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Powell River Environmental Effects Monitoring (EEM) Cycle Seven Interpretive Report

March 2016

Prepared for:

Catalyst Paper Corporation
Powell River, BC

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POWELL RIVER

ENVIRONMENTAL EFFECTS MONITORING CYCLE SEVEN INTERPRETIVE REPORT

Prepared for:

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LIST OF ACRONYMS

ADt	air-dried tonnes
AOX	adsorbable organic halides
BOD	biochemical oxygen demand
C	Celsius
cm	centimetre
CTMP	chemi-thermomechanical pulp
d	day
EEM	Environmental Effects Monitoring
EPA	Environmental Protection Agency
g	gram
IC25	effluent concentration causing 25% inhibition of a biological function
kg	kilogram
km	kilometre
L	litre
LC50	effluent concentration causing 50% mortality of test organisms
m	metre
µg	microgram
mg	milligram
pg	picogram
ppb	parts per billion
PPER	Pulp and Paper Effluent Regulations
ppm	parts per million
s	second
t	tonne
TMP	thermomechanical pulp
TSS	total suspended solids
v/v	volume/volume
yr	year

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- Ms. Janice Boyd of Environment Canada; and
- Ms. Sarah Barkowski of Catalyst Paper Corporation.

Contributors to this EEM program at Hatfield included Mr. Colin Schwindt, Mr. Martin Davies, Mr. John Wilcockson, Ms. Betty Rebellato, and Ms. Susan Stanley.

EXECUTIVE SUMMARY

The Cycle Seven Environmental Effects Monitoring (EEM) program for Catalyst Paper Ltd., Powell River Division, extended from May 2013 to April 2016, and included studies of the sublethal toxicity of effluent, and a benthic invertebrate community survey, including associated sediment and water quality assessments. Because effluent is diluted to 1% concentrations within 250 m of the outfall, the mill was exempt from fish population surveys in Cycle Seven, as per the Pulp and Paper Effluent Regulations. The mill was also exempt from a fish-tissue survey due to low or non-detectable concentrations of dioxins/furans previously measured in fish tissue and mill effluent, respectively.

Sublethal toxicity testing was undertaken six times between 2013 and 2015 for the Powell River pulpmill. Results showed variability in sublethal response over Cycle Seven, with average effects of effluent of 5.5% on algal reproduction and 35.4% on echinoderm reproduction. Due the rapid diffusion of effluent discharge from the multi-port diffuser installed at the Power River Pulpmill, the potential for sublethal effects of effluent extends only to the immediate vicinity of the outfall, to a maximum extent of 21.8 m from the effluent diffuser.

Similar to Cycle Five, the Cycle Seven benthic invertebrate survey was conducted in the vicinity of the Powell River pulpmill in March 2015 using a gradient survey design consisting of 13 stations located northwest and southeast of the mill diffuser. Two samples were collected from each station to assess benthic invertebrate communities and sediment chemistry with a third collected for sediment composition and chlorinated phenolic compounds. Adult invertebrate data were used for statistical analysis and evaluation of impacts for five key effects endpoints as well as describing community composition.

Benthic invertebrate communities exhibited differences in taxa richness, evenness and Simpson's diversity along a gradient of effluent exposures that were statistically significant but not biologically significant based on EEM guidance. Taxa richness and evenness generally increased with distance from the diffuser, while evenness and Simpson's diversity generally decreased. Similar community composition (calculated as Bray-Curtis index) was observed along exposure gradients. Continued improvements in sediment conditions near the diffuser (i.e., declining organic content and increasing oxidative state) likely contributed to the reduction in the magnitude of observed effects.

While an overall improvement in the condition of sediments is evident from Cycle One to Cycle Seven, sediments closest to the diffuser and within Cycle Three near-field area continue to exhibit a mild organic enrichment relative to far-field stations, although no longer exhibit anoxic conditions. Given large improvements in effluent quality, in terms of significant decreases in discharged volumes of biological oxygen demand and suspended solids, and the consistent declines in organic content of sediments over time, the cause of the mild enrichment is clearly historical.

DISTRIBUTION LIST

The following individuals/firms have received this document:

Name	Firm	Hardcopies	CDs	Email
Sarah Barkowski	Catalyst Paper, Powell River Division	3	#	✓
Janice Boyd	Environment Canada	1	#	✓

AMENDMENT RECORD

This report has been issued and amended as follows:

Issue	Description	Date	Approved by	
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2	Final version of Powell River – Environmental Effects Monitoring Cycle Seven Interpretive Draft Report	20160317	Martin Davies Project Director	Colin Schwindt Project Manager

1.0 INTRODUCTION

Pulpmills in Canada are required by the *Pulp and Paper Effluent Regulations* (PPER) under the federal *Fisheries Act* to conduct Environmental Effects Monitoring (EEM) studies on a regular basis. EEM studies are typically conducted in three-year cycles, each of which includes a study design phase, study implementation, data analysis, and reporting. The required components of an EEM study typically include:

- Sublethal toxicity testing of effluent, to examine the effect of chemicals or chemical mixtures on the reproduction and growth of representative aquatic organisms;
- A biological monitoring program, to assess the potential effects of effluent on fish populations, benthic invertebrate communities, and fish tissue in the receiving environment; and
- Water and sediment quality measurements, to support interpretation of biological monitoring results.

Effluent sublethal toxicity testing is conducted twice per year for mills that discharge effluent over a period of more than 120 days. The fish population and benthic invertebrate surveys and supporting environmental measurements are conducted once per cycle, or once every two cycles (i.e., once every six years) if no effects in these components have been observed in the two most recent EEM cycles. In addition, a mill is exempt from a fish survey and a benthic invertebrate community survey if the concentration of effluent in the exposure area is 1% or less within 250 m or 100 m, respectively, of the effluent outfall. An assessment of dioxin/furan concentrations in the tissue of fish captured from the exposure area is required if the effluent contains measurable concentrations of these chemicals, or if concentrations in fish tissue reported in the most recent interpretive report exceeded Health Canada consumption guidelines (Government of Canada 2008).

