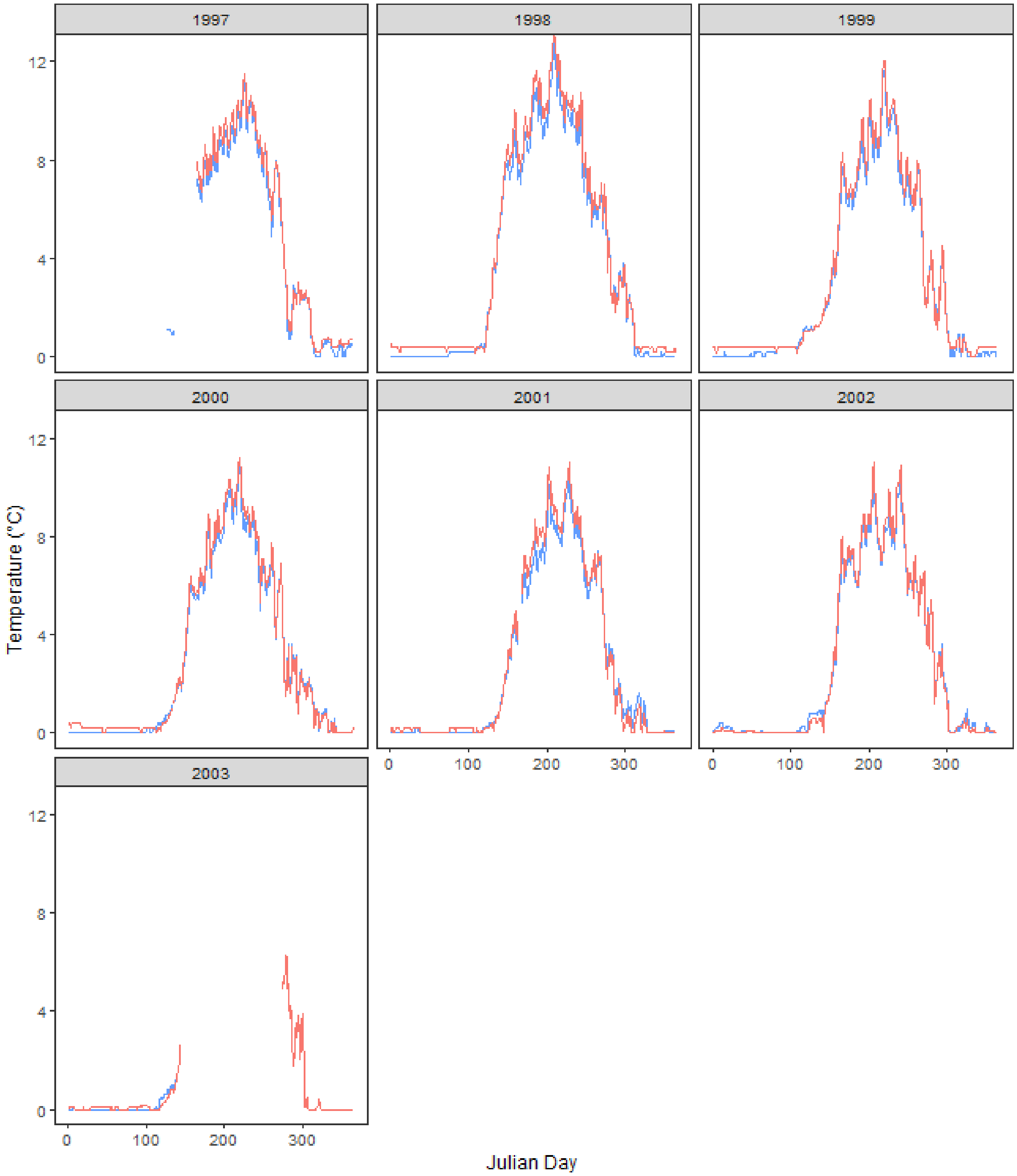

Figure 20: Mean daily stream temperature in B4, the unharvested control stream, measured for a thermal recovery study. Blue lines are for temperatures at B4RCDS, downstream of the logging road. Red lines are for temperatures at B4LO, 170 m downstream of B4 in unharvested forest.

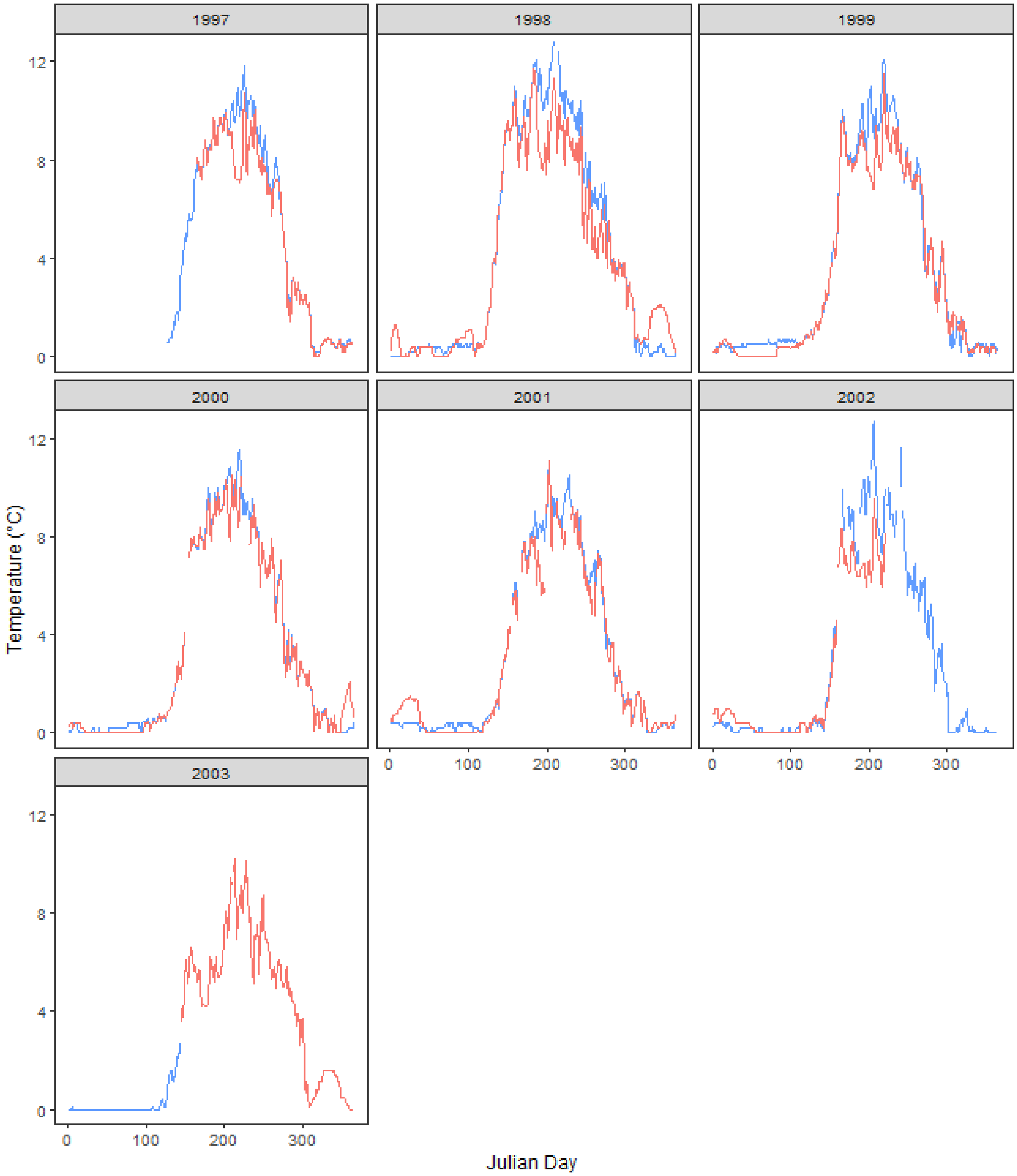

Figure 21: Mean daily stream temperature in B5, the 20 m low-retention treatment stream, measured for a thermal recovery study. Blue lines are for temperatures at B5RCDS placed downstream of the logging road at the bottom of the cutblock. Red lines are for temperatures at B5LOLO, 170 m downstream of the road in unharvested forest.

