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Celgar Environmental Effects Monitoring (EEM) Cycle Four Interpretive Report

Final

March 2007

Prepared for:

Zellstoff Celgar Limited Partnership
Castlegar, British Columbia

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CELGAR

ENVIRONMENTAL EFFECTS MONITORING (EEM) CYCLE FOUR INTERPRETIVE REPORT

~ FINAL ~

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AOX	Adsorbable Organic Hallogens
BOD	Biological Oxygen Demand
BC	British Columbia
CCME	Canadian Council of Ministers of the Environment
COD	Chemical Oxygen Demand
CFU	Coliform Units
CRIEMP	Columbia River Integrated Environmental Monitoring Program
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EC	Environment Canada
EEM	Environmental Effects Monitoring
FM	Fibremat
IOC	Investigation of Cause
MOE	Ministry of the Environment
NA	Not Applicable
NF	Non-Fibremat
OM	Organic Matter
OP	Orthophosphates
PPER	Pulp and Paper Effluent Regulations
QA/QC	Quality Assurance/Quality Control
STP	Sewage Treatment Plant
TDP	Total Dissolved Phosphorus
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
VPDB	Vienna Pee Dee Belemnite

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Chad Doherty, Matt Henderson, and Rick McCulloch conducted the field program. Mr. Martin Davies reviewed the report prepared by Ms. Melanie Ptashynski, Ms. Heather Keith, Mr. John Wilcockson, Ms. Valerie Smith, and Ms. Susan Stanley.

EXECUTIVE SUMMARY

This report presents results from the EEM Cycle Four program for the Zellstoff Celgar pulpmill. In EEM Cycles Two and Three, enrichment effects were observed in fish from the near-field area of the Columbia River relative to fish from the Slocan River reference area. However, the benthic invertebrate surveys conducted in the Columbia River did not show evidence of enrichment, and comparisons with fish from the Slocan River were confounded by differences in habitat, productivity, and dietary items (benthic invertebrates) present. For Cycle Four, an Investigation of Cause (IOC) study was conducted to further investigate potential enrichment of the near-field area suggested by these fish surveys. The survey had two components: an expanded traditional benthic invertebrate survey, which provided better spatial representation and reduced variability in the fibremat and reference areas; and, a stable isotope survey. The expanded benthic invertebrate survey was conducted to confirm the lack of enrichment response observed in previous studies. The isotope surveys were conducted to identify a potential-mill related source of nutrients by comparing carbon and nitrogen signatures in sediment and biota in reference and near-field fibremat and non-fibremat areas. Results of the two surveys were evaluated using a weight-of-evidence approach to determine whether the mill has or is enriching the near-field environment. Findings from this survey and from sublethal toxicity testing conducted during Cycle Four are described below.

IOC STUDY

Benthic Invertebrate Survey

- The survey confirms that mill operations are not resulting in enrichment effects in the benthic invertebrate community downstream of the mill, in both fibremat and non-fibremat areas. Communities in reference, near-field fibremat and non-fibremat areas were similar, healthy, and diverse, dominated by facultative taxa. Differences in community composition (indicated by Bray-Curtis index) between the reference and fibremat and non-fibremat areas were likely driven by the change in habitat (faster flows) in the downstream area. Relative abundances of benthic invertebrate food items, such as chironomids and oligochaetes, consumed by mountain whitefish were generally similar in composition and abundance in reference and fibremat areas, and dissimilar in the non-fibremat areas.

- Supporting sediment quality surveys confirm that the historical fibremat is continuing to breakdown over time, resulting in continuing decreases in TOC and dioxin and furan concentrations. TOC was still elevated in the near-field fibremat area relative to the reference area; however, concentrations are very low (0.3 to 4%) and it is expected they will eventually decrease to levels found in the upstream reference area.

- Water quality surveys do not show evidence of increased nutrient concentrations downstream of the mill, which could result in enrichment; in fact, concentrations of nitrogen and phosphorus were highest immediately downstream of the dam, suggesting upstream inputs from Arrow Lake system are an important source of nutrients.

Isotope Survey

- Isotope surveys indicate that carbon signatures found in sediments and benthic invertebrates in the fibremat are distinct from those observed in the reference and non-fibremat areas; benthic invertebrates in the fibremat area reflect the carbon signature found in sediments from the historical fibremat. However, the benthic invertebrate community does not show any evidence of effects related to the fibremat.

- The similarity in carbon signatures between the reference and near-field area suggests that current day operations are not impacting water quality downstream of the mill.

- Carbon signatures in fish were slightly lower in the near-field area than in the reference area.

Results of the IOC survey do not support the enrichment effects in mountain whitefish from the near-field area, relative to fish from the Slocan River reference area, observed in Cycle Two. These differences were likely influenced by the differences in habitats, nutrient concentrations, and benthic invertebrate food resources found in these areas.

SUBLETHAL TOXICITY TESTING

- Sublethal toxicity testing indicates that effluent did not affect survival of rainbow trout or *Ceriodaphnia dubia*.

- Effects on *Selenastrum capricornutum* growth were observed in 1/6 tests at an IC25 geomean of 83% effluent.

- Effects on *C. dubia* reproduction were observed in 4/6 tests with an IC25 geomean of 72% effluent.

- The maximum potential zones of sublethal effects from the effluent discharge point were 82 m for invertebrate reproduction and 72 m for algal growth. However, concentrations of effluent observed in the receiving environment are much lower than the concentrations modeled.

- Results in Cycle Four suggested that overall toxicity was reduced relative to Cycle Three.

DISTRIBUTION LIST

The following individuals/firms have received this document:

Name	Firm	CD	Hardcopies
Janice Boyd	Environment Canada, Environmental Protection Division	3	3
Robyn Roome	BC Ministry of Environment	1	1
Fiona MacKay	Zellstoff Celgar Limited Partnership	3	3

1.0 INTRODUCTION

Under the federal *Pulp and Paper Effluent Regulations*, originally released in 1992 and revised in May 2004 (Government of Canada 2004), pulpmills are required to monitor the chemistry and toxicity of mill effluent, and its potential effects on the receiving environment. Effluent chemistry (limited to total suspended solids and biological oxygen demand) and lethal toxicity are measured to evaluate effluent quality and its potential to affect aquatic biota. However, given there are many factors that can alter the chemistry and toxicity of effluent in the receiving environment, Environmental Effects Monitoring (EEM) studies also are conducted to directly assess the effects of mill effluent on fish, fish habitat, and use of fisheries resources in the vicinity of the effluent discharge (Environment Canada 2005). EEM studies usually include:

- A fish population survey to assess the health of fish;
- Fish tissue surveys, to assess concentrations of dioxins and furans (only required for mills where dioxins and furans are measurable in mill effluent, or remain above 30 pg/g concentrations in biota) or the palatability of edible portions of fish (where there has been a recent complaint of fish taint);
- A benthic invertebrate community survey to assess the condition of fish habitat;
- Supporting water quality data to help interpret findings from fish and benthic invertebrate surveys; and
- Sublethal toxicity testing to assess effects of effluent on growth and reproduction of representative aquatic organisms.

EEM programs typically are conducted in three-year cycles, which begin with the development of a study design, followed by study implementation, data analysis, and reporting. Where a mill has not observed an effect on fish, fish tissue or benthos in two consecutive EEM cycles, that mill may proceed to a six-year cycle of field studies. EEM Cycle One, initiated following the release of the original PPER, was completed between 1993 and 1996. Cycles Two and Three were completed between 1997 and 2000 and 2001 and 2004, respectively. All components of an EEM program are conducted in accordance with the *Pulp and Paper Technical Guidance for Aquatic Environmental Effects Monitoring*, which was recently updated in July 2005 (Environment Canada 2005).

This report presents results from the EEM Cycle Four program for the Zellstoff Celgar mill. The program, previously described in the study design (Hatfield Consultants 2005), included sublethal toxicity testing of mill effluent and an Investigation of Cause survey, where the cause of enrichment effects on fish observed in previous cycles was investigated through an expanded benthic

invertebrate survey and stable isotope study. Information on changes in mill processes, effluent treatment, and/or the receiving environment that have occurred during Cycle Four is also presented. The sections in this report include:

- Section 2 — Mill, Study Area, and Cycle Four Design Update;
- Section 3 — Sublethal Toxicity Testing of Mill Effluent;
- Section 4 — Investigation of Cause Survey
- Section 5 — Conclusions;
- Section 6 — References;
- Section 7 — Glossary;
- Section 8 — Closure; and
- Appendices.

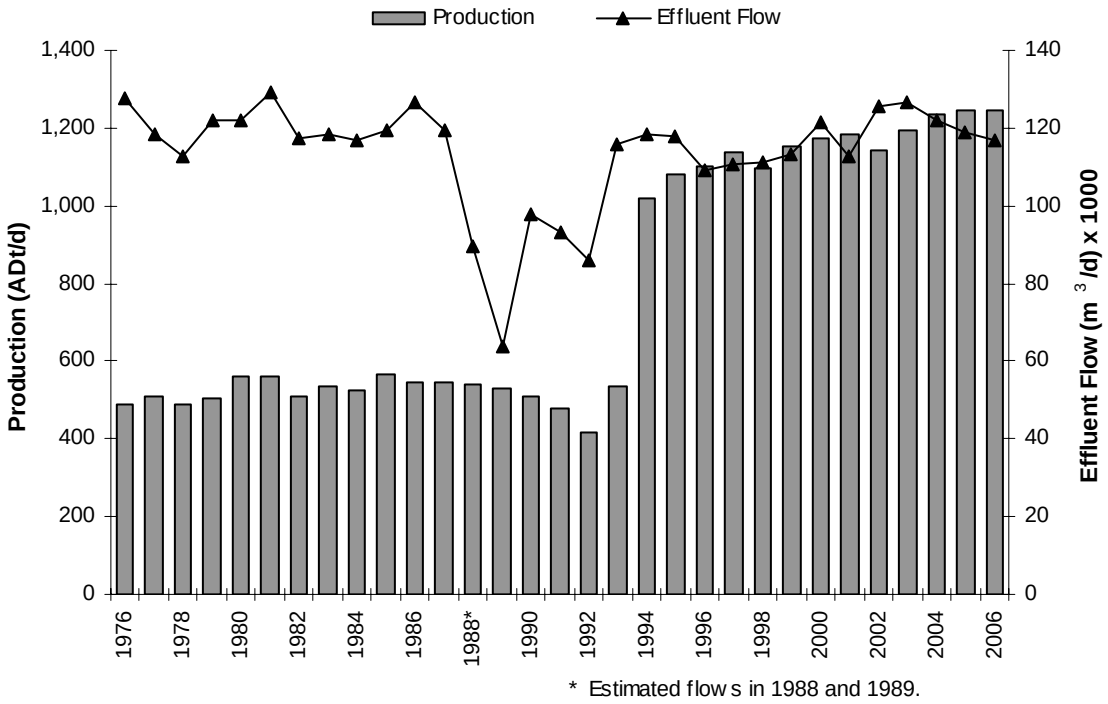
2.0 MILL, STUDY AREA AND CYCLE FOUR DESIGN UPDATE

2.1 MILL OPERATIONS

2.1.1 Process Description and Update

The Zellstoff Celgar Limited Partnership bleached Kraft pulpmill is located north of the confluence of the Columbia and Kootenay rivers at Castlegar, British Columbia, Canada. The original mill, built in 1961, had a production capacity of 454 ADt/d of bleached softwood Kraft pulp. The company expanded operation in 1993 with construction of a new mill, and presently has a target production capacity of 1,200 ADt/d. Daily pulp production (annual averages) between 2004 and 2006 ranged from 1,233 to 1,247 ADt/d (Figure 2.1). Annual effluent flow for this same period ranged from 116,811 to 122,009 m^3/d. The mill processes seven softwood species, including hemlock, cedar, spruce, balsam, fir, larch, and pine.

Figure 2.1 Historical summary of Zellstoff Celgar pulp production and effluent flow (annual averages), 1976 to 2006.



The expansion of the mill in 1993 included the addition of a lime kiln, recausticizing plant, ClO_2 generator, effluent treatment system, pulp machine, evaporators, recovery boiler, and Kamyr fibre line. In April 1993, chlorine dioxide (ClO_2) replaced the use of elemental chlorine in the bleaching process (with 100% ClO_2 substitution). The average amount of ClO_2 used in the bleach plant in 2006 was 36.6 t/day (F. Mackay, *pers. comm*. 2007b); the maximum

amount produced was 53.5 t/day. The bleaching sequence used at the mill is DoEopD1D2 (D = chlorine dioxide, E = caustic extraction, o = oxygen, p = peroxide). A more detailed description of the bleaching process is presented in Hatfield Consultants (1994). Other improvements include the completion of dredging of No. 1 spill pond in 2003 and repairs to the clarifiers and to the liner in the aeration basin. More recently, in August 2006, the mill went to a single grade of pulp (F. Mackay, *pers. comm*. 2007a). As a result of this grade change, the furnish target is now 30% fir/larch, 30% hemlock, 15% cedar, and 25% spruce/ balsam/pine.

The mill is currently in the design and construction phase of a $28.5 million optimization project (known as the Blue Goose Project), which will improve pulping processes, energy utilization, reduce the temperature load to the effluent system, and reduce chemical consumption in the fibreline. In November 2006, two new washers were installed. Modifications to the pulp machine dryer are scheduled for the Spring 2007 mill shutdown (*pers. comm.* Mackay 2007a).

The mill ownership changed in early 2005, when the Celgar Pulp Company, was purchased by Mercer International, and renamed Zellstoff Celgar Limited Partnership.

2.1.2 Effluent Quality

Effluent quality variables are routinely measured as required by provincial permits and federal regulations; annual average levels are presented in Table 2.1 for 2000 to 2006 for Zellstoff Celgar pulpmill.

Pulp production has increased gradually since mill modernization in 1994 (Figure 2.1); despite the increased pulp production, effluent flows have remained relatively constant. Annual average effluent flows decreased slightly in Cycle Four relative to Cycle Three.

Conventional effluent quality variables, including colour, temperature, TSS, BOD were generally similar in Cycle Four to previous cycles, with the following exceptions. Conductivity and pH decreased slightly in Cycle Four.

Loadings of phosphorus released in Cycle Four were similar to those released in previous cycles; however, loadings of ammonia and nitrate decreased and nitrite and TKN increased in Cycle Four.

Adsorbable organic halogens (AOX) were lower in Cycle Four than those reported previously. Concentrations of these AOX, along with TSS and BOD, decreased considerably in 1994 following the expansion and improvements at the mill (Figure 2.2).

Dioxins and furans, which are analyzed once or twice a year, were non-detectable in Cycle Four; concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF have not been detected (<2.0 pg/L) since 1994, when elemental chlorine was removed from the bleaching process.

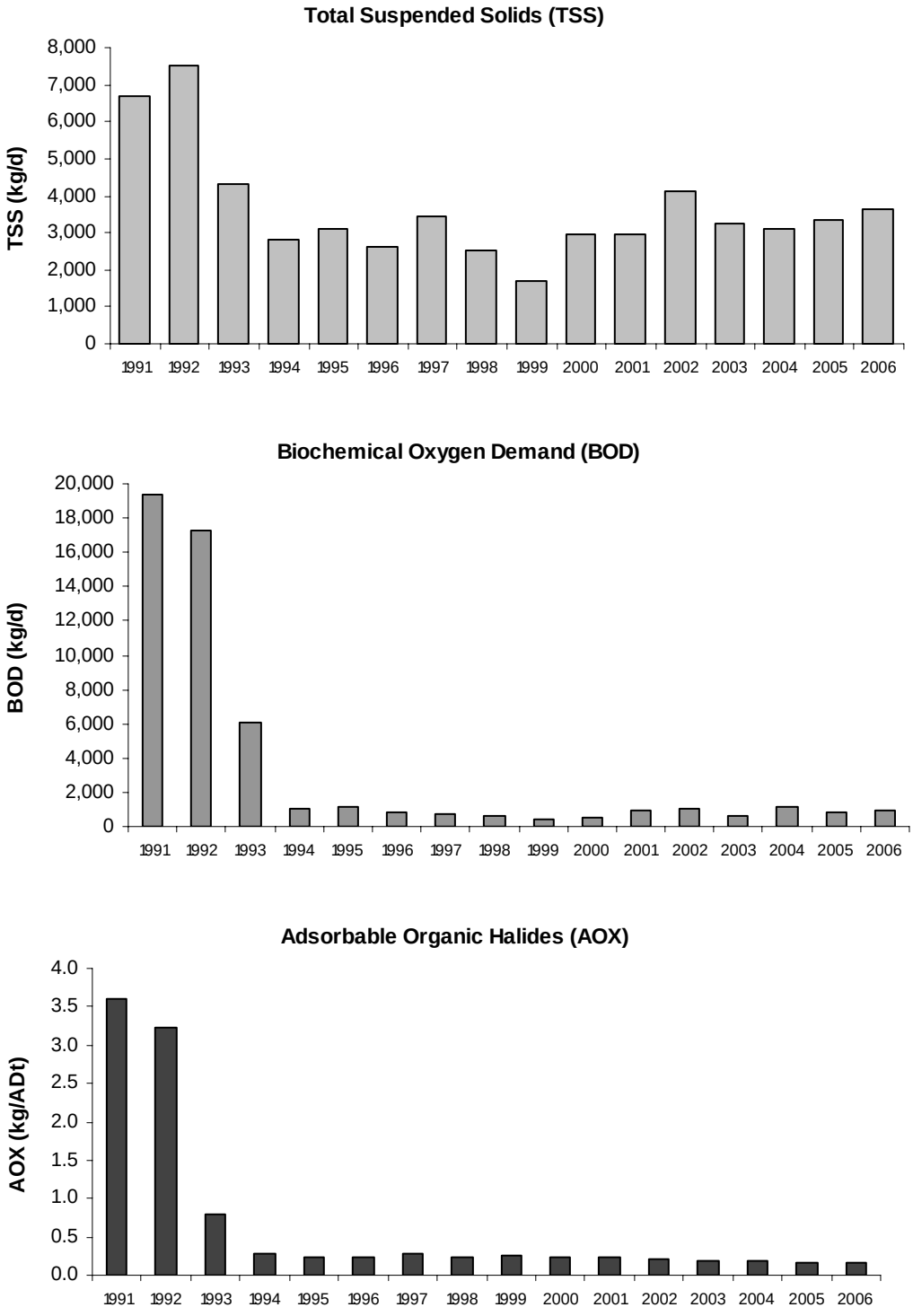
Table 2.1 Annual average values for process effluent quality variables, Zellstoff Celgar mill, 2000 to 2006.

Variable	2000	2001	2002	2003	2004	2005	2006
Total production (ADmt/d)	1,172	1,186	1,141	1,196	1,233	1,247	1,244
Effluent flow (m^3/d)	121,705	112,751	125,344	126,650	122,009	118,788	116,811
Colour (ppm)	221	219	216	383	343	318	286
pH	7.5	7.5	7.5	7.5	7.4	7.2	7.1
Temperature (°C)	33	30.6	30.8	32.1	33.7	32.7	32.6
Conductivity (µS/cm)	1,638	1,693	1,615	1,553	1,406	1,428	1,193
TSS (kg/d)	2,970	2,941	4,133	3,235	3,091	3,357	3,617
BOD (kg/d)	540	964	1,038	671	1102	826	958
AOX (kg/ADt)	0.240	0.225	0.208	0.176	0.181	0.175	0.169
Orthophosphate (kg/d)	50.6	36.4	42.5	50.9	25.2	28.1	52.2
Total Phosphate (kg/d)	73.0	87.0	108.8	103.7	86.1	73.0	111.2
Ammonia nitrogen-NH_3 (kg/d)	14.5	14.0	35.4	17.7	17.5	11.2	11.8
Nitrite nitrogen-NO_3 (kg/d)	46.1	17.2	55.3	2.2	2.4	2.4	2.3
Nitrate nitrogen-NO_2 (kg/d)	3.3	2.0	2.5	9.6	1.2	36.1	5.0
TKN-NH_3 (kg/d)	235.3	193.9	572.8	675.7	1,088.6	640.6	938.6
2,3,7,8 TCDD (pg/L)	nd	nd	nd	nd	nd	nd	nd
2,3,7,8 TCDF (pg/L)	nd	nd	nd	nd	nd	4.2	nd
Rainbow trout 96-hr LC50 (% effluent) – number of tests showing no effect	>100 12 of 12	>100 20 of 20	>100 18 of 18	>100 16 of 18	>100 12 of 12	>100 15 of 15	>100 26 of 26
Daphnia magna 48-hr LC50(% effluent) – number of tests showing no effect	>100 58 of 58	>100 75 of 75	>100 68 of 68	>100 58 of 65	>100 53 of 53	>100 58 of 58	>100 75 of 75

Celgar undertakes regularly scheduled acute toxicity testing using rainbow trout and the cladoceran Daphnia magna. Acute toxicity of final effluent was not observed during Cycle Four. There were no tainting reports submitted.

With the exception of a number of missed samples at the point of discharge due to either sample pump failure or sampling failure, Celgar was compliant with the amended PPER from 2004 to 2006.

Figure 2.2 Annual averages of effluent variables from 1991 to 2006, Zellstoff Celgar Mill.



2.1.3 Spills to the Receiving Environment

Zellstoff Celgar reported the following spills during Cycle Four:

- In September 2003, a soap spill resulted in the issuance of a Pollution Prevention Order on November 27, 2003 from the Ministry of Environment (*pers. comm.* Mackay 2007a). The order required the mill to conduct the following activities: dredging of the spill ponds, training operations on new soap handling operations, conforming with new reporting requirements, developing spill contingency plans, and conducting an environment impact assessment on the Columbia River. In late 2003 and early 2004, approximately 2,700 dry tones of material were dredged from the No. 1 spill pond; the No. 2 spill pond was dredged in 2005. Details of the soap spill are provided in the environmental impact assessment report (Hatfield Consultants 2004) and the mill's performance report (2003 Environment Performance Report, Celgar Pulp Company 2004).

- In two separate incidents, which took place on September 9, 2004 and December 6, 2004, Celgar's two boom boats (Kraft I and II) sank near the dock. Kraft I sank as a result of high winds and a leaking hatch, while Kraft II sank due to a malfunction on the propeller shaft. The sinking of these boats resulted in the release of an estimated 100 to 200 L of diesel fuel (per incident) into the surrounding environment; fortunately, a majority of the fuel was contained and absorbed by log booms. Subsequently, both boats were successfully removed from the water and retrofitted with secondary bilge systems. Further safety measures were taken to prevent future incidents including providing training to woodroom crews. As an additional preventative measure, boats are now removed from the water during extended woodroom shutdowns. The mill received a letter of warning from Transport Canada in late December of 2004, as a result of two similar incidents. However, the letter recognized that there was minimal environmental impact as a result of these accidents.

- In December 2004, there was a minor spill on a local roadway, when a half dump truck load of dredged materials was lost when it was being transported to the landfill. The material was removed from the roadway and deposited to the landfill.

- In April 2005, a break in a 3-inch abandoned pipeline from the primary clarifier to the main untreated effluent line was discovered. As a result, the mill was shutdown until the pipeline was capped off. This incident resulted in the audit of all effluent treatment pipelines and a schedule for pipeline inspections. Additional testing was conducted at the foam tank at the request of the MOE.

- In April 2005, as a result of mill start-up, there was an accidental release of approximately 100 gallons of weak black liquor into the river. The incident was reported to the MOE.

- During the late summer of 2005, there were episodes of flooding at both clarifiers as a result of a downstream pipeline obstruction. In late 2005, another spill occurred when the flooded clarifier overflowed to the ground. The volume of released liquid was small and the impact minimal as the liquid is non-toxic. In 2006, to address the issue of flooding of clarifiers, a majority of the treated effluent pipeline was cleaned. Additional pipeline cleaning is scheduled in 2007. Divers also inspected the river ports in June 2006; two obscured ports that were identified during this inspection will be cleaned in the summer of 2007.

- There were two minor spills in 2006. In June 2006, an overflow from a newly installed manhole resulted in a ground spill of treated effluent. Then in December 2006, very weak black liquor spilled to the ground when conditions in the fibreline were upset.

2.2 STUDY AREA UPDATES

There were no changes to the study area in Cycle Four.

2.3 CYCLE FOUR STUDY DESIGN UPDATE

There were no major changes to the study design in Cycle Four (Hatfield Consultants 2005). Stable isotope analysis excluded sulphur isotopes because analyses could not be conducted on sediments. Isotope analysis of near-bottom (benthic) water was not feasible due to absence of suspended materials needed for isotope analyses.

3.0 SUBLETHAL TOXICITY TESTING OF MILL EFFLUENT

Summary of Cycle Four Sublethal Toxicity Testing (Winter 2004 through Summer 2006) for Zellstoff Celgar Ltd. Mill:

- No effects of effluent on rainbow trout (*Oncorrhynchus mykiss*) embryo survival (EC25>100%) and *Ceriodaphnia dubia* survival (LC50>100%) were observed.
- Effects on *Selenastrum capricornutum* growth were observed in 1/6 tests resulting in an IC25 geomean of 83% effluent.
- Effects on *C. dubia* reproduction were observed in 4/6 tests resulting in an IC25 geomean of 72% effluent.
- Using Environment Canada's dilution model to predict downstream extent of sublethal effects, the maximum potential zone of sublethal effect from the effluent discharge point was 82 m for invertebrate reproduction and 72 m for algal growth. However, concentrations of effluent observed in the receiving environment are much lower than the concentrations modeled. All other tests resulted in an undetectable sublethal zone of effect due to the absence of toxicity.
- Results observed in Cycle Four fell in a similar range to those reported in previous cycles, but were higher (i.e., less toxicity) than those reported in Cycle Three.

Federal and provincial government regulations require pulp and paper mills to undertake toxicity testing as part of their EEM programs, to determine potential lethality or inhibitory effects of their effluent on fish and fish habitat. Current EEM regulations require the use of sublethal toxicity tests to help meet the following objectives:

- Contribute to the field program as part of a weight-of-evidence approach;
- Compare process effluent quality between mill types, and measure changes in effluent quality as a result of effluent treatment and process changes; and
- Contribute to the understanding of a mill's relative contribution to downstream water quality in multiple discharge situations (Environment Canada 2005).

Sublethal toxicity testing for Celgar EEM Cycle Four included the following tests, as stipulated in Annex 1 for freshwater mills west of the Rocky Mountains (Environment Canada 1997):

- Fish early life stage development test, using rainbow trout (*Oncorhynchus mykiss*);
- Invertebrate reproduction and survival toxicity tests, using the cladoceran *Ceriodaphnia dubia*; and
- Plant toxicity test, using the alga *Selenastrum capricornutum*.

Sublethal toxicity testing was undertaken by Cantest Inc. (formerly Vizon SciTec Inc. in Vancouver, British Columbia). Complete reports were submitted to Environment Canada as required within 90 days of test completion. A summary of reported endpoints is included with this Cycle Four interpretive report.

3.1 METHODS

3.1.1 General Methods and Definitions

EEM guidance stipulates sublethal toxicity testing of process effluent twice a year per three-year cycle, for a total of six test periods. Testing for Cycle Four was initiated in Winter 2004, and continued until Summer 2006. In Cycle Four, assigned test seasons were not necessarily representative of the date the test was conducted. The first test period of each year (the "Winter" test period) was usually carried out in May. The second test period (the "Summer" test period) was carried out in November and December. The apparent discrepancy in the naming of test seasons was the result of delays that occurred in Cycle Three as a result of scheduled retests and restrictions associated with trout egg availability. The primary intent of having two test periods per year was to ensure tests were evenly spaced within the EEM cycle and; therefore, the apparent discrepancy is of no concern. Figures presented in this section provide both the test season name and actual test date to prevent any confusion.

On each test date, a grab sample of effluent was collected by mill personnel according to the methodology described in the Technical Guidance Document (Environment Canada 1998a). Sublethal toxicity testing involved exposure of organisms to a series of effluent dilutions. All sublethal toxicity tests were conducted with controls in order to assess the "background response" of test organisms and determine the acceptability of the test using predefined criteria. In addition, in-house cultures were tested with a reference toxicant to monitor the health and sensitivity of the culture. For reported EEM Cycle Four test endpoints, controls met or exceeded all protocol requirements.

Sublethal toxicity tests report LC50, EC25 or IC25 endpoints. The EC25 endpoint, reported for the fish early-life-stage development test, is an estimate of the effective concentration of effluent that causes 25% of embryos to be non-viable. Both algal and invertebrate tests provide IC25 endpoints, which are estimates of the concentration of effluent that causes 25% inhibition of a quantitative biological function, such as reproduction or growth. The invertebrate test also yields an LC50 endpoint, which is the effluent concentration that is lethal to 50% or more of the test organisms. Confidence limits are calculated for each endpoint where possible.

A zone of effluent mixing was determined by a plume delineation study undertaken for the Cycle One pre-design study (Hatfield Consultants 1994a). This survey determined the maximum extent of effluent concentrations of 1% (i.e., 100:1 dilution) or greater potentially present in the receiving water

environment. This 1% effluent zone originally was used to conservatively define near-field and far-field study areas for environmental sampling.

The 1% effluent zone represents conditions of minimum dilution, maximum extent, and long-term average conditions (i.e., long-term effect of effluent discharge) (Environment Canada 2005), and therefore represents worst-case effluent dilution conditions. In riverine systems, such conditions usually occur in late winter, when river flows are seasonally low. For the Celgar EEM study, the maximum extent of 1% effluent was defined as extending approximately 6.0 km downstream of the pulpmill diffusers (Hatfield Consultants 1994a).

A maximum potential zone of sublethal effect was calculated for each test species from the geometric mean of the IC25, EC25, or LC50 endpoints and the extent of the 1% effluent concentration zone, as per Environment Canada (2005). This potential zone of sublethal effect describes the downstream area where the effluent concentrations exceeds the geometric mean of the IC25, EC25, or LC50 endpoint, and is the maximum distance from the effluent discharge where a specified effect may be expressed for a test species. This maximum zone of potential sublethal effect was calculated as follows:

$$\text{Zone (m)} = \frac{\text{Extent of 1\% effluent zone (m)}}{\text{Geometric mean of IC25, EC25 or LC50 endpoints}}$$

As discussed in the Results and Discussion section (Section 3.2.4), this model may not be realistic for the Celgar Mill, given that the highest measured concentrations downstream of the outfall were much less than the EC25 of the most sensitive sublethal toxicity endpoint.

3.1.2 Sublethal Toxicity Test Methods

General procedures for conducting the rainbow trout (*Oncorhynchus mykiss*) tests were based on Environment Canada's *Biological Test Method: Toxicity Tests Using Early Life Stages of Salmonid Fish (Rainbow Trout)*, Second Edition (EPS 1/RM/28) (Environment Canada 1998b and earlier versions). The fish early life stage test is conducted as a static-renewal 7-day embryo test using newly fertilized rainbow trout eggs exposed to a series of effluent concentrations. The resulting endpoint is the effluent concentration for a 25% effect measured as percent viable embryos (EC25) relative to controls.

The invertebrate reproduction test was conducted as three brood (7±1 day) static renewal tests using the cladoceran *Ceriodaphnia dubia*. General procedures for culturing *C. dubia* and conducting tests were based on Environment Canada's *Biological Test Method: Test of Reproduction and Survival Using the Cladoceran Ceriodaphnia dubia* (EPS 1/RM/21) (Environment Canada 1992a, and November 1997 amendments). Daphnids are exposed to a series of different effluent concentrations to assess the survival of the first generation (survival LC50) and to compare the reproductive success (reproduction IC25) in a sample to a control

which must produce three broods of neonates during a 7±1 day period. The LC50 endpoint is the percent effluent concentration at which 50% of the daphnids survive while the IC25 endpoint is the percent effluent concentration whereby reproduction is reduced by 25% from control reproduction rates.

The aquatic plant toxicity test was conducted as a 72-hour algal growth inhibition test using the freshwater alga *Selenastrum capricornutum*. The general procedures used for conducting tests and culturing were based on Environment Canada's *Biological Test Method: Growth Inhibition Test Using the Freshwater Alga Selenastrum capricornutum* (EPS 1/RM/25) (Environment Canada 1992b, and November 1997 amendments). Algal cells are grown in various concentrations of effluent for 72 hours, after which cell populations of each replicate are calculated. Test results (growth IC25 endpoints) represent the algal cell growth of the experimental concentrations compared to the growth of a control. Test effluent concentrations that indicate an enrichment response are excluded from the statistical calculation of the IC25 endpoint as per Environment Canada's *Guidance Document on Statistical Methods for Environmental Toxicity Tests* 5th Draft (Report EPS/RM/draft) (Environment Canada 2003). To calculate the IC25, the control value was assigned to all concentrations showing hormesis (i.e., an enrichment response).

3.2 RESULTS AND DISCUSSION

Celgar conducted six sublethal toxicity tests between Winter 2004 and Summer 2006. Results of these six tests are presented herein.

There were no reported problems with any of the tests, except that the Winter 2006 *Oncorhynchus mykiss* test and the *C. dubia* test were repeated due to poor performance in the test control group. Appendix A1 provides a summary of Celgar Cycle Four sublethal toxicity test results, including dose-response curves for all tests conducted.

3.2.1 Rainbow Trout Early Life Stage Development Test

Figure 3.1 presents a summary of Cycle Four EC25 endpoints for the rainbow trout embryo survival test for Celgar. No effect of effluent was noted on rainbow trout survival (i.e., EC25 >100% v/v effluent).

3.2.2 *Ceriodaphnia dubia* Invertebrate Reproduction and Survival Tests

IC25 reproduction and survival endpoints and confidence limits from Cycle Four tests for *C. dubia* are summarized in Figure 3.2 and Figure 3.3.

Reproduction IC25 endpoints ranged from 51.3 to >100% v/v effluent for a geometric mean of 72.4%. The Winter 2006 testing period exhibited the greatest toxicity in Cycle Four. There was no apparent trend to toxicity during Cycle Four. As well, IC25 endpoints for *C. dubia* were >51.3% effluent, and therefore, well above effluent concentrations that would be observed in the receiving environment.

Figure 3.1 Rainbow trout (*Oncorhynchus mykiss*) embryo survival EC25 endpoints for the Zellstoff Celgar EEM Cycle Four.