Six EEM cycles have been completed since the release of the original PPER in 1992: Cycle One, from 1993 to 1996; Cycle Two, from 1997 to 2000; Cycle Three, from 2001 to 2004; Cycle Four, from 2004 to 2007; Cycle Five, from 2007 to 2010; and Cycle 6, from 2010 to 2012. All components of the Powell River pulpmill EEM programs have been conducted in accordance with applicable regulatory requirements, with implementation guided by the most current and applicable technical guidance documents produced by Environment Canada.

The Powell River pulpmill EEM Cycle Seven program was designed in accordance with the 2008 amendments to the PPER (Government of Canada 2008), with guidance from the pulp-and-paper EEM Technical Guidance Document (Environment Canada 2010). The study design is described in Hatfield (2014).

In March 2012, the Powell River mill began to utilize spare boiler and generator capacity to generate electricity. The implementation of the G12 Power Increase Project (G12 Project) (Hatfield 2010b) resulted in a large increase in the volume of water/effluent discharged from the mill's primary outfall. The increased volume through the effluent-carrying outfall (Outfall #1) is predicted to expand the 1% effluent zone to >100 m (but not >250 m) from two of the diffuser ports, based on pre-project modeling and confirmation of post G12 discharge (Hatfield 2010b Hatfield 2014). The resulting increase in the 1% zone beyond the 100 m trigger distance required the mill to conduct a benthic invertebrate community survey as part of the Cycle Six program and, as annual average discharges continue to be within the range predicted to increase the 1% effluent beyond a 100 m radius, the mill was also required to conduct a benthic survey as part of the Cycle Seven program to confirm results observed in Cycle Six.

Given that the 1% effluent concentration zone of Powell River mill's primary outfall is not projected to exceed 250 m with the implementation of the G12 Project, the mill maintained its exemption from the fish-population survey requirement. An exemption from fish-tissue dioxin/furan monitoring was also maintained, due to low dioxin/furan concentrations in previous fish-tissue evaluations and non-detectable concentrations measured in effluent during previous cycles.

2.0 SITE CHARACTERIZATION

2.1 STUDY AREA

The Catalyst Paper Powell River pulpmill is located at the north end of Malaspina Strait in the northern Strait of Georgia, British Columbia, Canada (Figure 2.1). Malaspina Strait is a deep (>300 m), steep-sided channel separated from the Strait of Georgia by Texada Island. Water temperatures in the area are relatively constant (about 7°C) at depths below approximately 50 m. A thermocline develops in summer between generally at about 10 m and 20 m depth, but becomes largely broken down by early October when surface waters cool (Hatfield 2013). Tides at Powell River are mainly diurnal, with a mean range of 3.35 m; flood tides move north up the strait while ebb tides flow south (Hatfield 1994).

The marine environment in the vicinity of Powell River supports numerous species of aquatic organisms, including fish and benthic invertebrates. The eastern portion of the Strait of Georgia between Texada Island and Desolation Sound and Malaspina Strait are important migratory routes for juvenile salmon. Several areas within the region are important for salmon and herring rearing, as well as Pacific hake, walleye pollock, herring, and Pacific cod spawning. Near-shore marine waters support numerous species of invertebrates, including oysters, prawns, and clams (Hatfield 1994).

With the exception of the G12 Project, no new large-scale human influences or significant natural changes in the Powell River study area are known to have occurred since the beginning of the EEM program in 1993.

2.2 MILL OPERATIONS

When operations began in 1912, the Powell River mill was the first newsprint mill in western Canada (Catalyst Paper 2009), and used groundwood and sulphite pulping processes. The sulphite mill closed in 1969, and was replaced by a kraft mill that began production in 1967. A refiner mechanical pulp mill was started in 1969, and used surplus refiners from the sulphite mill; this mill continued operation until 1982. Thermomechanical pulp (TMP) production began in 1975, and was converted to chemi-thermomechanical pulp (CTMP) production over the period 1982 to 1985 by means of sodium sulphite treatment of wood chips (Hatfield 1994).

Further details on the operational history of the Powell River pulpmill are available in the pre-design report (Hatfield 1994).

In 1991, elemental chlorine use in the kraft mill bleach plant was substantially replaced by a chlorine dioxide system. Use of elemental chlorine during bleaching was completely eliminated in October 1996. In 2000, the bleaching sequence changed again with the inclusion of peroxide in the alkali extraction process (Hatfield 2001). Elimination of elemental chlorine bleaching led to the virtual elimination of dioxins and furans in mill effluent (Hatfield 1994) and greatly reduced effluent adsorbable organic halide (AOX) concentrations (Figure 2.3) (Hatfield 2001).

The Powell River pulpmill currently uses an aerobic, activated-sludge secondary treatment system, installed in December 1992. This system consists of a three-train bioreactor, two secondary clarifiers, and the submerged effluent diffuser. During EEM Cycle Four (2004 to 2007), the mill bypassed an existing oversized primary clarifier and converted a much smaller, swing clarifier into a permanent primary clarifier. This modification helped to reduce odour problems related to septicity in the old primary clarifier. In August 1997, liquid ammonia nitrogen (liquid fertilizer) replaced anhydrous ammonia (gas) as the source of nitrogen added to the secondary treatment system (Hatfield 2001). Additional details on the mill's secondary treatment system can be found in the pre-design report (Hatfield 1994).

Since 1993, the combined, treated effluent from all Powell River mill operations has entered the receiving environment through a submarine outfall (Hatfield 1994). This outfall, extends approximately 820 m into Malaspina Strait. Thirty-six diffuser ports, equally spaced along the length of the outfall starting at the 345 m point, discharge effluent at depths between 57.3 and 72.5 m below low water. Effluent from the CTMP and groundwood mills, papermill, and woodroom were discharged from a surface tailrace (after primary treatment) until fall 1992, when the secondary treatment system became operational (Hatfield 1994). Additional discharges from the Powell River pulpmill include cooling and storm waters from the TMP and woodroom areas (Outfall #2, surface discharge to Malaspina Strait); cooling waters from the steam plant and paper machines, and stormwater (Outfall #4, surface discharge to Malaspina Strait); and block flume transport water from Powell Lake, discharged to the Powell River estuary (Outfall #3) (Hatfield 2001).