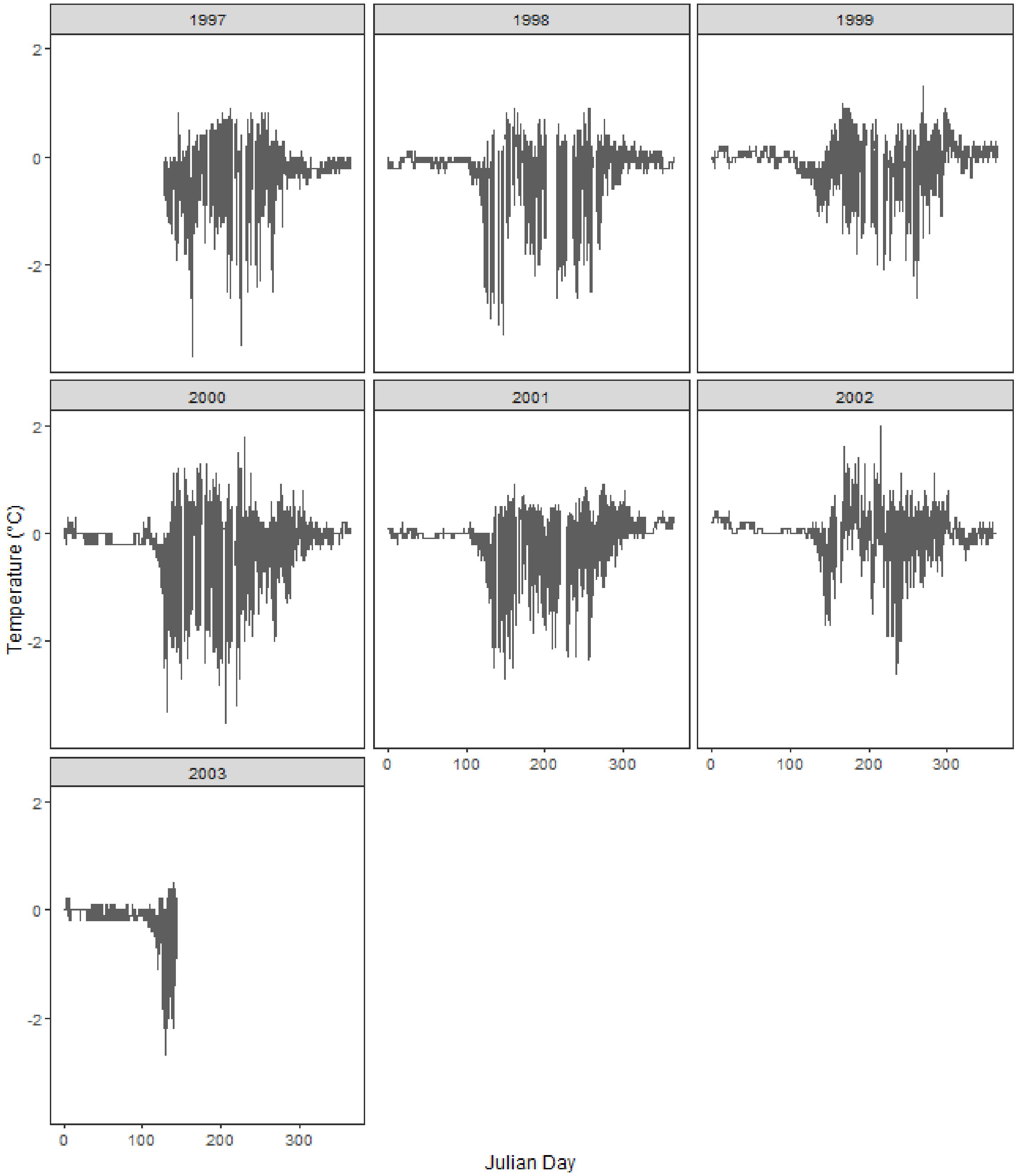

Figure 22: Hourly stream temperature difference at B3B2, the unharvested downstream station relative to B3RCDS, the upstream impact station for B3, the 20 m high-retention buffer stream.

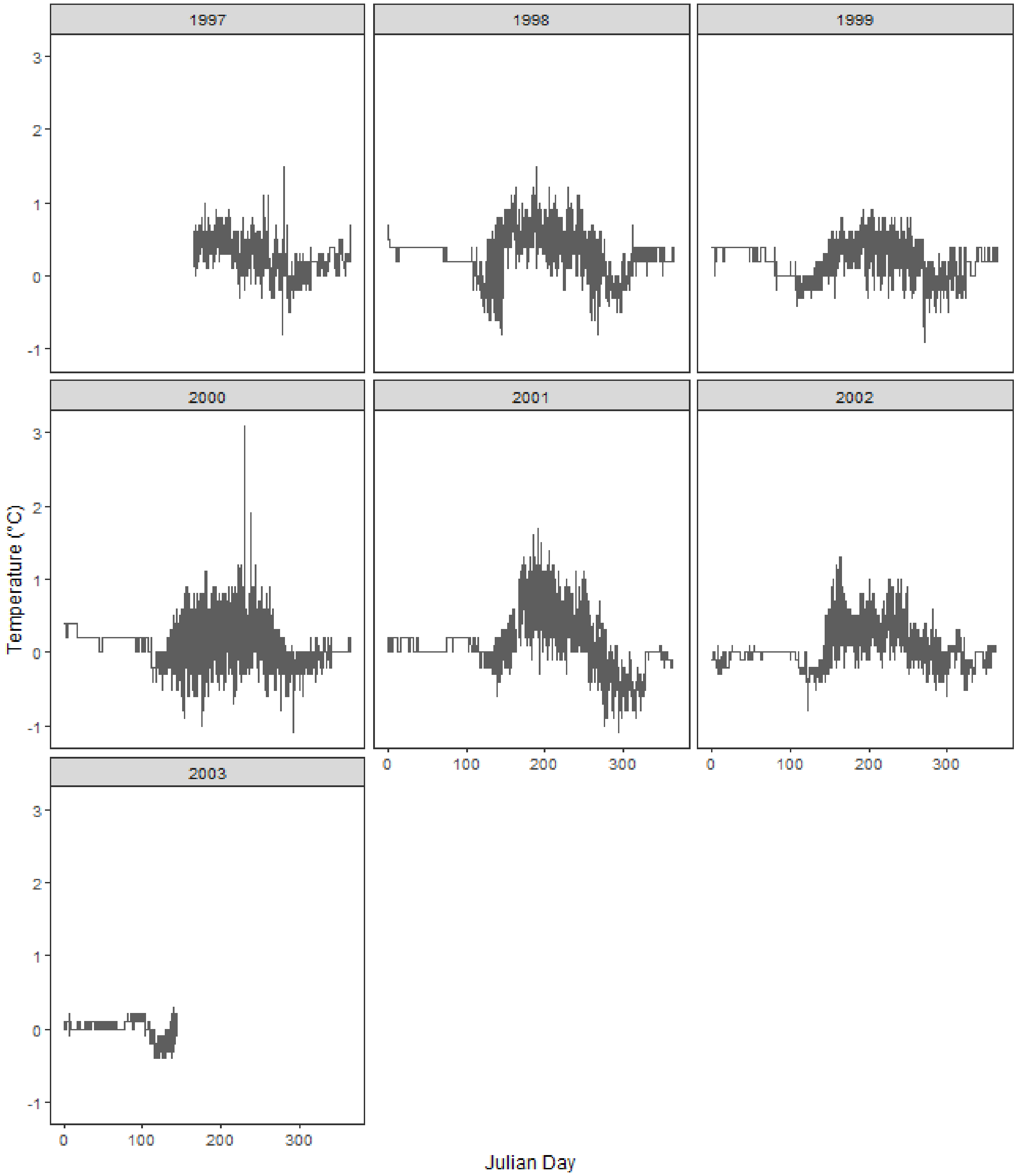

Figure 23: Hourly stream temperature difference at B4LO, the unharvested downstream station relative to B4RCDS, the upstream impact station for B4, the unharvested control stream.

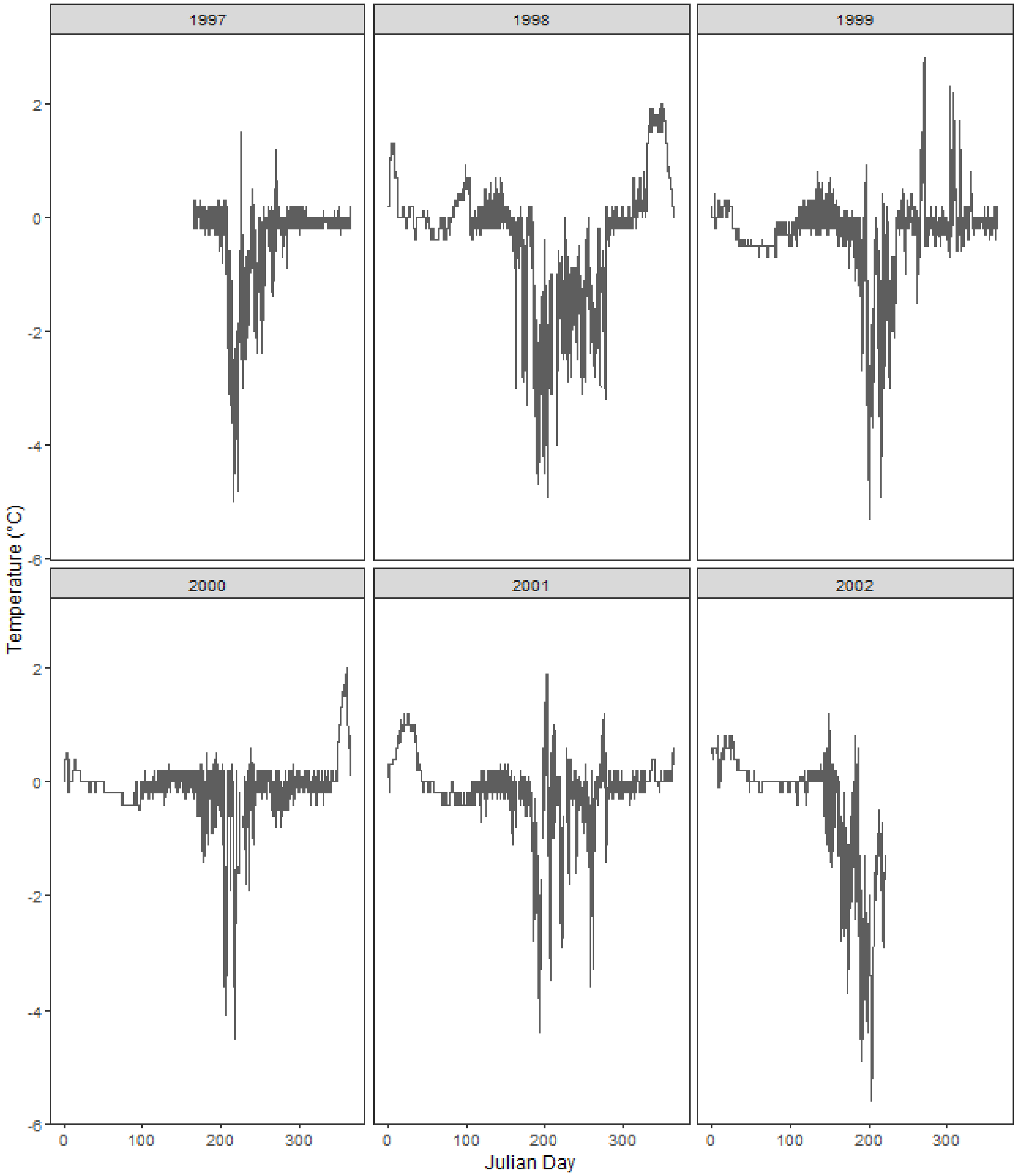

Figure 24: Hourly stream temperature difference at B5LOLO, the unharvested downstream station relative to B5RCDS, the upstream impact station for B5, the 20 m low-retention buffer stream.