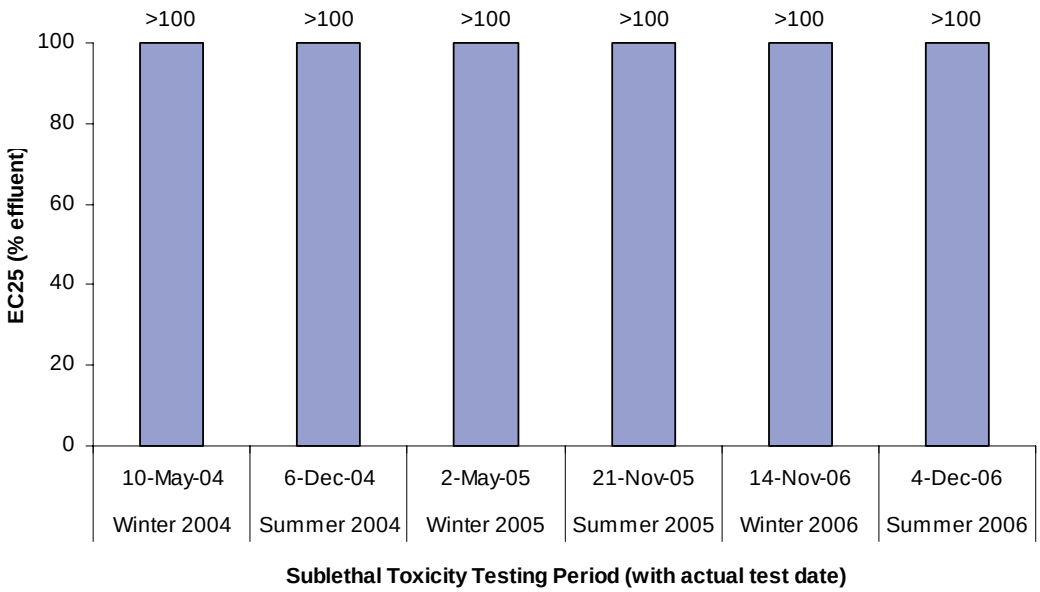


Figure 3.2 Invertebrate tests – *Ceriodaphnia dubia* reproduction IC25 endpoints (± 95% confidence limits) for the Zellstoff Celgar EEM Cycle Four.

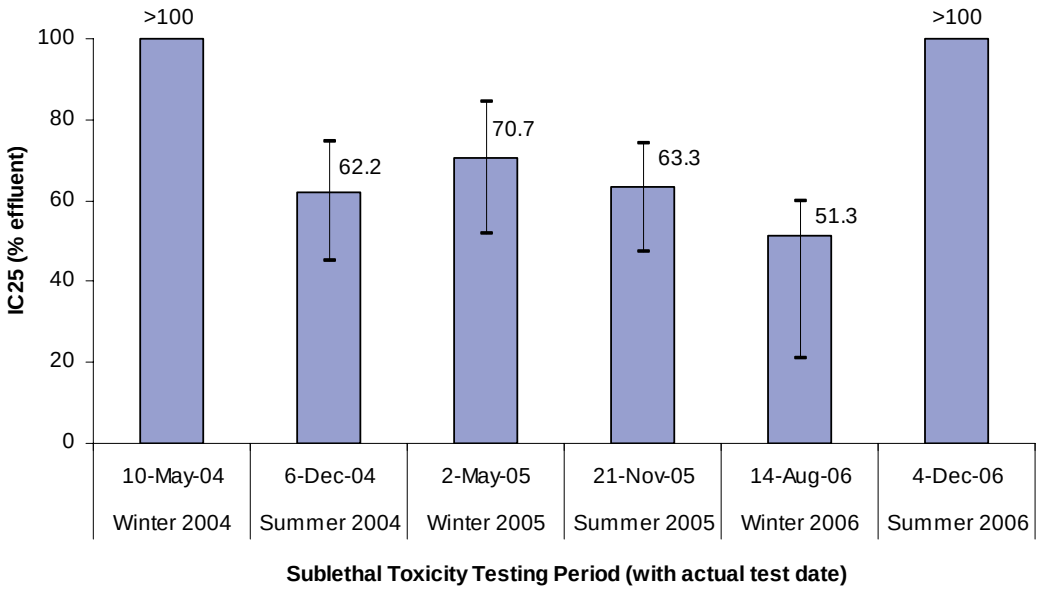
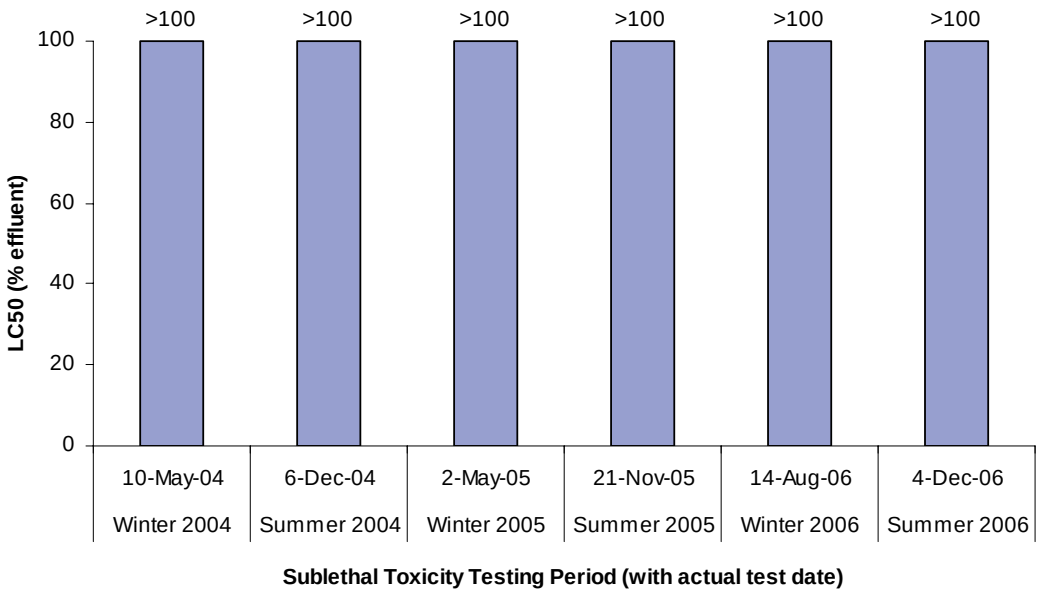


Figure 3.3 Invertebrate tests – *Ceriodaphnia dubia* survival LC50 endpoints for the Zellstoff Celgar EEM Cycle Four.



The Summer 2005 testing period exhibited slight enrichment of *C. dubia* reproduction at the 6.2, 12.5 and 25% effluent concentrations (Appendix A1). Effluent quality data did not provide any insight as to why this particular term elicited an enrichment effect while others did not. Dose-response curves were relatively consistent throughout Cycle Four (Appendix A1).

No effect of effluent was noted on *C. dubia* survival (i.e., LC50 >100% v/v effluent).

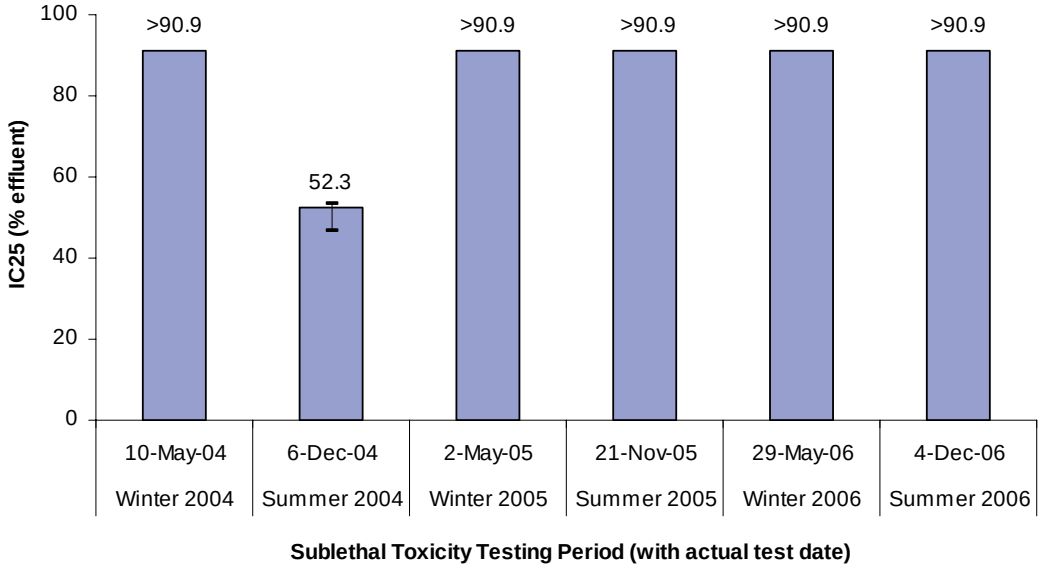
3.2.3 *Selenastrum capricornutum* Plant Toxicity Test

The IC25 endpoints and confidence limits for Cycle Four tests for *S. capricornutum* plant toxicity tests are summarized in Figure 3.4.

Growth IC25 endpoints ranged from 52.3% to >90.9% v/v effluent for a geometric mean of 82.9%. All testing periods in Cycle Four indicated an enrichment effect (i.e., enhanced growth relative to controls) on *S. capricornutum* growth at lower effluent concentrations (Appendix A1).

S. capricornutum growth endpoints during Cycle Four indicated an absence of measurable toxicity with the exception of Summer 2004 (Figure 3.4). However, pattern of toxicity observed for *S. capricornutum* was not observed in the other sublethal tests during the Summer 2004 testing period.

Figure 3.4 Plant toxicity tests – *Selenastrum capricornutum* growth IC25 endpoints (± 95% confidence limits) for the Zellstoff Celgar Mill, EEM Cycle Four.



3.2.4 Maximum Potential Zone of Sublethal Effect

The 1% zone of effluent concentration for Celgar varies seasonally based on river flows, additionally there are daily fluctuations that occur due to the operation of the Hugh Keenleyside Dam. The pre-design identified a zone of incomplete effluent mixing from the diffuser to Robson, or the old ferry crossing, 6 km downstream, which would constitute the predicted maximum extent of effluent concentrations of 1% or greater at lowest winter flows (i.e., worst-case dilution conditions) (Hatfield Consultants 1994a). The regional report by Environment Canada assigned the 1% effluent concentration zone as 4 km (Colodey *et al.* 1999). For maximum potential zone of sublethal effect calculations, 6 km was used as the 1% effluent zone for a conservative estimate.

Table 3.1 presents the geometric means of the IC25, EC25, and LC50 endpoints for each test species for all four cycles, and the resulting maximum potential zones of sublethal effect calculated using the 6 km length for the 1% effluent zone. Calculations of geometric means and maximum potential zones of sublethal effects can be found in Appendix A1.

A maximum potential zone of sublethal effect could not be calculated for the rainbow trout and *C. dubia* survival tests as no toxicity due to effluent was observed. The Cycle Four zone of sublethal effect for *S. capricornutum* growth was 72 m. The maximum zone of sublethal effect for *C. dubia* was 82 m.

Table 3.1 Maximum potential zone of sublethal effect for the Zellstoff Celgar Mill, EEM Cycle Four.

Sublethal Toxicity Test Species	IC25/EC25/LC50 Geometric Mean (% v/v)				Maximum Potential Zone of Sublethal Effect[1] (m)			
	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 1	Cycle 2	Cycle 3	Cycle 4
Rainbow trout Viability EC25	>100%	>100%	>100%	>100%	<60 m	<60 m	<60 m	<60 m
Ceriodaphnia dubia Reproduction IC25	43.70%	82.40%	54.60%	72.40%	137 m	72 m	109 m	82 m
Ceriodaphnia dubia Survival LC50	>100%	>100%	>100%	>100%	<60 m	<60 m	<60 m	<60 m
Selenastrum capricornutum Growth IC25	90.90%	49.80%	37.70%	90.90%	66 m	103 m	159 m	66 m

[1] Based on 1% effluent zone of 6,000 m.

Effluent concentrations equal to a geometric mean of IC25, EC25, or LC50 endpoints have not been observed downstream of the Celgar diffuser (Hatfield Consultants 1994, 1997). The highest concentration of effluent observed in the near-field area during Cycle One was 1.03% effluent, based on sodium levels measured in October 1994 (Hatfield Consultants 1997); this concentration is well below the lowest geometric mean (IC25 of 72.4%) calculated for *C. dubia* in Cycle Four. The maximum potential zone of sublethal effect distance from the Celgar diffuser is approximately 82 m.

3.2.5 Comparison with Historical Data

Geometric means for all four endpoints for Cycles One to Four are presented in Table 3.1. The rainbow trout and *C. dubia* survival endpoints have been >100% effluent for all four cycles. *C. dubia* reproduction and *S. capricornutum* growth IC25s fell into the range observed in previous cycles, but represent a decrease in toxicity relative to IC25s observed in Cycle Three. Corresponding trends were observed for the zone of sublethal effect.

3.3 CONCLUSIONS

Results of Cycle Four tests showed effects on *S. capricornutum* growth (1/6 tests, geomean IC25 of 83%) and *C. dubia* survival (4/6; geomean IC25 of 72%) tests; no effects on *C. dubia* or rainbow trout survival were observed. Overall results were consistent with previous cycles.

Results of Cycle Four sublethal toxicity testing suggests that Celgar effluent may have the potential to affect aquatic organisms to a maximum distance of 82 m downstream of the diffuser in worst-case (i.e., lowest river flow) conditions. Maximum potential zones of sublethal effect decreased slightly for both the *C. dubia* reproduction and *S. capricornutum* growth endpoints relative to Cycle Three, reversing the apparent trend of increased toxicity observed from Cycle One to Cycle Three.

4.0 INVESTIGATION OF CAUSE

4.1 INTRODUCTION

4.1.1 Nutrient Enrichment

Nutrients, including nitrogen, phosphorus, and carbon, are essential elements for plant and animal growth. In both terrestrial and aquatic systems, low concentrations of these nutrients can limit plant growth. However, when present in excessive amounts in aquatic systems, these nutrients can result in nutrient enrichment. Typically, enriched environments are characterized by the presence of high nutrient concentrations, which stimulate blooms of algae (i.e., periphyton and phytoplankton). The occurrence of eutrophication has been linked to nutrient-rich discharges from pulpmills and sewage treatment plants (STPs) (Chambers *et al.* 2001).

Given that a eutrophic system is highly biologically productive, eutrophication can have positive effects in some systems by providing nutrients that can help local fisheries flourish; in some waterbodies, nutrients are actually added to increase aquatic productivity and fish production (e.g., Arrow Lake). However, eutrophication also may result in the excessive production of algal blooms that can clog waterways, reduce oxygen levels, increase pH, which can adversely affect fish and other biota, as well as affecting the odour, appearance, and taste of drinking water, and affecting recreational users (USDA 1999). An enriched environment can result in increased densities and diversity and reduced richness of benthic invertebrates (Dodds and Welch 2000, Culp *et al.* 1996, Dubé and Culp 1996). The biomass or size of the invertebrates can also be larger in enriched systems, as a result of increased growth. However, high concentrations of nutrients, such as nitrates or ammonia, can also cause toxic effects in the benthic invertebrate community. Algal growth can enhance fish populations by providing more food resources. However, excessive algal blooms may adversely affect fish by reducing dissolved oxygen concentrations, affecting the abundance and diversity of benthos and fish species, or physically modifying habitats (Urban Systems Ltd. 2002).

4.1.2 Investigation of Cause Study on Enrichment in the Columbia River

In the Columbia River, algal blooms are apparent in some years, particularly in shallow sections of the river; however, the source of these blooms does not appear to be linked to the mill or STP discharges (CRIEMP 2005), and likely is a result of the elevated nutrient concentrations found upstream of the mill. Periphyton communities are generally similar upstream and downstream of the mill (CRIEMP 2005).

Results from the past two EEM cycles indicated that differences observed between fish from the Columbia River near-field area and Slocan River reference area were suggestive of enrichment (i.e., fish in the near-field were bigger than

fish in the reference area). Differences in condition in male and female fish in near-field and reference areas (15% to 24%) exceeded the critical effects size (10%) in two cycles; differences in relative gonad size in male fish (286%) from reference and near-field areas greatly exceeded the critical effect size (25%) for one cycle. However, interpretation of these results is confounded by differences in habitat, nutrient concentrations, and food items consumed by whitefish (reflective of benthic invertebrate communities) in these areas.

Furthermore, effects of enrichment on benthic invertebrate communities were not evident downstream of the mill in the Cycle Two and Three surveys. In Cycle Two, an erosional benthic invertebrate survey indicated significantly lower densities in the near-field relative to the reference area. In Cycle Three, density and richness did not differ significantly between reference and exposure depositional areas, but community composition (Bray-Curtis indices) was significantly dissimilar.

For Cycle Four, Hatfield Consultants addressed the discrepancy between the fish and benthic invertebrate surveys by investigating potential nutrient enrichment through an Investigation of Cause study (IOC). The survey had two components: an expanded traditional benthic invertebrate survey, which provided better spatial representation and reduced variability in the fibremat and reference areas, and a stable isotope survey. The expanded benthic invertebrate survey was conducted to confirm the lack of enrichment response observed in previous studies. The isotope surveys were conducted to identify a potential-mill related source of nutrients by comparing nutrient signatures in sediment and biota in reference and near-field fibremat and non-fibremat areas. Results of the two surveys were evaluated using a weight-of-evidence approach to determine whether the mill has or is enriching the near-field environment

Methods and key findings of these surveys are described in this section of this report.

4.2 IOC COMPONENT 1 - BENTHIC INVERTEBRATE SURVEY

4.2.1 Introduction

A traditional control/impact benthic invertebrate community survey was conducted in depositional areas of the Columbia River, near the Celgar pulpmill, in September 2005 to satisfy federal environmental effects monitoring (EEM) Cycle Four requirements as outlined in the design document (Hatfield Consultants 2005). The objective of the expanded benthic invertebrate survey was to assess whether benthic invertebrate communities in the near-field area and within near-field fibremat and non-fibremat subareas are enriched. To better understand the potentially confounding influence of the STP on the community, samples also were collected upstream and downstream of the STP.

4.2.2 Study Design

A depositional benthic invertebrate survey was conducted due to the generally lake-like characteristics of the Columbia River in the vicinity of the pulpmill. The expanded study design used for the survey in Cycle Four differed from the design used in previous EEM Cycles as follows:

- Reference stations were all moved to the section of the river downstream of the dam to reduce variability among stations in the reference area;
- The number of stations in the near-field area was increased within fibremat and non-fibremat areas to allow for more statistically powerful comparisons of differences between these areas.
- Two stations were added upstream and downstream of the Castlegar STP to assess potential impacts of the STP on the receiving environment.

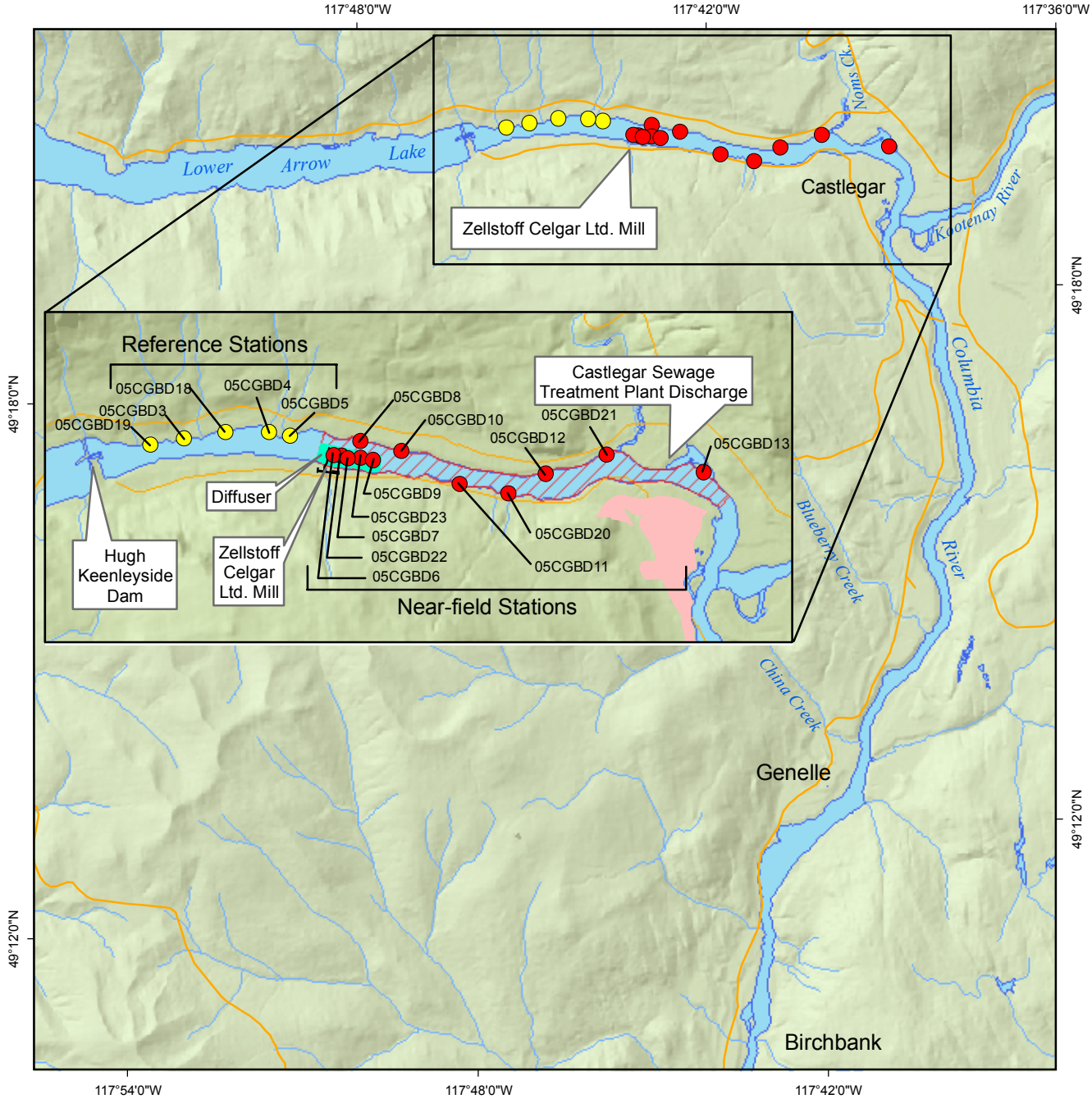
A total of 17 stations were sampled for benthic invertebrates including 5 reference stations downstream of the Hugh Keenleyside dam and upstream of the mill discharge, and 12 stations located in the near-field area downstream of the mill (included 5 stations within the fibremat area, 5 stations outside of the fibremat area, and two stations located up and downstream of the STP). Station locations and descriptions are presented in Table 4.1 and Figure 4.1.

Table 4.1 Location, distance from diffuser, and date of sampling for the IOC survey, Celgar EEM Cycle Four.

Station	Description	Latitude[1] (dd°mm"ss.ss')	Longitude[1] (dd°mm"ss.ss')	Distance (m)	Sampling Date
Reference Area (Downstream of the Dam)					
CGBD 3	2 km U/S of Diffuser	49°20"30.7'	117°45"13.2'	-2,000	28-Sep-2005
CGBD 4	1 km U/S of Diffuser	49°20"28.3'	117°44"12.0'	-1,050	28-Sep-2005
CGBD 5	0.6 km U/S of Diffuser	49°20"26.1'	117°43"57.1'	-600	29-Sep-2005
CGBD 18	1.5 km U/S of Diffuser	49°20"31.4'	117°44"43.1'	-1,500	29-Sep-2005
CGBD 19	2.6 km U/S of Diffuser	49°20"29.4'	117°45"37.2'	-2,600	29-Sep-2005
Near-Field Area					
Fibremat					
CGBD 6	120 m D/S of Diffuser	49°20"14.6'	117°43"27.7'	120	03-Oct-2005
CGBD 7	325 m D/S of Diffuser	49°20"12.4'	117°43"18.0'	325	03-Oct-2005
CGBD 9	700 m D/S of Diffuser	49°20"10.1'	117°42"59.9'	700	03-Oct-2005
CGBD 22	200 m D/S of Diffuser	49°20"13.8'	117°43"22.1'	200	03-Oct-2005
CGBD 23	500 m D/S of Diffuser	49°20"11.9'	117°43"8.9'	500	03-Oct-2005
Outside Fibremat					
CGBD 8	400 m D/S of Diffuser	49°20"19.6'	117°43"7.5'	450	28-Sep-2005
CGBD 10	1 km D/S of Diffuser	49°20"12.8'	117°42"38.9'	1,050	03-Oct-2005
CGBD 11	2 km D/S of Diffuser	49°19"54.4'	117°42"00.3'	1,940	03-Oct-2005
CGBD 12	3.2 km D/S of Diffuser	49°19"54.3'	117°40"57.8'	3,230	03-Oct-2005
CGBD 13	5.5 km D/S of Diffuser (downstream of STP)	49°19"46.4'	117°39"05.3'	5,500	03-Oct-2005
CGBD 20	2.7 km D/S of Diffuser	49°19"47.4'	117°41"26.2'	2,700	03-Oct-2005
CGBD 21	4 km D/S of Diffuser (upstream of STP)	49°19"59.7'	117°40"13.0'	4,100	03-Oct-2005

[1] Latitude and longitude: dd=degrees, mm=minutes, ss=seconds.

Figure 4.1 Benthic invertebrate, sediment, and benthic water sampling stations for Investigation of Cause study, Celgar EEM Cycle Four, September 2005.



LEGEND

- Lakes / Ponds / Major Rivers
- Rivers / Streams
- Major Roads
- Castlegar City Limit
- 1% Effluent Concentration Zone
- Fibre Mat and 1% Effluent Concentration Zone
- Exposed Sampling Station
- Reference Sampling Station

Hatfield CONSULTANTS

N

0 1.25 2.5 5 Km

Projection: Albers Equal Area - NAD83

K:\Data\Project\CG1140\GIS_MXD\CG1140_SSites_2007JAN04.mxd

4.2.3 Methods

4.2.3.1 Sample Collection

Benthic Invertebrates

The benthic invertebrate survey was conducted between September 28, 2005 and October 3, 2005. Three replicate sub-samples were collected at each station using a 23-cm stainless steel Ponar grab (surface area 0.05 m^2), which was deployed using a davit and pulley system from a 6-m jet boat. Upon retrieval, the grab was placed in a plastic tub and checked to ensure a sufficient volume of sample (>50%) was collected. Grabs with sufficient sample volume were transferred to plastic tubs and taken to the shoreline for field sieving with a 200-µm box sieve. Samples were sieved and gently washed with water, then transferred with debris into 1-L plastic jars and preserved with ethanol; ethanol was used because other fixatives commonly used (e.g., formalin) may interfere with isotope analysis. The sample jar and lid were labeled with the station identification number; in addition, a piece of labeled waterproof paper was enclosed in each jar.

Supporting Effluent and Water Quality

A number of water quality variables were measured to aid in the interpretation of the benthic invertebrate data. Standard *in situ* water quality variables were measured at each station during sample collection using a portable water quality meter:

- Temperature (±0.1 °C);
- Dissolved oxygen (±0.1 mg/L);
- pH; and
- Conductivity (±0.1 µs/cm).

Water samples also were collected at each station at near-bottom depths using a Kemerrer bottle for chemical analyses and shipped to ALS Environmental (Vancouver, BC) for the laboratory analyses; effluent samples were also collected during field surveys and analyzed for the same set of variables.

Supporting Sediment Quality

A composite sample from a minimum of two separate grabs was collected for sediment quality analyses. Using a stainless steel spoon, the top 2 cm of each sample was removed and placed in a jar. The composite sample was transferred into three heat-treated 250-mL wide-mouth glass jars with Teflon lids (one for dioxin and furan analysis and two for the remaining analytes). Each sediment jar and lid was clearly labeled with a sample identification number. A matching set of labels was affixed to data sheets for each station. All sediment samples were stored on ice and kept in the dark prior to and during shipment to the laboratories (AXYS [Sidney, BC] for dioxin and furan analysis and ALS for other analytes).

4.2.3.2 Sample Analysis

Benthic Invertebrate Taxonomy

An experienced invertebrate taxonomist, Biologica Environmental Services (Victoria, BC), conducted taxonomic analyses. Freshwater benthic invertebrate samples were re-sieved in the laboratory at 500 µm and approximately 200 µm; the 500 µm fraction was analyzed for all samples; the 200 to 500 µm was either analyzed or archived. Benthic invertebrates were identified to the lowest taxonomic level readily possible (i.e., genus and species), to ensure comparisons could be made with historical data sets. Different life stages of benthic organisms (i.e., larvae, nymphs, pupae, adults) were identified and enumerated separately. Organisms were identified using standard keys.

Samples were analyzed in accordance with QA/QC requirements. A minimum of 10 % of the samples were re-sorted and checked to ensure a ≥ 90 % sorting efficiency was observed. To check subsampling error, 10% of the individual benthic samples subsampled were sorted in their entirety to ensure that subsampling accuracy and precision were <20% error.

Water Samples

Water and effluent samples were analyzed for the following variables:

- Hardness (mg/L $CaCO_3$);
- Total phosphorus and total dissolved phosphorus (mg/L);
- Total nitrogen, nitrate-nitrite, and ammonia (mg/L);
- Total organic carbon (TOC) and dissolved organic carbon (DOC) (mg/L); and
- Sodium (as an effluent tracer).

Sediment Samples

Sediment samples were analyzed for the following variables:

- Particle size;
- TOC; and
- Dioxins and furans (only at 3 fibremat stations).

Dioxin and furan analyses were conducted at AXYS (Sydney, BC); particle size and TOC analyses were conducted at ALS. Dioxin and furan analyses were conducted for the provincial monitoring program under BC MOE directives.

4.2.3.3 Data Analysis

Benthic Invertebrate Data

a) Community Metrics

Four community metrics, described below, are designated EEM effects endpoints used to identify effects in the benthic invertebrate community.

Density - The density of each taxon was calculated by dividing the raw count data by the area of the grab. Average density was calculated for each station by averaging the three replicate subsamples.

Richness – Total taxa richness for each station was calculated by summing the number of different taxa observed in all three replicate subsamples.

Evenness – The evenness index takes into consideration the abundance of each taxon in proportion to total abundance, and the taxonomic richness at the station Smith and Wilson (1996). Evenness ranges from 0 to 1, with 1 representing a community where the relative abundance is evenly distributed among a large number of taxa and 0 representing a community where the relative abundance is attributed to a small number of taxa. Evenness is calculated as:

$$E = 1 \Big/ \sum_{i=1}^{s} [pi]^2 / s$$

where E = Evenness;
p_i = proportion of i^{th} taxon at the station; and
s = number of taxa in the sample.

Bray-Curtis Dissimilarity Coefficients - Bray-Curtis dissimilarity coefficients were calculated to compare the degree of similarity between individual stations and the reference median using the five reference stations. The Bray-Curtis dissimilarity co-efficient is a distance measurement that reaches a maximum value of 1 for two stations that are entirely different and a minimum of 0 for two stations that have nearly identical communities (Bray and Curtis 1957). Dissimilarity coefficients for the reference median and individual stations were calculated using SYSTAT 10 (SPSS 2000).

The Bray-Curtis index is calculated as follows:

$$B - C = \frac{\sum_{i=1}^{n} |y_{i1} - y_{i2}|}{\sum_{i=1}^{n} (y_{i1} + y_{i2})}$$

where: B-C = Bray-Curtis distance between stations 1 and 2;
y_{i1} = count for species i at station 1;

y_{i2} = count for species i at station 2; and

n = total number of species present at the two stations.

In addition to the designated EEM effects endpoints Simpson's diversity index was calculated. This index takes into account both the abundance patterns and the taxonomic richness of the community and determines for each taxonomic group at a station, the proportion of individuals that it contributes to the total in that station. Diversity ranges from 0 to 1, with 1 representing a community with high diversity of species and 0 representing a community with a low diversity of species. Diversity is calculated:

$$D = 1 - \sum_{i=1}^{s} [pi]^2$$

where: D = Simpson's index of diversity;

S = the total number of taxa at the station; and

p_i = the proportion of the i^{th} taxon at the station.

b) Statistical Analysis

All statistical analyses were conducted using Excel 2000 and SYSTAT 10 (SPSS 2000).

Summary Statistics

Summary statistics, including means, medians, standard deviations (SD), standard errors (SE), minima, and maxima, were calculated for benthic invertebrate community metrics.

Analysis of Variance (ANOVA)

Two-tailed ANOVAs and Tukey's multiple comparisons were conducted for benthic community metrics to identify differences between reference and near field area/subareas. Residuals from the ANOVA were saved and evaluated for normality and homogeneity of variance qualitatively using residual plots. If data failed to meet the assumptions of the ANOVA model, ANOVAs were conducted using $\log_{10}$-transformed variables. If assumptions of the model were not met using the transformed variables, ANOVAs and Tukey's comparisons were conducted using ranked data. All tests were conducted at a significance level of $\alpha = 0.10$ (Environment Canada 2005).

Cluster Analysis

Cluster analysis is a multivariate procedure for detecting natural groupings in data. It is based on the relative abundance of taxa from each station; taxa that are abundant tend to influence the cluster analysis more than rare taxa. The cluster analysis was conducted on Bray-Curtis dissimilarity coefficients created from abundance data for individual taxa. These Bray-Curtis dissimilarity coefficients differ from those described in the preceding section in that they include pair-wise

comparisons for all stations, rather than being restricted to comparisons to the reference median. Cluster analysis was conducted using hierarchical clustering with average linkages in SYSTAT 10 (SPSS 2000).

Correlations

Spearman's rank correlations were used to evaluate the relationships between benthic community metrics and supporting environmental variables.

Power Analysis

Power analysis was used to evaluate the possibility of false negative results (i.e., concluding that no difference in a variable exists when in fact they do). Statistical power is a function of sample size, variability and magnitude of difference (i.e., effect size) one wishes to detect. The effect size recommended for benthic invertebrate data is two times the standard deviation of the reference area (Environment Canada 2005).

Post-hoc power analyses were conducted to evaluate the potential to detect differences between areas (e.g., Reference vs. Near-field). The approach, described in the Pulp and Paper EEM Technical Guidance Document (Environment Canada 2005) is for a basic control/impact design which calculates power for a t-test comparison of two areas, the reference and near-field.