During summer 2001, all paper machines were converted to neutral papermaking processes. In late 2001, the groundwood pulpmill, wood mill operations, and kraft mill operations were discontinued. These changes resulted in a significant reduction in effluent flow (Figure 2.2) and changes in effluent characteristics. Currently, Powell River pulp and paper operations include a thermomechanical pulpmill, three repulpers for purchased kraft pulp, and two paper machines. All pulp produced is used for the production of newsprint and groundwood specialties paper. The mill currently produces 15,000 tonnes of newsprint and 376,000 tonnes of specialty papers per year for clients throughout the world (Catalyst Paper 2015). In 2015, average paper production at the Powell River mill was 933 ADt/d and average daily effluent discharges were 80,733 m^3/d.

In March 2012 the mill began to utilize spare boiler and generator capacity to generate additional electricity at the Powell River mill (Hatfield 2010b). The implementation of the G12 Project significantly increased the daily volume of water/effluent discharged from the mill's outfalls. Daily average flow from Outfall #1 (effluent-carrying, sub-surface outfall) increased from a pre-project flow of 93,278 m^3/day to 157,245 m^3/day in 2012, 144,776 m^3/day in 2013 and 163,831 m^3/day in 2014. Currently, the mill is permitted to discharge a daily maximum of 245,000 m^3/day. Under rare circumstances (e.g. during the hottest days of the year), excess cooling water would be redirected to Outfall #4 (non-effluent carrying surface outfall). During these rare events, maximum daily flow from Outfall #4 may reach up to 90% of the permitted maximum flow of 94, 700 m^3/day (i.e., 85, 230 m^3/day).

In October 2014 the mill shutdown the #9 paper machine (#9PM) due to decreased market demand, and in December 2015 indefinitely shut down the #9PM.

Figure 2.1 Location of Catalyst Paper, Powell River Division, in Powell River, British Columbia.