2.0 Groundwater Temperature

Metal standpipes were placed throughout the Baptiste watershed to measure groundwater temperatures (Figure 25). The standpipes are 2 m deep metal wells with 1/8" holes drilled along the entire length that have been fitted with Vemco Minilogs with an accuracy of ±0.2°C. These loggers recorded hourly groundwater temperatures between 1996 and 2005 (Table 6). The placement of the standpipes created spatial controls with standpipes upstream of logging influence, and temporal controls through collecting temperature data before and after harvesting occurred.

An initial study by Macdonald et al. (2003a) looked at groundwater temperature in B3 and B5, using a logger placed above the cutblock on B5 as a spatial control. This study found that groundwater temperatures near B3 and B5 rose slightly after harvesting occurred, however there was a one year delay in temperature rise on B5 (Figure 26-31). Both locations experienced temperatures rise by up to 1.5°C at the treatment stations relative to the control stations.

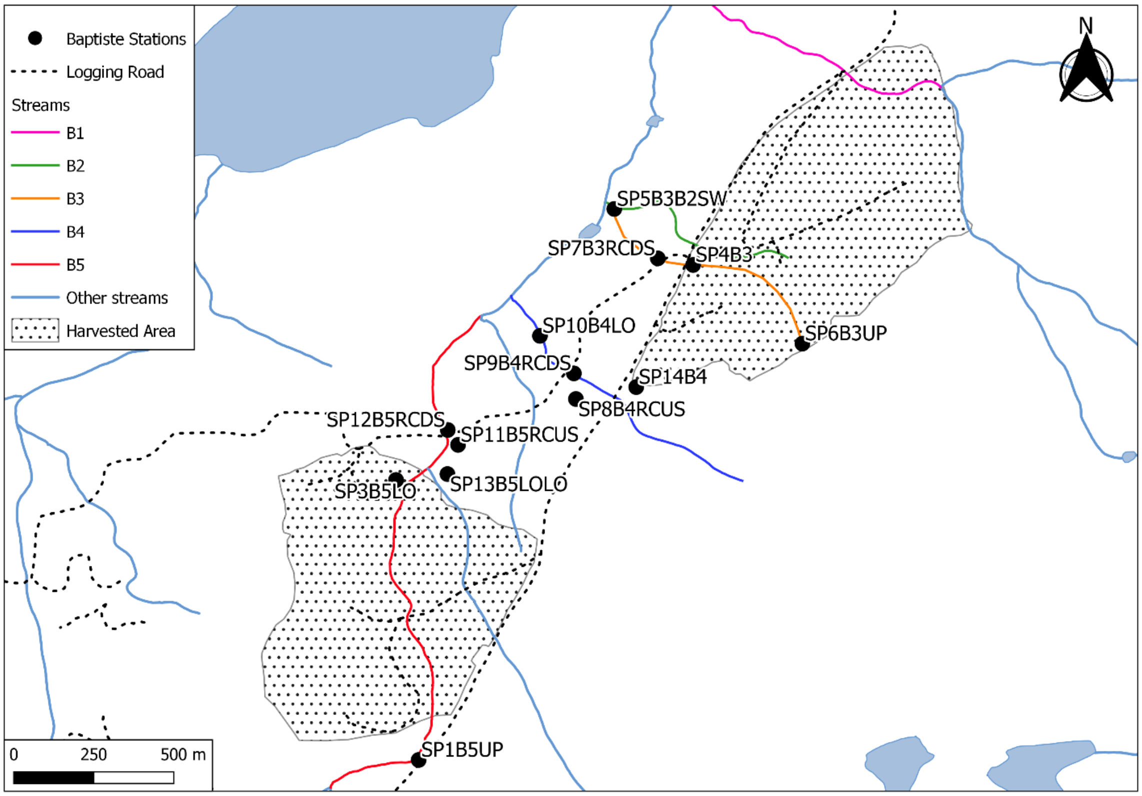

Figure 25: Map indicating the location of the groundwater temperature monitoring station locations where temperature loggers were deployed in the Baptiste watershed.

Table 6: Groundwater temperature station information, sampling dates, and associated riparian buffer treatment for the Baptiste watershed.

Stream	Station	Installation Date	Removal Date	Treatment
B5	SP1B5UP	1996-06-20	2005-09-13	Upstream control for 20 m low-retention
	SP3B5LO	1996-06-20	2005-09-26	20 m low-retention
	SP11B5RCUS	1997-06-14	2003-05-24	20 m low-retention; Upstream control for right-of-way
	SP12B5RCDS	1997-06-14	2003-05-24	30 m right-of-way
	SP13B5LOLO	1997-06-14	2005-09-26	20 m low-

Stream	Station	Installation Date	Removal Date	Treatment
				retention
B4	SP8B4RCUS	1997-06-14	2001-09-27	Upstream control for right-of-way
	SP9B4RCDS	1997-06-14	2002-08-09	20 m right-of-way
	SP10B4LO	1997-06-14	2005-09-06	Downstream recovery
	SP14B4	1997-06-14	2005-09-26	Unharvested control stream; upstream control for 20 m right-of-way
B3	SP4B3	1996-06-20	2005-09-26	Upstream control for 50 m right-of-way
	SP5B3B2SW	1996-07-13	2005-09-06	Downstream recovery
	SP6B3UP	1996-09-23	2002-08-09	Upstream control for 20 m low-retention
	SP7B3RCDS	1997-06-14	2003-05-24	50 m right-of-way

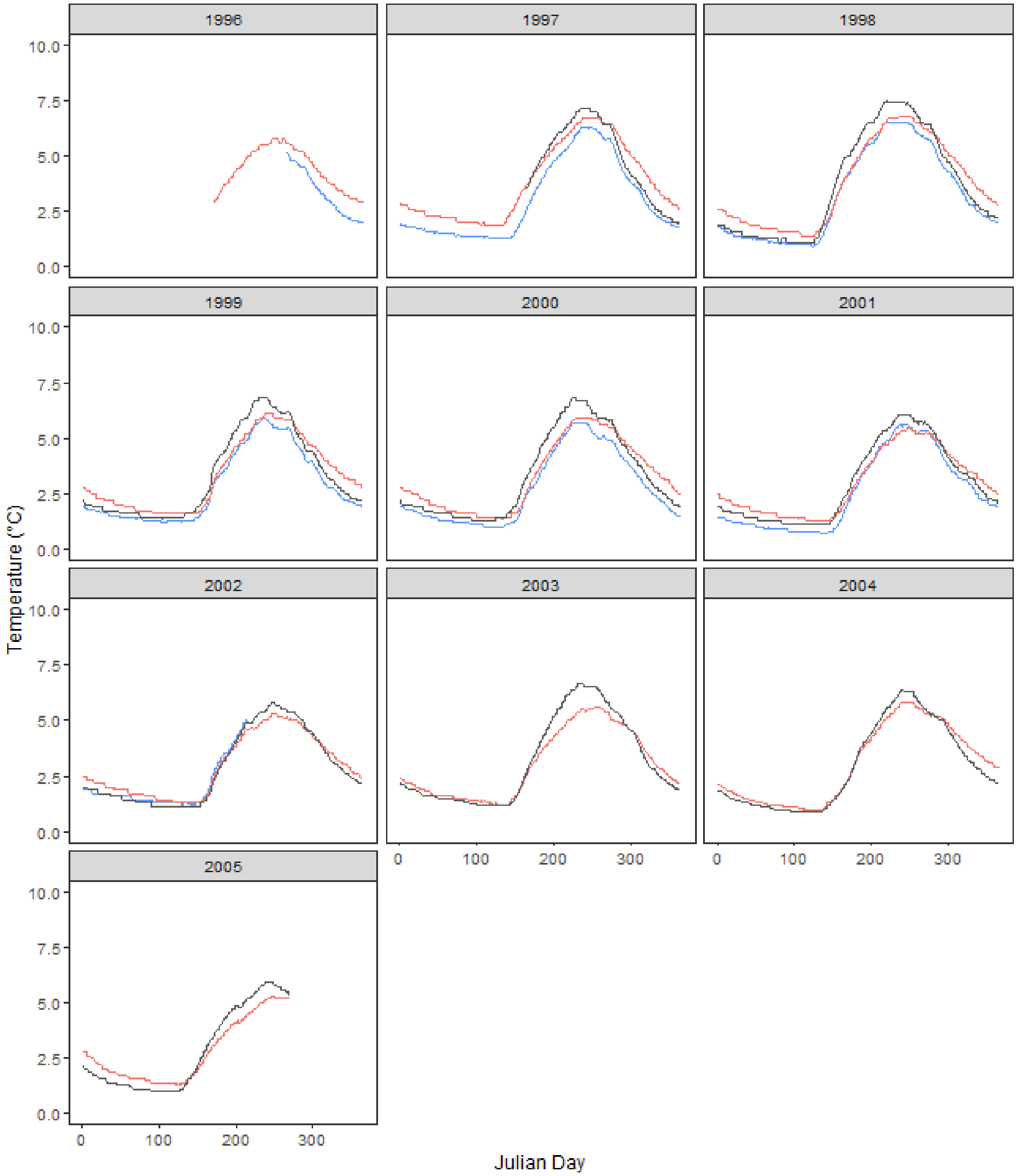

Figure 26: Mean daily groundwater temperatures for B3, the 20 m high-retention treatment stream. The blue line is for temperature at the upstream station, the red line is for temperature at the downstream station, and the grey line is for temperature at B4, the unharvested control stream.