Power was calculated using the following formula:

$$t_{1-\beta} = \left(\frac{\delta}{\sigma}\right)\left(\sqrt{\frac{n}{2}}\right) - t_{\alpha}$$

where: β = Type II error, which occurs when the null hypothesis that there is no effect is falsely accepted, was set to 0.10;

$t_{1-\beta}$ = t value for 1-β significance level;

δ = effect size, which is equal to 2 SD;

σ = SD within areas, which is equal to 1;

t_{α} = t value for α significance level;

n = sample size/area; and

df for t are a(n–1), where a = the number of groups.

Statistical comparisons were considered to have sufficient power (P, probability of detecting an effect size) when P≥ 0.90. All analyses were conducted using G*Power software (Faul and Erdfelder 1992).

Supporting Water and Sediment Chemistry Data

Summary statistics and ANOVAs were also used to summarize and evaluate differences in water and sediment quality between reference and near-field areas using methods described above.

Water and sediment quality data were screened against relevant Ministry of Environment *Ambient Water Quality Objectives for the Columbia River (Hugh Keenleyside Dam to Birchbank)* (MOE 1992) and Canadian Council of Ministers of the Environment *Environmental Quality Guidelines* (CCME 2005).

The MOE objectives were developed to protect a variety of water uses in the Columbia River including aquatic life (and their habitats), wildlife consuming aquatic life, recreational use, aesthetic values, and drinking water. The objectives apply to all areas of this reach except the initial dilution zones of pulpmill and STP discharges where adverse biological conditions are expected to occur. According to these objectives, initial dilution zones of the mill and STP effluent extend from the diffuser to 100 m downstream, and up to 50 % of the width of the river for the pulpmill discharge and up to 25 % of the width of the river for all other discharges.

4.2.4 Results and Discussion

Raw benthic data are presented in Appendix A2. Summary tables and figures are presented below.

4.2.4.1 Benthic Invertebrates

Community Metrics

a) Cycle Four Results

Densities of benthic invertebrates occupied a similar range of variability (8.026 to 30,591 organisms/m^2) within and between areas, with the exception of four stations (Figure 4.2). Two near-field fibremat stations, CGBD6 and CGBD9, and CCDB8, a non-fibremat station, exhibited higher densities, ranging from 50,069 to 61,693 organisms/m^2, and one non-fibremat station, CGBD11, exhibited a lower density (1,080 organisms/m^2) which fell outside the range of natural variability (± 2 SD) observed in the reference area. Despite these differences, densities were not statistically different between reference and near-field areas/subareas (Table 4.2).

Richness (total number of taxa) was similar and did not vary significantly between reference and near-field areas/subareas, ranging from 17 to 32 (Figure 4.3). The only observation that fell outside of the range of natural variability (± 2 SD) observed in the reference area was CGBD11 which is located 2 km downstream of the diffuser across from a boat launch. This was the same station that exhibited the lowest densities.

Evenness was generally low, ranging from 0.12 to 0.47, indicating that a small number of taxa contributed to the total abundance observed, and did not vary significantly between reference and near-field areas/subareas (Figure 4.4). All observations were within the range of natural variability observed in the reference area.

Figure 4.2 Mean (±SD) benthic invertebrate density by station relative to the reference area mean (± 2 SD), Celgar EEM Cycle Four.

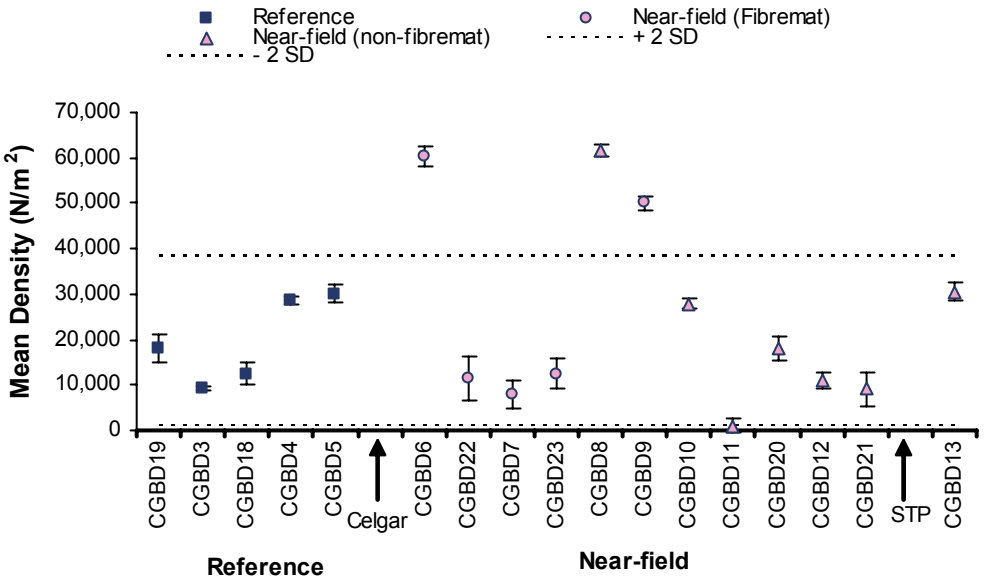


Table 4.2 Results of ANOVAs and Tukey's comparisons conducted to test for differences in benthic invertebrate community metrics between reference and near-field areas/subareas, Celgar EEM Cycle Four.

Effect	ANOVA	Tukey's Comparisons (p-value)[2]				Pattern[2]
Endpoint	(p-value)[2]	Ref vs. NF	Ref vs. FM	Ref vs. non FM	FM vs. non FM	
Density[3]	0.759	0.806	0.738	0.949	0.913	-
Taxa Richness	0.827	0.562	0.816	0.933	0.969	-
Evenness	0.352	0.861	0.613	0.797	0.326	-
Bray-Curtis[3]	**0.085**	**0.045**	0.553	**0.071**	0.436	non FM > Ref (15.4% diff) NF > Ref (27.6% diff)
Other Community Metrics						
Diversity	0.390	0.454	0.420	1.000	0.479	-

[1] Areas include reference (Ref), near-field fibremat (FM) and near-field non-fibremat (non FM).

[2] Significant result ($p \leq 0.10$); significant values are in bold. Patterns are provided for significant values only.

[3] Data were log-transformed for Ref vs. NF comparison for density.

Figure 4.3 **Total benthic invertebrate richness by station relative to the reference area mean (± 2 SD), Celgar EEM Cycle Four.**

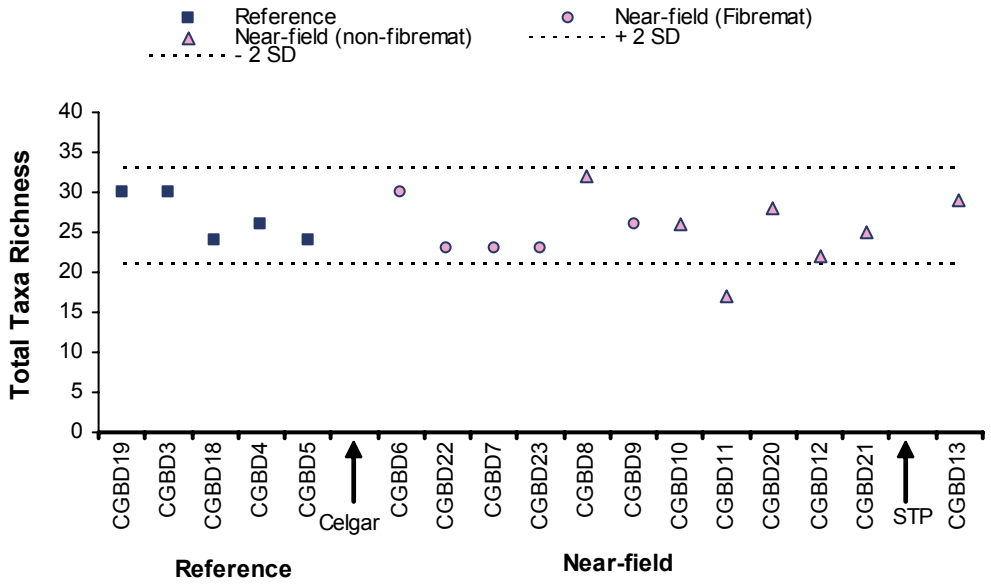
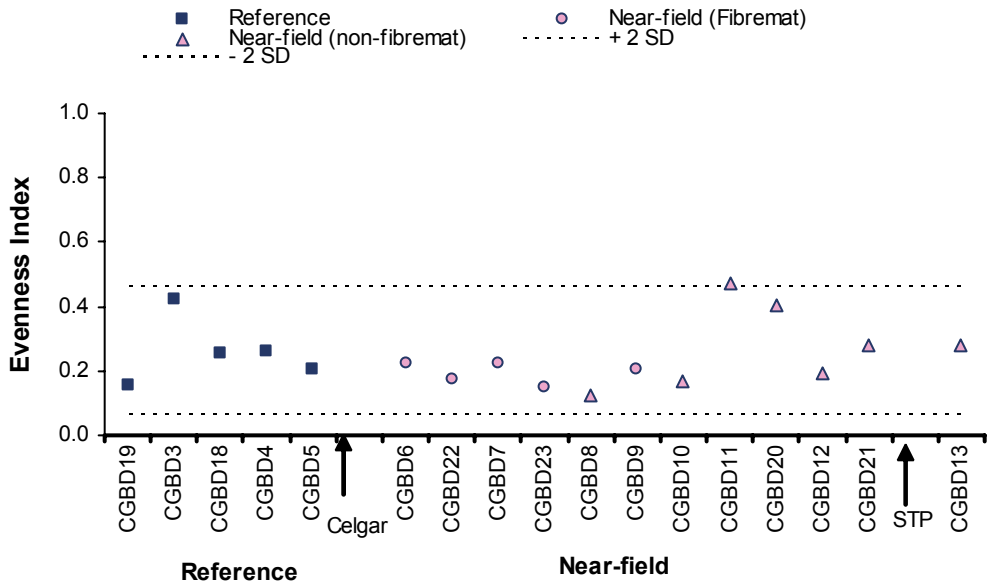
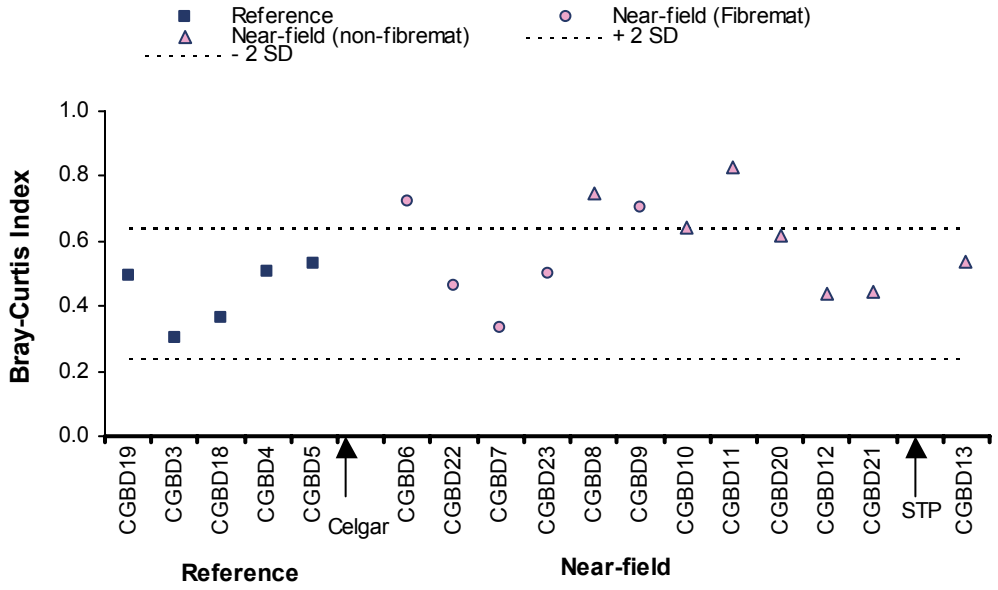


Figure 4.4 **Evenness index by station relative to the reference area mean (± 2 SD), Celgar EEM Cycle Four.**



Bray-Curtis indices varied between and within reference and near-field areas/subareas, ranging from 0.30 to 0.53 in the reference area, 0.33 to 0.72 in the near-field fibremat area, and 0.44 to 0.83 in the near-field non-fibremat subarea (Figure 4.5). This index, which provides an indication of how similar stations are to the reference area median, was significantly higher in the near-field area and non-fibremat subarea relative to the reference area; the near-field fibremat area, which represents the area most impacted by historical mill operations, was not significantly different from the reference area. Four of the near-field stations, CGBD6, CGB23, CGBD9, and CGBD11, fell outside of the range of natural variability observed in the reference area, indicating that according to the EEM decision framework (statistical difference > 2 SD of the reference area mean), there were effects on the benthic invertebrate community.

Figure 4.5 Bray-Curtis index by station relative to the reference area mean (± 2 SD), Celgar EEM Cycle Four.



Results from power analyses, which were conducted to evaluate the possibility of false negative results when testing for differences between reference and near-field areas/subareas for the four EEM effects endpoints for benthic invertebrate surveys (density, richness, evenness, and Bray-Curtis), indicate there was sufficient statistical power to detect differences between areas/subareas (Table 4.3).

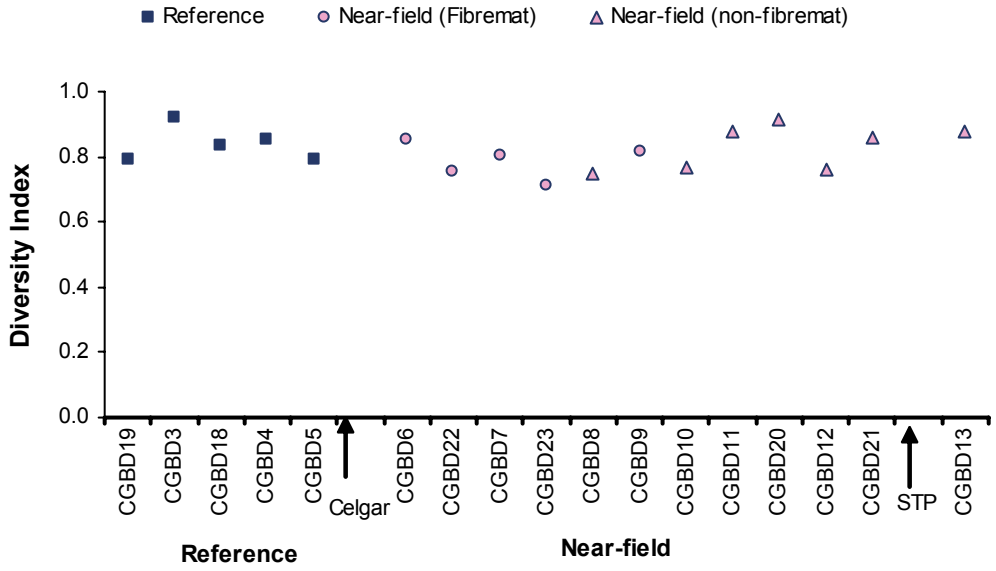
Diversity, which is not an EEM-effects endpoint, but is of interest, was high in both the reference and near-field areas, ranging from 0.71 to 0.92, and did not vary significantly between these areas (Figure 4.6). These results indicate all stations exhibited a wide range of taxa.

Table 4.3 Power for benthic invertebrate data for two-area control/impact study design, Celgar EEM Cycle Four.

Design	Comparison		
	NF vs. Ref	FM vs. Ref	Non FM vs. Ref
Power			
Two-area control/impact	0.97	0.09	0.94

[1] NF is near field; Ref is reference; FM is fibremat zone; Non FM is non fibremat zone areas.

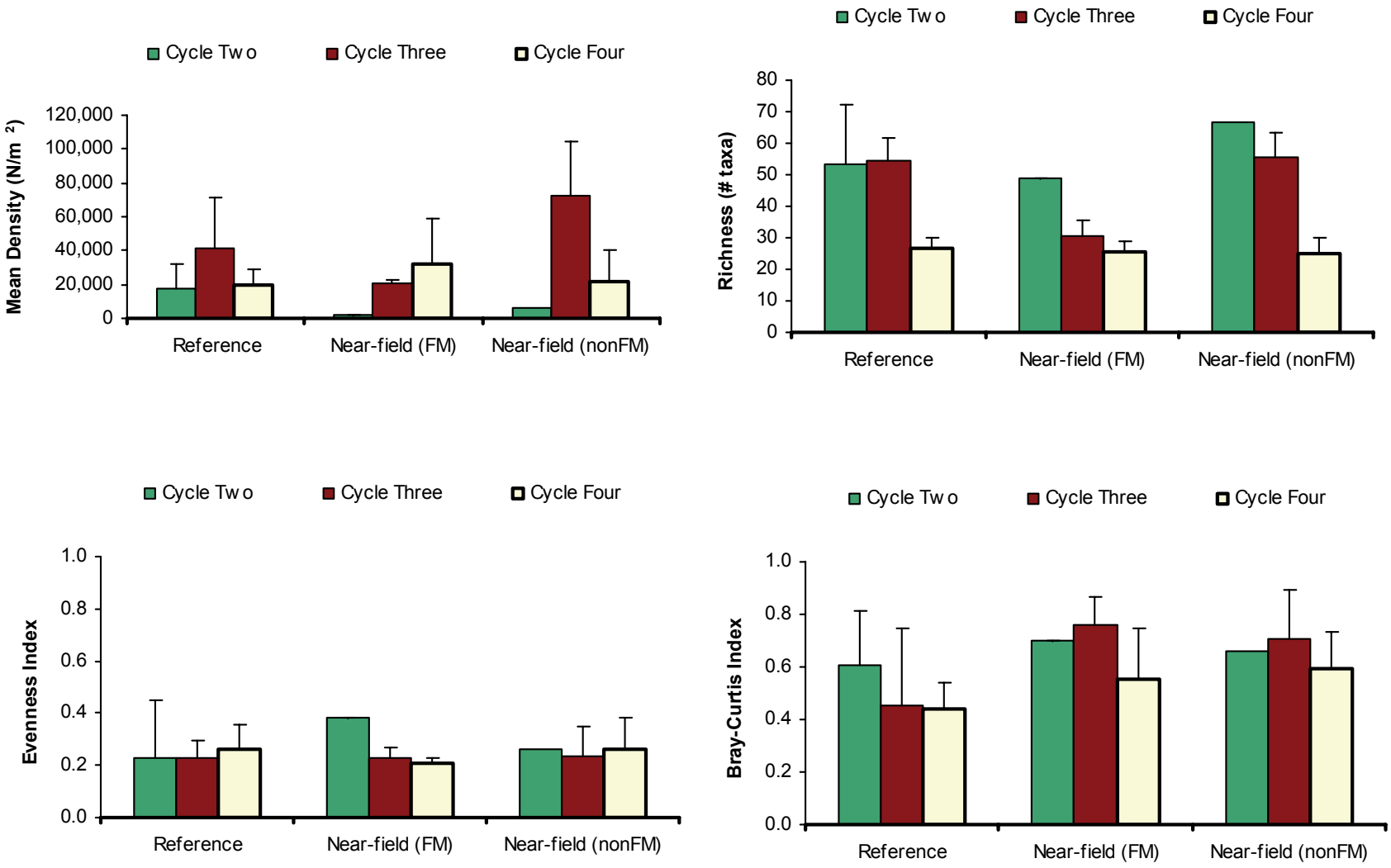
Figure 4.6 Diversity index by station, Celgar EEM Cycle Four.



b) Comparison with Historical Data

Comparison with historical EEM data (Hatfield Consultants 2000, 2004) indicates that community metrics have not changed in a consistent manner over time and space (Figure 4.7); it is important to note that to ensure comparisons across cycles were consistent, reference stations located upstream of the Hugh Keenleyside Dam in Cycle Three were excluded from calculations. Mean densities were variable but generally similar across sampling events; the area where the highest densities were observed varies from cycle to cycle. The highest density observed was in the non-fibremat area in Cycle Three. Densities appear to be increasing in the fibremat area over time, but the range of densities observed is generally similar to those observed in other areas and, accordingly, does not suggest an enrichment effect. Richness was similar between areas/subareas within a sampling event; however, the richness values observed in Cycle Four were lower than those observed in previous cycles. Bray-Curtis indices also were slightly lower in Cycle Four relative to previous cycles across areas, indicating the reference and near-field area are becoming more similar over time. Evenness has been consistently low across areas in all three cycles.

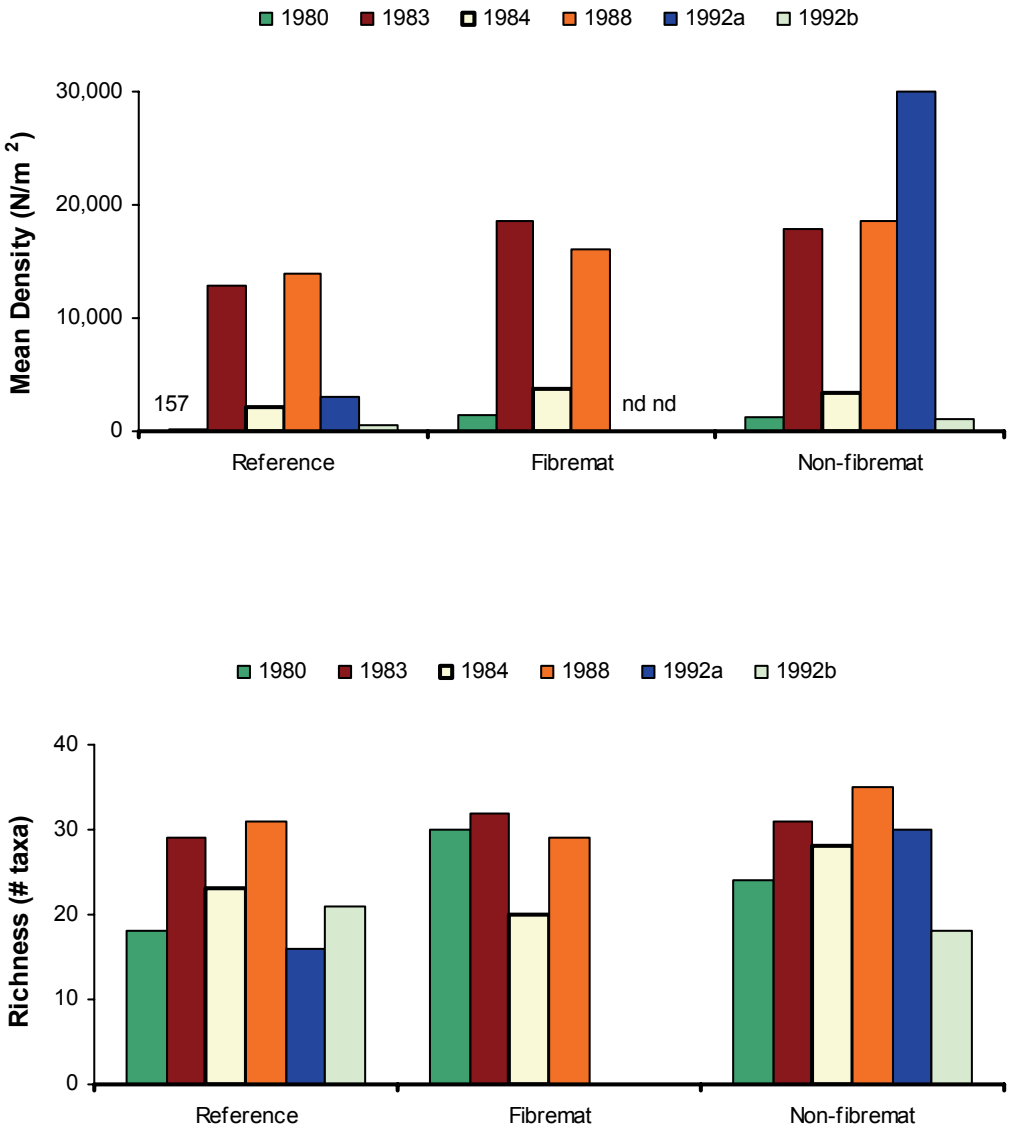
Figure 4.7 Mean (± SD) benthic invertebrate density, richness, evenness indices, and Bray-Curtis indices in reference and near-field areas, EEM Cycle Two to Four.



Cycle Three reference area means exclude stations located upstream of the Hugh Keenleyside Dam.

Comparison with pre-EEM metrics indicates that the range of density and richness values observed during the EEM cycles were slightly higher than those observed in the early 1980s to early 1990s (Figure 4.8). The high degree of variability in densities observed among years was attributed to organic enrichment and fluctuations in water levels/discharges related to dam operation (Hatfield Consultants 1994). Richness values were generally consistent across pre-EEM sampling events.

Figure 4.8 Density and richness of benthic invertebrates in pre-EEM surveys, 1983 to 1992.



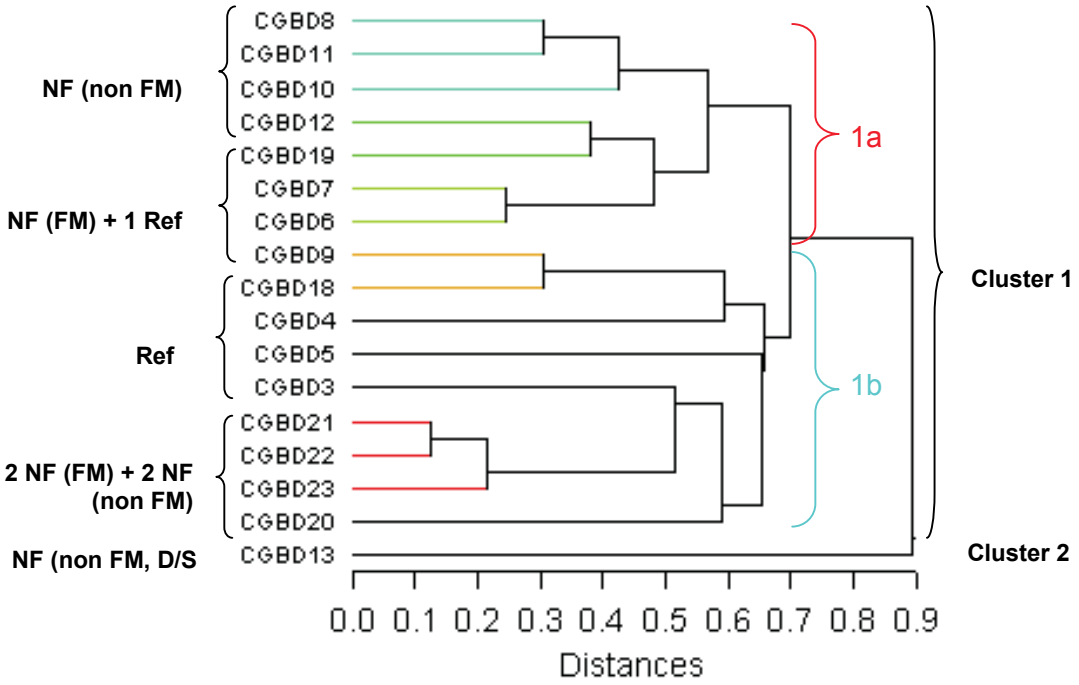
Overall, community metrics observed in Cycle Four do not show evidence of a general enrichment response in the near-field area. Mean densities and richness were not higher in the near-field area in Cycle Four. Significantly different Bray-Curtis indices suggest that there were differences in community composition between reference and near-field (particularly non-fibremat) areas, which were also observed in Cycle Three. These differences in community composition will be evaluated further in the following section. There were no clear differences in community metrics between the station located downstream of the STP and all other near-field and reference stations.

Community Composition

a) Cycle Four Results

A dendrogram derived from Bray-Curtis dissimilarity measures in community structure indicates that there was one station that separated out distinctly from all other near-field and reference stations at a distance of 0.9 – CGBD13 (Figure 4.9). This station located downstream of the STP had a community that was different from all of the other stations. Within the first major cluster, there were two secondary clusters formed at a distance of 0.7 m. In the first secondary cluster, four of the non-fibremat, two fibremat, and one reference station were grouped. In the second secondary cluster, the remaining reference stations, three fibremat stations, and two non-fibremat stations were clustered.

Figure 4.9 Dendrogram describing cluster analysis using the Bray-Curtis dissimilarity coefficient for benthic invertebrate density, Celgar EEM Cycle Four.



To further investigate the community differences identified through cluster analysis, abundance and presence of key taxa at each station were examined. The top five taxa observed in reference and exposure stations (grouped by area) are presented in Table 4.1. The following patterns were observed:

- Key taxa found among stations in Cluster 1a, which consisted primarily of near-field stations along with one reference station, included sphaerid clams, the asellid isopod *Caecidotea occidentalis*, and chironomid midges. Both of the subclusters had large numbers of these taxa. However, the two subclusters can be distinguished by the higher numbers of gammarid amphipods, nematode worms and naidid worms in the first subcluster (1a-1), and higher numbers of bryozoan lophopodids and harpactacoids in the second subcluster (1a-2).

- Key taxa found in Cluster 1b, which consisted of equal representation reference and near-field stations, included tubificid worms, bryozoan Lophopodidae, and asellids; pollution tolerant tubificid worms were the key taxa present in Cluster 1b that were generally found in low numbers in Cluster 1a. In the first subcluster (1b-1), which included two reference and one near-field (fibremat) station, there were particularly high numbers of asellids, as well as higher numbers of harpactacoids, which generally were absent from the other stations grouped in Cluster 1b. Reference Station CGBD5 formed its own cluster (1b-2), distinguished by a very high abundance of the bryozoans (Phylactolaemata). The third subcluster (1b-3) was comprised of a mixture of one reference and four near-field stations (mixture of fibremat and non-fibremat stations). This subcluster was distinguished by its high numbers of pollution tolerant lumbriculid worms.

- Cluster 2, comprised solely of near-field non-fibremat station CGBD13, which was distinguished by high numbers of asellids, chronominid midges, sphaerid clams, *Hyalella* amphipods, and *Hydra*. The distinct difference in this station could possibly be linked to the influence of the STP (influence of STP will be evaluated further in the Stable Isotope Section that follows).

Results of the cluster analysis and examination of the top five taxa indicate that there were similar key taxa, such as tubificid worms, asellid isopods, and sphaerid clams found throughout near-field and reference areas. Most of the key taxa found were facultative, adaptable to a wide range of environmental conditions and exposure to pollutants. Few of the top 5 taxa were only found within the reference or near-field areas, with the following exceptions. The byrozoan Phylactolaemata was only found in the reference area. Gammarids, hyalellids, orthocladiinae midges, and leptoceridae caddisflies were only found in higher numbers in the near-field non-fibremat area; the caddisflies were the only pollution sensitive taxon (i.e., taxa belonging to families ephemoptera, trichoptera, or plecoptera) found in the study area in large numbers. The

oligochaete worm Enchytraeid was only found in the fibremat area; Lumbriculid worms were only found in the near-field area. Both of these taxa are pollution tolerant taxa.

Overall, the near-field fibremat and reference communities were very similar, containing high numbers of tubificid worms, asellid isopods, and bryozoans; the near-field non-fibremat community was slightly different from these communities, because it contained a high number of taxa generally not found in other areas belonging to the families Leptoceridae (caddisfly), Orthocladiinae (midge), Naididae (worm), Nematode (worm), Hyallelidae (amphipod), Gammarididae (amphipod), and Hydrozoans. The presence of these taxa resulted in a significantly higher Bray-Curtis index, which is derived from community composition dataset, in the non-fibremat area. The differences among these areas are likely attributed to habitat differences. The river is slower-flowing in the reference and fibremat areas and faster-flowing in the downstream non-fibremat area, resulting in the presence of taxa not observed in the upstream areas.

b) Comparison with Historical Data

The presence of primarily facultative organisms, such as chironomids, clams, and worms, in the Columbia River have been reported historically in studies that pre-date EEM (Hatfield Consultants 1994a). These organisms tend to prefer finer-grained sediments, such as sand and silt, and lower water velocities, which are typical of the Columbia River.

During the 1980s the Columbia River predominantly contained facultative fauna (27 to 99%). Through 1984, a high portion of tolerant taxa were found at stations downstream of Celgar to the Kootenay River confluence, particularly within one of the fibremat stations (65 to 72%). Sensitive organisms were most abundant in 1980 and 1983 (up to 16%), then decreased noticeably at all stations throughout the mid-to-late 1980s. During this decade, the mill's influence on species composition was noticeable. Within the fibremat, pollution-tolerant enchytraeid and tubificid worms and facultative nematode worms dominated the community.

By the end of the 1980s, improvements in mill processing and effluent quality resulted in an increase in facultative species and a decrease in tolerant species. Furthermore, there was evidence of improved water quality with distance downstream from the mill, especially after the addition of the Kootenay River waters.

By the early 1990s, there was no distinguishable negative impact of the mill on benthic invertebrate communities (Hatfield Consultants 1994). Community composition changed to consist mainly of facultative organisms with only a few tolerant and sensitive species. At one of the stations within the near-field area, the facultative organisms were mainly pollution tolerant varieties; however,

these species were also present upstream of the mill and may be attributed to substrate type and water velocity rather than pulpmill effects. A 1992 CRIEMP monitoring program indicated that the primary physical factor affecting species distribution in the Columbia River was water level (Norecol 1993).

The current study supports these findings that the mill is not having distinguishable effects on the benthic invertebrate community in the near-field area.

To provide a relevant context for relating potential enrichment in the benthic invertebrate to enrichment effects in fish, relative abundances of key taxa identified as being important diet items for mountain whitefish in the Cycle Two fish survey were evaluated. These data were examined to determine if abundances of these taxa differed greatly between areas; if elevated abundances were observed in key dietary items, this result could explain the observed enrichment effect in fish. This comparison assumes the community composition in the Columbia Rivers in Cycles Four and Two were similar.

As illustrated in Figure 4.10, the relative abundances and taxa found in the near-field fibremat and reference area were generally similar, with the exception of the station located immediately downstream of the mill, which exhibited higher densities of oligochaetes and chironomids. Nonetheless, overall these areas were very similar. In the near-field non-fibremat area, the relative abundances and specific taxa observed differed.

4.2.4.2 QA/QC and Verifications

All QA/QC reports are presented in Appendix A2. Verification reports indicated a high degree of agreement (only 3 discrepancies in IDs) between the independent benthic invertebrate taxonomists. Re-sort checks confirmed that samples met the <10 % requirement for missed organisms. Sample resorting conducted on 10% of the samples subsampled (2 samples) indicated there was a high degree of variability in subsampling accuracy.