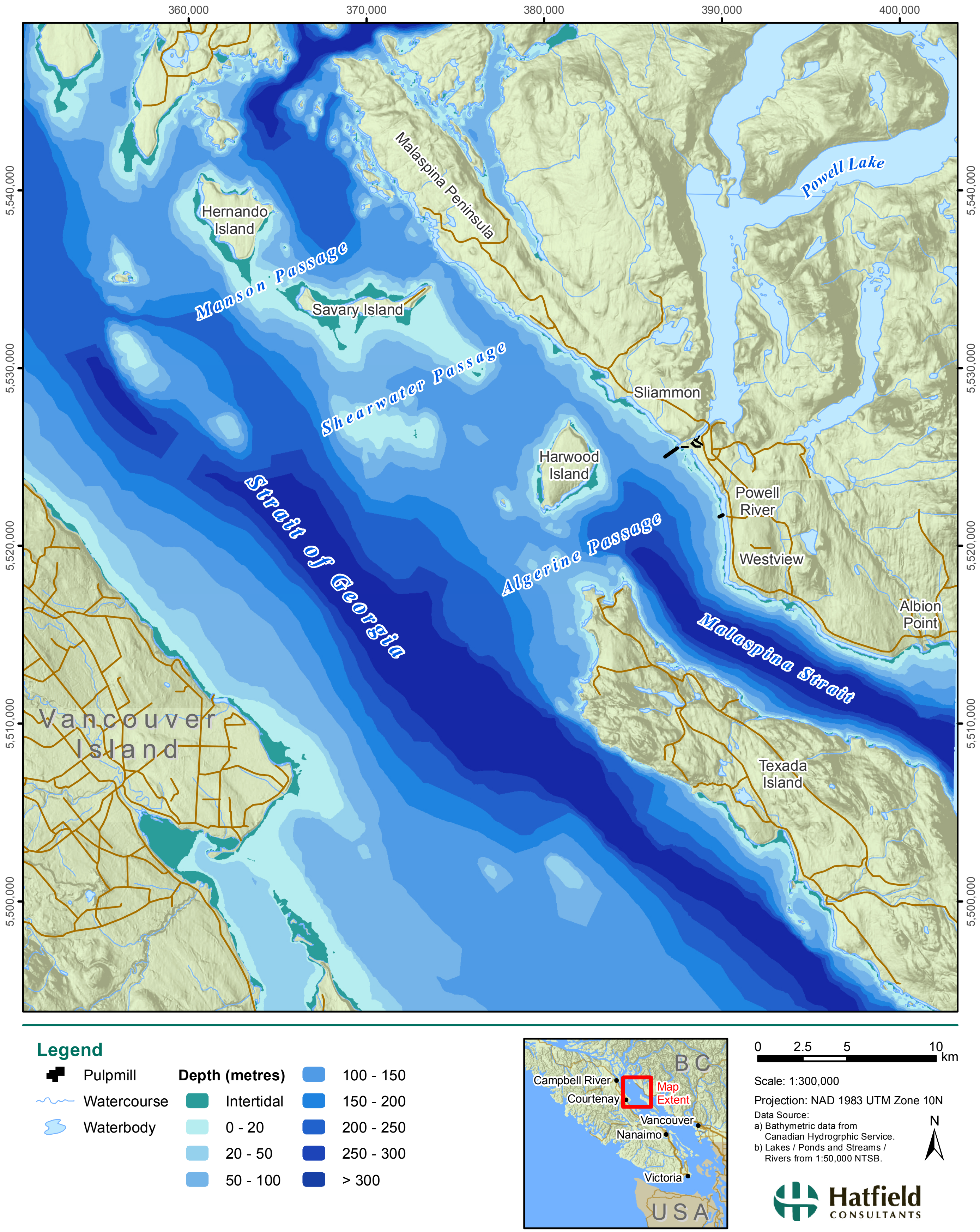

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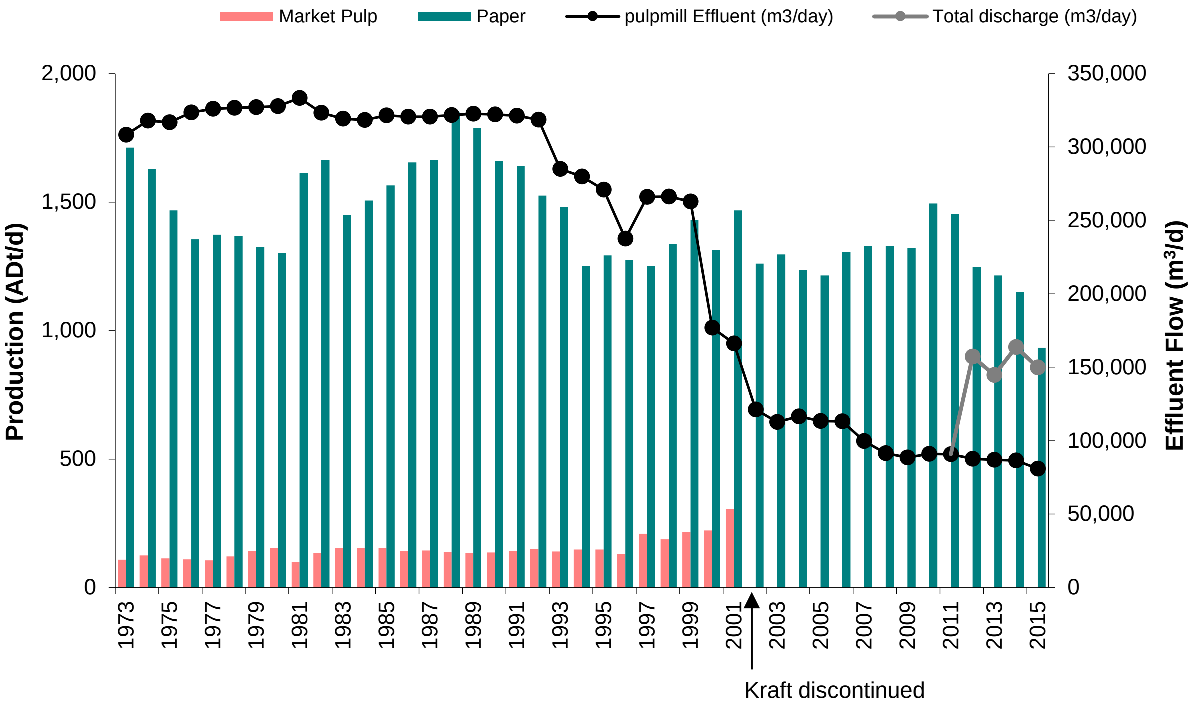
Figure 2.2 **Average annual paper and market pulp production and effluent flows, Powell River pulpmill, 1974 to 2015.**



Total discharge include excess cooling water from the G12

2.3 EFFLUENT DILUTION (EFFLUENT MIXING)

Since 1993, the combined, treated effluent from all Powell River mill operations has entered Malaspina Strait through the submarine outfall (Hatfield 1994). Given numerous process changes since 1992, average effluent discharge rates from the Powell River pulpmill decreased from 318,522 m^3/day in 1992 to approximately 80,733 m^3/day in 2015 (Figure 2.2). These lower volumes of effluent continue to be released to the receiving environment via the mill's diffuser, resulting in much more rapid dilution of effluent than occurred when higher flows of effluent were released previously.

Dispersion of mill effluent from the Powell River pulpmill prior to 1992 was examined through dye dispersion, oceanographic modeling, and water quality studies. These studies indicated that the 1% effluent zone could be delineated as a circle extending 1 km in radius from the outfall diffuser (Hatfield 1994). Effluent flows from the outfall increased in late 1992, when mill effluent flows were combined and released through the submarine outfall rather than the surface tailrace. The various effluent dispersion studies indicated that while patterns of effluent dispersion were expected to remain similar, the effluent 1% zone should be expanded to a circle extending 3 km in radius from the outfall diffuser (Hatfield 1994). Oceanographic modeling suggested that effluent would disperse along two main paths: south along Malaspina Strait to Jervis Inlet, or north to Savary Island and into the Strait of Georgia (Hatfield 1994). Additional information on these early effluent dispersion studies can be found in the pre-design reference document (Hatfield 1994).

Following the discontinuation of the kraft mill in 2001, effluent dispersion flows were re-modeled by Hay and Company (Hayco) (i.e., Hayco 2002, Hayco 2007) using the U.S. EPA PLUMES (UM) model. Modeled scenarios included effluent flows of 113,000 m^3/day and 120,000 m^3/day (characteristic of then operational conditions; average flow in 2007 was 99,758 m^3/day), and a range of ambient current velocities (data collected by the Canadian Hydrographic Service at a nearby meter). The U.S. EPA PLUMES (UM) model was used to ensure consistency with historical modeling of effluent dispersion. Modeling was conducted at the most shoreward (shallowest) port (#36), as dilution at this port was generally poorest (Hayco 2007) and provided the most conservative approach.

Modeling results indicate that except for short periods of time when ambient currents drop below 3 cm/s, pulpmill effluent is diluted to over 100:1 (i.e., less than 1% of release) immediately above the diffuser (port #36), with the depth of maximum rise estimated to be approximately 30 m. At lower ambient current velocities (at or below 3 cm/s), lower dilution ratios of approximately 87:1 to 98:1 were predicted to occur through vertical rise only. Through mixing upwards to the point of maximum rise, the effluent plume is predicted to spread horizontally to a diameter of approximately 9 to 11 m. Additional dilution associated with horizontal mixing at this final trapping depth would result in dilutions above 100:1 (i.e., concentrations below 1% of release) within 50 m from the diffuser. Consequently, the 50 m value was assigned as the 1% zone of effluent concentration.

2.3.1 Effluent Dilution after the G12 Power Increase Project

As part of the G12 Power Increase Project and subsequent release of increased amounts of non-contact cooling water into Malaspina Strait through OF#1, effluent dispersion flows were re-modeled by EBA Engineering (formerly Hayco) in 2010 (Appendix 2). Modeled scenarios included a pre-project discharge flow rate of 93,278 m^3/day with an effluent temperature of 34.9°C and a post-project discharge flow rate of 153,425 m^3/day (including additional cooling water) with an effluent temperature of 38°C. All discharge scenarios were analyzed for all four seasons (spring, summer, fall and winter) at all ports.