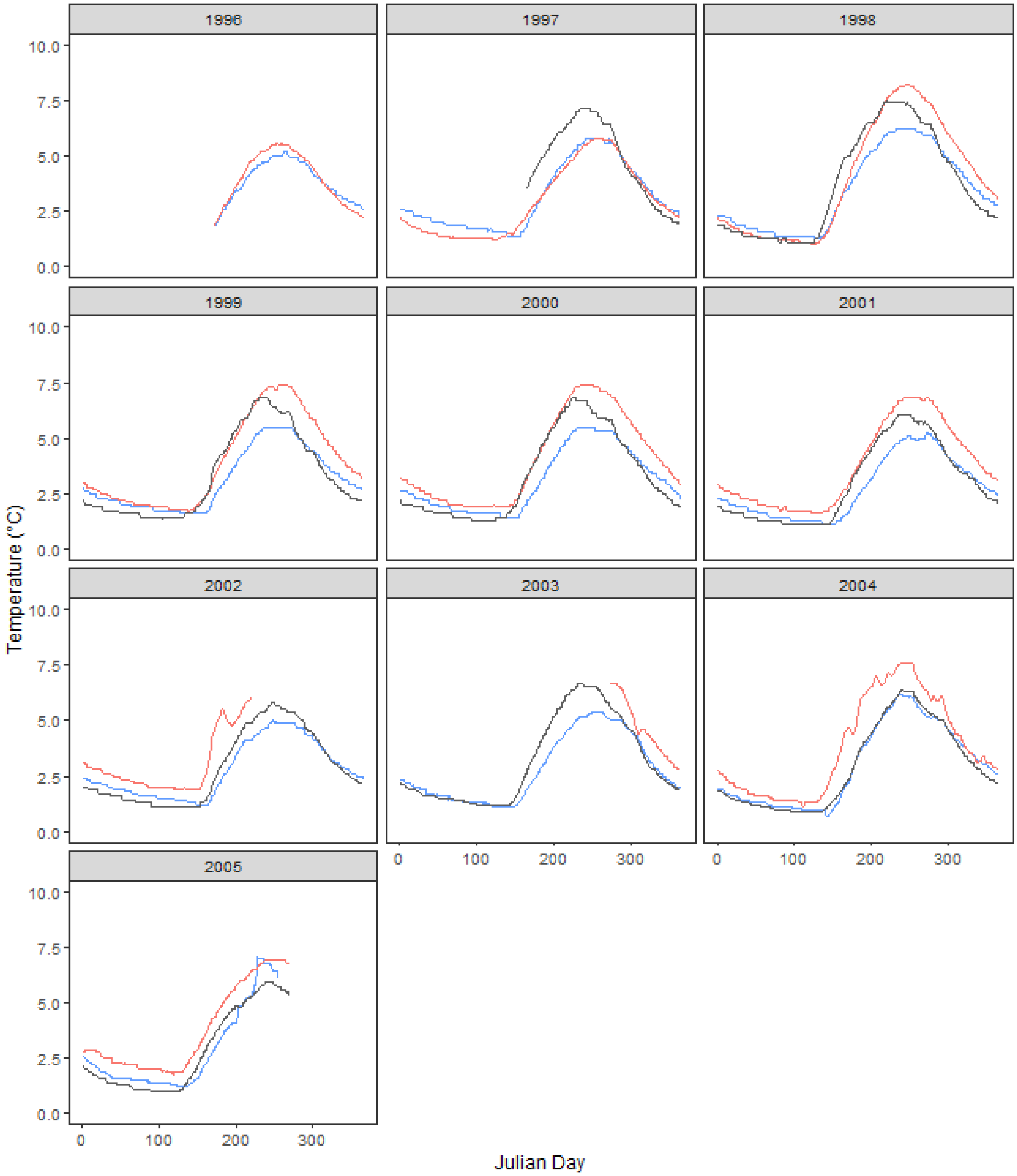

Figure 27: Mean daily groundwater temperatures for B5, the 20 m low-retention treatment stream. The blue line is for temperature at the upstream station, the red line is for temperature at the downstream station, and the grey line is for temperature at B4, the unharvested control stream.

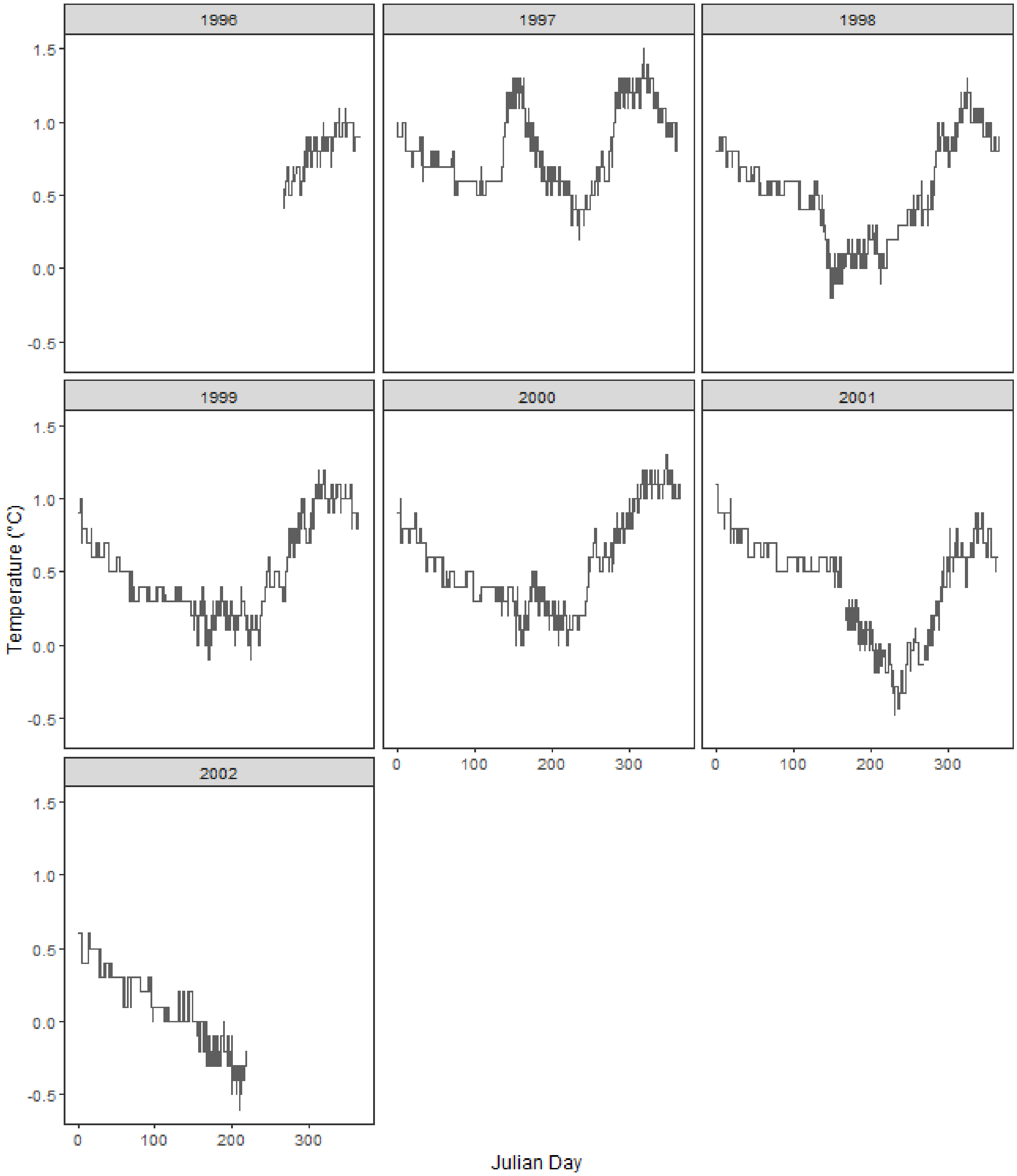

Figure 28: Hourly groundwater temperature difference at the downstream impact station relative to the upstream control station in B3, the 20 m high-retention treatment stream.