4.2.4.3 Supporting Water and Sediment Quality

Sediment Quality

a) Particle Size and TOC

Sediment composition can influence benthic invertebrate community composition, so it is important to confirm that any differences in community metrics or composition noted above were not attributed to differences in substrates (Figure 4.11). Results indicate that substrates generally were similar between areas; although, the fibremat had significantly lower percent fines (i.e., silt and clay) relative to the non-fibremat area (Table 4.5). Sediments were primarily composed of sand, with smaller amounts of fines (silt and clay). Generally, gravel was not present or present at very low concentrations.

Figure 4.10 Relative abundances of key dietary items of mountain whitefish (Hatfield Consultants 2000) in reference and near-field areas, Celgar EEM Cycle Four.

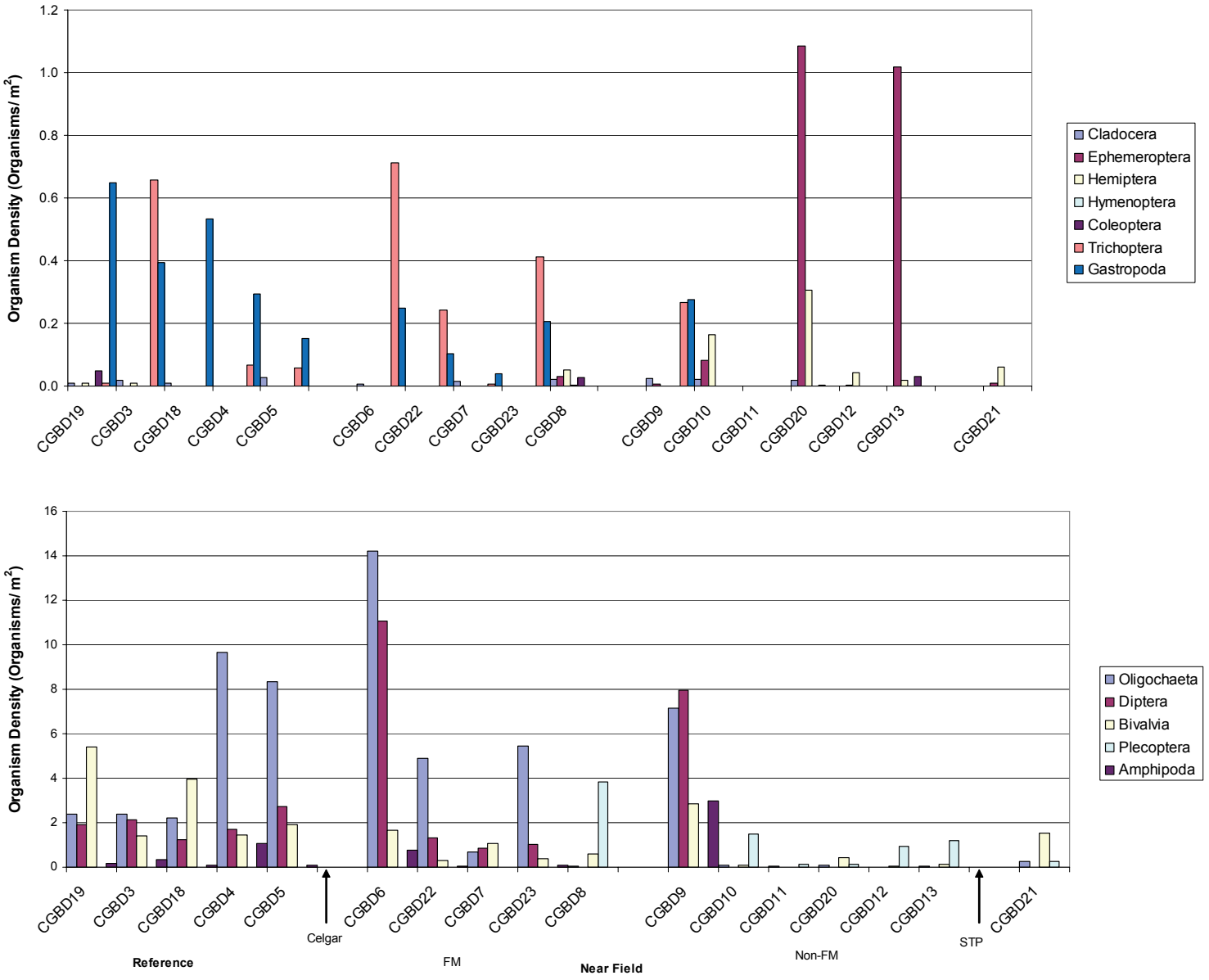


Table 4.4 Top five taxa observed at each station (highlighted by shading), Celgar EEM Cycle Four. (Five most abundant taxa per station are bolded and shaded).

Phylum	Order	Taxa	Reference					Near-field (non-Fibremat)							Near-field (fibremat)				
			CGBD 19	CGBD 18	CGBD 4	CGBD 5	CGBD 3	CGBD 8	CGBD 11	CGBD 10	CGBD 12	CGBD 21	CGBD 20	CGBD 13	CGBD 7	CGBD 6	CGBD 9	CGBD 22	CGBD 23
Annelida	Oligochaeta	Lumbriculidae	4.2	4.0	2.8	3.1	1.5	1.5	1.2	0.4	0.3	26.1	3.5	0.6	0.8	5.7	0.5	27.1	18.9
Annelida	Oligochaeta	Tubificidae	3.0	8.0	19.9	7.5	13.0	9.6	0.6	4.6	0.2	21.8	11.0	5.4	3.6	25.1	17.7	24.0	30.4
Bryozoa	Phylactolaemata	Lophopodidae	13.1	15.4	19.3	9.1	2.1	1.3	0.6	0.0	1.2	9.3	0.0	4.1	5.5	7.4	0.0	8.4	4.2
Arthopoda	Diptera	Chironomidae	5.4	4.0	1.4	0.7	4.6	3.4	14.8	3.9	8.1	6.3	10.8	3.2	6.6	14.2	19.2	6.7	4.3
Arthopoda	Isopoda	Asellidae	37.4	27.1	7.6	2.6	11.7	45.7	0.0	40.9	3.0	6.2	2.9	28.7	6.6	21.8	32.3	6.4	8.6
Arthopoda	Diptera	Chironomini	1.9	1.8	1.8	3.1	5.2	0.8	14.2	1.1	9.6	5.8	8.5	8.2	5.5	7.3	1.3	5.6	3.2
Mollusca	Veneroidea	Sphaeriidae	21.2	22.4	3.6	4.5	10.7	9.6	17.9	8.3	13.3	4.5	1.3	6.1	18.0	3.7	7.7	3.5	4.0
Annelida	Oligochaeta	Enchytraeidae	0.3	0.0	0.0	2.2	1.8	0.1	4.3	0.4	0.1	4.2	0.8	0.1	3.7	0.1	0.0	4.9	7.3
Arthopoda	Trichoptera	Leptoceridae	0.0	0.0	0.2	0.1	4.9	0.4	0.6	0.6	0.2	3.3	10.1	4.5	0.1	1.5	0.7	2.9	4.5
Arthopoda	Diptera	Orthocladiinae	0.1	0.7	0.7	2.2	1.6	0.4	1.2	0.1	8.6	2.4	1.1	0.4	2.1	0.3	0.8	1.5	0.3
Annelida	Oligochaeta	Naididae	2.0	0.6	1.3	6.9	1.5	0.1	12.3	0.0	0.5	1.9	14.4	5.2	3.6	0.8	1.1	1.7	2.4
Nematoda	-	Nematoda indet.	0.5	1.7	0.9	8.8	2.1	0.1	16.0	0.2	5.3	1.8	2.9	0.2	2.4	1.4	0.9	2.0	3.7
Arthopoda	Amphipoda	Hyalellidae	0.5	0.0	2.7	0.2	2.5	5.8	0.6	1.2	0.1	0.5	0.0	8.1	0.0	1.7	4.7	0.5	1.0
Arthopoda	Amphipoda	Gammaridae	0.1	0.2	0.0	0.0	0.0	13.3	0.6	21.6	0.0	0.0	10.2	0.0	0.1	0.0	3.3	0.0	0.0
Cnidaria	Hydroida	Hydridae	1.2	1.3	14.1	0.8	3.3	0.9	0.0	8.2	2.8	0.0	0.8	8.9	1.8	2.0	0.5	0.0	0.0
Arthopoda	Harpacticoida	Harpacticoida	5.5	7.7	20.3	5.7	8.3	3.0	4.9	3.9	44.1	0.0	0.4	3.3	37.9	1.5	5.2	0.0	0.0
Bryozoa	Phylactolaemata	Phylactolaemata	0.0	0.0	0.0	41.3	12.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Figure 4.11 Particle size and percent TOC in sediments from near-field and reference areas, Celgar EEM Cycle Four.

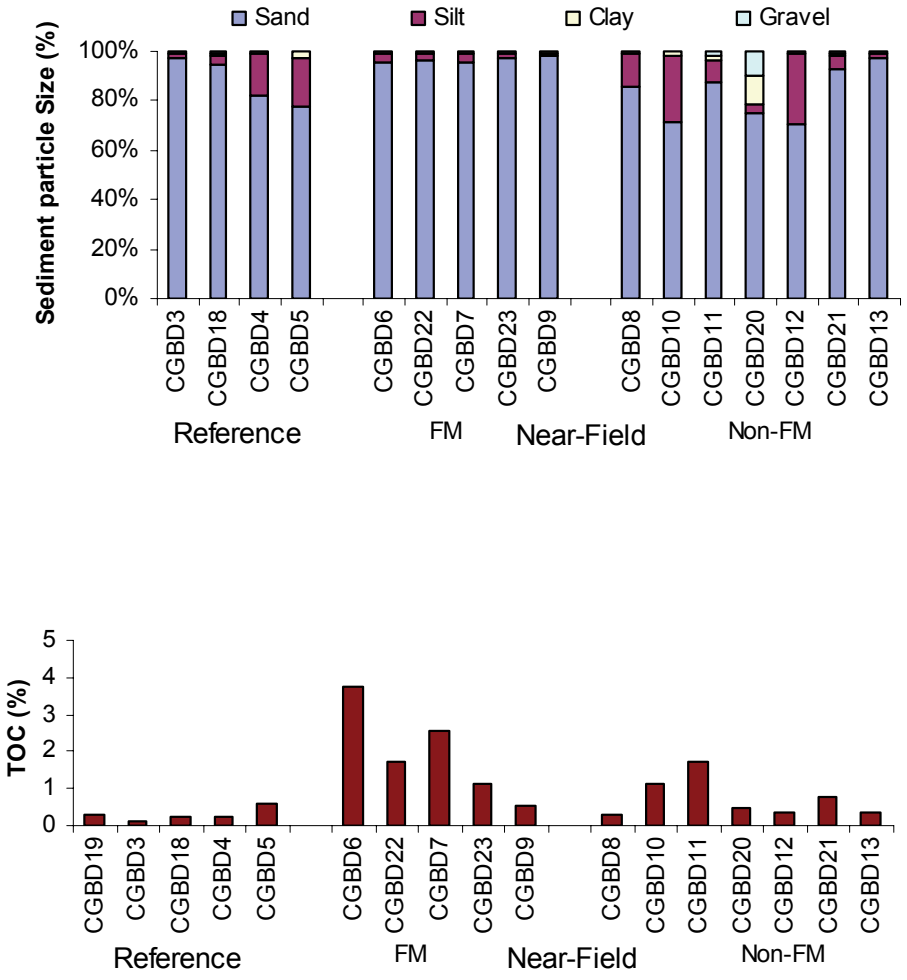


Table 4.5 Results of ANOVAs and Tukey's comparisons conducted to test for differences in sediment quality among areas, Celgar EEM Cycle Four.

Dependent Variable	ANOVA (p-value)[1]	Tukey's Comparisons (p-value)[1]			Pattern
		Ref vs. FM[2]	Ref vs. non FM[2]	FM vs. non FM[2]	
Sediment					
Percent fines[3]	**0.049**	0.188	0.770	**0.043**	Non FM > FM
Percent sand[4]	0.150	0.180	0.975	0.221	-
TOC[3]	**0.003**	**0.002**	0.133	**0.050**	FM > Ref FM > non FM

[1] Significant result ($p \leq 0.10$). Significant values are in bold.

[2] Areas include Reference (Ref); Near-field fibre mat (FM) and Near-field non fibre mat (non FM).

[3] ANOVA was conducted using log-transformed data.

[4] ANOVAs excluded outlying concentrations.

The substrate of CGBD13, which was identified as being dissimilar from all other stations in cluster analysis, was similar to that of other stations, indicating that substrate was not a contributing factor to the community difference observed.

TOC was significantly greater in the fibremat area relative to non-fibremat and reference areas. The elevated TOC observed is reflective of influence of the historical fibremat. Despite the presence of elevated TOC at these stations, increased densities were not evident at all stations.

b) Dioxins and Furans

Seventeen dioxin and furan congeners were measured at three fibremat stations in Cycle Four to assess whether concentrations of these analytes are decreasing in the fibremat; these measurements were taken to satisfy BC MOE monitoring requirements for the Columbia River. Concentration of total tetra, penta, hexa, hepta, and octa congeners are summarized in Table 4.6. Total concentrations of 7/10 these congeners were low or non-detectable at CGBD9. At CGBD6 and CGBD7, much higher concentrations of dioxins and furans were observed. Most dioxin and furans observed at these stations were 1 to 5 times higher than those observed at CGBD9, with the exception of hexadioxin, tetrachlorodibenzofuran, and pentachlorodibenzofuran, which were 9 to 13 times higher. Overall, the congener that exhibited the highest concentrations was tetrachlorodibenzofuran (up to 34 pg/g).

Table 4.6 Dioxin and furan concentrations in sediment (pg/g) from near-field and reference areas, Celgar EEM Cycle Four.

Variable (pg/g)	Fibremat Stations		
	CGBD9	CGBD6	CGBD7
Dioxins			
Total T4CDD (tetradioxin)	<0.0694	0.238	0.316
Total P5CDD (pentadioxin)	<0.0694	<0.0576	<0.0930
Total H6CDD (hexadioxin)	<0.139	1.25	1.22
Total H7CDD (heptadioxin)	<0.139	0.723	0.375
Total O8CDD (octadioxin)	1.43	6.83	4.87
Furans			
Total T4CDF (tetrachlorodibenzofuran)	2.64	26.7	33.9
Total P5CDF (pentachlorodibenzofuran)	0.093	0.91	0.88
Total H6CDF (hexachlorodibenzofuran)	<0.139	0.377	0.187
Total H7CDF (heptachlorodibenzofuran)	<0.139	0.723	0.375
Total O8CDF (octachlorodibenzofuran)	<0.347	0.455	<0.465
Screening Against Guidelines			
% TOC	0.52	3.76	2.56
MOE Objective (based on TOC > 1%)	*0.7*	*2.632*	*1.792*
CCME Guideline	*0.85*	*0.85*	*0.85*
Measured TEQ (ND = ½ DL)	0.274	**1.53**	**1.98**

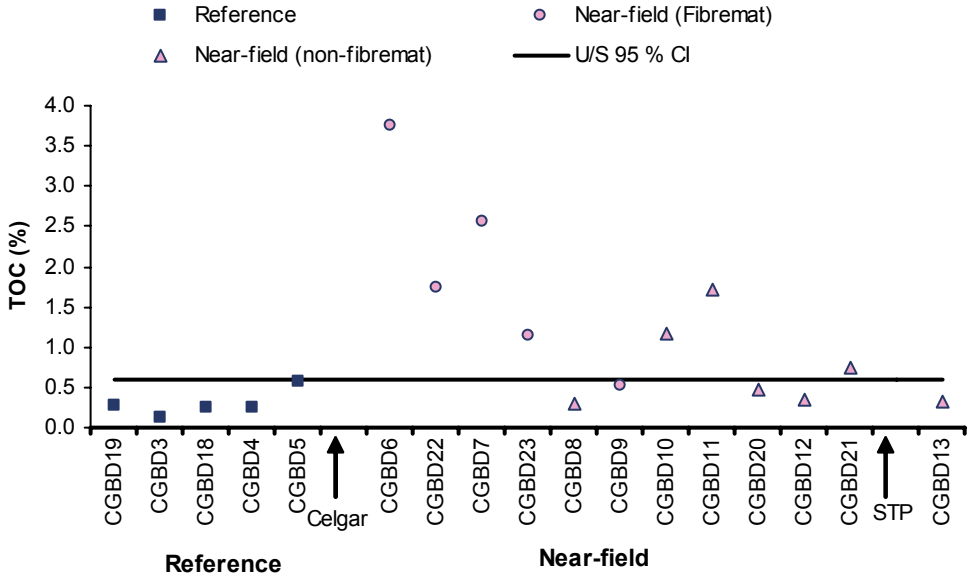
Bolded values exceed guidelines.

c) Screening Against Columbia River Sediment Quality Guidelines

Sediment quality data for TOC and dioxins/furans were screened against relevant *Ambient Water Quality Objectives for the Columbia River (Hugh Keenleyside Dam to Birchbank)* (MOE 1992) and Canadian Council of Ministers of Environment (CCME) Guidelines for Sediment Quality (CCME 2005). In accordance with MOE objectives, stations 100 m downstream of the mill and STP diffusers, were excluded from these comparisons.

In Cycle Four, TOC exceeded objectives (95% confidence interval of upstream TOC concentrations) at all stations in the fibre mat area (except CGBD9), and three stations in the non-fibremat area (CGBD10, CGBD11 and CGBD21) (Figure 4.12).

Figure 4.12 Screening of TOC in sediments against Columbia River water quality objectives.



Tetradioxin TEQ concentrations, which are based on the relative toxicity of each congener, were screened against MOE Columbia River and CCME guidelines for sediment quality. CGBD7 exceeded the Columbia River objective by 1.1 times and both CGBD6 and CGBD7 exceeded CCME guidelines by 1.8 and 2.3 times, respectively (Table 4.6).

d) Comparison with Historical Data

After the mill started operating, sediment quality immediately downstream of the mill decreased due to contamination with organochlorines (AOX), dioxins, furans, and chlorinated phenolics (MOE 1992). A fibremat also accumulated over time comprised of decomposed pulp fibres, fine sediments and a slime covering (EVS 1995). Historically, two types of fibremats have been identified downstream

of Celgar pulpmill diffuser, characterized by algae and sediment present within the mat. Only remnants of the fibre/ slime mat remain and the fibre/ black silt mat has greatly reduced in size over time. The fibre/ silt mat is characterized by a thin black silt layer covering bleached fibres, inner bark, chip fines, bark material and fine chips. The EVS (1995) study reported that a purple or green algae covered approximately 30,500 m^3 area with a mat 5 to 60 cm in depth. In 1990, the total estimated volume of the mat was 40,500m^3; by 1994, the mat volume decreased to 16, 000m^3. The dramatic reduction in fibremat area was most likely due to the installation of the effluent treatment plant and the closure of the woodroom between 1986 and 1993. Both of these changes caused a decrease in fibremat inputs. Results from Cycle Four and CRIEMP's monitoring program indicated that sediment quality immediately downstream of the mill has improved in recent years due to a decrease in organochlorines in mill discharge and reduced concentrations of dioxins and furans in the fibremat across cycles, (CRIEMP 2005). Concentrations of tetradioxins in sediments have decreased over time (Table 4.7). In 1994, concentrations at CGBD6 were 45.3 TEQ; in Cycle Four concentrations at this station were 2.63 TEQ.

Table 4.7 Historical TCDD TEQs concentrations in sediments.

2,3,7,8-TCDD TEQ	BC Water Quality Stations		
	CGBD6 E249078	CGBD7 E249079	CGBD9 E249080
2002 (Cycle Three)	7.08	1.96	1.14
1998	14.2	NA	NA
1994	45.3	NA	3.50

TOC concentrations have decreased dramatically in the near-field area across cycles (Figure 4.13). In Cycle Four, TOC concentrations were six times lower than those in sediments measured in Cycle Two. Field observations, reporting only thin streaks of black (representing the fibremat) and magnitude of the concentrations observed suggest the historical fibremat has broken down substantially. The absence of enrichment of invertebrates in the fibremat area suggests these taxa are not limited by carbon as a nutrient.

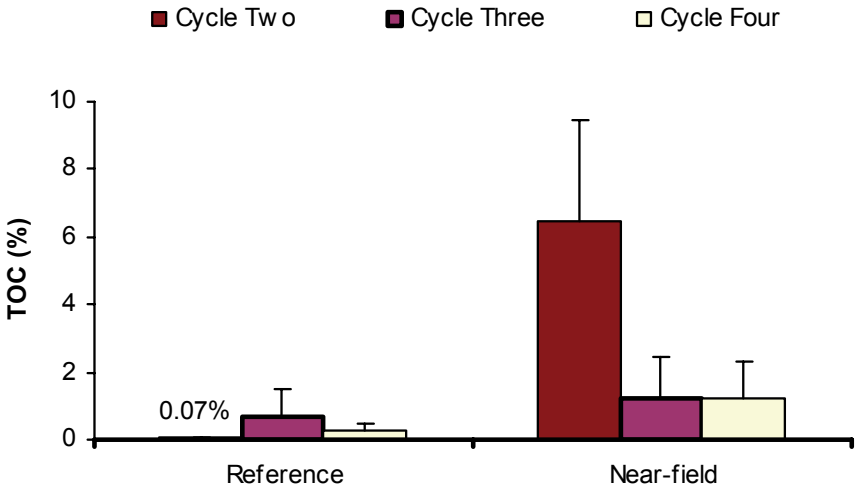
Water Quality

a) Sodium and Nutrients

Spatial trends for sodium and nutrients measured in river water in each area/subarea are summarized in Figure 4.14. Mean concentrations of sodium, an effluent tracer, and TOC were similar across areas/subareas. DOC concentrations were significantly higher in the fibremat area relative to the reference area and non-fibremat area (Table 4.8); however, this difference was relatively small in magnitude. Similarly, total nitrogen concentrations were significantly higher in the reference area relative to the near-field fibremat area; although, this difference was small in magnitude. TKN, and nitrate+nitrite appeared similar among areas with the exception of the decrease in these constituents observed

just upstream of the STP. Total phosphorus concentrations were significantly lower in the near-field non-fibremat area relative to the reference area, and were lower in the fibremat area, suggesting there are upstream sources of phosphorus, likely originating from Arrow Lake, which receives nutrient additions to improve productivity. Because the increases in total phosphorus in the reference area were not reflected in the dissolved phosphorus, which was non-detectable at all stations (< 0.002 mg/L), these increases appear to be due to particulate forms of phosphorus. These nutrient data suggest that the mills inputs of nutrients do not noticeably change nutrient concentrations in the near-field area and that nutrient concentrations are highest immediately downstream of the dam.

Figure 4.13 Total organic carbon (TOC) in reference and near-field areas, Celgar EEM Cycles Two, Three and Four.



b) In Situ Variables

In situ variables measured in the field, including dissolved oxygen, temperature, pH, and conductivity generally were similar between areas/subareas (Figure 4.15). Temperature was significantly higher in the reference area relative to the near-field area. Conductivity was significantly greater in the fibremat area relative to the non-fibremat and reference areas; however, this difference was very small in magnitude. A larger decrease in conductivity, particularly at the bottom surface, and slight decrease in hardness was observed at the station immediately upstream of the STP. Generally, *in situ* chemistry showed that these variables were similar between areas.

Figure 4.14 Mean (± SD) values of nutrients measured in support of the benthic invertebrate survey, Celgar EEM Cycle Four.

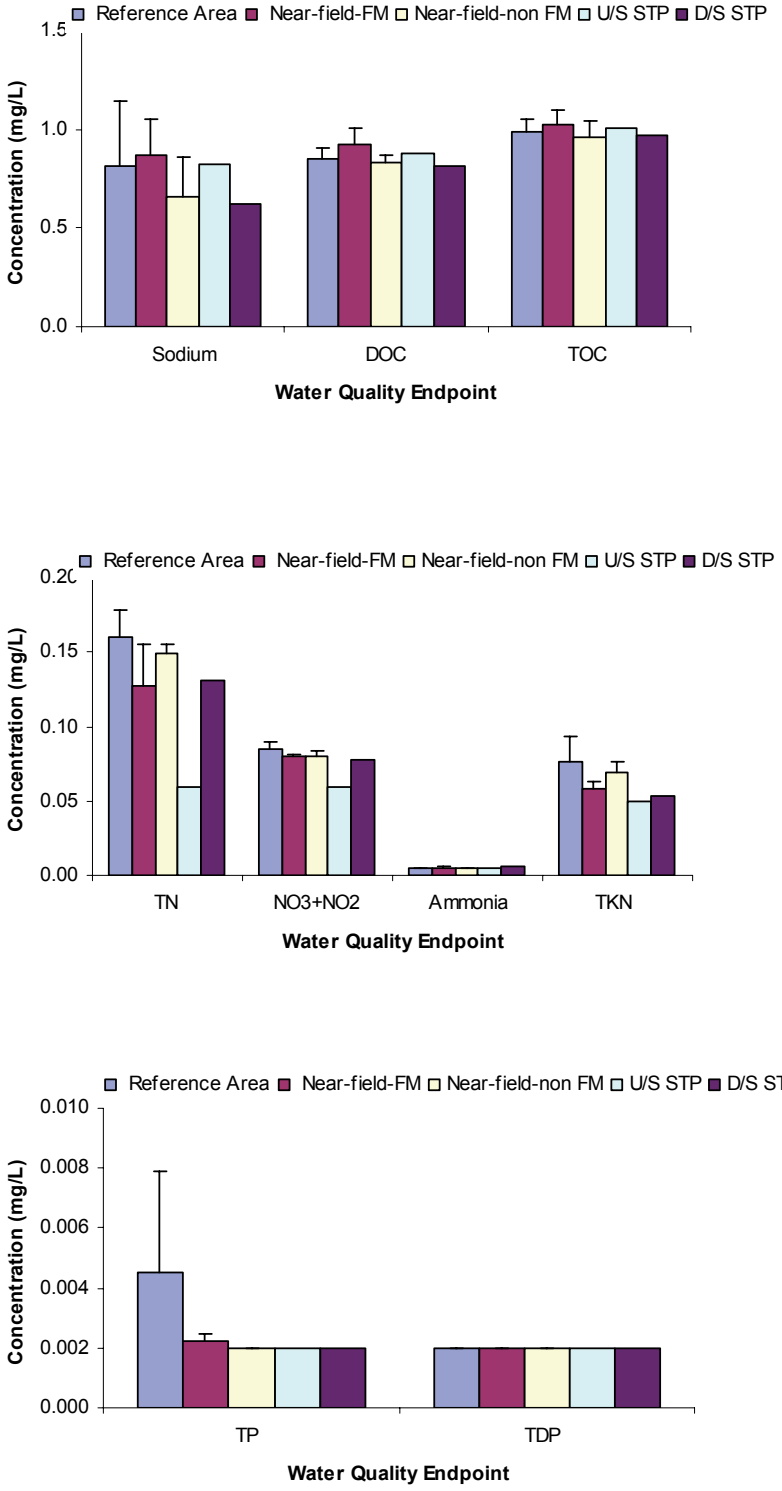


Table 4.8 Results of ANOVAs and Tukey's comparisons conducted to test for differences in water and sediment quality among and between areas[2] (independent variable), Celgar EEM Cycle Four.

Dependent Variable	ANOVA (p-value)[1]	Tukey's Comparisons (p-value)[1]			Pattern
		Ref vs. FM[2]	Ref vs. non FM[2]	FM vs. non FM[2]	
Water Quality					
Sodium	0.354	0.915	0.592	0.353	-
TOC	0.377	0.652	0.885	0.348	-
Dissolved Organic Carbon[3]	**0.051**	0.169	0.831	**0.046**	FM > nonFM
Nitrate+Nitrite[5]	0.110	0.147	0.157	0.991	-
Total Nitrogen[5,6]	0.100	**0.084**	0.495	0.388	Ref > FM
TKN[6]	0.279	0.250	0.698	0.597	-
Ammonia[3]	0.584	0.637	0.628	0.998	-
Total Dissolved Phosphorus[4]	-	-	-	-	-
Total Phosphorus[6]	**0.066**	0.633	**0.059**	0.309	Ref>non FM
Dissolved Oxygen[3,5]	0.179	0.186	0.828	0.316	-
Temperature	**<0.001**	**<0.001**	**0.002**	0.369	Ref > FM Ref > non FM
pH[5]	0.223	0.238	0.266	0.977	-
Conductivity	**0.028**	**0.039**	0.934	**0.05**	FM > non FM FM > Ref
Hardness[5]	0.526	0.910	0.506	0.763	-

[1] Significant result ($p \leq 0.10$). Significant values are in bold.

[2] Areas include Reference (Ref); Near-field fibremat (FM) and Near-field non fibremat (nonFM).

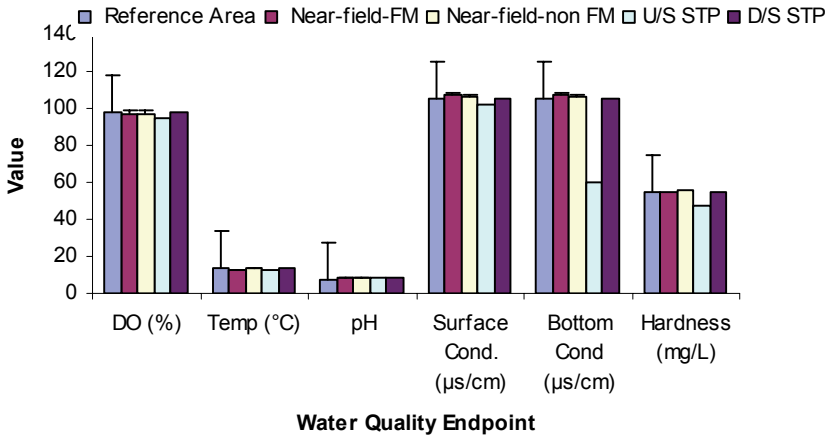
[3] ANOVA was conducted using log-transformed data.

[4] All values for TDP at all stations were that same.

[5] ANOVAs excluded outlying concentrations.

[6] ANOVA was conducted using untransformed ranked data.

Figure 4.15 Mean (± SD) values of in situ water quality variables measured in support of the benthic invertebrate survey, Celgar EEM Cycle Four.



c) Screening against Columbia Water Quality Guidelines

Water quality data for pH and dissolved oxygen were screened against the *Ministry of Environment's Ambient Water Quality Objectives for the Columbia River (Keenleyside dam to Birchbank)* (MOE 1992). These were the only variables included under the objectives tested in the Cycle Four program. Stations 100 m downstream of the mill and STP diffusers, were excluded in accordance with the objectives.

Dissolved oxygen and pH were within objectives, with the exception of low DO observed at station CGBD12, located 3.2 km downstream of the mill (Table 4.9).

Table 4.9 Screening of water quality data from Cycle Four and Pre-EEM monitoring studies (1992) against water quality objectives for the Columbia River (MOE 1992).

Variable	Columbia River Objective[1]	Pre-EEM Data[2]		Cycle Four				
		Near-field	Ref	Near-field FM	Near-field non-FM	Ref	U/S STP	D/S STP
pH	6.5-8.5	7.3-8.0	7.3-8.0	8.05	8.1	7.87	7.99	8.06
Dissolved oxygen	>10 mg/L	10.3-12.6	10-12.8	10.32	9.79	10.18	10.07	10.31

Bolded values exceed objectives.

[1] MOE (1992).

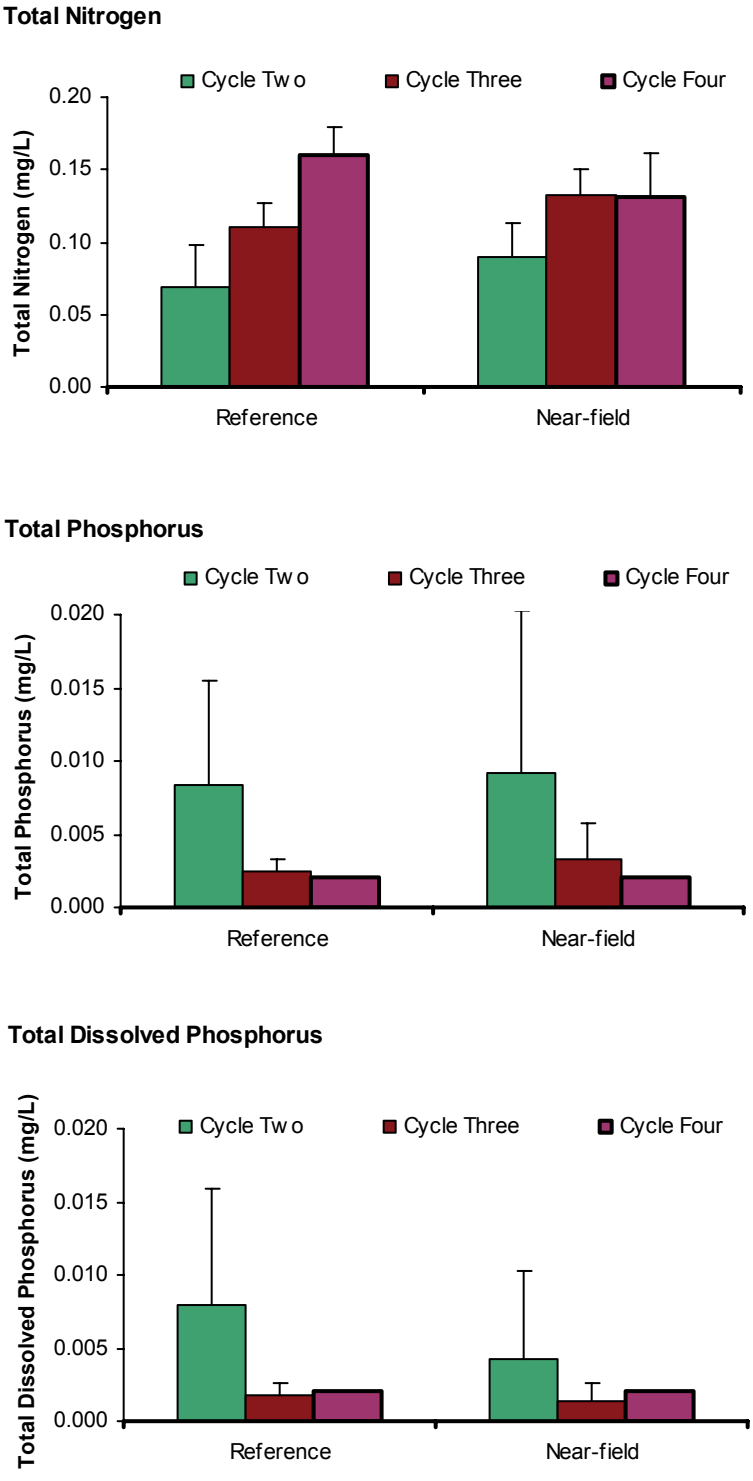
[2] Hatfield Consultants (1994).

d) Comparison with Historical Data

After the mill started operating, water quality, immediately downstream of the mill decreased due to high levels of BOD, suspended solids, organochlorines AOX) and toxicity from the pulpmill effluent discharge. Colour changes were also attributed to the pulpmill (MOE 1992). Nutrient concentrations were generally similar or lower downstream of the mill (Hatfield Consultants 1994); although, total phosphorus concentrations were slightly higher downstream of the mill but have not resulted in excessive algal growth. Other variables such as dissolved oxygen, suspended solids and pH have been minimally influenced by the pulpmill. Variables monitored under the Columbia River water quality objectives including pH and DO were generally similar to those observed in the early 1990s (Table 4.9); although the DO concentration observed in the non-fibremat area was slightly lower than results reported previously.