Modeling results indicated that except for ports #1 and #2 in the summer, all ports achieve 100:1 dilution within 100 m for the pre and post-project cases. Ports #1 and #2 are estimated to have a 100:1 dilution plume extent of 120.6 and 105.4 m respectively in summer, with remaining seasons <100 m from end of pipe. The average horizontal plume extent at 100:1 dilution for the pre and post project (40°C) flows is respectively 6.3 and 10.3 m in spring, 23.2 m and 45.5 m in summer, 8.8 m and 16.4 m in fall, and 12.5 and 34.7 m in winter (Hatfield 2010b). In all four seasons, compared to the lower pre-project flow case, the higher post project flow case causes the dilution ratio at maximum rise to decrease by 15-16% and the trapping depth to decrease by 0.3 to 1%.

Since the G12 project came online in March 2012, the annual average combined discharge from OF#1 (the mills primary discharge) was 144,776 m^3/day in 2013, 163,642 m^3/day in 2014 and 149,810 m^3/day in 2015. These annual average effluent discharges are near the modeled average presented above.

Given the maximum predicted extent of effluent of ≥1% effluent of 120 m, EEM requirements required a benthic invertebrate community study to be undertaken in Cycle Seven (for which an exemption is grated at <100 m extent of 1% effluent) but that a fish survey was not required (for which an exemption is granted at <250 m extent of 1% effluent).

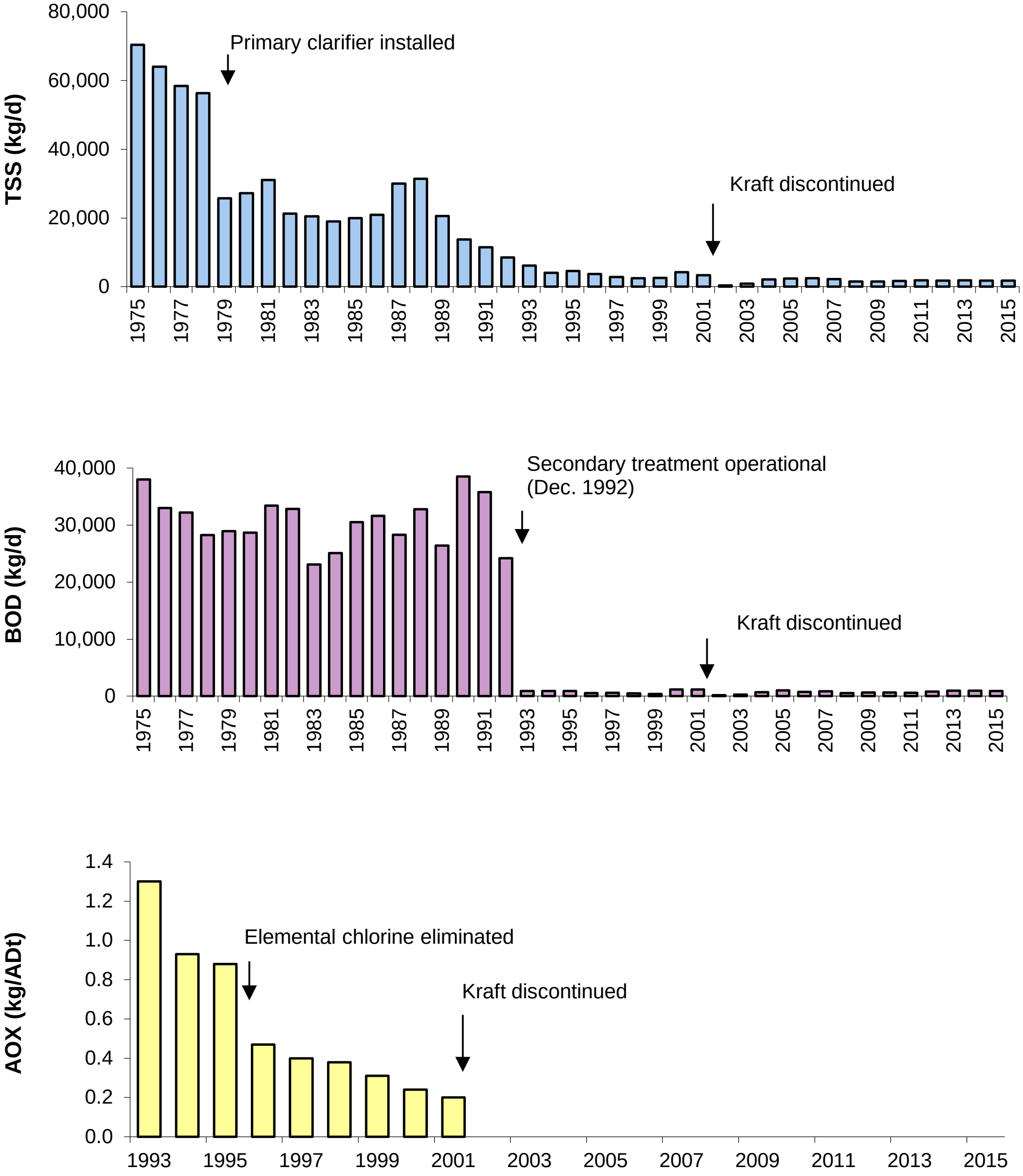
2.4 EFFLUENT CHEMISTRY AND ACUTE TOXICITY

Pulpmill effluent quality variables are routinely measured in accordance with provincial permits and federal PPER requirements. All pulpmill effluent sampling and subsequent results are of treated pulpmill effluent only, which is sampled prior to the introduction of non-contact cooling from the G12 Project. Annual average values for all pulpmill effluent quality variables measured are presented in Figure 2.3.

Implementation of secondary effluent treatment in 1992 and closure of the kraft mill in 2001 have resulted in improved effluent quality, including reductions in total suspended solids (TSS) and biochemical oxygen demand (BOD) and elimination of AOX and dioxin/furans (Figure 2.3). With the closing of the kraft mill in November 2001, dioxin/furan and AOX monitoring is no longer required. Effluent quality variables measured most recently during Cycle Seven (2010-2013) were generally similar to those reported in Cycle Five and Six (2008 to 2012).