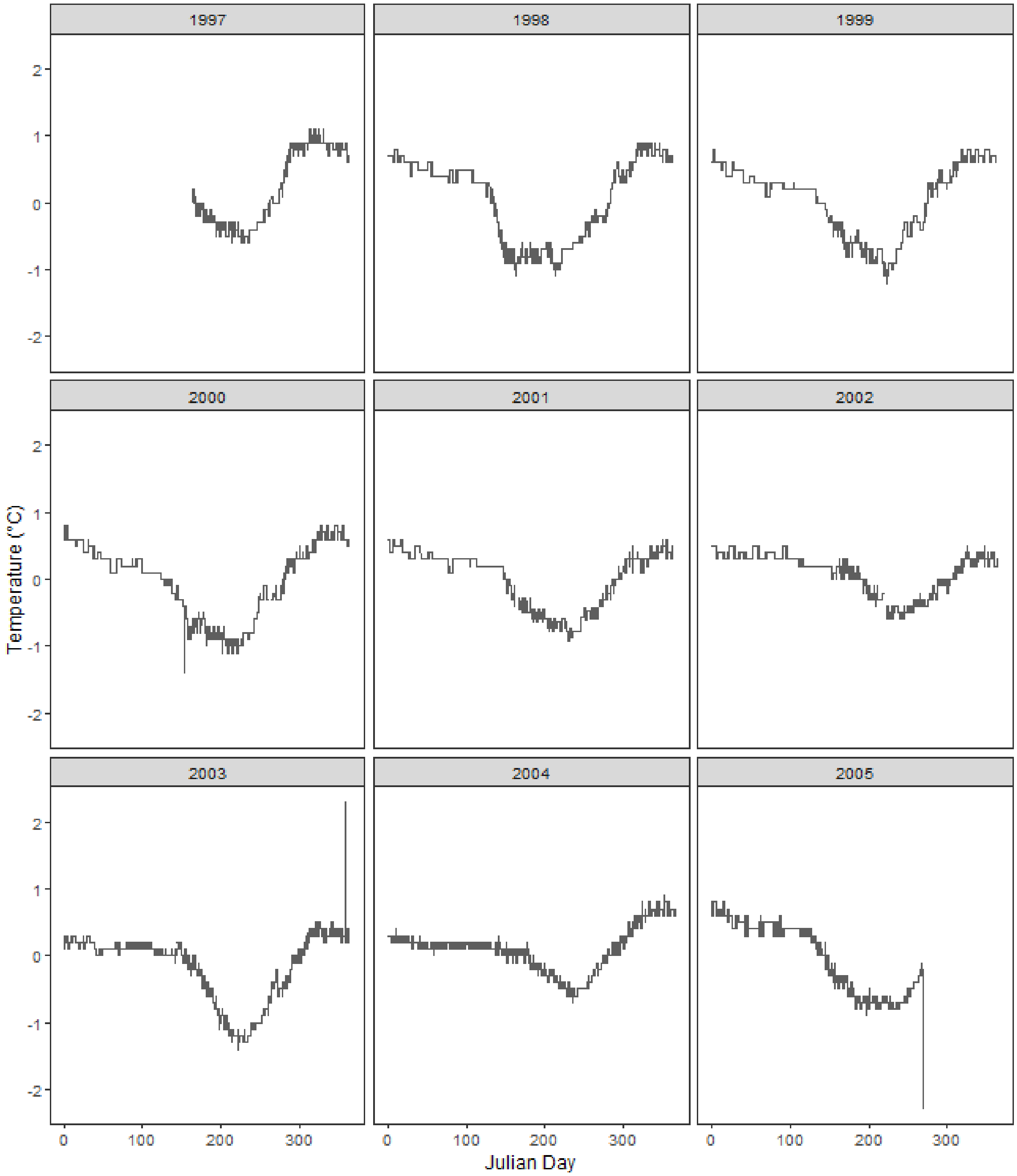

Figure 29: Hourly groundwater temperature difference at the downstream station in B3, the 20 m high-retention treatment stream relative to B4, the unharvested control.

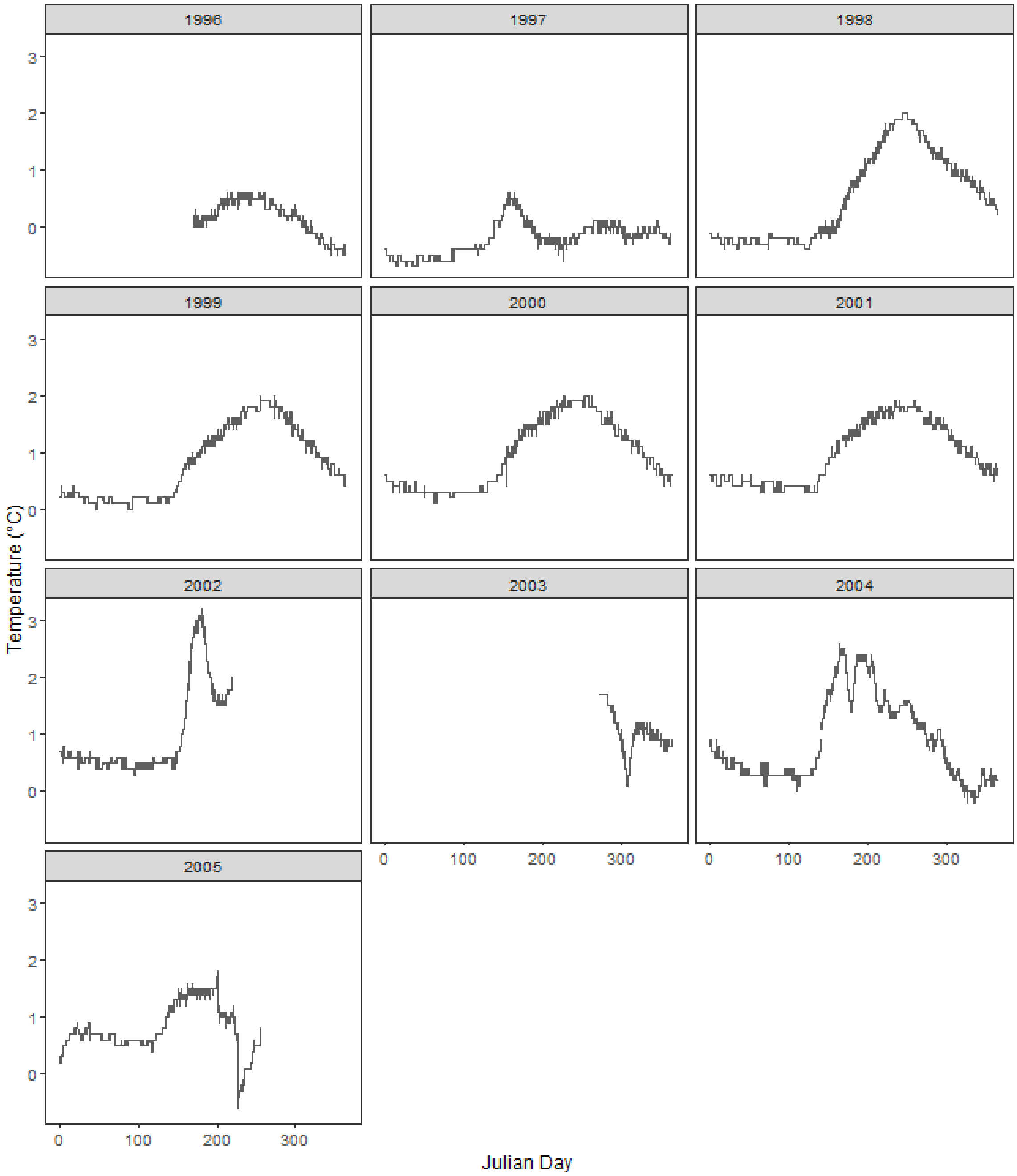

Figure 30: Hourly groundwater temperature difference at the downstream impact station relative to the upstream control station in B5, the 20 m low-retention treatment stream.

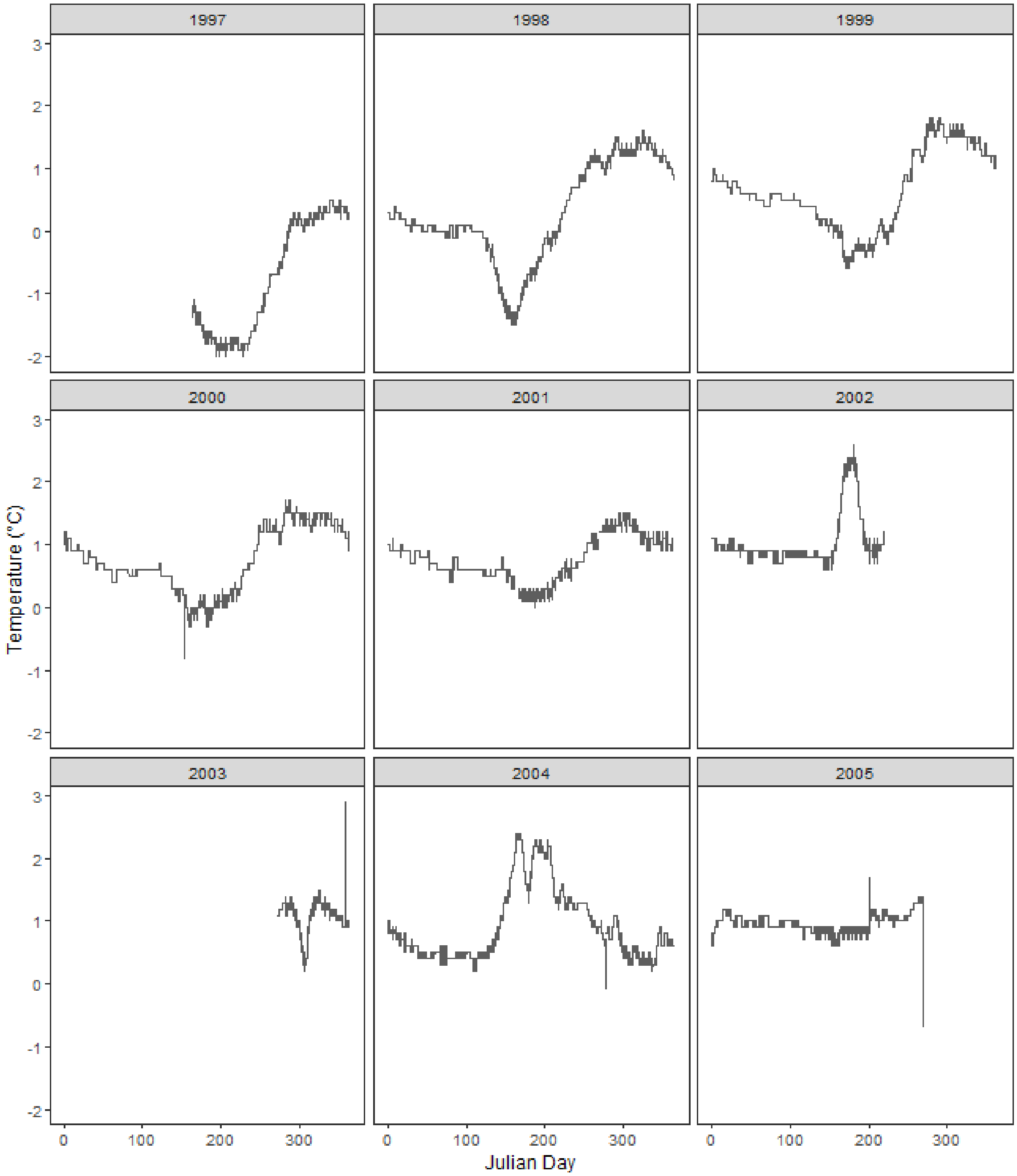

Figure 31: Hourly groundwater temperature difference at the unharvested control B4 relative to the downstream station in B5, the 20 m low-retention treatment stream.

3.0 Aquatic Macroinvertebrates

The invertebrate studies looked at the impacts of different logging treatments on invertebrate communities. Invertebrates were sampled each summer from 1996 to 1999 from three streams: B3, B4, and B5 (Table 7). Samples were taken using colonization baskets (1996 – 1999) and paired Mason drift samplers (1999). During harvesting B3 was left with a 20 m high-retention buffer (conservative treatment), while B5 was left with a 20 m low-retention buffer, with no merchantable timber retained. B4 was an unharvested control stream, and both B3 and B5 had upstream control sites in unlogged areas. Samples were taken at B5RCUS to assess downstream recovery, as this station is in an unharvested area downstream of the cutblock.