Mean (+ SD) nutrient concentrations in reference and near-field areas from Cycles Two to Cycle Four from each area are summarized in Figure 4.16. In general, total nitrogen concentrations have increased across cycles for all areas by approximately 50%. Total and dissolved phosphorus concentrations have decreased across cycles. Historical reports indicate that the background nutrient concentrations in the Columbia River are dictated by the limnology and seasonal nutrient status of Arrow Lake (Hatfield Consultants 1994). Hydro began adding nutrients to Arrow Lake in the early 1990s to improve the productivity of the system to enhance fish populations.

Figure 4.16 Total nitrogen, total phosphorus and total dissolved phosphorus in reference and near-field area, Celgar EEM Cycles Two, Three and Four.



4.2.4.4 Relationships between Benthic Invertebrate Metrics and Water and Sediment Quality

Spearman's rank correlations were used to investigate relationships between benthic invertebrate community metrics and supporting environmental variables (Table 4.10). Strong and moderate correlations were observed between a number of community metrics and nutrients and grain size. Density exhibited strong positive correlations ($|r_s| > 0.75$) with total Kjeldahl nitrogen, total nitrogen, and percent silt. These correlations indicate that where concentrations of these nutrients or silt were higher, densities were higher. The relationship between nitrogen and density appears to be a positive linear relationship. The reference area exhibited the highest nitrogen concentrations but did not exhibit the highest densities. The relationship between silt and density appears to be driven solely by a high percent fines observed at near-field station CGBD20. Density also exhibited weaker moderate positive correlations with nitrate+nitrite and percent clay and negative correlations with percent sand.

Table 4.10 Spearman correlation coefficients (r_s) for supporting environmental variables versus benthic invertebrate community metrics, Celgar EEM Cycle Four.

Environmental Variable	Mean Density	Taxa Richness	Diversity	Evenness	Bray-Curtis
Dissolved Oxygen	0.056	-0.148	-0.065	-0.056	0.103
Temperature	0.141	0.109	**0.454**	**0.428**	0.077
pH	0.353	0.185	-0.121	-0.181	**0.539**
Conductivity	0.020	-0.126	-0.186	-0.177	-0.146
Hardness	0.165	0.335	0.061	-0.061	0.097
Sodium	-0.413	-0.368	0.032	0.167	**-0.519**
DOC	-0.380	**-0.415**	0.027	0.128	**-0.577**
Water TOC	-0.167	-0.052	0.371	0.401	-0.367
Nitrate-Nitrite	**0.510**	0.075	**-0.523**	**-0.594**	0.162
Ammonia	-0.277	-0.212	-0.061	0.044	0.227
Total Kjeldahl nitrogen	**0.812**	**0.460**	0.055	-0.120	**0.428**
Total nitrogen	**0.777**	0.340	-0.062	-0.197	0.383
Total dissolved phosphorus	-	-	-	-	-
Total Phosphorus	0.128	-0.132	0.166	0.157	-0.228
% Gravel	0.085	0.217	**0.478**	0.385	0.008
% Sand	**-0.703**	**-0.498**	-0.179	-0.054	**-0.424**
% Silt	**0.767**	**0.449**	-0.123	-0.252	**0.468**
% Clay	**0.561**	0.253	0.041	-0.049	**0.522**
Sediment TOC	0.104	-0.061	**-0.486**	**-0.490**	-0.023

Bolded values represent significant correlations where $r_s \geq |0.414|$ for n =17.

Diversity and evenness were moderately negatively correlated with nitrate-nitrite; however, the strength of the relationship was reduced by the outlying observation at CGBD21 (upstream of the STP). Overall, the lowest evenness and diversity were observed at the stations with the highest nitrate and nitrite concentrations; however, the range of evenness and diversity values observed was similar between areas.

Bray-Curtis dissimilarities were moderately positively correlated with pH and percent clay and negatively correlated with sodium and DOC; however, scatterplots of these relationships failed to demonstrate any elucidating relationships. The Bray-Curtis index did not vary in a meaningful way with pH, which varied little forming a straight line at a pH of 8 (with the exception of one outlier). Similarly, the Bray-Curtis index occupied a similar range of values in the near-field area regardless of the percent clay present in sediments. Patterns observed for DOC and sodium were similar.

4.2.5 Summary

Key findings from the benthic invertebrate survey include:

- Benthic invertebrate communities exhibited similar high densities, richness, and diversity, and low evenness in both reference and exposure areas. Overall, community metrics observed in Cycle Four do not show evidence of an enrichment response in the near-field area. However, significantly different Bray-Curtis indices suggest that there were differences in community composition between areas (particularly between the reference and non-fibremat area).

- There were similar key taxa, such as tubificid worms, asellid isopods, and sphaerid clams found throughout near-field and reference areas. Most of the key taxa found were facultative, adaptable to a wide range of environmental conditions and exposure to pollutants. The near-field fibremat and reference communities were very similar; the near-field non-fibremat community was different from these communities, containing a high number of taxa generally not found in other areas including the families Leptoceridae (caddisfly), Orthocladiinae *(*midge), Naididae (worm), Nematode (worm), Hyallelidae (amphipod), Gammarididae (amphipod), and Hydrozoans. These differences were attributed to habitat differences (flows) between the reference and near-field fibremat areas and the non-fibremat area.

- Substrate characteristics were similar between areas (primarily sandy substrates with small percentage of fines), and likely did not represent an important source of variability in benthic invertebrate communities; although, the non-fibremat area had a slightly higher percentage of fines relative to reference and fibremat areas.

- Sediment quality in the fibremat area continues to improve as concentrations of TOC and dioxins and furans decrease over time. Higher TOC was observed in the fibremat area relative to the non-fibremat and reference areas, suggesting there is the potential for nutrient enrichment in the fibremat area; however, a consistent enrichment response was not observed in benthic invertebrates.

- Water quality was generally similar between areas and did not suggest nutrient enrichment in the near-field. In fact, slightly higher nutrient concentrations were observed in the reference area immediately downstream of the dam. Dissimilar water quality was observed at the station located immediately upstream of the STP; the source of these dissimilarities is unclear.

- Overall, results suggest that communities in reference area and fibremat area are similar. An enrichment response was not evident in the near-field fibremat area despite the presence of increased TOC.

4.3 IOC COMPONENT 2 - STABLE ISOTOPE ANALYSIS

4.3.1 Introduction

An isotope tracer study, comparing nutrient signatures in effluent to other nutrient sources (i.e., sediments, benthic water) and relating them to signatures in biota (benthic invertebrates and small-bodied fish) in the receiving environment, is the second component of the IOC study. This study component was conducted to determine the source of any observed nutrient enrichment. The tracer study included two phases, which are described below:

- Phase 1 – separation of nutrient sources; and

- Phase 2 – evaluation of nutrients in benthic communities and small-bodied fish.

In the first phase of the analyses, ratios of carbon and nitrogen in mill and STP effluent and other nutrient sources in the receiving environment (fibremat/sediment and benthic water samples) were compared to determine nutrient signatures and whether nutrients present in near-field area water and sediments are a result of current operations, represent historical deposits, or are from a confounding source.

In the second phase of the analyses, carbon and nitrogen signatures in benthic invertebrates and small-bodied fish will be compared between reference and near-field areas and to nutrient signatures of effluent, sediment, and water to determine the source of any observed enrichment.

4.3.2 Background Information on Stable Isotopes

Stable isotopes are non-radioactive atomic weight variations of an element, which are based on the number of neutrons in the nucleus (Jardine *et. al.* 2003). An element is defined by its atomic number, equal to the number of protons in the nucleus, and is often given a weight value that is a weighted average of isotopes. The isotope is termed stable when it is non-radioactive because it does not decay over time.

Isotopes are generally measured, using isotope ratio mass spectrometry (IRMS), as a ratio of heavy and light isotopes which are quantified based on comparison with a reference standard. Delta (δ) is used to denote the isotope ratio, with an increase in the δ value indicating an increase in heavy isotopes, and a decrease indicating a decrease in heavy isotopes and corresponding increase in the proportion of light isotopes, according to the following formula:

$$\delta X = [(R_{sample}/R_{standard})-1] \times 10^3$$

X denotes the heavier isotope and R denotes the isotope ratio.

In the current study, the isotopes of interest are carbon isotopes ($^{13}C/^{12}C$) and nitrogen isotopes ($^{15}N/\ ^{14}N$). The isotope ratio is presented as $\delta^{13}C$ and $\delta^{15}N$ and is described in units of *permils*. The relative magnitude of the isotope ratio gives an indication of how enriched with ^{13}C or ^{15}N the samples are to each other and to the reference standard. The higher (or more positive) the isotope ratio, the more enriched the sample is with ^{13}C or ^{15}N relative to the reference standard (for which the isotope ratio is known); the opposite is true for low isotope ratios.

These isotope ratios can be used to gain understanding about environmental conditions and changes (Peterson and Fry 1987; Jardine *et. al.* 2003). Differences in fractionation (measurable effect from the addition or subtraction of neutron mass) and equilibrium reactions that take place over time and space result in distinct signatures. These signatures can be used to provide information on spatial patterns, temporal patterns and food web relationships.

There is evidence that stable isotope analysis may identify distinct nutrient signatures in biosolids of effluent (mixed solids from secondary treatment) that can be linked to nutrient signatures in physical media (i.e., historical fibre mats, sediments, and suspended sediments) and biota in the receiving environment. Incorporation or uptake of effluent signatures into aquatic food webs has been documented at multiple trophic levels. For example, Velinsky *et al.* (2003) measured stable isotopes of carbon and nitrogen in pulpmill effluent and suspended sediments in a stream located upstream of a mill. Results indicated that effluent solids were enriched in ^{13}C and depleted in ^{15}N relative to suspended material in stream water. Signatures of effluent and suspended sediments from upstream areas were then compared to those observed in filter-feeding invertebrates. The carbon isotopic composition of filter feeders was most similar to effluent solids just below the discharge. Farther downstream,

macroinvertebrate carbon values were comparable to those observed in suspended sediments upstream of the facility. The isotopic enrichment of nitrogen between the effluent solids and macroinvertebrates was well within the expected shift in isotope ratios observed in related studies. This study illustrated that pulpmill effluent solids are a source of carbon and nitrogen to downstream organisms and can be used successfully to trace the movement of nutrients through aquatic food webs.

In the current study, stable isotopes of carbon and nitrogen were examined to provide information on the nutrient sources and flows in the aquatic environment.

4.3.3 Methods

4.3.3.1 Phase One – Separation of Nutrient Sources

Stable isotopes of carbon and nitrogen were used to compare nutrient signatures of fibremat/sediments and benthic water between near-field and reference areas to identify any spatial patterns. Isotopes of these media also were compared to the signatures of mill and STP effluents to identify the source of nutrients found in sediments and water.

Sample Collection

Samples of fibremat/sediment deposits, and benthic water samples were collected from the same 17 stations used for the benthic invertebrate survey (described in the previous section and illustrated in Figure 4.1 in September 2005). Sediment/fibremat and benthic water samples for isotope analyses were collected by Hatfield personnel (Table 4.11). Whole treated effluent (2-L samples) was collected by mill personnel three times prior to, during, and following the field program.

Table 4.11 Samples collected for stable isotope (carbon and nitrogen) analyses, Celgar EEM Cycle Four.

Location	Phase One	Phase Two
Mill Effluent Discharge	3 effluent biosolids samples	na
STP Effluent discharge	1 effluent sample	na
Near-field Area	1 fibremat /sediment sample x 12 stations	1 composite sample/representative benthic invertebrate x 3 representative benthic invertebrates X 12 stations
	1 benthic water sample x 12 stations	5 small-bodied fish
Reference Area	1 sediment sample x 5 stations	1 composite sample/representative benthic invertebrate x 3 representative benthic invertebrates X 5 stations
	1 benthic water sample x 5 stations	5 small bodied fish

na = not applicable

Sediment samples were collected using a Ponar grab as described in Section 4.2.3.1. A small sample of sediment (1 cm x 0.5 cm x 1 cm) was collected from the surface of one benthos grab from each station and transferred to a vial. Benthic water samples were collected using a Kemerrer bottle and transferred to a 1-L labeled amber glass bottle, as described in Section 4.2.3.1. Effluent samples were collected in an amber glass bottle. Samples were placed on ice then frozen.

Sample Preparation and Analysis

Effluent and water samples were shipped to ALS (Vancouver, BC) for filtering. Samples were filtered using 0.7 µm pre-combusted glass fibre filters, then the filter was placed in a labeled vial and frozen.

Filters and sediment samples were shipped frozen to the Stable Isotope Nature Laboratory at the University of New Brunswick for stable isotope analysis. Unfortunately, samples from fibremat stations CGBD07 and CGBD22 did not meet sample holding requirements due to improper storage and were not analyzed for stable isotopes.

Information on methods of isotope analysis is provided in Appendix A3.

4.3.3.2 Phase Two – Nutrients in the Food Web

The objective of Phase Two was to compare nutrient signatures in fish and benthic invertebrates (which represent a food resource for fish) from near-field and reference areas and to determine which nutrient sources are being used by biota. Three representative invertebrate species were selected based on their feeding behavior and their distribution and abundance in the study area.

Small-bodied fish, sculpins, were collected from near-field and reference areas to directly assess nutrient uptake in fish. Small-bodied fish were chosen because of their limited mobility relative to large-bodied species, which provides a greater certainty that fish reside in the area they were collected from.

Sample Collection

Benthic invertebrates were collected from depositional habitats using a Ponar grab, as described in Section 4.2.3.1. One grab was collected at each station. Contents of the grab were carefully transferred to a tub, then sieved on-shore through a box sieve with 200 µm mesh size. Particles and organisms larger than the mesh size retained in the box sieve were washed into a sample collection bottle. Samples were preserved with ethanol and subsequently shipped to the consulting taxonomist for sorting.

A small number of small-bodied fish were collected from riffle habitats along the shoreline of reference and near-field areas using seines and a backpack electrofishing unit. A total of 5 prickly sculpin (*Cottus asper*) were collected from the reference area (near station CGBD4) and 5 prickly sculpin were collected from the near-field area (near station CGBD12).

Sample Analysis

Representative invertebrate organisms had to be present in sufficient abundance in reference and near-field areas (at least 5 to 10 organisms per station) to provide an adequate sample for stable isotope analysis (minimum of 5 mg wet weight). Preserved samples were sorted in the laboratory and the taxonomic dataset was reviewed to identify taxa that were present in sufficient numbers across most stations to provide a comprehensive assessment of isotopes across all stations and a range of feeding guilds. Three taxa were selected:

- ***Pisidium*** sp. (Bivalvia: Sphaeridae) – a clam species referred to as a "filter feeder" in this investigation;
- ***Limnodrilus*** sp. (Annelida; Tubificidae) – a worm referred to as a "deposit feeder" in this investigation; and,
- ***Caecidotea*** sp. (Crustacea: Isopoda) – an omnivorous isopod referred to as an "omnivore/predator" in this investigation.

A separate composite for each representative organism was prepared for each station and analyzed for carbon and nitrogen isotopes.

Five prickly sculpin whole body samples from the near-field and reference areas were homogenized and analyzed for the same isotopes.

Interpretation of Isotope Results

Results of ^{13}C:^{12}C and ^{15}N:^{14}N isotope ratios were reported as:

$$\delta X = [(R_{sample}/R_{standard}) - 1] * 1000$$

where: X = ^{15}N or ^{13}C and $R = {}^{15}N/{}^{14}N$ or $^{13}C/{}^{12}C$.

The isotope ratio of the sample was determined through comparison to a known isotope ratio in a reference standard (a certified material known to yield both accurate and precise isotope ratio results). Vienna Pee Dee Belemnite (VPDB), used as a carbon reference standard, is derived from naturally occurring carbonate in a limestone formation (T. Jardine, *pers. comm.* 2007; Coplen *et al.* 1983; Craig 1957). The reference standard for nitrogen is atmospheric nitrogen gas (T. Jardine, *pers. comm.* 2007; Mariotti 1983).

When comparing ratios among samples, isotope signatures are considered to be enriched, when they are more positive, and depleted, when they are more negative, relative to other samples.

Data Analysis

Comparisons of isotope signatures were conducted using graphical methods and ANOVAs (as described in Section 4.2.3.3).

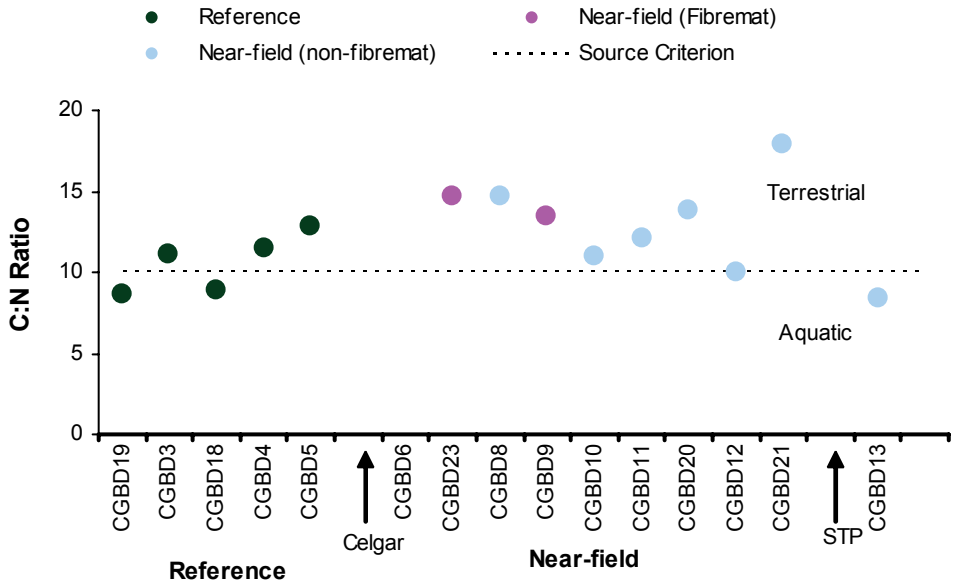
4.3.4 Results

4.3.4.1 Phase I: Separation of Nutrient Sources

Nitrogen and carbon ratios (signatures) in sediments and effluent are presented below. Analyses of benthic water were not feasible because an insufficient amount of suspended material was collected.

Carbon to nitrogen ratios in sediments were significantly higher in near-field fibremat sediments relative to reference sediments (Table 4.11). A higher C:N ratio (greater than 10, as illustrated in Figure 4.17) generally indicates that sediments contain a higher proportion of organic matter derived from terrestrial sources (Kukal 1971 as cited in Faganeli 1988, Davide *et al.* 2003). The reference station closest to the outfall (CGBD5) exhibited a higher C:N relative to other reference stations and similar to the fibremat stations, possibly suggesting that this reference station was influenced by the mill. The plume delineation studies conducted in the early 1990s suggests that during periods when flows from the dam are very low and flows from the Kootenay River are very high, water levels in the Columbia River rise (up to 3 m) due to hydraulic damming. Under these conditions, effluent moves upstream of the diffuser. C:N ratios suggest that this reference station was influenced by the diffuser.

Figure 4.17 Carbon to nitrogen (C:N) ratios in sediments from reference and near-field areas, Celgar EEM Cycle Four.



Carbon isotope ratios in sediment, which ranged from -18.0 to -26.1 permils, and nitrogen isotope ratios, which ranged from -0.5 to 2.33 permils, were not statistically different between reference and near-field areas/subareas (Table 4.12 and Figure 4.18). Carbon signatures were slightly higher in the non-fibremat

stations CGBD20 and CGBD13 (downstream of the STP). The reference station (CGBD05) located just upstream of the diffuser exhibited a carbon signature that was lower than the other reference stations and similar to the near-field fibremat stations, suggesting this station was influenced by the diffuser (as noted in the previous discussion on C:N).

Table 4.12 Results of ANOVAs and Tukey's comparisons conducted to test for differences in carbon isotope ratios, nitrogen isotope ratios, and C:N in sediments and biota between reference and near-field areas/subareas, Celgar EEM Cycle Four.

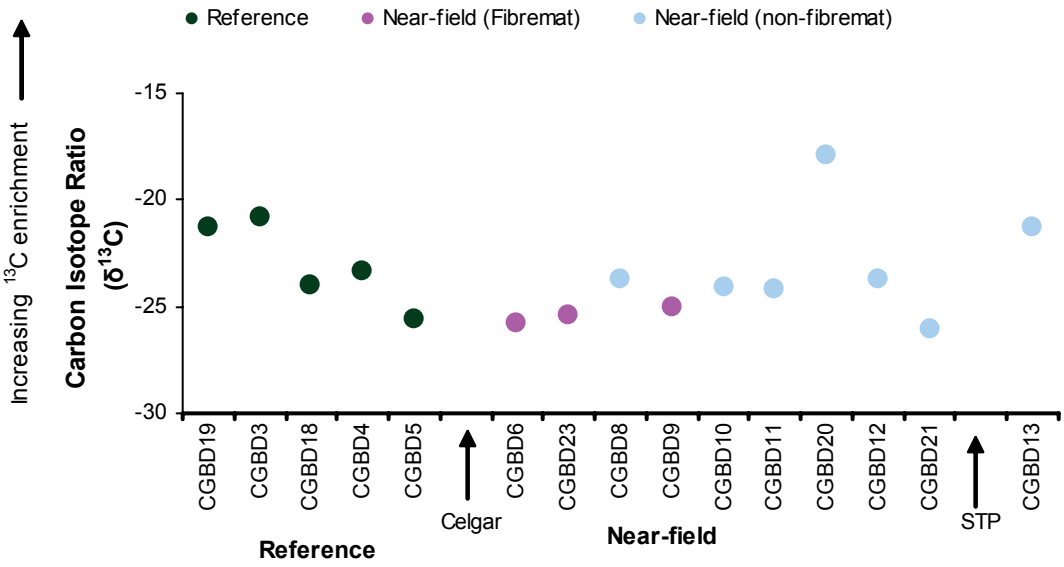
Effect	ANOVA	Tukey's Comparisons (p-value)[2]				Pattern[2]
Endpoint	(p-value)[2]	Ref vs. NF	Ref vs. FM	Ref vs. non FM	FM vs. non FM	
Sediment $\delta^{13}C$	0.165	0.346	0.166	0.93	0.224	
Sediment $\delta^{15}N$	0.42	0.187	0.488	0.497	0.963	
Sediment C:N ratio	**0.059**	0.148	**0.051**	0.661	0.14	FM > Ref
Filter Feeder $\delta^{13}C$	**0.004**	0.671	**0.037**	0.588	**0.003**	FM < Ref
Filter Feeder $\delta^{15}N$	0.841	0.741	1	0.876	0.876	
Deposit Feeder $\delta^{13}C$	**0.027**	0.687	**0.097**	0.817	**0.023**	FM < Ref
Deposit Feeder $\delta^{15}N$	**0.007**	**0.015**	**0.005**	0.127	**0.104**	FM < Ref
Omnivore $\delta^{13}C$	**0.001**	**0.045**	**0.001**	0.699	**0.005**	FM < Ref
Omnivore $\delta^{15}N$	**0.076**	0.234	0.986	**0.099**	0.13	non FM < Ref
Fish $\delta^{13}C$	NA	0.497	NA	NA	NA	
Fish $\delta^{15}N$	NA	**0.071**	NA	NA	NA	NF < Ref

Bolded values represent significant differences between areas.

When mean sediment nitrogen and carbon isotopes for each area are plotted together in an ordination plot, spatial differences in isotope signatures become more apparent (Figure 4.19). The overall variability in carbon signatures in sediments among stations within a given area was much higher than the variability in nitrogen signatures. The sediments in the near-field non-fibremat and reference areas have nearly identical signatures; sediments from the fibremat area have a less-enriched carbon signature.

The signatures of the mill and STP effluent are also plotted on this graph. The mill effluent (mean of three samples) has a similar carbon signature and slightly lower (less ^{15}N-enriched) nitrogen signature than the sediment samples; it was more similar to the reference and non-fibremat samples, indicating that the signature for the historical fibremat was distinct from the current effluent signature. The carbon signature for the STP effluent fell within a similar range to sediments and the mill effluent, but the nitrogen signature was much more ^{15}N-enriched; the sediment sample located downstream of the STP did not show a similar signature to the STP effluent (N = 1.85 permils, C = -21.32 permils).

Figure 4.18 Carbon (δ13C) and nitrogen (δ15N) isotope ratios in sediments from reference and near-field areas, Celgar EEM Cycle Four.



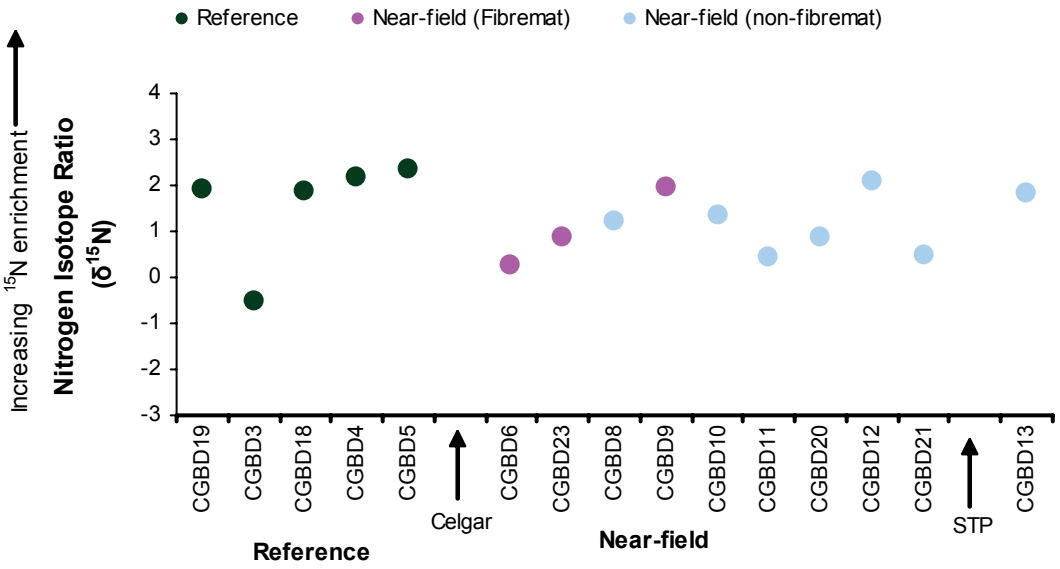
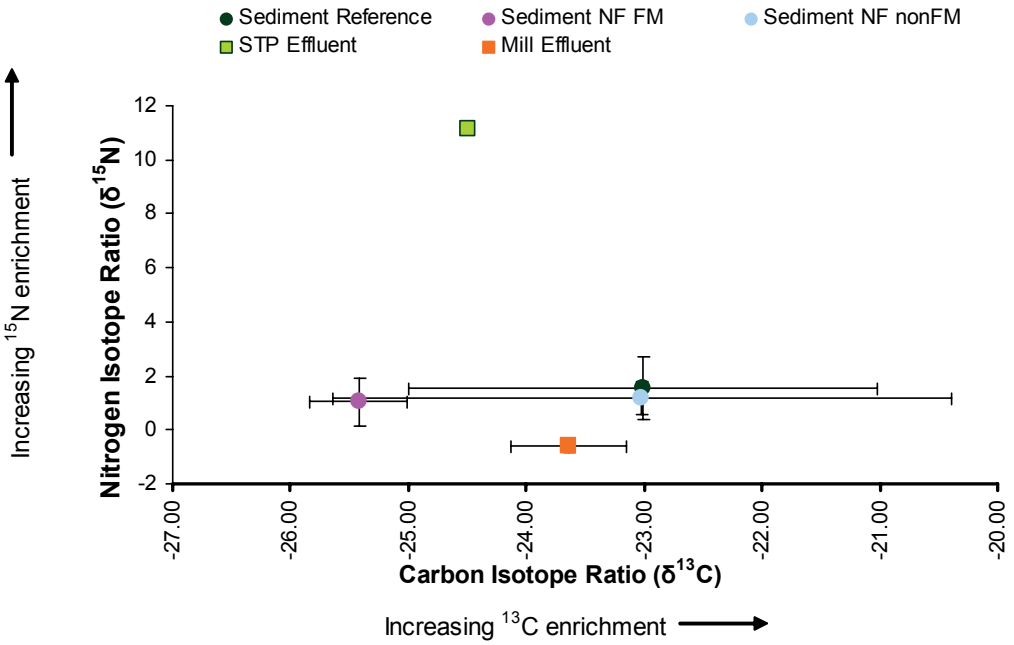


Figure 4.19 Mean carbon and nitrogen isotope signatures in STP effluent, mill effluent, and sediment samples, Celgar Cycle Four EEM.



4.3.4.2 Phase II: Nutrients in the Food Web

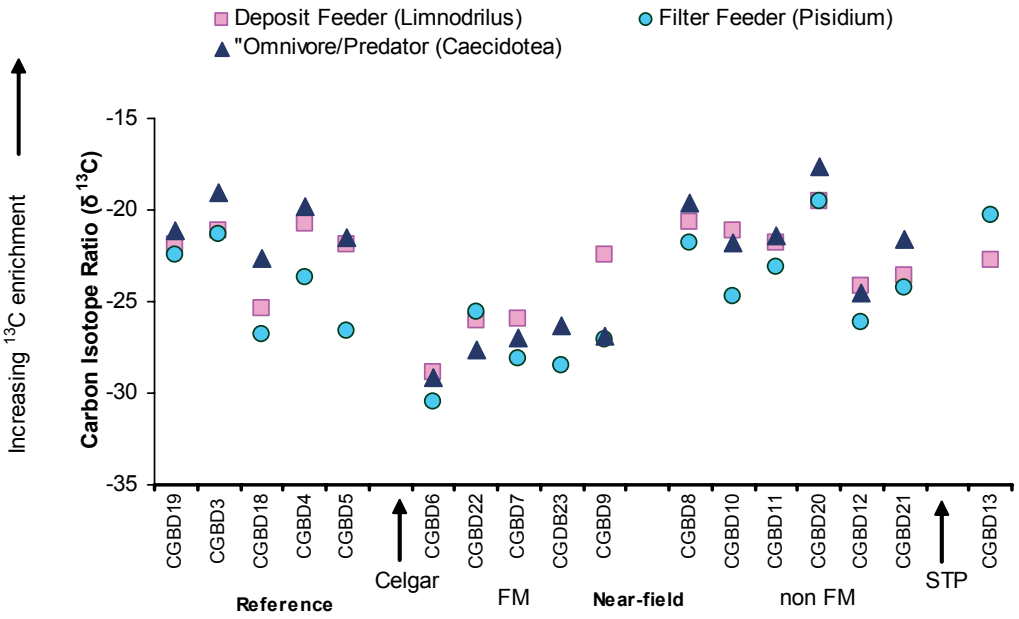
Carbon and nitrogen isotope signatures in the following three benthic invertebrate organisms are presented in Figure 4.20:

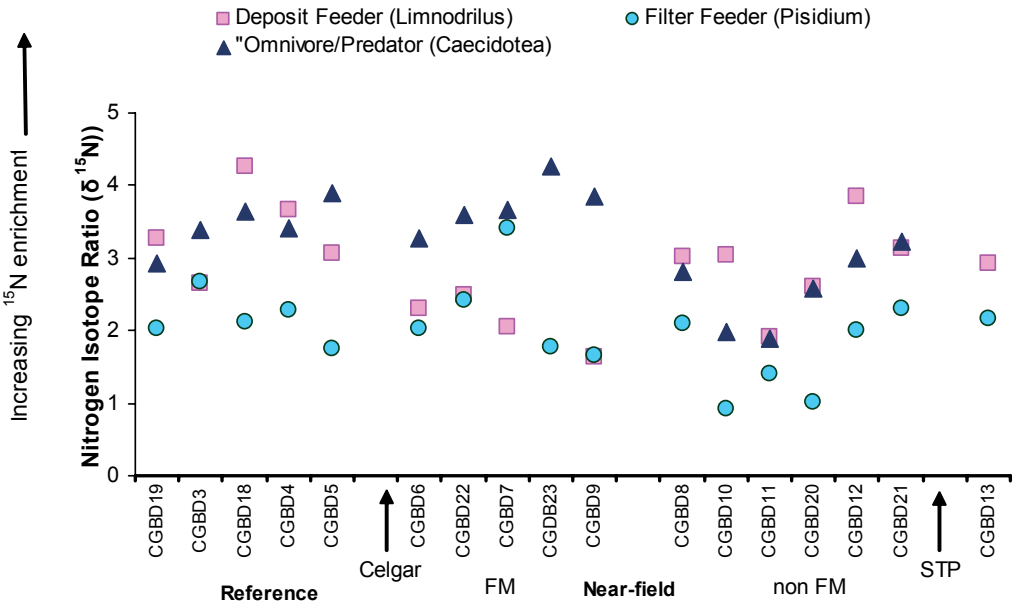
- Filter feeder - the sphaerid clam *Pisidium*;
- Deposit feeder – the tubificid worm *Limnodrilus*; and
- Omnivore – the asellid isopod *Caecidotea*.

Carbon signatures fell into a generally similar range for all three organisms in the reference and near-field non-fibremat area, but were significantly lower (i.e., less ^{13}C- enriched) for all organisms in the fibremat area. At most stations, carbon signatures for filter feeders, which represents the lowest trophic level in this study, were the lowest (i.e., least ^{13}C-enriched) and signatures for the omnivore, belonging to the highest trophic level, were the highest observed (i.e., the most ^{13}C-enriched). The reference station located closest to the diffuser exhibited carbon signatures similar to the other reference stations.