Acute toxicity values were greater than 100% effluent in Cycle Seven, indicating effluent was not lethal to fish and invertebrates tested.

Figure 2.3 Effluent quality (annual averages), Catalyst Paper Corporation, Powell River Division, 1973 to 2015.



AOX not measured after 2001.

Table 2.1 Annual averages of process effluent quality variables for Catalyst Paper Powell River Division, 2003 to 2015.

Parameter	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Production (ADt/d)													
Paper	1,296	1,235	1,215	1,305	1,328	1,330	1,322	1,268	1,453	1,248	1,215	1,150	931
Market Pulp	0	0	0	0	0	0	0	0	0	0	0	0	0
Pulpmill discharge (m^3/d)	112,670	116,600	113,440	113,134	99,758	91,388	88,688	94,121	90,741	87,680	86,999	87,424	81,058
Total discharge (m^3/d)[1]	-	-	-	-	-	-	-	-	-	157,254	144,776	163,642	149,810
TSS (t/d)	0.9	2.1	2.4	2.5	2.2	1.5	1.5	1.7	1.54	1.24	1.9	1.8	1.7
BOD (t/d)	0.3	0.70	1.0	0.78	0.86	0.55	0.65	0.66	0.57	0.54	0.96	0.95	0.91
Conductivity (µS/cm)	790	820	854	920	937	834	881	848	773	789	785	854	694
Rainbow trout 96-hr LC50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Daphnia 48-hr LC50	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100	>100
Fibre losses (t/d)													
Net to Clarifier	69	60	66	75	38	39	55	70	70	84	80	66	59
Out of Clarifier	5.5	5.5	3.7	3.5	3.8	3.5	3.9	2.1	2.8	2.5	3.2	2.1	5.1
% Solids Removal	93	76	95	95	94	95	93	97	96	97	96	96	90

[1] Total discharge includes excess cooling water from the G12

2.5 SPILLS TO THE RECEIVING ENVIRONMENT AND PERMIT EXCEEDANCES

A summary of spills to the receiving environment that occurred during Cycle Seven are provided in Table 2.2.

Table 2.2 Summary of environmental events at Powell River mill, April 2013 to March 2015.

Date Reported	Incident
April 29, 2013	On 4/29, the mill experienced a power outage and released about 400 m3 of material at outfalls #2, #3, and #4
June 13, 2013	On 6/2/2013, a maximum of 50 m3 of untreated effluent from manhole #3 was released through outfall #3.
Sep 14, 2014	Unauthorized bypass occurred on 9/14/2014 around bioreactor and secondary treatment while preparing for total mill outage. About 34 m3 of primary treated effluent was combined with treated effluent and released at the diffuser.

2.6 SUMMARY OF ENVIRONMENTAL MONITORING

This section summarizes results from previous biological monitoring studies focusing on fish populations, fish tissue, and benthic invertebrate communities, as well as water quality and sediment quality surveys. These summaries are based on information presented in the Powell River pre-design document (Hatfield 1994) and the Cycle One, through Cycle Six interpretive reports (Hatfield 1997, 2000, 2004, 2007, 2010, 2013 respectively) (Table 2.3).

Table 2.3 Summary of environmental monitoring conducted during the Powell River pulpmill EEM cycles One through Six, 1993-2013.

Study Component		EEM Cycle					
		Cycle One 1993 to 1996	Cycle Two 1997 to 2000	Cycle Three 2001 to 2004	Cycle Four 2004 to 2007	Cycle Five 2007 to 2010	Cycle Six 2010 to 2013
EEM Component	Sublethal Toxicity Testing	√	√	√	√	√	√
	Fish Populations	√	√	√[1]	-	-	-
	Fish Tissue	√	√	-	-	-	-
	Benthic Invertebrates	√	√	√	-	-	√
Supporting Studies	Plume Delineation	-	-	√[2]	√[3]	√[4]	-
	Water Quality	√	√	√	-	-	√
	Sediment Quality	√	√	√	√	-	√

[1] A 28-day topsmelt survival and growth test was conducted as an alternate fish survey.

[2] Plume modelling study conducted by Hayco in 2002.

[3] Plume modelling study conducted by Hayco in 2007.

[4] Plume modelling study conducted by EBA in 2010.

2.6.1 Receiving Water Quality

Water quality variables analyzed in receiving water at Powell River during Cycle One included chloroform (as an effluent tracer), colour, tannins and lignins, total suspended solids, total phenols, total organic carbon, resin and fatty acids, and chlorinated phenolic compounds. None of these variables indicated the presence of effluent at surface or near-bottom (55 to 80 m) sample locations. Variables related to mill effluent (e.g., chloroform, resin/fatty acids, chlorinated phenolic compounds) were non-detectable in all samples.

Water quality variables (dissolved oxygen, salinity, temperature) were measured in Cycle Two, Three and Six as supporting variables for the benthic invertebrate surveys; results were generally similar among stations. In Cycle Six, dissolved oxygen, salinity, and temperature were measured as supporting variables for the benthic invertebrate survey. Dissolved oxygen ranged from 8.1 to 9.8 mg/L at depths from 31 m to 60 m, while salinity ranged from 24.3 to 26.8 ppt and temperature ranged from 7.1°C to 7.9°C (Hatfield 2013).

2.6.2 Sediment Quality

Sediment collected in the vicinity of Powell River has consisted predominantly of sand, with smaller fractions of silt, clay and gravel. Total organic carbon concentrations are higher at near-field stations relative to far-field stations, likely due to historical fibre mat deposition near the mill.

In Cycle One sediments collected from the near-field zone exhibited slightly higher levels of resin/fatty acids and chlorinated phenolics relative to far-field and reference stations. Several resin/fatty acids were detected in all sediments; trace levels of chlorinated phenolics were observed in several near- and far-field sediments but not in reference sediments. Phenolic compounds may indicate historical contamination rather than effects from more recent effluent discharge.