Samples from the colonization baskets and drift samplers were identified to family level and functional group (Merritt and Cummins 1996). Colonization baskets sample invertebrates living in the substrate, while drift samplers target invertebrates being carried downstream in suspension. Invertebrate communities were described in terms of family presence, abundance, and biomass using dry weight methods. The study found that the high-retention treatment station on B3 had higher average invertebrate abundance and biomass than the upstream control (Figure 32). This increase was mostly due to increases in abundance of Diptera and Ephemeroptera. On B5, the low-retention treatment, there were no large differences in abundance or biomass between the treatment station and the upstream control (Figure 32). No relationship was found between invertebrate abundance, biomass, and treatment type. There were differences in invertebrate community structure between control and impact sites, although there was evidence of recovery at the downstream recovery station.

Table 7: Invertebrate sampling station information and associated riparian buffer treatment.

Stream	Station	Treatment
B3	B3	20 m high-retention
	B3UP	Upstream control
B4	B4	Unharvested control
B5	B5RCUS	Downstream recovery
	B5LO	20 m low-retention
	B5CCMID	20 m low-retention
	B5UP	Upstream control

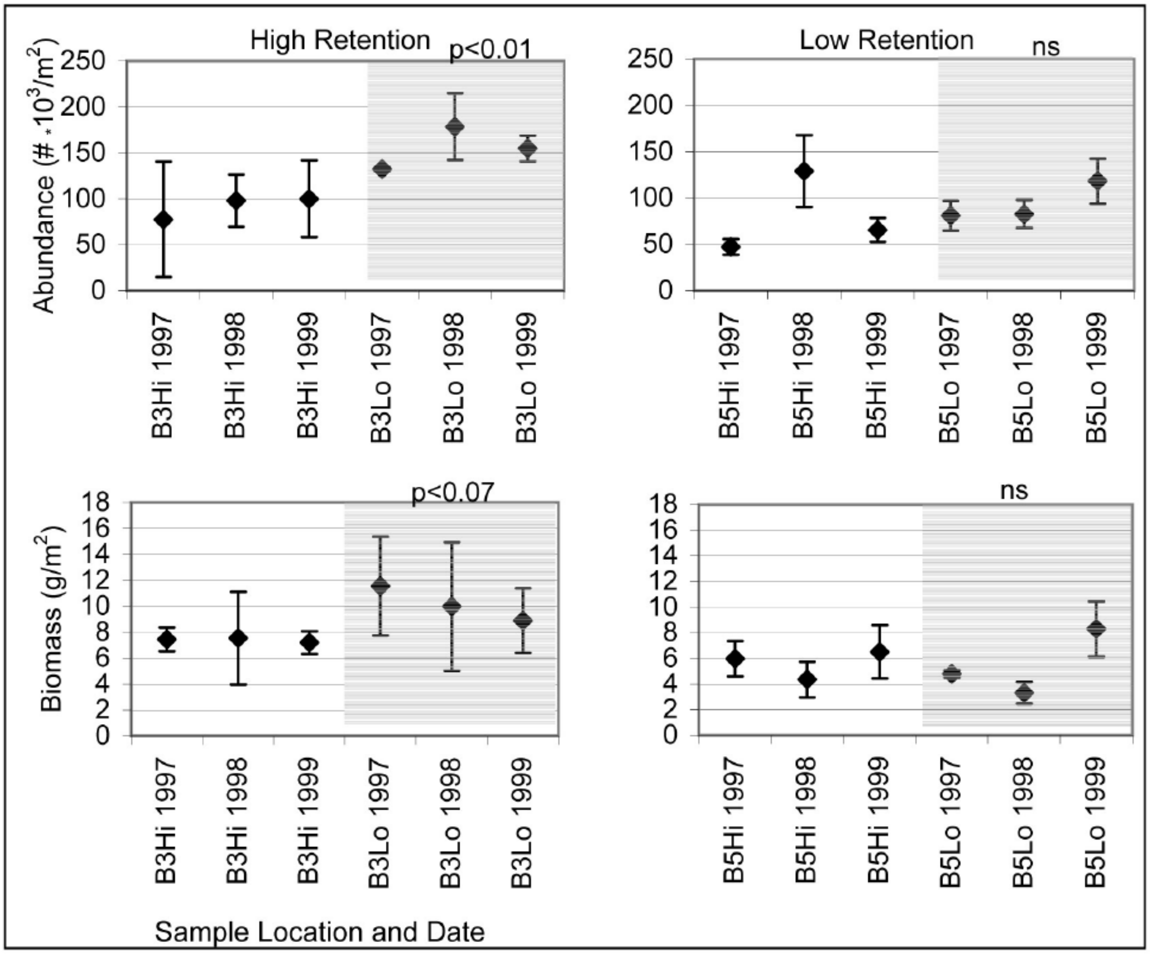

Figure 32: Mean annual (95% CI) invertebrate biomass and relative abundance levels at the control sites (white background) and the treatment sites (shaded background) on B3 and B5. Significant differences between control and treatment sites are noted above the shaded box, with ns meaning not significant. Plots taken from Herunter et al. (2004).

4.0 Nutrients and Water Quality

The effects of high and low riparian harvest retention on stream nutrients and water quality parameters were studied (Table 8). Water chemistry grab samples were collected monthly from May – September in 1997, 1998, and 1999, and pre-harvest samples were collected in August and September of 1996. Samples were collected from upstream control sites and downstream treatment sites. The following variables were collected: nitrate (NO_3-), soluble reactive phosphorus (SRP), total phosphorus (TP), total dissolved phosphorus (TDP), turbidity, total suspended solids (TSS), conductivity, and pH.

Analyzing TDP, NO_3-, and conductivity, Herunter et al. (2004) found higher levels of TDP at both treatment sites relative to their upstream controls (Figure 33). Nitrate levels were higher at B5 relative to the upstream control, but no differences in conductivity were found (Figure 33).

Table 8: Nutrients and water quality study station information and associated riparian buffer treatment for the Baptiste watershed.

Stream	Station	Treatment
B3	B3B2SW	20 m high-retention
	B3RCDS	20 m high-retention below road
	B3RCUS	20 m high-retention above road
	B3	20 m high-retention
	B3UP	Upstream control
B4	B4RCDS	Unharvested control below road
	B4RCUS	Unharvested control above road
	B4	Unharvested control
	B4HI	Unharvested control
B5	B5RCDS	20 m low-retention below road
	B5RCUS	20 m low-retention above road
	B5LO	20 m low-retention
	B5UP	Upstream control
B6	B6	Unharvested control

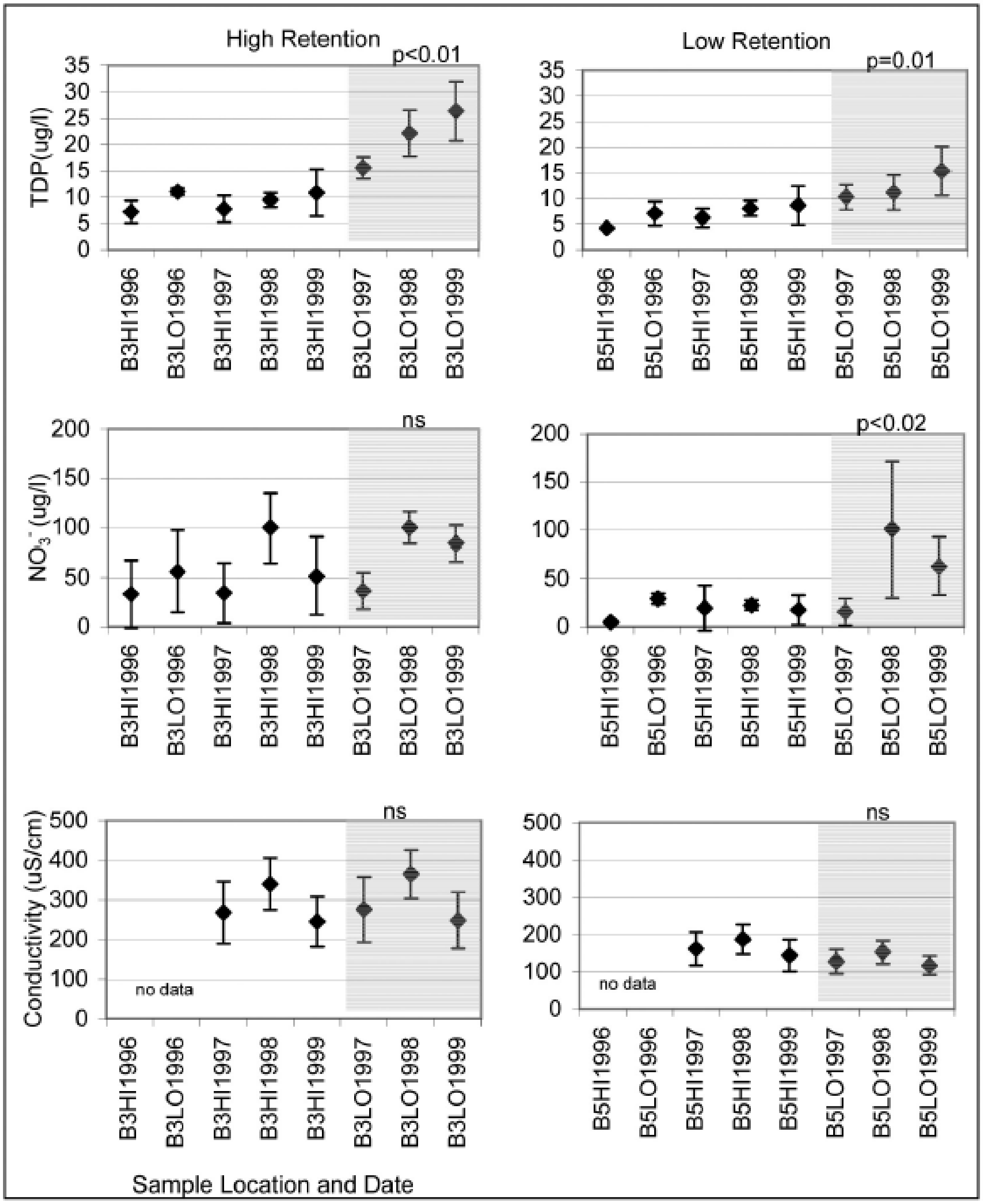

Figure 33: Mean annual (95% CI) TDP, NO3-, and conductivity levels at the control sites (white background) and the treatment sites (shaded background) on B3 and B5. Significant differences between control and treatment sites are noted above the shaded box, with ns meaning not significant. Plots taken from Herunter et al. (2004).