Nitrogen signatures fell into a similar range for all three organisms in the reference and near-field fibremat area, but were lower (i.e., less ^{15}N-enriched) in the non-fibremat area. Omnivores exhibited significantly lower signatures in the non-fibremat area relative to the reference area; filter feeders exhibited lower signatures in the fibremat area relative to the reference area. At most stations, signatures for filter feeders were the lowest and signatures for the omnivores and deposit feeders were the highest observed.

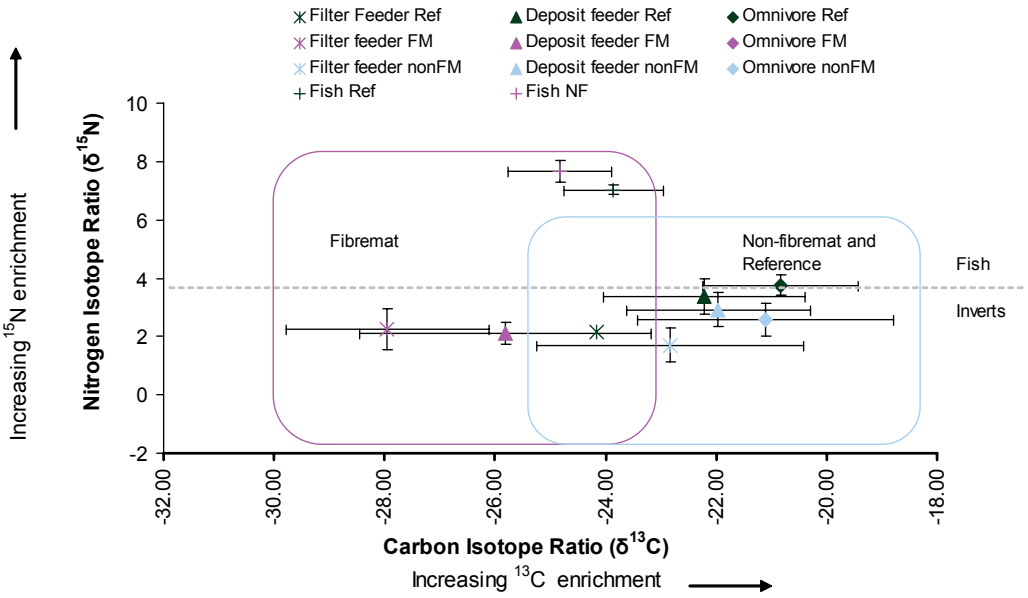
Figure 4.20 Carbon and nitrogen isotope ratios in benthic invertebrate filter feeder, deposit feeder, and omnivore from reference and near-field areas, Celgar EEM Cycle Four.





Isotopes were also measured in prickly sculpin collected from reference and near-field areas. Mean (± SD) signatures for fish in each area, along with those for benthic invertebrate deposit feeders, filter feeders, and omnivores are presented in Figure 4.21. Nitrogen provided a clear separation of differences in signatures between trophic levels. Fish had noticeably higher nitrogen isotope ratios than the benthic invertebrates. The benthic invertebrate filter feeders (the lowest trophic level) had the lowest nitrogen signature. Nitrogen signatures for fish in the near-field area were lower than those observed in the reference area. The preferred food items for prickly sculpin are aquatic insect larvae, especially chironomid and trichopeteran larvae, and other invertebrates such as bivalves, which are found throughout the near-field and reference area (Scott and Crossman 1979).

Figure 4.21 Mean carbon and nitrogen isotope signatures in benthic invertebrate filter feeders, deposit feeders, omnivores, and sculpin, Celgar Cycle Four EEM.

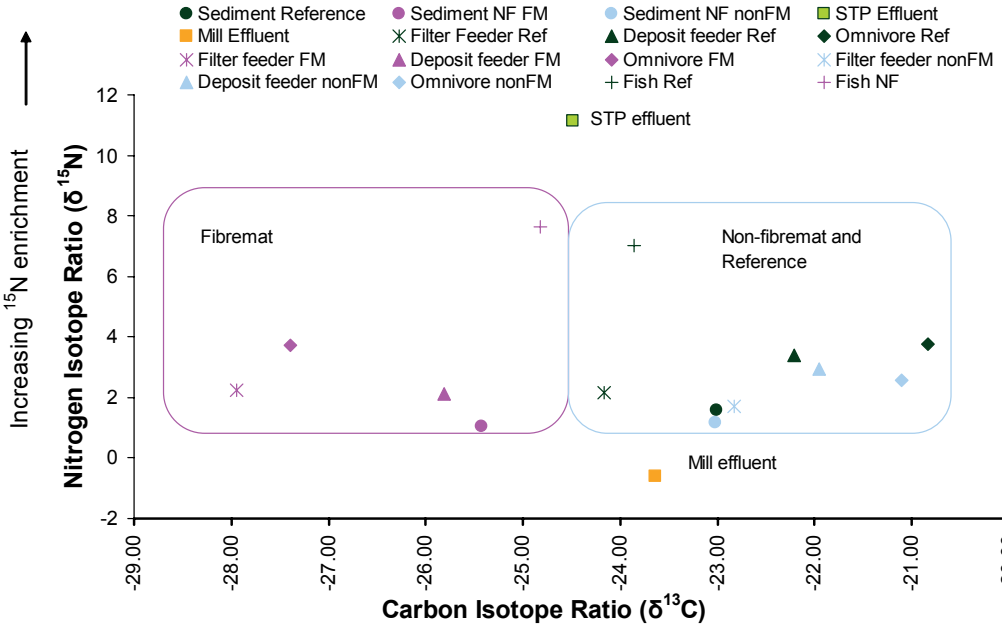


Carbon exhibited a higher degree of variability within areas than nitrogen, but still provided a clear separation of spatial differences in signatures between near-field and reference areas. Overall, the fibremat area exhibited lower carbon isotope ratios than the reference and fibremat areas, showing a lesser degree of ^{13}C-enrichment. The isotopes for fish fell in the middle of the range of those for benthic invertebrates. Benthic invertebrates in the reference and non-fibremat area had noticeably higher (^{13}C-enriched) carbon signatures relative to those in the fibremat area.

4.3.4.3 Relationships between Nutrient Sources and Nutrients in the Food Web

Mean carbon and nitrogen isotope signatures in nutrients sources (sediments and effluents) and those in the food web (benthic invertebrates and fish) are compared graphically in Figure 4.22. Carbon isotopes clearly grouped by area for all media including sediments, benthic invertebrates and fish. Overall, the fibremat area exhibited lower carbon isotope ratios in all media than those observed in the reference and non-fibremat area. Within the fibremat area, sediments had carbon signatures that were higher than those observed in benthic invertebrates and lower than that observed in fish.

Figure 4.22 Mean carbon and nitrogen isotope signatures in benthic invertebrates, fish, sediments, and effluents, Celgar Cycle Four EEM.



Nitrogen isotopes clearly separated trophic levels in the food web. Benthic invertebrates and sediments had lower ratios than from fish, with fish, the top predator in the food web, exhibiting the highest isotope ratios; nitrogen signatures in sediments were slightly lower than those observed in benthic invertebrates. Deposit feeding and filter-feeding benthic invertebrates should show a strong relationship with the nitrogen signature in sediments given that they ingest sediments.

Mill and STP effluents exhibited similar carbon isotope ratios (approximately -24 permils), which were generally lower than those observed in the reference and non-fibremat area and higher than those observed in sediments and biota in the fibremat area; they were most similar to those observed in reference sediments and filter feeders. Nitrogen isotope ratios for effluents were highly dissimilar (11 permils in STP effluent and -0.6 permils in mill effluent) from each

other and other media. Mill effluent exhibited lower nitrogen ratios than those observed in all other media. Mill effluent nitrogen isotopes were slightly lower than those observed in benthic invertebrates and much lower than those observed in fish. The STP effluent had higher nitrogen isotope ratios (^{15}N-enriched) compared to all media.

The areas with the highest and lowest relative enrichment for carbon and nitrogen isotopes in effluents, sediments, and biota are summarized in Table 4.13. From this table, it is apparent that carbon isotopes for the fibremat area were distinctly lower from those observed in the reference and non-fibremat areas. Carbon sources in the fibremat area were distinctly different from those found in present-day sediments from upstream areas and present-day effluent. The source of carbon found in the fibremat is likely linked to historical inputs from the mill, given the spatial pattern observed and lack of similarity with current mill effluent signatures. Downstream of the fibremat area, sediments returned to carbon signatures similar to those found in reference sediments.

Table 4.13 Summary of isotope enrichment patterns by area for each media type.

	Isotope Enrichment Pattern (from most enriched to least enriched)	
	Nitrogen Isotope Ratio (δ15N)	**Carbon Isotope Ratio (δ13C)**
Fish	NF > Ref	Ref > NF
Omnivore	Ref ~ NF (FM) > NF (non FM)	Ref ~ NF (non FM) > NF (FM)
Deposit Feeder	Ref > NF (non FM) > NF (FM)	Ref > NF (non FM) > NF (FM)
Filter Feeder	NF (FM) > Ref > NF (non FM)	NF (non FM) > Ref > NF (FM)
Sediments	Ref > NF (non FM) > NF (FM)	Ref ~ NF (non FM) > NF (FM)
Effluents	STP >> mill	mill > STP

A comparison of the carbon signatures observed in effluent, sediment, and biota to scientific literature indicates that signatures observed were typical of aquatic systems, with the exception of the fibremat samples (Table 4.14). According to literature, terrestrial signatures and aquatic signatures separate at approximately -27 to -28 permils. The fibremat filter feeder and omnivore were above this value, while the deposit feeder and sediments were slightly below this value, indicating the fibremat had a characteristic terrestrial signature. The STP effluent also had a borderline terrestrial signature; the signature observed in the current study is similar to that reported by Faganeli (1989) (-25 permils). The remaining reference and non-fibremat sediment, benthic invertebrate, fish from both areas, and mill effluent had a characteristic aquatic signature. The mill effluent signature is not reflective of a terrestrial signature possibly due to changes caused by processing of pulp through recovery and recausticizing processes.

Table 4.14 Comparison of literature-based carbon signatures observed in aquatic environments with those observed in Cycle Four.

Literature Based Values		Cycle Four Values	
Carbon Isotope Ratio (δ13C)	Component	Carbon Isotope Ratio (δ13C)	Component
Terrestrial			
-29.3	Upland C3 plants[1]		
-28	River particulate organic matter[2]		
-27.8	Terrestrial detritus[3]	-27.4 to 27.9	FM filter feeder and omnivore
Aquatic			
-27	Algae – filamentous[4]	-24.5 to -25.8	FM deposit feeder and sediments, STP effluent
-22.6	Algae – generic[3]	-22.0 to -24.2	Ref filter feeder, deposit feeder, fish, sediments; NonFM filter and deposit feeder and sediments, mill effluent
-21.3	Plankton[1]	-20.8 to -21.1	Non-FM deposit feeder and omnivore, Ref omnivore
-17	Diatoms[4]		
-12.9	Aquatic C4 plants[1]		

[1] Peterson 1999.

[2] Faganeli 1989.

[3] Doucett 1996.

[4] France 1995.

The carbon signatures of benthos in the fibremat area were more depleted than the sediments in the fibremat area. However, other studies indicate that organisms generally have a carbon signature that is 1 permil more enriched than the food they consume (Peterson 1999; Faganeli *et al.* 1988). This discrepancy could be due to preferential feeding patterns of organisms living in the fibremat, where a more depleted carbon signature (originating from the fibremat) results in a more depleted $\delta^{13}C$ signature being carried up the food chain. Preferential feeding behavior by benthic organisms invertebrates has been observed in other stable isotope studies (Peterson 1999, Rossi 2004).

The nitrogen isotopes did not clearly identify any area-based trends; although the reference area exhibited slightly higher isotope ratios in the omnivores, deposit feeders and sediments. The nitrogen isotopes clearly distinguished between mill effluent and STP effluent.

The separation of trophic levels through nitrogen isotopes is one of the key applications for isotope analysis. The nitrogen isotopes distinguished between the food source for benthic invertebrates (sediments), sediment ingesting benthic invertebrates (deposit feeders and filter feeders), and fish, which consume invertebrates. The finding that nitrogen was superior to carbon in differentiating between trophic levels is not surprising, given that for nitrogen isotopes,

signatures of different trophic levels differ by 3 to 3.5 permils, while for carbon isotopes, signatures may differ by up to 1.5 permils between trophic levels (Peterson 1999, Doucett 1996, France 1995). Fish and benthic invertebrate nitrogen signatures fell within this range. The lack of distinction between feeding guilds could be related to the similarities in materials consumed by organisms. The deposit and filter feeder both ingest sediments, while the omnivore isopod may consume plant material, which has a similar signature.

The nitrogen signatures of benthos were very similar among areas; these signatures were 1 to 2 permils more ^{15}N-enriched than sediments and 3 permils more ^{15}N-enriched than mill effluent. Benthos were ^{15}N-depleted compared to STP effluent (by about 6 permils). These results suggest that the mill is a more likely source of nutrients, given that organisms typically exhibit $\delta^{15}N$ signatures that are approximately 3 permils higher than the signature of the food they consume (Peterson 1999; Faganeli *et al.* 1988).

The C:N ratios observed support the separation of the fibremat from the reference and non-fibremat areas suggested by carbon signature data. As indicated in Figure 4.17, C:N ratios less than 10 are generally indicative of aquatic sources of organic matter, while those greater than 10 are indicative of terrestrial sources (Kukal 1971 as cited in Faganeli 1988, Davide *et al.* 2003). The results for the current investigation indicate that there was a slight increase in C:N ratios in the fibremat area. Farther downstream, in the non-fibremat area, C:N ratios decreased, but were elevated relative to the reference stations. These results suggest that pulpmill operations (historical and/or current) are the key source for the organic matter observed in fibremat sediments. There also appears to be a smaller pulpmill-related influence in sediments collected from the non-fibremat area of the 1% zone. The single station collected downstream of the STP outfall has a distinctly lower C:N ratio, which would be expected downstream of an STP, given the high nitrogen content of human waste (Davide *et al.* 2003).

4.3.5 Summary

Sediments and biota from the fibremat have a different carbon signature from those observed in the reference and non-fibremat area, indicative of terrestrial - based organic matter coming from the historical fibremat deposit. The similarity in carbon signatures between the reference and near-field area suggests that current day operations are not impacting water quality downstream of the mill. Carbon isotope signatures of fibremat sediments appear to be influenced slightly by the isotope signature of present-day mill effluent, suggesting that current operations may be adding small amounts of organic matter to the existing fibremat. Carbon signatures in sediment also suggest that the reference station located just upstream of the diffuser may be influenced by the mill effluent.

4.4 INTEGRATED ASSESSMENT OF ENRICHMENT

In EEM Cycles Two and Three, enrichment effects were observed in fish from the near-field area of the Columbia River relative to fish from the Slocan River reference area. However, the benthic invertebrate surveys conducted in the Columbia River did not show evidence of enrichment, and comparisons with fish from the Slocan River were confounded by differences in habitat, productivity, and dietary items (benthic invertebrates) present. In Cycle Four, an Investigation of Cause (IOC) study, comprised of an expanded benthic invertebrate survey and stable isotope survey, was conducted to further investigate potential enrichment of the near-field area suggested by these fish surveys. Results of the Cycle Four traditional benthic invertebrate survey and isotope surveys were evaluated, along with results from fish population surveys in Cycles Two and Three, using a weight-of-evidence approach to determine whether the mill has been, or is, enriching the near-field environment. The integrated assessment of potential enrichment downstream of the mill included of the following lines of evidence.

Cycle Four Benthic invertebrate Survey - The criteria used to evaluate results from the benthic invertebrate survey for potential enrichment effects included:

- Community metrics – was there evidence of differences in community metrics between reference and near-field areas; in particular, were there increases in density and diversity and increase/decreases in richness in the near-field area, which would be indicative of enrichment effects?

- Community composition – was there a difference in community composition between the reference and near-field areas; in particular, were there increased numbers of facultative and pollution tolerant taxa and decreased numbers of pollution sensitive taxa?

- Sediment chemistry – were there increased concentrations of TOC in sediments downstream of the mill?

- Water chemistry – were there increased concentrations of nutrients in river water downstream of the mill?

Cycle Four Stable Isotope Survey - The criteria used to evaluate results from stable isotope survey included:

- Isotope signatures - Were there differences in the isotope signatures between sediments from reference and near-field fibremat and non-fibremat areas? Did sediments in the near-field area have a similar signature to present day mill effluent?

- Nutrient uptake - Were there differences in the isotope signatures between benthic invertebrates and fish from reference and near-field fibremat and non-fibremat areas? Were the isotope signatures observed in sediments and effluents reflected in biota?

Historical Fish Surveys - The criteria used to evaluate results from Cycle Two and Three fish surveys included:

- Did Columbia River near-field fish indicate evidence of enrichment (e.g., a greater energy usage or storage) relative to Slocan River reference fish?

- Were habitats, nutrient concentrations, and food resources similar between the two areas?

Results from the Cycle Four surveys and historical fish surveys are screened against these criteria in Table 4.15. Key findings are summarized below.

Cycle Four Benthic Invertebrate survey - The screening indicated that communities in the non-fibremat area were different from those found in the fibremat and reference areas. These differences were likely due to habitat differences between the reference and fibremat and non-fibremat areas, and were not suggestive of enrichment. The river is slow-flowing in the reference and fibremat sections and gradually becomes faster flowing with distance downstream in the non-fibremat area. There was no evidence of increased densities, diversities, and decreased richness, which would indicate enrichment. Densities of taxa identified as important dietary items for mountain whitefish in the Cycle Two survey were generally similar between near-field and fibremat areas, with the exception of the station immediately downstream of the mill, which exhibited higher densities.

The supporting sediment quality survey indicated there was potential for enrichment in the fibremat area due to elevated TOC concentrations; however, TOC, which persists in the fibremat from historical effluent releases, appears to be decreasing over time, as the fibremat breaks down. Benthic invertebrate communities do not appear to be responding to increased levels of these nutrients, possibly because carbon is not a limiting nutrient for productivity in this system. Historical studies have shown the Columbia River is phosphorus-limited (Hatfield Consultants 1994). Supporting water quality data suggests that nutrient inputs upstream of the mill were higher than those observed downstream of the mill; these increases are likely a result of nutrient additions in the upstream Arrow Lake system.

Cycle Four Stable Isotope Survey – The screening indicated that the sediments and biota in the fibremat area have a distinct carbon signature compared to those observed in the reference and non-fibremat area, which is largely reflective of historical organic matter inputs. Biota (from deposit feeders to fish) were utilizing organic matter from the fibremat. The similarities observed in carbon signatures between the reference and non-fibremat area suggest the current-day impacts of the mill effluent on the downstream community are small. Nitrogen signatures did not provide evidence of enrichment, and were mainly used to distinguish between trophic levels in the food web.

Table 4.15 Weight-of-evidence assessment of mill-related enrichment in the Columbia River.

Survey Component	Pattern/Effect Observed			Suggestive of Mill-Related Enrichment?	
	Reference	**Fibre-mat**	**Non fibre-mat**		
Traditional benthic invertebrate survey (Cycle Four)					
Community metrics	Similar density, richness, evenness, and Bray Curtis index	Similar density, richness, and evenness, and **higher Bray Curtis index**		X	Likely due to habitat differences or STP
Community composition	Similar facultative taxa			X	-
	-	-	Station downstream of STP different from other stations	X	Likely due to habitat differences or STP
Sediment Chemistry	Similar TOC	**Higher TOC**	Similar TOC	✓	↑ TOC in FM due to historical mill inputs
Water Chemistry	Similar TP	**Lower TP**		X	↑ TP From upstream sources (Arrow Lake)
	Similar TN	**Lower TN**	Similar TN	X	↑ TN From upstream sources (Arrow Lake)
Isotope Survey (Cycle Four)					
Sediment signatures	Similar carbon signature	**Lower carbon signature**	Similar carbon signature	✓	Different signature in FM due to contribution of historical mill inputs
	Nitrogen: no obvious pattern			X	-
Benthic invertebrate signatures	Similar carbon signature	**Lower carbon signature**	Similar carbon signature	✓	Pattern observed in sediments also observed in benthic invertebrates, indicates that invertebrates are ingesting organic material from the fibremat
	Nitrogen: no obvious pattern			X	-
Fish signatures	Similar carbon signature	**Slightly lower carbon signature**		✓	Pattern observed in sediments also observed in benthic invertebrates, indicates that invertebrates are ingesting organic material primarily from a pulpmill source.
	Similar nitrogen signature	**Slightly higher nitrogen signature**	Similar nitrogen signature	X	Cannot be related back to a unique source.
Historical Fish Survey (Cycles Two and Three)					
Whole fish metrics	Lower energy use and storage	**Greater energy use and storage**		≈ ✓	Possible, however confounding influence of habitat differences make conclusions dubious.
Overall Assessment					
				X	Evidence of increased TOC and unique carbon signature in FM due to historical inputs No evidence of enrichment in benthic invertebrate community

Historical Fish Surveys – The screening indicated there was evidence of enrichment (increased condition and gonad size) in near-field fish relative to the fish from Slocan Lake reference area. However, findings from this study were confounded by differences in habitat between the two areas, differences in productivity, and differences in the benthic invertebrate food items consumed in the two areas (Hatfield Consultants 2000). The habitat in the Columbia River is slower flowing and deeper. Nitrogen concentrations in the Columbia River are higher, likely due to upstream inputs from Arrow Lake, as well as the natural productivity of the system (Table 4.16). Benthic invertebrates found in mountain whitefish stomachs in Cycle Two indicated that the Columbia River had a lower proportion of mayflies, caddisflies, and stoneflies, and a higher proportion of chironomids.

Table 4.16 Nutrient concentrations in water in the Columbia and Slocan Rivers.

Location	n	Concentration in Water (mg/L)		
		Nitrate+Nitrite	Orthophosphate	Total Phosphorus
Columbia River	19	0.119	<0.003	0.005
Slocan River	8	0.020	0.002	0.003

Columbia River 400 m downstream of the mill, monthly sampling September 1991 to October 1992 (CRIEMP 1993).

Slocan River at Passmore at Swinging Bridge, July to October 1992 (source CRIEMP).

Overall, results suggest that findings from the Cycle Four survey do not support the conclusions drawn from the Cycle Two and Three fish surveys, which suggest the mill is enriching the environment. Benthic invertebrates, which are used as a food source for fish, do not show evidence of enrichment. The historical fibremat does result in differences in TOC concentrations and differences in carbon signatures in sediments and biota from the area; however, these differences do not result in an enrichment response in the benthic invertebrate community.

5.0 CONCLUSIONS

Sublethal toxicity testing indicates that effluent did not affect survival of rainbow trout or *Ceriodaphnia dubia*. Effects on *Selenastrum capricornutum* growth were observed in 1/6 tests at an IC25 geomean of 83% effluent. Effects on *C. dubia* reproduction were observed in 4/6 tests with an IC25 geomean of 72% effluent. The maximum potential zones of sublethal effects from the effluent discharge point were 82 m for invertebrate reproduction and 72 m for algal growth. However, concentrations of effluent observed in the receiving environment are much lower than the concentrations modeled. Results in Cycle Four suggested that overall toxicity was reduced relative to Cycle Three.

The Investigation of Cause (IOC) survey indicates that mill operations are not resulting in enrichment effects in the benthic invertebrate community downstream of the mill. Communities in reference and near-field areas were similar, healthy, and diverse, dominated by facultative taxa. Differences in community composition, indicated by the Bray-Curtis index, between the reference and fibremat and non-fibremat areas were likely driven by the change in habitat in the downstream area. Relative abundances of benthic invertebrate food items consumed by mountain whitefish exhibited similar densities between reference and near-field areas.

Supporting sediment quality surveys confirm that the historical fibremat is continuing to break down over time, resulting in continuing decreases in TOC and dioxin and furan concentrations. TOC is still elevated in the near-field fibremat area relative to the reference area; however, concentrations are very low (0.3 to 4%) and it is expected they will eventually decrease to levels found in the upstream reference area. Water quality surveys do not show evidence of increased nutrient concentrations downstream of the mill, which could result in enrichment; in fact, concentrations of nitrogen and phosphorus were highest immediately downstream of the dam, suggesting that upstream inputs from Arrow Lake system are an important source of nutrients.

Isotope surveys indicate that carbon signatures found in sediments and benthic invertebrates in the fibremat are distinct from those observed in the reference and non-fibremat areas. Benthic invertebrates in the fibremat area reflect the carbon signature found in sediments from the historical fibremat; however, the benthic invertebrate community does not show any evidence of effects related to the fibremat. The similarity in carbon signatures between the reference and near-field area suggests that current day operations are not impacting water quality downstream of the mill. Carbon signatures in fish were slightly lower in the near-field area than in the reference area.

Results of this survey do not support the earlier observations of enrichment effects in mountain whitefish from the near-field area, relative to fish from the Slocan River reference area, reported in Cycle Two. These differences were likely influenced by the large habitat differences (Columbia River was slower flowing

and deeper), nutrient concentrations (higher nitrogen concentrations were observed in the Columbia River), and differences in benthic invertebrate food items (Columbia River had more chironomids and less EPT taxa) found in these areas.

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7.0 GLOSSARY

Acute	With reference to toxicity tests with fish, usually means an effect that happens within four to seven days, or an exposure of that duration. An acute effect could be mild or sublethal, if it were rapid.
ANCOVA	Analysis of covariance. ANCOVA compares regression lines, testing for differences in either slopes or intercepts (adjusted means).
ANOVA	Analysis of variance. An ANOVA tests for differences among levels of one or more factors. For example, individual sites are levels of the factor site. Two or more factors can be included in an ANOVA (e.g., site and year).
BEAST	Benthic assessment of sediment. BEAST is a tool for evaluating the health of freshwater benthic invertebrate communities by using predictive models that relate site habitat attributes to an expected community, commonly referred to as a reference condition (see CABIN and RCA, below).
Benthos	Organisms that inhabit the bottom substrates (sediments, debris, logs, macrophytes) of aquatic habitats for at least part of their life cycle. The term benthic is used as an adjective, as in benthic invertebrates.
BOD	Biochemical oxygen demand. The test measures the oxygen utilized during a specified incubation period for the biochemical degradation of organic material and the oxygen used to oxidize inorganic material such as sulfides and ferrous iron. Usually conducted as a 5-day test (i.e., BOD_5).
CABIN	Canadian aquatic biomonitoring network. CABIN is a collaborative programme developed and maintained by Environment Canada to establish a network of reference sites (see RCA, below) available to all users interested in assessing the biological health of fresh water in Canada.
Caustic	Also known as sodium hydroxide; an odourless corrosive, clear or slightly cloudy liquid, often used to control odour in effluent treatment systems.
Chlorophyll *a*	The primary photosynthetic pigment of most plants.
CL	Confidence limits. A set of possible values within which the true value will lie with a specified level of probability.

Colour

True colour of water is the colour of a filtered water sample (and thus with turbidity removed), and results from materials which are dissolved in the water. These materials include natural mineral components such as iron and calcium carbonate, as well as dissolved organic matter such as humic acids, tannin, and lignin. Organic and inorganic compounds from industrial or agricultural uses may also add colour to water. As with turbidity, colour hinders the transmission of light through water, and thus "regulates" biological processes within the body of water.

Community

A set of taxa coexisting at a specified spatial or temporal scale.

Concentration Units

See table:

Concentration Units	Abbreviation	Units
Parts per million	ppm	mg/kg or µg/g or mg/L
Parts per billion	ppb	µg/kg or ng/g or µg/L
Parts per trillion	ppt	ng/kg or pg/g or ng/L
Parts per quadrillion	ppq	pg/kg or fg/g or pg/L

Condition Factor

A measure of the plumpness or fatness of aquatic organisms. For oysters and mussels, values are based on the ratio of the soft tissue dry weight to the volume of the shell cavity. For fish, the condition factor is based on length-weight relationships.

Conductivity

A numerical expression of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, valence and relative concentrations, and on the temperature of measurement.

Covariate

An independent variable; a measurement taken on each experimental unit that predicts to some degree the final response to the treatment, but which is unrelated to the treatment (e.g., body size [covariate] included in the analysis to compare gonad weights of fish collected from reference and exposed areas).

$\delta^{13}C$ (permil)

Ratio of stable carbon isotopes ^{13}C and ^{12}C.

Diatoms

Unicellular or colonial algal species of the division Bacillariophyceae, with silicaceous cell walls. Typically the most abundant algal species in periphyton.

Dioxins/Furans

Polychlorinated dibenzo-para-dioxins (PCDDs) and dibenzofurans (PCDFs) are often simply called dioxins, although they are two separate groups of substances with similar effects. There are 210 different compounds, of which 17 are the most toxic.

DO	Dissolved oxygen, the gaseous oxygen in solution with water. At low concentrations it may become a limiting factor for the maintenance of aquatic life. It is normally measured in milligrams/litre, and is widely used as a criterion of receiving water quality. The level of dissolved oxygen which can exist in water before the saturation point is reached is primarily controlled by temperature, with lower temperatures allowing for more oxygen to exist in solution. Photosynthetic activity may cause the dissolved oxygen to exist at a level which is higher than this saturation point, whereas respiration may cause it to exist at a level which is lower than this saturation point. At high saturation, fish may contract gas bubble disease, which produces lesions in blood vessels and other tissues and subsequent physiological dysfunctions.
EC*p*	A point estimate of the concentration of test material that causes a specified percentage effective toxicity (sublethal or lethal). In most instances, the EC*p* is statistically derived by analysis of an observed biological response (e.g., incidence of nonviable embryos or reduced hatching success) for various test concentrations after a fixed period of exposure. EC25 is used for the rainbow trout sublethal toxicity test.
Eutrophication	An increase in the biological productivity of an aquatic ecosystem, typically through addition of nutrients.
Fecundity	The number of eggs or offspring produced by a female.
Gonad	A male or female organ producing reproductive cells or gametes (i.e., female ovum, male sperm). The male gonad is the testis, the female gonad is the ovary.
GSI	Gonadosomatic Index. Calculated by expressing gonad weight as a percentage of whole body weight.
Hardness	Total hardness is defined as the sum of the calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre.
IC*p*	A point estimate of the concentration of test material that causes a specified percentage impairment in a quantitative biological test which measures a change in rate, such as reproduction, growth, or respiration.
Intertidal	The area of the marine shoreline that is only covered with water a portion of the time. Three intertidal zones typically are identified: upper (which is out of water most of the time); mid (which is in or out of water roughly equal amounts of time); and lower (which is underwater most of the time). Each zone supports a unique assemblage of biological communities.

LC_{50}	Median lethal concentration. The concentration of a substance that is estimated to kill half of a group of organisms. The duration of exposure must be specified (e.g., 96-hour LC_{50}).
LSI	Liver Somatic Index. Calculated by expressing liver weight as a percent of whole body weight.
Macroinvertebrates	Those invertebrate (without backbone) animals that are visible to the eye and retained by a sieve with 500 µm mesh openings for freshwater, or 1,000 µm mesh openings for marine surveys (EEM methods).
$\delta^{15}N$ (permil)	Ratio of stable nitrogen isotopes ^{15}N and ^{14}N.
Negative control	Material (e.g., water) that is essentially free of contaminants and of any other characteristics that could adversely affect the test organism. It is used to assess the "background response" of the test organism to determine the acceptability of the test using predefined criteria.
Organochlorine	Chlorine that is attached to an organic molecule. The amount present is expressed as the weight of the chlorine. There are thousands of such substances, including some that are manufactured specifically as pesticides because of their toxicity.
Periphyton	A community of algae and heterotrophic (non-photo-synthesizing) microbes attached to submerged substrates, typically in rivers.
pH	A measure of the acid or alkaline nature of water or some other medium. Specifically, pH is the negative logarithm of the hydronium ion (H_30^+) concentration (or more precisely, activity). Practically, pH 7 represents a neutral condition in which the acid hydrogen ions balance the alkaline hydroxide ions. The pH of the water can have an important influence on the toxicity and mobility of chemicals in pulpmill effluents.
Plume	The main pathway for dispersal of effluent within the receiving waters, prior to its complete mixing.
Population	A group of organisms belonging to a particular species or taxon, found within a particular region, territory or sampling unit. A collection of organisms that interbreed and share a bounded segment of space.

Quality Assurance (QA)	Refers to the externally imposed technical and management practices which ensure the generation of quality and defensible data commensurate with the intended use of the data; a set of operating principles that, if strictly followed, will produce data of known defensible quality.
Quality Control (QC)	Specific aspect of quality assurance which refers to the internal techniques used to measure and assess data quality and the remedial actions to be taken when data quality objectives are not realized.
RCA	Reference condition approach. The key to assessing the condition of our waterways through CABIN is the use of the Reference Condition Approach. Reference sites are established based on minimal impacts by human use, and present users with a baseline for assessing potentially impaired sites. The reference sites represent as many different geographic regions and stream sizes as possible and are used to establish the type of community of organisms expected to occur in the range of natural habitat types present in regions covered by the CABIN network. Once the reference condition has been established, sites suspected of being impaired are sampled. Differences between the organisms found at the reference sites and the test-site indicate the extent, if any, of impairment at the site.
Redox Potential (Eh)	In marine sediments, the measurement of reduction and oxidation by testing electron movement and, consequently, available oxygen.
Reference Toxicant	A chemical of quantified toxicity to test organisms, used to gauge the fitness, health, and sensitivity of a batch of test organisms.
Regression (Stepwise)	A parametric statistical technique used to test relationships between a set of independent variables and a dependent variable. Stepwise multiple regression individual independent variables are sequentially added or removed from a model until the best-fitting model is achieved.
Resin Acids	Any of a class of vegetable substances, composed chiefly of esters and ethers of organic acids, that occur as a sticky yellow or brown substance exuded on the bark of various plants and trees, such as the pine and fir.
Salinity	A measure of the quantity of dissolved salts in seawater - in parts per thousand by weight.
SD	Standard deviation.
SE	Standard error.