In Cycle Two and Cycle Three sediments were primarily composed of sand with TOC, total nitrogen, C:N ratio, redox potential, total sulphides and chlorinated phenolics were higher at near-field stations relative to stations along either gradient. All of these variables, except redox, were significantly correlated with distance from the diffuser. In Cycle Two fecal coliform levels indicated sewage contamination near Westview and along the northwest gradient to Scuttle Bay. TOC and total sulphides values indicated low to gross impacts at near-field stations, based on “impact grades” presented in the *Pulp and Paper Technical Guidance for Aquatic Environmental Effects Monitoring*. Redox potential impacts ranged from “low” to “gross” on both gradients.

In Cycle Four, a sediment quality survey was conducted to provide ongoing monitoring data on bottom sediments in the vicinity of the pulpmill, with samples collected from 280 to 1,800 m from the diffuser. Based on Environment Canada criteria for marine sediments, sediments sampled near the Powell River mill exhibited moderate to gross enrichment. Redox potential values indicated moderate to gross effects; however, total sulphides values indicated no or low impacts at all stations (Hatfield 2007). Based on these criteria, potential impacts of sediments on benthic communities in the vicinity of the mill were similar in cycles Three and Four and showed continued improvement.

In Cycle Six a sediment survey was conducted to support the benthic invertebrate survey with samples analyzed for the same variables in Cycle Three. Sediment near the diffuser, while improving, remains organically enriched and exhibited reducing conditions to inhabiting biota. Remaining gradient stations further from the diffuser exhibited sediment conditions indicative of natural conditions/reference areas. As observed in Cycle Three, TOC, total nitrogen, C:N ratio, redox potential, total sulphides and chlorinated phenolics were higher at near-field stations relative to stations along either gradient. TOC and total sulphides values indicated “low” to “gross” impacts at near-field stations, while redox potential was grossly impacted at all stations, although concerns were raised in Cycle Six regarding the change in redox sample analyses personnel.

2.6.3 Benthic Invertebrate Community Surveys

August 1988 a subtidal benthic invertebrate survey was conducted in the vicinity of Powell River, prior to mill upgrades. Mean density of organisms at stations within 1 km of the diffuser were less than at stations greater than 1 km. Similar results were observed for taxa richness. Benthic invertebrate community structure throughout the study area was indicative of stable, unstressed systems. However, some evidence of organic enrichment was evident, especially at a station located near the tailrace. Although density and taxonomic richness were lower near the diffuser, no overt negative impacts of the bleached Kraft mill effluent discharge on benthic invertebrate communities could be detected.

The Cycle One benthic invertebrate survey was conducted in the vicinity of Powell River and at reference stations near Qualicum Beach. Generally, stations in the vicinity of Powell River exhibited lower densities (but similar taxonomic richness) relative to reference stations. Mean density at near-field stations was slightly lower relative to far-field and far-far-field stations. Taxonomic richness at near-field stations was most similar to far-far-field stations and reference stations, while far-field stations generally exhibited the highest taxonomic richness. Discriminant analysis and multivariate statistics indicated that differences between exposed and reference stations for Powell River were not statistically significant.

Benthic invertebrate surveys conducted in Cycles Two and Three found no effects of effluent on benthic invertebrate communities at Powell River, based on correlational and critical-effects-size analyses of density, richness and also on evenness and Bray-Curtis indices in Cycle Two (Hatfield 2004). No benthic invertebrate surveys were conducted in Cycle Four or Five, due to the absence of impacts observed in Cycles Two and Three and amendments made to the PPER exempting a mill from completing an EEM benthic invertebrate survey if the mill’s 1% effluent zone extended less than 100 m from the effluent outfall.

A benthic survey was conducted in Cycle Six in response to the increase effluent discharge from the G12 Project. The Cycle Six benthic survey was similar to the Cycle Three survey however; the four furthest stations were eliminated in Cycle Six due to the reduced zone of potential effect and absence of observed effects at these stations in Cycle Three. In addition, two new stations were added to the near-field area immediately adjacent to the diffuser. In Cycle Six, significant effects were observed for taxa richness and the Bray-Curtis index when compared to distance from the diffuser and C/N ratio while no were observed for density, Simpson’s diversity index or evenness. Although effects on benthic invertebrates were observed in Cycle Six, sediment conditions improved and benthic densities increased at nearly all stations, relative to previous cycles.

2.6.4 Fish Surveys

Alternative methods have been used for fish population surveys at Powell River given the lack of barriers to fish movement in marine waters. Insufficient numbers of finfish were collected during Cycle One for the adult fish survey; oysters were also collected and analyzed. In Cycle Two, a wild oyster survey was conducted as an alternative to the adult fish survey, given that oysters are sedentary and available along the coastline of Malaspina Strait (Hatfield 2000). Oysters collected in near-field and far-field areas exhibited similar values for condition and shell density, while reference area oysters exhibited significantly higher condition and lower shell density. However, the effect of pulpmill effluent on oysters was inconclusive, given the very low levels of resin acids measured in oyster tissue (Hatfield 2000).

Cycle Three used an extended sublethal toxicity test (28-day topsmelt), which indicated that effluent effects were not likely in the receiving environment; toxicity testing conducted in Cycle Four indicated that effluent had no effect on topsmelt survival and growth. No fish survey was conducted during Cycle Four or Cycle Five due to an exemption based on the limited 1% effluent zone (i.e., 50 from diffuser). This exemption also applied to Cycle Six when 1% effluent zone was modeled at an increase distance of 120 m from the diffuser. Given the lack of a finfish sentinel species and viable alternative methods for trapped effluent, EEM fish surveys have been inconclusive.

Fish tissues were analyzed for dioxins and furans in the late 1980s, which resulted in the closure of the crab and oyster fisheries in November 1989. The oyster fishery reopened in February 1995 given low tissue dioxin levels. Consistently low levels of dioxin/furans in crab tissues have enabled Fisheries and Oceans Canada (FOC) to lift the fish consumption advisories. However, sanitary shellfish closures continue from Myrtle Point to Scuttle Bay due to sewage contamination.

No EEM fish tissue surveys were required at Powell River for Cycle Three, Cycle Four, or Cycle Five as concentrations of dioxins/furans in fish tissue were below Health Canada consumption guidelines in previous EEM cycles; fishing closures and consumption advisories related to dioxins and furans were also lifted.