5.0 Periphyton

A periphyton study was done in 1999 on B3, B4, B5, and BEAST (Table 9). The following data were collected: Chlorophyll concentration (ChlConc), phaeophytin (Phaeo), corrected chlorophyll, which was corrected for phaeophytin (CorChl), filter weight, volume, dried filter weight (organic matter concentration), and ash filter weight. Mean values are plotted in Figure 34; this study remains unpublished.

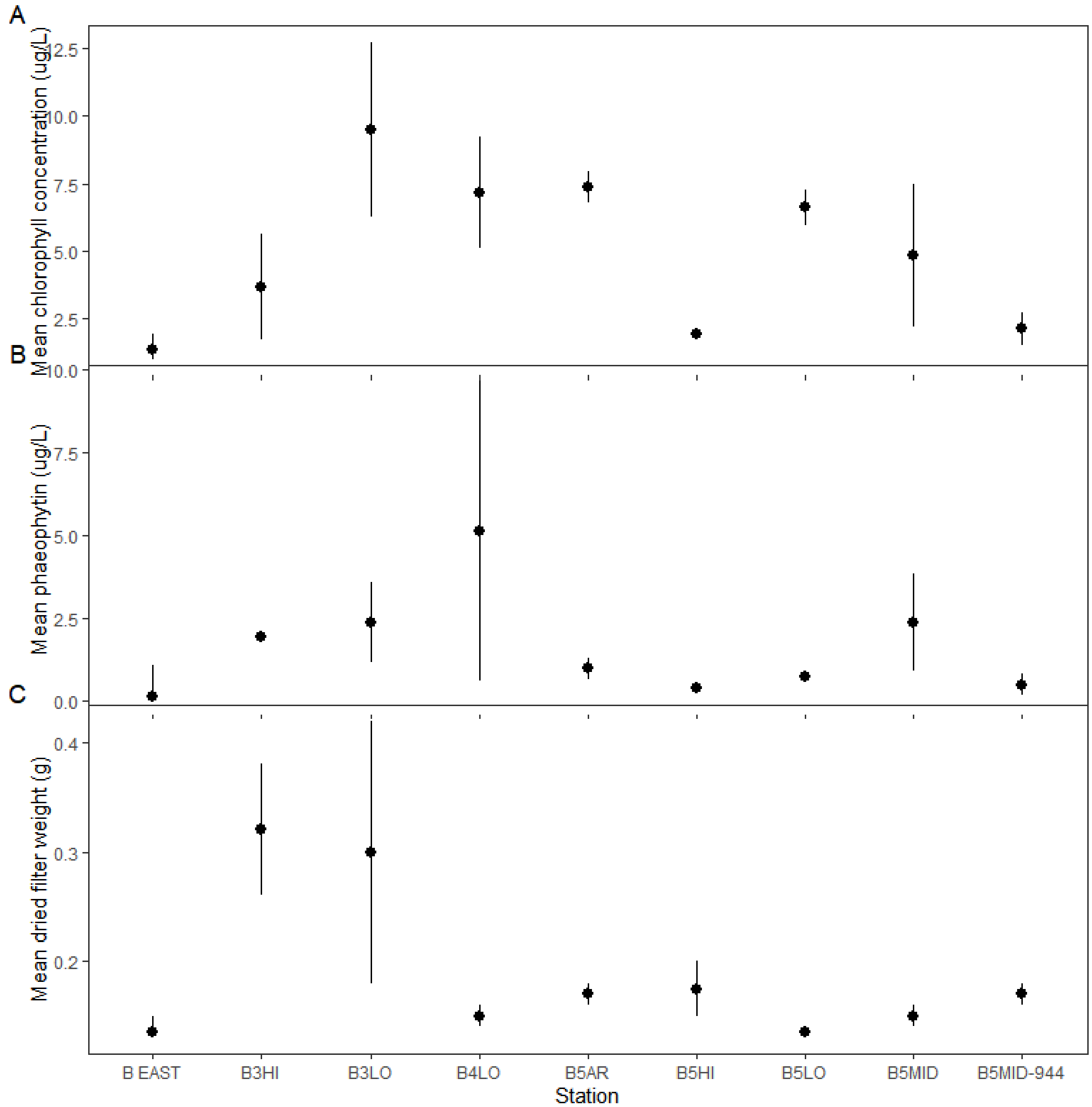

Figure 34: Plot of A) Mean chlorophyll concentration levels at each station in 1999; B) Mean phaeophytin levels at each station in 1999; and C) Mean dried filter weights at each station in 1999 in the Baptiste watershed. Vertical lines represent the range.

Table 9: Periphyton tiles station information and associated riparian buffer treatment in the Baptiste watershed.

Stream	Station	Treatment
B3	B3	20 m high-retention
	B3UP	Upstream control
B4	B4LO	Unharvested control stream
B5	B5RCUS	20 m low-retention downstream recovery
	B5LO	20 m low-retention
	B5MID	20 m low-retention
	B5UP	Upstream control
BEAST	BEAST	NA

6.0 Stream Sediment

Three studies (Beaudry 2003; Herunter et al. 2003; Macdonald et al. 2003c) examined how different forestry treatments influenced stream sediment (Table 10).

Table 10: Sediment station information and associated right-of-way and riparian buffer treatments in the Baptiste watershed.

Stream	Station	Treatment
B3	B3RCDS	20 m high-retention below road
	B3RCUS	20 m high-retention above road
	B3	20 m high-retention
	B3UP	Upstream control
B4	B4RCDS	Unharvested control below road
	B4RCUS	Unharvested control above road
	B4	Unharvested control
B5	B5RCDS	20 m low-retention below road
	B5RCUS	20 m low-retention above road
	B5LO	20 m low-retention
	B5UP	Upstream control

6.1 Riparian Buffer Width and Retention

Beaudry (2003) and Macdonald et al. (2003c) examined the influence of different riparian treatments on turbidity and suspended sediment concentrations. For this study, Parshall flumes were installed both above and below the cutblocks on B3 and B5 to create upstream controls and downstream impact stations. A Parshall flume was also installed on B4 as an unharvested control stream. The concentration of suspended sediments was monitored at the flume locations using an optical turbidity probe (OBS-3, D & A Instrument Company) and a pump water sampler (Sigma 800SL, American Sigma). Turbidity probe measurements were taken every 10 seconds and averaged over 15 minute intervals. Elevated turbidity levels activated the pump water sampler. These samples were filtered, dried, and weighed, and included organic and inorganic material. The samples were then used to establish a relationship between the turbidity probe readings and the concentration of suspended solids.

Sampling took place between the spring of 1996 and the summer of 2001, with harvest occurring in January of 1997. Both of the treatment streams saw increases in TSS after harvest, however the low-retention treatment (B5) had greater increases in TSS, with a 74% increase in

1998, while the largest increase seen at B3 was by 21%. The impacts also persisted longer in B5 than in the high-retention treatment, with TSS levels becoming lower than pre-harvest levels after two years in B3 and three years in B5.

6.2 Road Crossing Right-of-Way Width

Herunter et al. (2003) looked at the impact of different sized road right-of-ways on in-stream sediment (see section 1.2 Road Crossing Study for more details). Sediment monitoring stations were established upstream and downstream of stream crossings on B3, B4, and B5 in the spring of 1997 and were used until 1999. Grab samples were taken in 2000 at each station for size class analysis, and three sediment traps were placed at each station to measure interstitial sediment deposition. Samples from each station were pooled, weighted, and dry sieved according to size class. This study did not find any differences in deposition rates between upstream and downstream stations. Similarly, other than B4, which had coarser sediment at the downstream station, there were no large differences in sediment size between upstream and downstream stations.

7.0 Riparian Canopy Closure

Handheld densiometers were used to estimate canopy density on three streams: B3, B4, and B5, as described by Macdonald et al. (2003c) (Table 11). Canopy density was measured for each station during the summer months between 1997 and 2003, and then more sparsely between 2004 and 2009. Upstream controls were used to compare the loss of stream shade associated with both treatments. Initially, the high-retention treatment preserved nearly double the amount of canopy cover as the low-retention treatment and half of the original canopy cover (Figure 35). This difference in between treatments was negated by windthrow events in the winters of 1997, 1998, and 1999, which reduced the canopy to below 10% canopy closure in B3 and B5 (Figure 35).

Table 11: Densiometer station information and associated riparian buffer treatment for the Baptiste watershed.