Secondary Treatment	A stage of purification of a liquid waste in which micro-organisms decompose organic substances in the waste. In the process, the micro-organisms use oxygen. Oxygen usually is supplied by mechanical aeration and/or large surface area of treatment ponds (lagoons). Most secondary treatment also reduces toxicity.
Sentinel Species	A monitoring species selected to be representative of the local receiving environment.
Sloughing	A loss of periphyton biomass related to portions of the periphyton mat becoming unattached from the substrate surface and being carried into the water column.
Stressor	An environmental factor or group of factors eliciting a response by a community.
Sublethal	A concentration or level that would not cause death. An effect that is not directly lethal.
T_4CDD	2,3,7,8-tetrachlorodibenzo-para-dioxin, the most toxic dioxin.
TEQ	Toxic Equivalents.
TN	Total nitrogen.
TOC	Total organic carbon (TOC).
Total-TEQs	TEQs are calculated by multiplying the concentration of each congener with its respective International Toxicity Equivalency Factor (ITEF), to normalize concentrations to the level that would be produced by an equivalent amount of 2,3,7,8-T_4CDD, then summing all the concentrations.
Trophic structure	Sometimes referred to as the food web. The pathways through which energy and nutrients are cycled through biological communities. Trophic levels refer to different levels of producers and consumers in a community (e.g., primary producers, secondary producers, predators, detritivores, etc.).
TS	Total sulphides.
TSS	Total suspended solids (TSS) is a measurement of the oven dry weight of particles of matter suspended in the water which can be filtered through a standard filter paper with pore size of 0.45 micrometres.
Turbidity	Turbidity in water is caused by the presence of matter such as clay, silt, organic matter, plankton, and other microscopic organisms that are held in suspension.
v/v	volume/volume - used to define dilution ratios for two liquids.

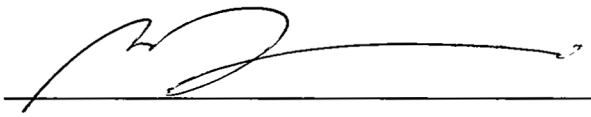
8.0 CLOSURE

We trust the above information meets your requirements. If you have any questions or comments, please contact the undersigned.

HATFIELD CONSULTANTS:

Approved by:  March 30, 2007

Melanie Ptashynski, Project Manager — Date

Approved by:  March 30, 2007

Martin Davies, Project Director — Date

APPENDICES

Appendix A1

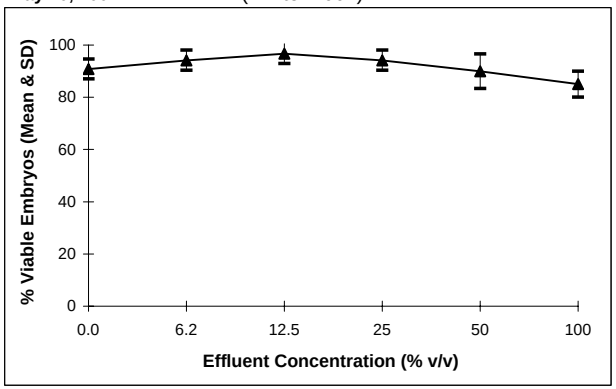
Sublethal Toxicity

Table A1.1 Effluent sublethal toxicity test results, Celgar EEM Cycle Four.

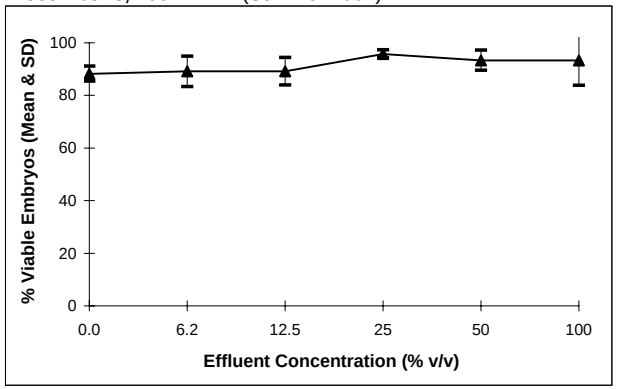
Testing Period	Project Number	Effluent Description (final, cooling, etc.)	Collection Date	Laboratory	Species Tested	Test Type	Flag LC50% > for greater than 100%	LC50 %	LC50 Lower 95% cl	LC50 Upper 95% cl	Flag EC25 or IC25% > for greater than 100%	EC25 or IC25 %	EC25 or IC25 Lower 95% cl	EC25 or IC25 Upper 95% cl	Comments
Winter 2004	pp1121	final	10-May-04	Vizon SciTec Inc.	*Oncorhynchus mykiss*	Survival					>	100			
	pp1121	final	10-May-04	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	10-May-04	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Reproduction					>	100			
	pp1121	final	10-May-04	Vizon SciTec Inc.	*Selenastrum capricornutum*	Growth					>	90.91			Enrichment at 1.091, 3.364, 10, 30, and 90.91% effluent concentrations.
Summer 2004	pp1121	final	06-Dec-04	Vizon SciTec Inc.	*Oncorhynchus mykiss*	Survival					>	100			
	pp1121	final	06-Dec-04	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	06-Dec-04	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Reproduction						62.21	44.88	74.59	
	pp1121	final	06-Dec-04	Vizon SciTec Inc.	*Selenastrum capricornutum*	Growth						52.31	46.46	53.14	
Winter 2005	pp1121	final	02-May-05	Vizon SciTec Inc.	*Oncorhynchus mykiss*	Survival					>	100			
	pp1121	final	02-May-05	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	02-May-05	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Reproduction						70.7	51.7	84.30	
	pp1121	final	02-May-05	Vizon SciTec Inc.	*Selenastrum capricornutum*	Growth					>	90.91			3.363, 10, 30, 90% treatment groups were corrected for hormesis.
Summer 2005	pp1121	final	21-Nov-05	Vizon SciTec Inc.	*Oncorhynchus mykiss*	Survival					>	100			
	pp1121	final	21-Nov-05	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	21-Nov-05	Vizon SciTec Inc.	*Ceriodaphnia dubia*	Reproduction						63.3	47.4	74.20	
	pp1121	final	21-Nov-05	Vizon SciTec Inc.	*Selenastrum capricornutum*	Growth					>	90.91			
Winter 2006	pp1121	final	14-Nov-06	Cantest Inc.	*Oncorhynchus mykiss*	Survival					>	100			retest
	pp1121	final	14-Aug-06	Cantest Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	14-Aug-06	Cantest Inc.	*Ceriodaphnia dubia*	Reproduction						51.3	20.8	59.70	
	pp1121	final	29-May-06	Cantest Inc.	*Selenastrum capricornutum*	Growth					>	90.91			
Summer 2006	pp1121	final	04-Dec-06	Cantest Inc.	*Oncorhynchus mykiss*	Survival					>	100			
	pp1121	final	04-Dec-06	Cantest Inc.	*Ceriodaphnia dubia*	Survival	>	100							
	pp1121	final	04-Dec-06	Cantest Inc.	*Ceriodaphnia dubia*	Reproduction					>	100			
	pp1121	final	04-Dec-06	Cantest Inc.	*Selenastrum capricornutum*	Growth					>	90.91			

Figure A1.1 Mean percent (± 1 standard deviation) viable rainbow trout embryos in test concentrations and controls for effluent sublethal toxicity tests, Celgar EEM Cycle Four.

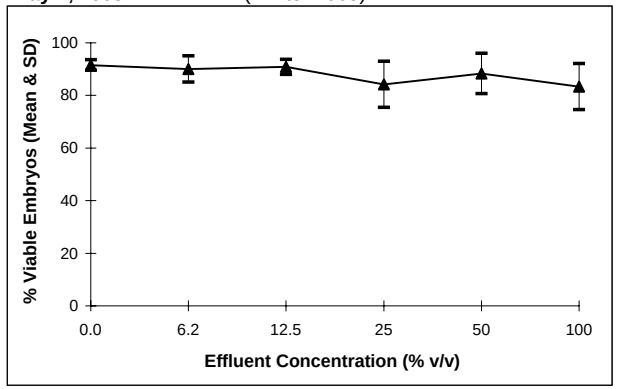
May 10, 2004 (Winter 2004)



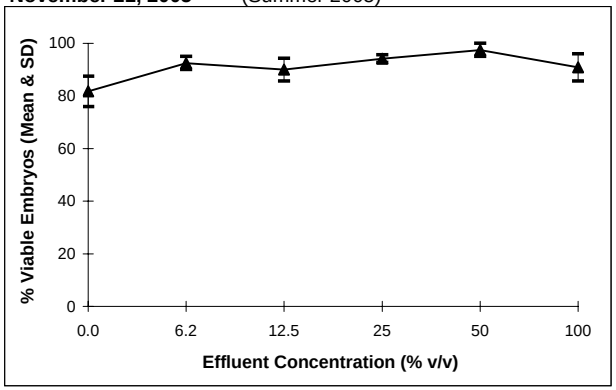
December 8, 2004 (Summer 2004)



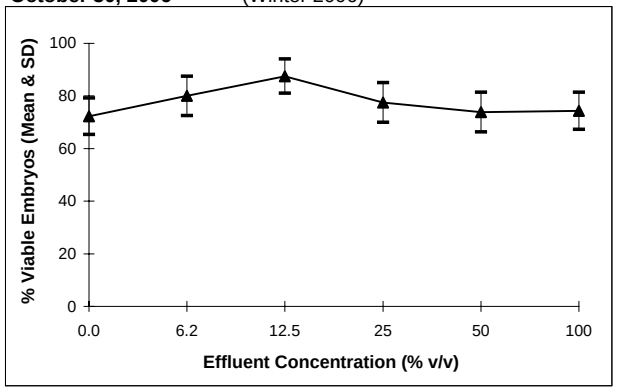
May 2, 2005 (Winter 2005)



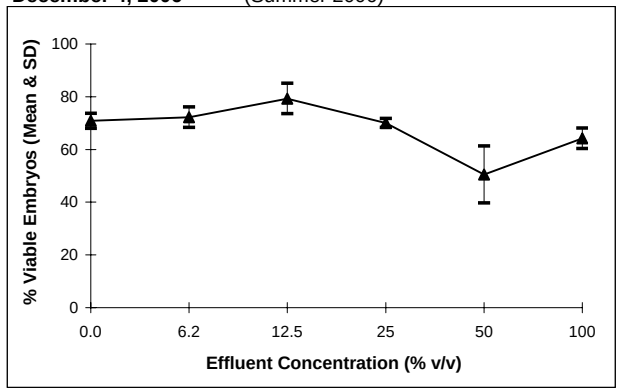
November 21, 2005 (Summer 2005)



October 30, 2006 (Winter 2006)



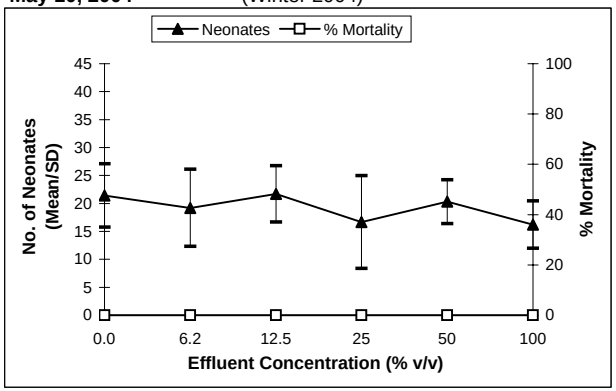
December 4, 2006 (Summer 2006)



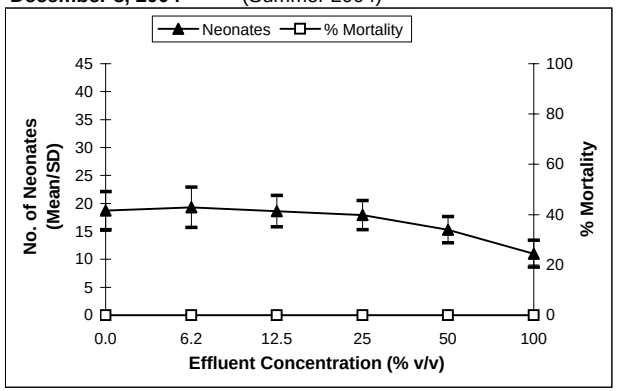
SD = Standard deviation, noted as one SD above and below the mean.

Figure A1.2 Mean percent mortality and number of neonates produced (± standard deviation) by *Ceriodaphnia dubia* exposed to effluent, Celgar EEM Cycle Four.

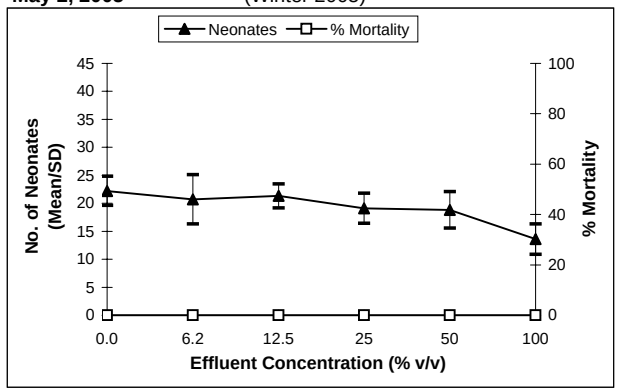
May 10, 2004 (Winter 2004)



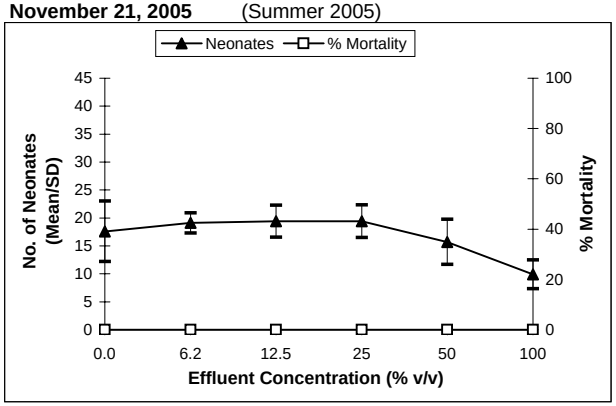
December 8, 2004 (Summer 2004)



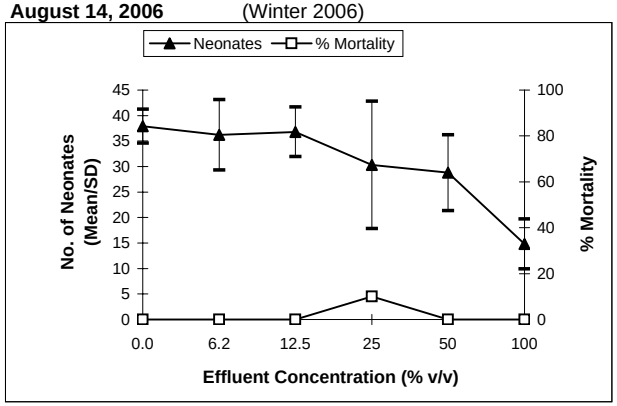
May 2, 2005 (Winter 2005)



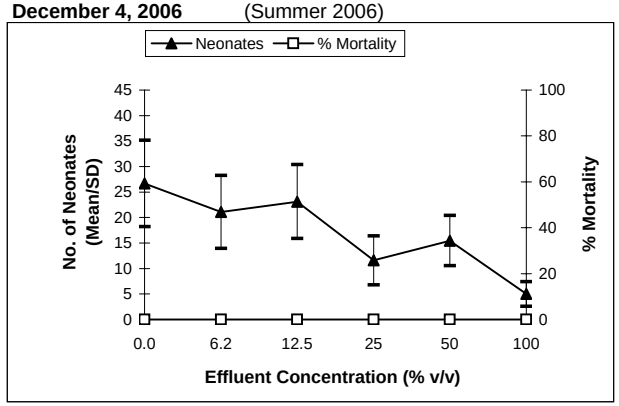
November 21, 2005 (Summer 2005)



August 14, 2006 (Winter 2006)



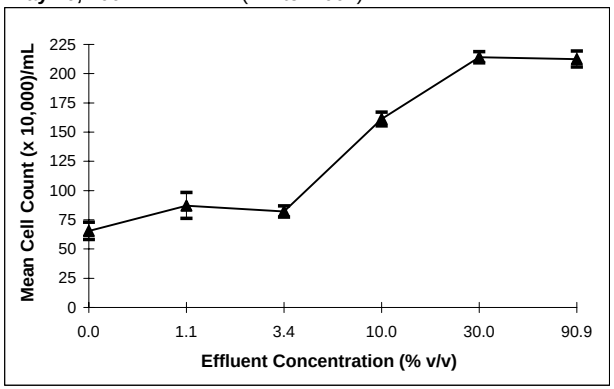
December 4, 2006 (Summer 2006)



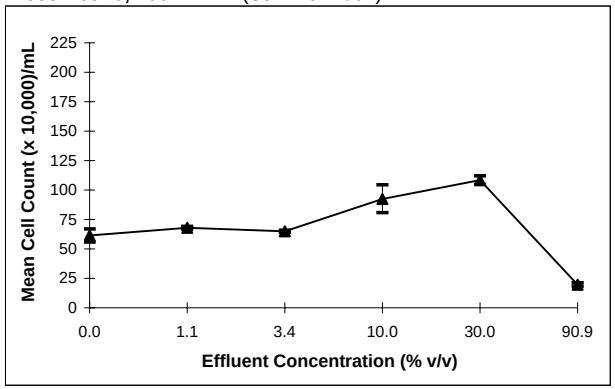
SD = Standard deviation, noted as one SD above and below the mean.

Figure A1.3 Mean cell counts (± standard deviation) of *Selenastrum capricornutum* following exposure to effluent, Celgar EEM Cycle Four.

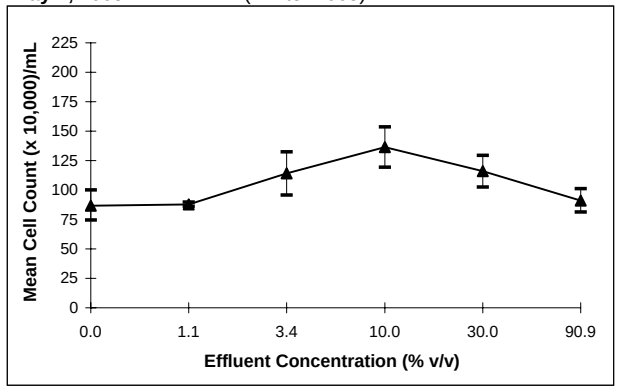
May 10, 2004 (Winter 2004)



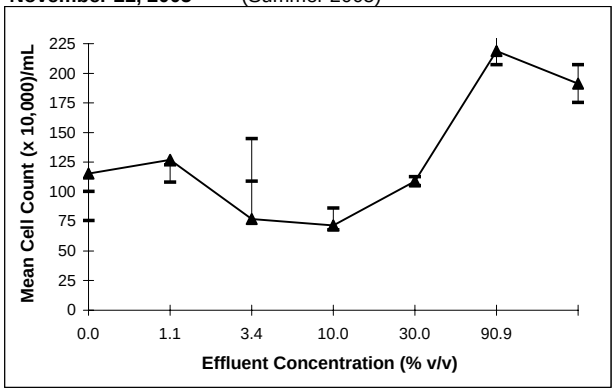
December 9, 2004 (Summer 2004)



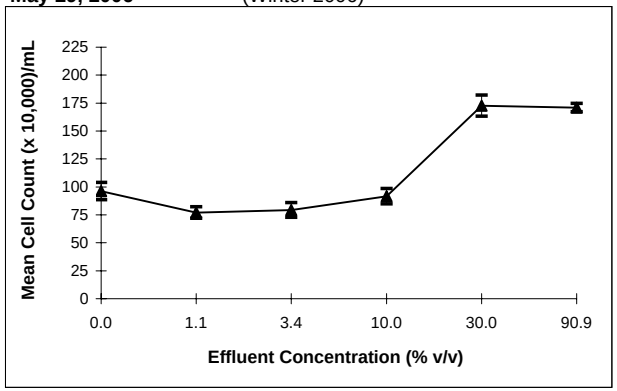
May 2, 2005 (Winter 2005)



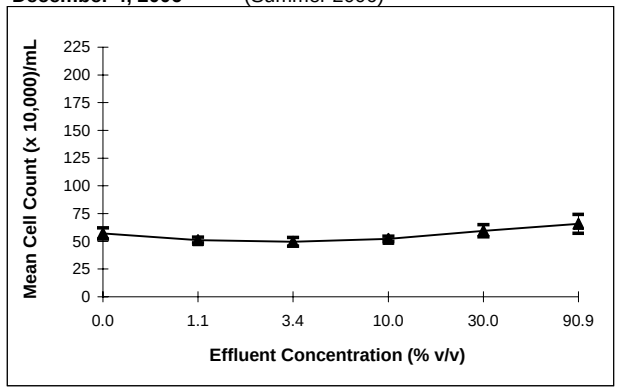
November 21, 2005 (Summer 2005)



May 29, 2006 (Winter 2006)



December 4, 2006 (Summer 2006)



SD = Standard deviation, noted as one SD above and below the mean.

Table A1.2 Calculation of geomeans and potential zones of sublethal effect, Celgar EEM Cycle Four.

	Fish				Invertebrate								Algae			
					Survival				*Reproduction*							
	Cycle 1 IC25	Cycle 2 IC25	Cycle 3 IC25	Cycle 4 IC25	Cycle 1 IC25	Cycle 2 IC25	Cycle 3 IC25	Cycle 4 IC25	Cycle 1 IC25	Cycle 2 IC25	Cycle 3 IC25	Cycle 4 IC25	Cycle 1 IC25	Cycle 2 IC25	Cycle 3 IC25	Cycle 4 IC25
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	34.50	66.80	49.34	100.00	90.90	90.90	58.78	90.91
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	68.00	71.14	46.22	62.21	90.90	90.90	4.85	52.31
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	78.80	79.80	68.88	70.70	90.90	21.97	90.91	90.91
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	19.80	100.00	85.78	63.60	90.90	18.51	18.90	90.91
		100.00	100.00	100.00		100.00	100.00	100.00		100.00	100.00	51.30		90.90	19.35	90.91
			100.00	100.00			100.00	100.00			45.16	100.00			52.47	90.91
			100.00				100.00				45.88				90.91	
			100.00				100.00				28.35				90.91	
Geomean	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	43.74	82.37	54.61	72.36	90.90	49.77	37.73	82.91
SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	7.0	8.5	8.4	0.0	17.3	12.6	6.4
1% Effluent Zone (m) 200	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	4.57	2.43	3.66	2.76	2.20	4.02	5.30	2.41

Appendix A2

Benthic Invertebrate Traditional Survey

Table A2.1 Taxon densities (#/m^2) of benthic invertebrates in replicate subsamples, Celgar EEM Cycle Four.

	CGDB 3-1	CGDB 3-2	CGDB 3-3	CGDB 4-1	CGDB 4-2	CGDB 4-3	CGDB 5-1	CGDB 5-2	CGDB 5-3	CGDB 6-1	CGDB 6-2	CGDB 6-3	CGDB 7-1	CGDB 7-2	CGDB 7-3	CGDB 8-1	CGDB 8-2	CGDB 8-3	CGDB 9-1	CGDB 9-2	CGDB 9-3	CGDB 10-1	CGDB 10-2	CGDB 10-3	CGDB 11-1	CGDB 11-2
Hydridae	320	60	540	6,520	4,184	1,440	703	0	0	0	420	60	604	60	0	1,964	0	1,646	140	220	80	100	1,300	340	80	517
Dugesiidae	320	20	500	280	103	300	0	0	0	0	0	0	121	0	0	220	161	542	20	40	0	680	1,400	1,485	180	1,381
Nematoda indet.	420	20	140	220	348	220	6,123	960	840	404	120	120	20	200	40	761	526	1,285	200	180	200	100	0	0	140	80
Enchytraeidae	480	0	20	0	0	20	522	380	1,088	0	0	0	40	120	0	100	0	100	300	340	240	0	100	0	0	0
Naididae	240	100	80	180	656	320	5,160	860	221	0	200	40	322	440	320	200	464	822	140	640	80	40	40	20	120	852
Lumbricidae	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbriculidae	360	0	60	340	1,066	980	1,245	1,100	424	201	940	360	782	861	601	4,248	2,595	3,453	80	100	20	1,220	1,200	381	0	434
Tubificidae	1,120	480	2,060	3,440	8,365	5,240	4,859	560	1,374	1,614	720	660	784	400	421	22,999	11,731	10,890	200	560	100	6,260	9,200	2,266	17,160	4,478
Erpobdellidae	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	201	0	0	0	100	0	0	100	98
Glossiphoniidae	0	0	20	20	103	20	0	0	0	0	100	0	0	0	0	0	101	0	0	0	0	200	100	241	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	200	0	20	20	197
Lymnaeidae	160	0	40	0	0	20	0	0	0	0	200	0	60	0	0	20	423	0	0	0	0	0	0	0	0	0
Hyrdobiidae	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planorbidae	60	40	60	180	308	40	0	0	20	0	600	0	40	0	321	20	40	301	20	0	0	800	700	201	200	120
Valvatidae	220	80	180	40	0	40	100	0	101	0	260	80	300	501	140	0	203	0	80	40	20	20	100	20	0	394
Unionidae	0	0	0	0	0	0	0	0	0	0	0	40	0	0	100	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae	1,740	80	1,200	780	1,343	960	3,509	240	341	4,237	3,080	1,060	5,145	2,503	3,783	1,521	4,015	1,122	1,700	1,100	1,540	3,240	11,300	3,285	2,740	5,459
Hydrachnidae	220	20	100	260	573	360	160	20	0	0	160	0	0	20	60	721	141	0	20	40	0	40	200	0	100	394
Oribatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,205	0	20	0	0	0	0	0	0
Daphnidae	20	0	0	0	0	0	40	20	0	0	20	0	0	20	0	20	0	0	40	20	0	0	0	120	100	0
Sididae	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0
Calanoida	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	20	0	0	0
Cyclopoida	0	0	0	0	20	0	0	0	0	101	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	100
Harpacticoida	860	0	1,480	840	7,089	9,520	2,969	1,340	820	1,919	740	240	2,257	401	341	601	1,940	100	3,660	3,600	1,860	380	200	4,880	4,900	1,666
Ostracoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Cyprididae	0	0	0	0	0	0	0	0	0	0	0	0	20	0	20	0	0	201	0	0	0	0	0	0	0	0
Asellidae	2,560	40	680	1,480	2,800	2,220	1,506	160	686	4,037	3,560	2,560	7,089	6,849	6,248	5,690	13,767	20,075	380	1,020	180	11,460	31,300	41,749	4,000	18,959
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridae	0	0	0	0	0	0	0	0	0	0	60	0	0	0	80	0	80	0	0	20	0	6,460	9,240	8,983	4,340	0
Hyalellidae	280	60	360	760	793	740	100	40	20	0	0	0	222	0	40	360	1,144	1,544	0	0	0	100	5,700	4,997	200	3,793
Mysidae	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baetidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Lestidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphididae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0
Corixidae	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	100	0	0	0
Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101	0	0	0	0	0	0	100	0	0
Leptoceridae	980	0	400	0	0	140	100	0	20	0	0	0	20	0	0	661	1,600	522	0	20	0	100	620	80	0	886
Limnephilidae	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	0	0	0	60	0	60	140	0	0	0	100	20	20	0	0	761	1,845	1,064	0	0	0	120	200	0	0	0
Simulidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptychopteridae	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	560	180	560	420	430	320	402	120	80	202	180	1,120	1,002	842	1,082	8,194	9,112	8,547	200	800	580	4,300	600	1,361	7,340	9,591
Tanypodinae	60	0	20	0	0	0	40	0	0	0	100	0	20	0	40	40	384	301	0	20	0	20	140	20	0	0
Tanytarsini	860	0	380	100	20	0	301	0	0	0	0	0	0	0	0	220	243	402	80	0	0	0	0	20	0	0
Chironomini	800	160	500	300	616	660	1,606	200	950	201	160	300	180	561	301	2,244	5,009	6,044	520	280	520	640	500	422	40	1,578
Orthocladiinae	40	280	120	260	20	320	1,486	140	342	0	200	80	0	0	40	200	201	100	160	260	80	100	620	0	0	1,181
Phylactolaemata	3,580	0	0	0	0	0	21,285	0	15,888	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophopodidae	340	0	240	600	15,967	0	2,711	0	5,465	1,010	0	4,740	4,234	320	2,520	6,814	0	6,604	40	0	1,280	0	1,900	440	0	0
Total Density	**16,720**	**1,680**	**9,740**	**17,120**	**44,802**	**23,940**	**55,167**	**6,140**	**28,681**	**13,927**	**11,920**	**11,580**	**23,299**	**14,219**	**16,518**	**58,583**	**55,827**	**67,072**	**7,980**	**9,320**	**6,780**	**36,820**	**76,780**	**71,450**	**41,760**	**52,196**
Richness	**26**	**17**	**23**	**22**	**19**	**21**	**23**	**14**	**17**	**10**	**20**	**16**	**22**	**17**	**20**	**23**	**23**	**23**	**19**	**20**	**14**	**25**	**24**	**23**	**17**	**22**

Table A2.1 (Cont'd.)

	CGDB 11-3	CGDB 12-1	CGDB 12-2	CGDB 12-3	CGDB 13-1	CGDB 13-2	CGDB 13-3	CGDB 18-1	CGDB 18-2	CGDB 18-3	CGDB 19-1	CGDB 19-2	CGDB 19-3	CGDB 20-1	CGDB 20-2	CGDB 20-3	CGDB 21-1	CGDB 21-2	CGDB 21-3	CGDB 22-1	CGDB 22-2	CGDB 22-3	CGDB 23-1	CGDB 23-2	CGDB 23-3
Hydridae	195	0	599	6,264	0	0	0	400	204	317	1,100	5,510	1,580	418	20	0	0	0	0	304	94	0	991	193	292
Dugesiidae	1,550	0	797	230	0	0	0	40	0	99	240	846	340	99	0	20	0	0	20	0	0	0	0	0	0
Nematoda indet.	1,167	140	0	0	140	280	100	660	542	557	40	0	180	1,076	200	300	20	0	456	0	0	0	99	0	291
Enchytraeidae	0	120	0	195	20	60	60	20	0	0	100	0	20	239	99	100	20	197	913	0	200	0	99	296	582
Naididae	679	0	0	0	180	40	180	100	80	0	1,800	2,214	740	4,157	596	2,980	120	99	297	202	0	98	298	100	292
Lumbricidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lumbriculidae	293	240	100	0	0	40	0	80	0	20	0	242	320	1,810	99	0	900	3,845	2,355	1,207	0	483	0	200	195
Tubificidae	4,924	40	3,782	0	0	0	20	0	20	40	2,020	1,951	980	3,031	479	2,420	440	1,682	3,794	1,009	683	577	99	0	195
Erpobdellidae	98	0	100	0	0	0	0	0	0	0	0	0	0	0	0	80	0	0	0	0	0	0	0	0	97
Glossiphoniidae	195	100	200	0	120	20	20	0	0	0	600	302	180	99	0	0	80	99	20	0	0	295	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0	0	0	99	0	20	0	0	20	0	0	0	0	0	0
Lymnaeidae	0	0	0	220	0	0	0	0	0	0	0	0	20	200	378	200	20	0	40	100	0	0	99	96	194
Hyrdobiidae	0	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0
Planorbidae	188	0	399	230	0	0	0	0	0	0	2,660	966	140	1,992	60	780	0	0	179	0	0	0	297	0	779
Valvatidae	0	60	0	324	0	0	0	20	0	0	2,060	1,611	1,040	2,090	1,850	1,080	0	0	40	100	100	98	297	100	291
Unionidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeriidae	3,382	1,640	2,888	2,358	220	100	260	1,580	1,418	1,391	2,140	2,453	1,020	358	20	300	420	296	498	4,840	3,326	4,860	3,146	2,742	1,841
Hydrachnidae	98	60	398	295	0	0	0	40	20	139	0	20	60	20	1,374	20	100	99	80	100	100	0	196	0	0
Oribatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daphnidae	0	0	0	0	0	0	0	0	0	0	100	0	40	0	20	0	0	0	0	0	0	0	0	0	0
Sididae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calanoida	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94	0	0	0
Cyclopoida	0	0	0	0	0	0	0	0	0	0	0	0	0	20	20	0	0	0	99	0	188	0	0	0	0
Harpacticoida	1,313	40	3,083	100	60	80	20	620	13,680	297	600	2,440	0	219	0	0	0	0	0	7,894	188	17,574	98	2,899	2,532
Ostracoda	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprididae	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Asellidae	25,549	20	33,803	250	0	0	0	280	346	377	13,240	11,037	2,060	896	0	660	220	395	1,073	4,931	1,453	3,718	2,368	1,082	1,642
Amphipoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridae	683	0	18,004	40	20	0	0	0	0	0	0	0	0	1,315	40	4,160	0	0	0	0	0	0	0	0	0
Hyalellidae	3,133	0	998	0	0	20	0	20	0	0	3,920	2,308	1,180	0	0	0	20	0	119	0	94	0	0	0	0
Mysidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0
Baetidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
Lestidae	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Capniidae	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Aphididae	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trichoptera	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidostomatidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae	191	0	0	514	20	0	0	60	0	0	780	2,700	660	3,561	995	860	240	99	555	0	0	0	0	0	0
Limnephilidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coleoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hymenoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0
Ceratopogonidae	293	0	0	0	40	40	60	20	20	99	0	0	0	60	20	100	20	0	20	0	0	0	0	0	194
Simulidae	0	0	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptychopteridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chironomidae	11,929	180	1,891	1,188	200	220	60	1,480	630	575	700	1,993	220	1,196	1,414	3,200	180	990	537	202	100	1,768	495	686	1,458
Tanypodinae	0	0	0	115	0	0	0	80	102	0	320	20	100	339	40	180	180	0	396	0	100	0	0	0	0
Tanytarsini	0	80	0	0	0	0	0	60	142	0	0	0	40	20	119	0	80	0	0	0	0	0	0	0	0
Chironomini	390	340	100	499	200	140	120	1,640	814	733	3,740	2,559	1,220	1,849	199	2,520	300	889	400	201	301	98	297	196	195
Orthocladiinae	0	120	0	0	40	0	0	560	2,016	259	140	60	160	398	0	200	320	297	40	0	0	0	0	100	0
Phylactolaemata	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lophopodidae	0	0	0	0	20	0	0	0	280	119	100	3,642	0	0	0	0	620	1,389	520	7,669	2,204	0	495	5,013	7,092
Total Density	**56,251**	**3,180**	**67,140**	**13,030**	**1,280**	**1,060**	**900**	**7,780**	**20,314**	**5,022**	**36,560**	**42,874**	**12,340**	**25,564**	**8,064**	**20,180**	**4,320**	**10,376**	**12,471**	**28,758**	**9,133**	**29,663**	**9,374**	**13,804**	**18,163**
Richness	**19**	**14**	**15**	**18**	**13**	**12**	**10**	**20**	**15**	**14**	**24**	**19**	**23**	**25**	**21**	**20**	**20**	**13**	**23**	**13**	**14**	**11**	**15**	**14**	**17**

Table A2.2 Benthic invertebrate statistics (mean, median, SD, SE, minima, maxima) by area, Celgar EEM Cycle Four.

Parameter/Area	n	Mean	Median	SD	SE	Minimum	Maximum
Density (# Organisms/m^2)							
Reference	5	14,754	14,224	10,846	4,851	1,060	27,743
Near-Field; Fibre Mat	5	15,407	11,911	8,046	3,598	9,961	29,224
Near-Field; Outside Fibre Mat	7	29,973	17,737	24,228	9,157	7,420	60,663
Taxa Richness							
Reference	5	27	26	3	1	24	30
Near-Field; Fibre Mat	5	25	23	3	1	23	30
Near-Field; Outside Fibre Mat	7	26	26	5	2	17	32
Evenness							
Reference	5	0.259	0.25	0.100	0.045	0.16	0.42
Near-Field; Fibre Mat	5	0.196	0.21	0.032	0.014	0.15	0.22
Near-Field; Outside Fibre Mat	7	0.274	0.28	0.128	0.048	0.12	0.47
Simpson's Diversity							
Reference	5	0.838	0.836	0.053	0.024	0.789	0.921
Near-Field; Fibre Mat	5	0.787	0.804	0.055	0.025	0.711	0.852
Near-Field; Outside Fibre Mat	7	0.828	0.858	0.067	0.025	0.749	0.912
Bray-Curtis							
Reference	5	0.440	0.494	0.099	0.044	0.302	0.531
Near-Field; Fibre Mat	5	0.544	0.498	0.168	0.075	0.332	0.725
Near-Field; Outside Fibre Mat	7	0.608	0.619	0.147	0.056	0.441	0.828

Table A2.3 Verifications for benthic invertebrate taxonomic analyses, Celgar EEM Cycle Four.

	Species	ID	Comments
	OLIGOCHAETA		
	Naididae		
1	*Chaetognatha diaphanous*	OK	
2	*Dero nivea*	?	no anal gills
3	*Arctonais lomondi*	OK	
4	*Nais bretscheri*	?	no hair setae, but OK otherwise, and doesn't key out to anything without hair setae
5	*Nais variabilis*	OK	
6	*Ophidonais serpentina*	OK	
7	*Pristina aequiseta*	OK	
8	*Slavina appendiculata*	OK	
9	*Specaria josinae*	OK	
10	*Uncinais uncinata*	OK	
11	*Stylaria lacustris*	OK	
	Tubificidae		
12	*Aulodrilus limnobius*	OK	
13	*Aulodrilus pluriseta*	OK	
14	*Stilodrilus heringianus*	OK	
15	*Limnodrilus udekemanius*	OK	
16	*Limnodrilus hoffmesteri*	OK	
17	*Rhyacodrilus coccineus*	OK	
	Lumbriculidae		
18	*Lumbriculus* sp.	OK	
19	*Kincaidiana hexatheca*	OK	
	HIRUDINEA		
20	*Erpobdella punctata*	OK	
	BRYOZOA		
21	*Fredericella indica*	OK	
	MYSIDACEA		
22	*Neomysis mercedis*	No	*Mysis relicta*
	ODONATA		
	Zygoptera		
23	Lestidae	No	Anisoptera *Gomphus olivaceous*
	TRICHOPTERA		
	Limnephilidae		
24	*Ecclisomyia*	No	*Psychoglypha*
	Polycentropodidae		
25	*Polycentropus*	OK	
26	COLEOPTERA		
	Elmidae	OK	

Table A2.4 Benthic invertebrate sub-sampling accuracy for taxonomic analyses, Celgar EEM Cycle Four.

Subsample #	Number Inverts [counted]		Predicted #	Predicted - Actual	% Difference from Actual	Absolute Difference
Sample 1						
1	10		100	15	17.6	17.6
2	13		130	45	52.9	52.9
Total remaining		62				
Total in sample		**85**		**Mean Absolute sub-sampling error (%)**		**35.3**
(actual total count)					**Min % error**	**17.6**
					Max % error	**52.9**
Correction Factor: 10						
Precision between subsamples			**23%**			
Sample 2						
1	25		250	-20	-7.4	7.4
2	29		290	20	7.4	7.4
Total remaining		216				
Total in sample		**270**		**Mean Absolute sub-sampling error (%)**		**7.4**
(actual total count)					**Min % error**	**7.4**
					Max % error	**7.4**
Correction Factor: 10						
Precision between subsamples			**14%**			

Table A2.5 Benthic invertebrate sorting efficiencies for taxonomic analyses, Celgar EEM Cycle Four.

Summary and comments

Re-sorted 5 of 51 samples for a re-sort rate of 9.8%.
Estimated final recovery rate after QA re-sorts: >98%

This table is generated using unextrapolated final count data.

Sorting efficiency calculated only for re-sorted samples.
Calculation for % efficiency: [(total count – spot check and re-sort) / total count] x 100%

Efficiency of all other samples (>98%) estimated based on an average of QA resorts. See (†) note below.

Criterion for passing spot check: 3 or fewer organisms recovered per jar (up to 500 mL of debris).

Sample		Initial Count	# Recovered on spot check	# Recovered on first re-sort	Total Count	% Efficiency after QA
CGDB 3-2	†	85	0	1	86	98.8%
CGDB 8-3	†	1022	0	26	1048	97.5%
CGDB 10-3	†	1862	0	35	1897	98.2%
CGDB 21-1	†	216	0	6	222	97.3%
CGDB 22-3	†	305	0	3	308	99.0%

† Samples passed the spot check but were re-sorted for quality assurance.

Average **98.2%**

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Table A2.6 Physical characteristics of sediments collected form the Columbia River, Celgar EEM Cycle Four.

Stations	Depth (m)	Particle Size (%)				TOC
		Gravel	Sand	Silt	Clay	
Reference Area						
CGBD3	1	0.8	97.1	2.0	0.1	0.12
CGBD4	2.2	0.4	82.2	16.5	0.9	0.25
CGBD5	6.7	0.1	78.1	19.7	2.2	0.58
CGBD18	10	1.1	94.3	3.8	0.8	0.25
CGBD19	6	3.0	86.1	9.8	1.1	0.27
AVERAGE [2]	***5***	***1.1***	***87.6***	***10.4***	***1.0***	***0.29***
SD [1]	*4*	*1.1*	*8.0*	*7.7*	*0.8*	*0.17*
Near-field Fibre Mat Area						
CGBD6	8	0.1	95.2	4.4	0.4	3.76
CGBD7	-	0.1	95.5	3.8	0.7	2.56
CGBD9	5	0.1	98.0	1.5	0.5	0.52
CGBD22	8	0.1	96.7	2.8	0.5	1.75
CGBD23	-	0.1	97.7	1.5	0.8	1.14
AVERAGE [2]	***7***	***0.1***	***96.6***	***2.8***	***0.6***	***1.95***
SD [1]	*2*	*0.0*	*1.3*	*1.3*	*0.2*	*1.26*
Near-field non Fibre Mat Area						
CGBD8	2	0.1	85.5	13.7	0.8	0.31
CGBD10	7	<0.1	71.1	26.8	2.1	1.16
CGBD11	2.5	1.7	87.4	9.4	1.5	1.71
CGBD12	4.5	0.6	96.8	38.5	0.5	0.34
CGBD20	2	6.2	47.4	2.1	7.6	0.46
AVERAGE [2]	***4***	***2.2***	***77.6***	***18.1***	***2.5***	***0.80***
SD [1]	*2*	*2.8*	*19.2*	*14.5*	*2.9*	*0.62*
U/S STP						
CGBD21	2	0.5	93.1	5.5	0.9	0.75
D/S STP						
CGBD13	2.8	<0.1	97.4	2.0	0.6	0.33

[1] Gravel ≥ 2mm; sand=0.063 to 2 mm; silt = 0.004 to 0.063 mm; clay ≤ 0.004 mm.

[2] Negative (-) values are upstream of the diffuser; positive (+) values are downstream.

Table A2.7 Concentrations of dioxins and furans in sediments collected from the Columbia River, Celgar EEM Cycle Four.

CLIENT ID	05CGDB9	05CGDB6	05CGDB7	Lab Blank	Spiked Matrix
AXYS ID	L9753-1	L9753-2	L9753-3	WG21407-101	WG21407-102
WORKGROUP	WG21407	WG21407	WG21407	WG21407	WG21407
Sample Size	14.4 g (dry)	17.4 g (dry)	10.8 g (dry)	10.0 g	
UNITS	pg/g (dry weight basis)	pg/g (dry weight basis)	pg/g (dry weight basis)	pg/g	% Recov
2,3,7,8-TCDD	< 0.0694	0.135	0.219	< 0.100	98.6
1,2,3,7,8-PeCDD	< 0.0694	< 0.0576	< 0.0930	< 0.100	101
1,2,3,4,7,8-HxCDD	< 0.139	< 0.115	< 0.186	< 0.200	103
1,2,3,6,7,8-HxCDD	< 0.139	0.25	0.236	< 0.200	103
1,2,3,7,8,9-HxCDD	< 0.139	< 0.115	< 0.186	< 0.200	106
1,2,3,4,6,7,8-HpCDD	0.358	1.31	1.17	< 0.200	100
OCDD	1.43	6.83	4.87	< 0.500	100
2,3,7,8-TCDF	1.39	12.3	15.3	< 0.100	103
1,2,3,7,8-PeCDF	< 0.0694	0.114	0.136	< 0.100	98.6
2,3,4,7,8-PeCDF	< 0.0694	0.195	0.271	< 0.100	103
1,2,3,4,7,8-HxCDF	< 0.139	< 0.115	< 0.186	< 0.200	102
1,2,3,6,7,8-HxCDF	< 0.139	< 0.115	< 0.186	< 0.200	103
2,3,4,6,7,8-HxCDF	< 0.139	< 0.115	< 0.186	< 0.200	111
1,2,3,7,8,9-HxCDF	< 0.139	< 0.115	< 0.186	< 0.200	120
1,2,3,4,6,7,8-HpCDF	< 0.139	0.258	NDR 0.320	< 0.200	107
1,2,3,4,7,8,9-HpCDF	< 0.139	< 0.115	< 0.186	< 0.200	104
OCDF	< 0.347	0.455	< 0.465	< 0.500	98
Total Tetra-Dioxins	< 0.0694	0.238	0.316	< 0.100	
Total Penta-Dioxins	< 0.0694	< 0.0576	< 0.0930	< 0.100	
Total Hexa-Dioxins	< 0.139	1.25	1.22	< 0.200	
Total Hepta-Dioxins	0.677	2.46	2.2	< 0.200	
Total Tetra-Furans	2.64	26.7	33.9	< 0.100	
Total Penta-Furans	0.093	0.91	0.88	< 0.100	
Total Hexa-Furans	< 0.139	0.377	0.187	< 0.200	
Total Hepta-Furans	< 0.139	0.723	0.375	< 0.200	
TEQ (WHO 1998) ND=0	0.143	1.51	1.93	0	
TEQ (WHO 1998) ND=1/2DL	0.281	1.57	2.03	0.206	
TEQ (WHO 2005) ND=0	0.143	1.47	1.87	0	
TEQ (WHO 2005) ND=1/2DL	0.274	1.53	1.98	0.195	
% Moisture	26.8	41.5	35.3		

Table A2.8 Water quality variables analyzed for the benthic invertebrate survey, Celgar EEM Cycle Four.

Station	pH	Hardness (mg/L)	Sodium (mg/L)	DOC[1] (mg/L)	TOC[1] (mg/L)	TN[1] (mg/L)	NO_3+NO_2[1] (mg/L)	Ammonia (mg/L)	TKN[1] (mg/L)	TP[1] (mg/L)	TDP[1] (mg/L)
Reference Area											
CGBD3	7.83	56	0.878	0.82	1.05	0.134	0.078	<0.005	0.06	<0.0020	<0.002
CGBD19	8.01	55	0.472	0.84	1.06	0.169	0.086	<0.005	0.08	0.0077	<0.002
CGBD18	7.99	55	1.120	0.85	0.99	0.147	0.089	<0.005	0.06	<0.0020	<0.002
CGBD5	8.04	54	0.466	0.81	0.92	0.178	0.091	<0.005	0.09	0.0087	<0.002
CGBD4	10.16	55	1.120	0.95	0.93	0.172	0.079	<0.005	0.09	0.0021	<0.002
AVERAGE[2]	***8.41***	***55***	***0.811***	***0.85***	***0.99***	***0.160***	***0.084***	***<0.005***	***0.08***	***0.0045***	***<0.002***
SD[1]	*0.98*	*1*	*0.328*	*0.06*	*0.07*	*0.019*	*0.006*	*0.000*	*0.02*	*0.0034*	*0.000*
Near-field-FM											
CGBD6	8.04	55	1.040	1.02	1.11	0.139	0.078	<0.005	0.06	0.0024	<0.002
CGBD22	8.04	56	1.060	0.95	1.10	0.139	0.079	<0.005	0.06	<0.002	<0.002
CGBD7	8.09	56	0.621	0.83	0.96	0.142	0.081	<0.005	0.06	<0.002	<0.002
CGBD23	8.04	54	0.808	0.85	0.99	0.080	0.081	<0.005	0.05	<0.002	<0.002
CGBD9	8.02	54	0.822	0.98	0.98	0.139	0.080	0.006	0.06	<0.0026	<0.002
AVERAGE[2]	***8.05***	***55***	***0.870***	***0.93***	***1.03***	***0.128***	***0.080***	***<0.005***	***0.06***	***0.0022***	***<0.002***
SD[1]	*0.03*	*0.81*	*0.182*	*0.08*	*0.07*	*0.027*	*0.001*	*0.000*	*0.00*	*0.00028*	*0.000*
Near-field-nonFM											
CGBD8	8.04	54	0.457	0.79	1.02	0.146	0.085	<0.005	0.06	<0.002	<0.002
CGBD10	8.06	55	0.541	0.80	0.87	0.156	0.081	<0.005	0.08	<0.002	<0.002
CGBD11	8.04	56	0.899	0.86	1.03	0.156	0.079	<0.005	0.08	<0.002	<0.002
CGBD20	8.07	56	0.851	0.87	1.01	0.145	0.077	<0.005	0.07	<0.002	<0.002
CGBD12	8.04	56	0.535	0.83	0.89	0.145	0.081	<0.005	0.06	<0.002	<0.002
AVERAGE[2]	***8.1***	***55***	***0.657***	***0.83***	***0.96***	***0.150***	***0.081***	***<0.005***	***0.07***	***<0.002***	***<0.002***
SD[1]	*0.01*	*0.89*	*0.203*	*0.04*	*0.08*	*0.006*	*0.003*	*0.000*	*0.01*	*0*	*0.000*
U/S STP											
CGBD21	7.99	47.50	0.824	0.88	1.01	0.059	0.059	<0.005	0.05	<0.002	<0.002
D/S STP											
CGBD13	8.06	54.90	0.625	0.81	0.97	*0.131*	0.078	0.006	*0.05*	<0.002	<0.002
Effluent	na	157	241.000	46.30	56.40	0.900	0.072	0.072	0.88	0.549	0.311

[1] DOC - dissolved organic carbon; TOC = total organic carbon; N+N = nitrite plus nitrate; TKN = total Kjeldahl nitrogen; O-Ph = orthophosphate; TDP = total dissolved phosphorus; T. Phos. = total phosphorus; SD = standard deviation.

[2] One half of the detection limit used for calculations of means where non-detect was recorded.

[3] na = not applicable; ns = no sample.

Table A2.9 ***In situ*** **water quality variables measured in the field during the benthic invertebrate survey; Celgar EEM Cycle Four.**

Station	DO[1] (mg/L)	DO (% saturation)	Temp.[1] (°C)	pH	Surface Cond.[2] (µS/cm)	Bottom Cond.[2] (µS/cm)
Reference Area						
CGBD3	10.07	97.7	14.0	7.83	105	105
CGBD19	10.18	98.1	13.7	8.01	105	105
CGBD18	10.29	99.0	13.8	7.99	105	105
CGBD5	10.19	98.2	13.7	8.04	105	105
CGBD4	10.16	98.6	13.96	7.5	105	105
AVERAGE[2]	***10.18***	***98.3***	***13.8***	***7.87***	***105***	***105***
SD[1]	*0.08*	*0.5*	*0.14*	*0.22*	*0.0*	*0*
Near-field-FM						
CGBD6	10.61	100.0	12.9	8.04	109	108
CGBD22	10.17	96.2	12.5	8.04	109	108
CGBD7	10.49	98.3	12.8	8.09	106	107
CGBD23	10.12	95.8	12.9	8.04	106	107
CGBD9	10.20	96.0	12.9	8.02	107	na
AVERAGE	***10.32***	***97.3***	***12.8***	***8.05***	***107***	***108***
SD[1]	*0.22*	*1.8*	*0.17*	*0.03*	*1.5*	*0.58*
Near-field-nonFM						
CGBD8	10.37	100.0	13.7	8.04	106	105
CGBD10	10.16	96.2	12.9	8.06	105	na
CGBD11	10.23	96.9	13.1	8.04	107	na
CGBD20	10.17	96.7	13.1	8.07	107	107
CGBD12	8.04	96.2	13.1	8.04	105	na
AVERAGE	***9.79***	***97.2***	***13.2***	***8.1***	***106***	***106***
SD[1]	*0.98*	*1.6*	*0.32*	*0.01*	*1.0*	*1.41*
U/S STP						
CGBD21	10.07	94.8	12.34	7.99	102	60
D/S STP						
CGBD13	10.31	97.6	13.26	8.06	105	105

[1] DO = dissolved oxygen; Temp = temperature; Cond. = conductivity; SD = standard deviation.

[2] Surface/Depth. All other measurement from surface sampling.

Appendix A3

Stable Isotope Surveys

SINLAB INTERPRETATION GUIDE

Methodology

Samples in the SINLAB are analyzed for $\delta^{13}C$ and $\delta^{15}N$ using either a Thermo-Finnigan Delta Plus or Delta XP isotope-ratio mass spectrometer (Bremen, Germany) interfaced with a Carlo Erba NC2500 Elemental Analyzer (Milan, Italy) via the Conflo II or Conflo III, respectively. This is a continuous flow system using helium as a carrier gas. Samples are weighed into tin capsules, loaded into an AS128 autosampler and converted to a gaseous state via combustion.

Combustion occurs in a quartz tube filled with chromium oxide and silver cobaltous at a temperature of 1050^0C. A second quartz tube set at 780^0C is filled with copper and used for the reduction of nitrogen oxide to N2. CO_2 and N_2 peaks are separated while passing through a standard 2m GC column. A water trap of magnesium perchlorate & silica chips is located just prior to the GC column to remove water and other impurities.

Carbon and nitrogen data for animal tissues are corrected with three standards – NICOTINAMIDE, BLS, and SMB-M (See standards section below). Data for sediments and plant material are corrected with IAEA standards CH6, CH7, N1 and N2. All of these standards are calibrated against Peedee Belemnite carbonate (PDB) and atmospheric nitrogen (AIR) for carbon and nitrogen, respectively. Data are provided to clients in the form of an excel spreadsheet via email. Hard copies of the data may be obtained by request.

Column Headings

SINLAB ID = ID code assigned to the client's samples; each client is given (typically) a three letter identifier and samples numbered sequentially (starting at 001).
Date = date sample was analyzed in the lab
Position = position in the analytical "run" for that particular day; samples are weighed into 96-well ELISA trays, so a normal animal tissue run will consist of 73 client samples, 22 standards, and 1 blank
Weight = weight of the tissue analyzed; animal tissues are weighed at 0.200 ± 0.020 milligrams and plant tissues are weighed at 1.000 ± 0.200 milligrams.
CO2 amp = the amount of CO_2 gas measured on the mass spectrometer, a function of the weight of tissue used and the amount of carbon (%C) it contains
N2 amp = the amount of N_2 gas measured on the mass spectrometer, a function of the weight of tissue used and the amount of nitrogen (%N) it contains
$\boldsymbol{\delta^{13}C}$ = ratio of carbon-13 to carbon-12 in the sample according to the formula: $\delta^{13}C = [(R_{sample}/R_{standard})-1]*1000$ where R is $^{13}C/^{12}C$ and the standard is PDB (see above)
$\boldsymbol{\delta^{15}N}$ = ratio of nitrogen-15 to nitrogen-14 in the sample according to the formula: $\delta^{15}N = [(R_{sample}/R_{standard})-1]*1000$ where R is $^{15}N/^{14}N$ and the standard is AIR (see above)
%C = percent of the sample that is carbon by weight; e.g. 200 ug sample with 40% carbon has 80 ug carbon by weight
%N = percent of the sample that is nitrogen by weight; e.g. 200 ug sample with 10% nitrogen has 20 ug carbon by weight
C/N = Ratio of carbon to nitrogen in the sample; simple division of %C by %N

Standards

CH6 = sucrose standard issued by the International Atomic Energy Agency ($\delta^{13}C$ = -10.4‰)*
CH7 = polyethylene foil standard issued by the International Atomic Energy Agency ($\delta^{13}C$ = -31.8‰)*
N1 = ammonium sulfate standard issued by the International Atomic Energy Agency ($\delta^{15}N$ = 0.4‰)*
N2 = ammonium sulfate standard issued by the International Atomic Energy Agency ($\delta^{15}N$ = 20.3‰)*
ACETANILIDE = commercially available pure compound ($\delta^{13}C$ = -33.2‰, $\delta^{15}N$ = -1.1‰)
NICOTINAMIDE = commercially available pure compound ($\delta^{13}C$ = -34.2‰, $\delta^{15}N$ = -1.8‰)
BLS = bovine liver standard – developed by SINLAB ($\delta^{13}C$ = -18.7‰, $\delta^{15}N$ = 7.3‰)
SMB-M = smallmouth bass muscle – developed by SINLAB ($\delta^{13}C$ = -23.3‰, $\delta^{15}N$ = 12.4‰)
NIST 1547 = peach leaves ($\delta^{13}C$ = -25.7‰, $\delta^{15}N$ = 1.9‰)
NIST 8438 = wheat flour ($\delta^{13}C$ = -25.7‰, $\delta^{15}N$ = 4.4‰)
NIST 2711 = Montana soil ($\delta^{13}C$ = -17.1‰, $\delta^{15}N$ = 7.4‰)

Note: Isotope ratios for standards marked with asterisks (*) are those that are internationally accepted; others are values for the current batch measured by SINLAB.

Comment Codes

NR = no repeat; sample tissue volume too small to allow another analysis
Low amps = low amount of gas entering the mass spectrometer; normally isotope data generated with a sample that yields a value below 0.5 volts should be interpreted with caution
2nd N2 peak = likely a result of CO presence; client should consider repeating sample
Didn't drop = equipment malfunction wherein autosampler fails to turn; often leads to a "double-up" with the following sample
Double-up = two samples drop together
Drift = electronic phenomenon whereby isotope ratios shift slowly through time; this can be corrected for by using standards throughout the run
Lipid-rich = sample appeared to be oily when being weighed
Sample sticking out = material sticking out from edges of tin cup; common with feather samples
Whole bug = individual analyzed without grinding
Half bug = half of individual analyzed without grinding, normally cut in half along longitudinal plane
Double cup = two tin cups stuck together; can potentially cause interference with isotope ratio measurement
Large tin cup = necessary when sample is low in %C or %N and more tissue is required to obtain data
Max out = too much CO_2 or N_2 entering the mass spectrometer, beyond the capacity to measure; no data provided
Reduction tube chemicals = chemicals nearing exhaustion (typically changed every 500 samples); interpret data with caution
Spike = electronic malfunction that causes delta value to deviate dramatically from normal; no data provided
1/4, 1/8, 1/16, 1/32 = indicates the size of a filter paper sample that was cut into a "pie-slice" for analysis
Scraped from paper = filtered tissue was scraped from the top of filter rather than analyzed as a "pie slice"
Poor repeat = a delta value that is considerably different than when the sample was run previously; normally values within 0.5‰ are considered adequate, however certain tissue types (e.g. fish muscle) will give better repeats than others (e.g. fin clips, pooled invertebrates) due to differences in sample homogeneity

Reintegrated = sample peak wide or distorted, requiring manual adjustment; interpret data with caution
Lipid extraction = common technique to remove lipids (that have different $\delta^{13}C$ than proteins and carbohydrates) from tissues such as liver, eggs, and muscle of some marine fishes
Acid treatment = common technique to remove non-dietary carbonates (that have different $\delta^{13}C$ than organic tissue) from organisms such as shellfish

Colours

Gray shading = repeated sample as part of regular QA/QC routine (four of every 73 samples) – same day – or because problems suspected with data – different days
Red text = highlights low amps or a poor repeat (see above for definitions)

Questions about this document

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CANADIAN RIVERS INSTITUTE

SINLAB
Stable Isotopes in Nature Laboratory

Table A3.1 Results from carbon and nitrogen stable isotope analyses of sediments, fish, and mill ans STP effluent.

Project	Media	SampleID	SINLAB ID	DATE	Line	Amount	CO_2 Ampl	N_2 Ampl
CG 1140	sediment	CGDB19	HAT 089	17-Mar-06	36	10.02	0.611	0.244
CG 1140	sediment	CGDB3	HAT 078	17-Mar-06	20	10.427	0.271	0.080
CG 1140	sediment	CGDB18	HAT 088	17-Mar-06	35	10.286	0.305	0.120
CG 1140	sediment	CGDB4	HAT 079	17-Mar-06	21	10.234	0.512	0.153
CG 1140	sediment	CGDB5	HAT 080	17-Mar-06	22	10.103	0.968	0.262
CG 1140	sediment	CGDB6	HAT 081	17-Mar-06	23	10.264	0.978	0.131
CG 1140	sediment	CGDB23	HAT 092	17-Mar-06	39	10.316	0.443	0.104
CG 1140	sediment	CGDB8	HAT 082 R	17-Mar-06	40	10.527	0.858	0.203
CG 1140	sediment	CGDB9	HAT 083	17-Mar-06	30	10.303	0.341	0.085
CG 1140	sediment	CGDB10	HAT 084	17-Mar-06	31	10.199	1.757	0.568
CG 1140	sediment	CGDB11	HAT 085	17-Mar-06	32	10.032	1.200	0.349
CG 1140	sediment	CGDB20	HAT 090	17-Mar-06	37	10.112	1.166	0.292
CG 1140	sediment	CGDB12	HAT 086	17-Mar-06	33	10.234	0.306	0.105
CG 1140	sediment	CGDB21	HAT 091	17-Mar-06	38	10.087	1.300	0.258
CG 1140	sediment	CGDB13	HAT 087	17-Mar-06	34	10.011	0.230	0.094
CG 1140	fish	PV d/s	HAT 093	9-Mar-06	7	0.214	1.653	1.457
CG 1140	fish	PV d/s	HAT 093 (R)	9-Mar-06	24	0.189	1.463	1.252
CG 1140	fish	PV d/s	HAT 094	9-Mar-06	8	0.214	1.469	1.486
CG 1140	fish	PV d/s	HAT 095	9-Mar-06	9	0.205	1.601	1.495
CG 1140	fish	PV d/s	HAT 096	9-Mar-06	10	0.196	1.431	1.338
CG 1140	fish	PV d/s	HAT 097	9-Mar-06	11	0.220	1.588	1.545
CG 1140	fish	P Ref	HAT 098	9-Mar-06	12	0.189	1.323	1.108
CG 1140	fish	P Ref	HAT 098 (R)	9-Mar-06	23	0.206	1.601	1.422
CG 1140	fish	P Ref	HAT 099	9-Mar-06	13	0.208	1.709	1.399
CG 1140	fish	P Ref	HAT 100	9-Mar-06	14	0.195	1.477	1.199
CG 1140	fish	P Ref	HAT 101	9-Mar-06	15	0.225	1.763	1.733
CG 1140	fish	P Ref	HAT 102	9-Mar-06	16	0.206	1.589	1.499
CG 1140	effluent	Filter samples 1A	HAT 103	17-Mar-06	41	na	15.306	3.511
CG 1140	effluent	Filter samples 1B	HAT 104	17-Mar-06	45	na	3.076	0.669
CG 1140	effluent	Filter samples 1C	HAT 105	17-Mar-06	53	na	8.162	1.816
CG 1140	effluent	Filter samples 4A	HAT 112	17-Mar-06	44	na	5.210	1.204
CG 1140	effluent	Filter samples 4B	HAT 113	17-Mar-06	48	na	5.574	1.337
CG 1140	effluent	Filter samples 4C	HAT 114	17-Mar-06	56	na	8.880	2.203
CG 1140	effluent	Filter samples 3A	HAT 109	17-Mar-06	43	na	5.100	0.776
CG 1140	effluent	Filter samples 3B	HAT 110	17-Mar-06	47	na	4.871	0.498
CG 1140	effluent	Filter samples 3C	HAT 111	17-Mar-06	55	na	2.232	0.429
CG 1140	effluent	Filter samples 2A	HAT 106	17-Mar-06	42	na	4.003	2.015
CG 1140	effluent	Filter samples 2B	HAT 107	17-Mar-06	46	na	2.928	1.326
CG 1140	effluent	Filter samples 2C	HAT 108	17-Mar-06	54	na	2.994	1.495

Table A3.2 Results from carbon and nitrogen stable isotope analyses of benthic invertebrates.

Station ID	SAMPLE TYPE	SINLAB ID	Date	Line	Amount	corr d13C	d15N
CGBD19	- limnodrilus	MSKI 004	17-Jan-07	10	0.195	-21.89	3.26
CGBD3	- limnodrilus				0.204	-21.17	2.66
CGBD18	- limnodrilus	MSKI 007	17-Jan-07	13	**0.049**	-25.36	4.27
CGBD4	- limnodrilus	MSKI 013	17-Jan-07	19	0.197	-20.76	3.67
CGBD5	- limnodrilus	MSKI 010	17-Jan-07	16	0.197	-21.85	3.06
CGBD6	- limnodrilus	MSKI 016	17-Jan-07	22	0.197	-28.86	2.31
CGBD22	- limnodrilus	MSKI 019	17-Jan-07	30	0.207	-25.99	2.48
CGBD7	- limnodrilus	MSKI 022	17-Jan-07	33	0.198	-25.97	2.04
CGDB23							
CGBD9	- limnodrilus	MSKI 027	17-Jan-07	38	0.206	-22.43	1.64
CGBD8	- limnodrilus	MSKI 030	17-Jan-07	41	0.206	-20.66	3.01
CGBD10	- limnodrilus	MSKI 033	17-Jan-07	44	0.193	-21.16	3.03
CGBD11	- limnodrilus	MSKI 036	17-Jan-07	47	0.198	-21.83	1.91
CGBD20	- limnodrilus	MSKI 039	17-Jan-07	55	0.201	-19.52	2.59
CGBD12	- limnodrilus	MSKI 042	17-Jan-07	58	0.226	-24.18	3.85
CGBD21	- limnodrilus	MSKI 045	17-Jan-07	61	0.198	-23.58	3.13
CGBD13	- limnodrilus	MSKI 048	17-Jan-07	64	**0.028**	-22.77	2.93
CGBD19	- pisidium	MSKI 005	17-Jan-07	11	0.202	-22.47	2.02
CGBD3	- pisidium	MSKI 002	17-Jan-07	8	0.189	-21.30	2.68
CGBD18	- pisidium	MSKI 008	17-Jan-07	14	0.225	-26.77	2.12
CGBD4	- pisidium	MSKI 014	17-Jan-07	20	0.213	-23.67	2.29
CGBD5	- pisidium	MSKI 011	17-Jan-07	17	0.216	-26.62	1.76
CGBD6	- pisidium	MSKI 017	17-Jan-07	23	0.218	-30.50	2.03
CGBD22	- pisidium	MSKI 020	17-Jan-07	31	0.207	-25.54	2.43
CGBD7	- pisidium	MSKI 023	17-Jan-07	34	0.189	-28.14	3.40
CGBD23	- pisidium	MSKI 025	17-Jan-07	36	0.222	-28.47	1.77
CGBD9	- pisidium	MSKI 028	17-Jan-07	39	0.214	-27.08	1.65
CGBD8	- pisidium	MSKI 031	17-Jan-07	42	0.190	-21.76	2.10
CGBD10	- pisidium	MSKI 034	17-Jan-07	69	0.211	-24.71	0.91
CGBD11	- pisidium	MSKI 037	17-Jan-07	53	0.207	-23.10	1.40
CGBD20	- pisidium				0.192	-19.56	1.02
CGBD12	- pisidium	MSKI 043	17-Jan-07	59	0.209	-26.12	2.01
CGBD21	- pisidium	MSKI 046	17-Jan-07	62	0.192	-24.27	2.30
CGBD13	- pisidium	MSKI 049	17-Jan-07	65	0.227	-20.26	2.17
CGBD19	- caecidotea	MSKI 006	17-Jan-07	12	0.217	-21.17	2.93
CGBD3	- caecidotea	MSKI 003	17-Jan-07	9	0.222	-19.08	3.39
CGBD18	- caecidotea	MSKI 009	17-Jan-07	15	0.201	-22.60	3.64
CGBD4	- caecidotea	MSKI 015	17-Jan-07	21	0.203	-19.80	3.40
CGBD5	- caecidotea	MSKI 012	17-Jan-07	18	0.212	-21.55	3.90
CGBD6	- caecidotea				0.200	-29.16	3.27
CGBD22	- caecidotea	MSKI 021	17-Jan-07	32	0.204	-27.67	3.60
CGBD7	- caecidotea	MSKI 024	17-Jan-07	35	0.193	-26.96	3.66
CGBD23	- caecidotea	MSKI 026	17-Jan-07	37	0.189	-26.31	4.26
CGBD9	- caecidotea	MSKI 029	17-Jan-07	40	0.192	-26.86	3.84
CGBD8	- caecidotea	MSKI 032	17-Jan-07	43	0.189	-19.62	2.80
CGBD10	- caecidotea				0.215	-21.79	1.97
CGBD11	- caecidotea				0.201	-21.46	1.89
CGBD20	- caecidotea	MSKI 041	17-Jan-07	57	0.216	-17.65	2.58
CGBD12	- caecidotea	MSKI 044	17-Jan-07	60	0.201	-24.56	2.99
CGBD21	- caecidotea	MSKI 047	17-Jan-07	63	0.222	-21.59	3.23
CGBD13							