Stream	Station	Treatment
B5	SP1B5UP	20 m low-retention upstream control
	SP2B5LO	20 m low-retention
	SP3B5LO	20 m low-retention
	SP11B5RCUS	20 m low-retention above road
	SP12B5RCDS	20 m low-retention below road
	SP13B5LOLO	20 m low-retention
B4	SP8B4RCUS	Unharvested control above road
	SP9B4RCDS	Unharvested control below road
	SP10B4LO	Unharvested control
	SP14B4	Unharvested control
B3	SP4B3	20 m high-retention
	SP5B3B2SW	20 m high-retention
	SP6B3UP	20 m high-retention upstream control
	SP7B3RCDS	20 m high-retention below road

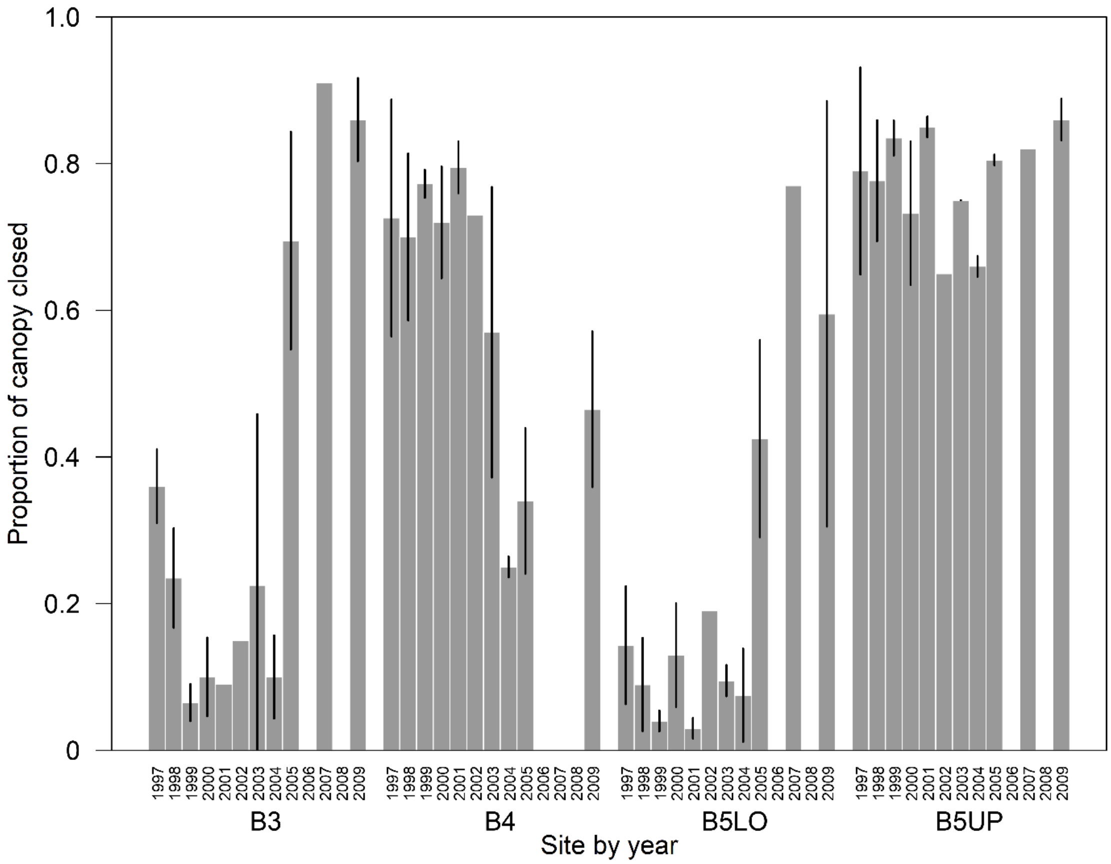

Figure 35: Plots of the proportion of canopy closure by site and year between 1997 and 2009. Significant windthrow events occurred in 1997, 1998, 1999 in B3 (20 m high-retention treatment) that dramatically reduced the canopy cover to similar levels that were observed in B5 (20 m low-retention). Bars are the mean values for all stations within the treatment or control site and vertical lines represent ± 2 standard deviations.

DISCUSSION

Studies done in the headwaters of Baptiste Creek as part of the Stuart-Takla Fish-Forestry Interaction Project (STFFIP) found evidence of immediate and persistent effects on stream temperatures that can be attributed to logging. Stream temperatures at stations below cutblocks were found to be warmer than those at upstream control stations, unharvested control streams, and to pre-logging temperatures. Stream temperatures at impacted stations were higher and more variable than stream temperatures at control streams and stations. Additionally, the method of riparian harvest influenced the magnitude of the temperature effects, which were larger in the stream that had more intensive riparian harvesting (patch retention treatment). The studies also found that road right-of-ways contributed to higher and more variable temperatures. In addition to temperature impacts, these studies showed elevated levels of total suspended solids below cutblocks and changes to macroinvertebrate communities. However, unlike the temperature impacts, which persisted past the most recent analyses and are visible in the data through 2009, the impacts to sediment and macroinvertebrates were transient and showed recovery in 2-3 years.

The Baptiste Creek studies have generated valuable insights on the interactions between forestry and the ecology and hydrology of inland headwater streams. However, the last year of data published was for 2004 and the long-term effects on and recovery of these streams remains unknown. Most notable is that there is no indication from the data collected up to 2009 that any temporal recovery in stream temperatures downstream of cutblocks has occurred. Since 2009, it is not known if stream temperature recovered, and if so, what the trajectory this recovery looked like. It is also not clear if there were delayed, long term physical responses to forestry such as changes in sediment dynamics. These questions and others could be informed by revisiting the data and replicating the original studies

An important feature of this experimental watershed is that logging has not taken place in the watershed since the original experiment harvest, thus preserving the initial forest harvest treatments. This provides a unique opportunity to understand long-term impacts and recovery from forest harvest. Most long-term studies of forest harvest in the Pacific Northwest have been subject to multiple harvest events (Tschaplinski and Pike 2017; Blandon et al. 2018; Gronsdahl et al. 2019). This means that detection of long-term impacts are confounded by more recent harvest impacts. Furthermore, understanding recovery from a single harvest event is difficult as the system is subject to multiple disturbance events, all with their own timelines of impact and recovery.

One of the inspirations for the STFFIP was the Carnation Creek Watershed Experiment, which began in 1970 and is still being monitored at the time of this writing. Long-term monitoring at Carnation Creek revealed patterns in temperature recovery and long acting, delayed responses to physical habitat such as sediment, large woody debris, and channel structure (Tschaplinski and Pike 2017). Continued monitoring of the Baptiste Creek headwaters could further develop our limited knowledge of the long-term impacts of forestry in interior headwater streams.

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APPENDIX A

Table A1: Baptiste station coordinates, alias names and a summary of the studies each station was used in. Abbreviated column headings are SWT = surface water temperature, GWT = groundwater temperature, AMI = aquatic macroinvertebrates, N&WQ = nutrients and water quality, P = periphyton, S = sediment.

Stream	Station	Alias	Latitude	Longitude	SWT	GWT	AMI	N&WQ	P	S
B1	B1	None	54.85660	-125.32650	x					
B1	B1AN	B1A	54.85687	-125.32240	x					
B1	B1AS	B1A	54.85687	-125.32240	x					
B1	B1LO	B1 lower	54.85513	-125.33120	x					
B2	B2	None	54.85210	-125.33390	x					
B3	B3	B3LO	54.85168	-125.33430	x		x	x	x	x
B3	B3B2	B3B2SW, B3-B2 swamp	54.85325	-125.33810	x					
B3	B3B2SW	B3B2, B3-B2 swamp	54.85325	-125.33810	x			x		
B3	B3CCMID	None	54.85147	-125.33120	x					
B3	B3RCDS	B3BR	54.85187	-125.33600	x			x		x
B3	B3RCUS	B3AR	54.85125	-125.33580	x			x		x
B3	B3UP	B3Hi	54.84948	-125.32900	x		x	x	x	x
B4	B4	B4Hi, B4A	54.84827	-125.33710	x		x	x		x
B4	B4A	B4, B4Hi	54.84827	-125.33710	x					
B4	B4Hi	B4, B4A	54.84827	-125.33710	x			x		
B4	B4LO	B4LOW, B4Lo	54.84970	-125.34180	x				x	
B4	B4RCDS	B4BR	54.84865	-125.34010	x			x		x
B4	B4RCUS	B4AR	54.84793	-125.34000	x			x		x
B5	B5CCBOT	None	54.84607	-125.34800	x					
B5	B5CCMID	None	54.84175	-125.34790	x		x		x	
B5	B5CCTOP	None	54.83987	-125.34670	x					
B5	B5LO	B5L, B5Low	54.84613	-125.34680	x		x	x	x	x
B5	B5LOLO	B5Low	54.84792	-125.34630	x					
B5	B5RCDS	B5BR	54.84707	-125.34620	x			x		x
B5	B5RCUS	B5AR	54.84665	-125.34570	x		x	x	x	x

Stream	Station	Alias	Latitude	Longitude	SWT	GWT	AMI	N&WQ	P	S
B5	B5UP	B5U, B5Hi	54.83603	-125.34570	x		x	x	x	x
B5	B5UPFLUME	None	54.83563	-125.34510	x					
B6	B6	None	54.87240	-125.31040	x			x		
BEAST	BEASTST4	None	54.86438	-125.23470	x					
BEAST	BEASTST5	None	54.86410	-125.23630	x					
BEAST	BEASTST7	None	54.86267	-125.23890	x					
B5	SP1B5UP	B5UP-SP1	54.83783	-125.34765		x				x
B5	SP2B5LO	B5LO20-SP2	54.84567	-125.34875		x				x
B5	SP3B5LO	B5LO10-SP3	54.84567	-125.34875		x				x
B5	SP11B5RCUS	B5RCUS-SP11	54.84665	-125.34573		x				x
B5	SP12B5RCDS	B5RCDS-SP12	54.84707	-125.34623		x				x
B5	SP13B5LOLO	B5LOLO-SP13	54.84583	-125.34625		x				x
B4	SP8B4RCUS	B4RCUS-SP8	54.84793	-125.34000		x				x
B4	SP9B4RCDS	B4RCDS-SP9	54.84865	-125.34010		x				x
B4	SP10B4LO	B4LO-SP10	54.84970	-125.34175		x				x
B4	SP14B4	B4-SP14	54.84827	-125.33707		x				x
B3	SP4B3	B3-SP4	54.85168	-125.33430		x				x
B3	SP5B3B2SW	B3B2SW-SP5	54.85325	-125.33813		x				x
B3	SP6B3UP	B3UP-SP6	54.84948	-125.32898		x				x
B3	SP7B3RCDS	B3RCDS-SP7	54.85187	-125.33602		x				x