Tiley and Bocking (2009) measured bioaccumulative contaminants in intertidal bivalves, including littleneck clams (*Protothaca staminea*), manila clams (*Venerupis philippinarum*), Nuttall's cockles (*Clinocardium nuttalli*), butter clams (*Saxidomus giganteus*), and Pacific oysters. intertidal bivalves were collected in July 2008 from eleven beaches within Sliammon traditional territory. These beaches included Scuttle Bay, Okeover Inlet, and Harwood Island beaches, Waterfront Beach, and Theodosia Inlet beaches (reference site). The study found only trace concentrations of dioxin and/or furan congeners, but elevated concentrations of four metals (cadmium, zinc, aluminum, and iron) that were sufficiently high that potential health risks could occur in the absence of consumption guidelines.

3.0 SUBLETHAL TOXICITY OF EFFLUENT

Summary of Sublethal Toxicity Testing (Winter 2013 through Summer 2015) for Catalyst Paper, Powell River Division:

- During Cycle Seven, six test periods of sublethal toxicity testing were conducted on two species between April 2013 and November 2015;
- Echinoderm fertilization was affected at a mean effluent concentration of 35.4% (IC25);
- Algal reproduction was affected at a mean effluent concentration of 5.5% (IC25); and
- Based on a maximum 1% effluent concentration zone of 120 m from the Powell River outfall, maximum potential zones of sublethal effect from the effluent discharge point were 3.4 m for invertebrate fertilization, and 21.8 m for algal reproduction.

Federal and provincial government regulations require pulp and paper mills to undertake toxicity testing as part of their EEM programs to determine any potential lethality or inhibitory effects of their effluent on fish populations and fish habitat. Current EEM regulations require the use of sublethal toxicity tests to help meet the following objectives (Environment Canada 2010):

- 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 relative contributions of the mill to multiple discharge situations.

For Catalyst Paper, Powell River Division, which discharges to a marine receiving environment, Cycle Seven sublethal toxicological testing included the following tests, as stipulated in the EEM Technical Guidance Document (Environment Canada 2010):

- Invertebrate fertilization test using the echinoderm, (*Strongylocentrotus purpuratus*); and
- Algal reproduction test, using the marine red alga *Champia parvula*.

As with effluent chemistry samples, all effluent samples collected for sublethal toxicity were of treated pulpmill effluent only, which is sampled prior to the introduction of non-contact cooling from the G12 Project. Sublethal toxicity testing of echinoderms for Powell River Division was performed by Nautilus Environmental, Burnaby, BC (Nautilus). *Champia* tests were subcontracted to AquaTox Testing & Consulting Inc., Guelph, Ontario (Aquatox). A summary of reported endpoints are included with this Cycle Seven interpretive report.

3.1 SUBLETHAL TOXICITY TEST METHODS

3.1.1 General Methods and Definitions

During Cycle One, quarterly tests were required for the year field studies were conducted. Since Cycle Two, the *Pulp and Paper EEM Guidance Document* (Environment Canada 2010) stipulates sublethal toxicological testing of process effluent twice a year. Tests were performed and reported as winter and summer test periods. Testing for Cycle Seven was initiated in Winter 2013 and continued until Summer 2015.

Similar to previous years, the name of the test period does not align with the date of the test. In Cycle Seven, the first test period of each year (the "winter" test period) was carried out in April. The second test period of each year (the "summer" test period) was carried out in November. Figures presented in this section provide both the test season name and actual test date to prevent confusion. The intent of having two test periods per year is to ensure tests are evenly spaced approximately six months apart.

On each test date, a grab sample of effluent was collected by mill personnel according to the methodology described in the *Pulp and Paper EEM Guidance Document* (Environment Canada 2010) and shipped to Nautilus for testing; subsamples were shipped by Nautilus to Aquatox for *Champia* testing. Sublethal toxicity testing involved exposure of organisms to a series of effluent dilutions. All sublethal toxicity tests were conducted with controls which assessed the response of test organisms to laboratory control water only. The organism response in the control treatments determines the acceptability of the test using predefined criteria. In addition, test organisms were tested with a reference toxicant to monitor the health and sensitivity of the culture.

An IC25 is calculated from the algal reproduction and invertebrate fertilization tests. The IC25 is an estimate of the concentration of effluent that results in a 25% reduction (or "inhibition") of a quantitative biological function, such as reproduction or growth. Confidence limits are given for each endpoint where possible.

3.1.2 Sublethal Toxicity Test Methods

General procedures for the echinoderm fertilization tests are based on the methodology document *Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars)*, Report EPS 1/RM/27, (December 1992, and November 1997 amendments) (Environment Canada 1997). The test assesses the fertilization success of the purple sea urchin *Strongylocentrotus purpuratus*. Male and female gametes are exposed to the test effluent for 20 minutes. The percentage of eggs successfully fertilized is compared between the controls and the sample concentrations to determine if any significant inhibition of fertilization is observed. The IC25 generated from this test represents the percent effluent concentration that results in a 25% reduction of fertilization relative to the control treatment.

Procedures for conducting the marine algae (*Champia parvula)* tests are based on *Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Marine and Estuarine Organisms*, Third Edition, EPA-821/R/02-014, October 2002 (US EPA 2002). The *Champia* test is a static, non-renewal, marine algal reproduction test. Male and female plants are exposed to a test sample for a 48-hour period, followed by a six- to eight-day recovery period. The IC25 generated from this test represents the percent effluent concentration that results in a 25% reduction of cystocarp reproduction, at the end of the recovery period, relative to the control treatment.

In Cycle Seven, Powell River conducted six sublethal toxicity tests from Winter 2013 to Summer 2015. Due to poor health of the algal culture during the Summer 2014 test period, the *Champia* test was redone in February 2015 once a healthy culture was established. Appendix A1 provides a summary of Cycle Seven sublethal toxicity test results, including dose-response plots for all tests conducted.

Algal growth in test treatments can demonstrate an enrichment response (i.e., greater growth than in the control), called hormesis. Hormesis is a response characterized by greater growth or reproduction in the lower test concentrations followed by inhibition at higher concentrations. This response is often observed in algal toxicity tests but may occur in other test as well. It is usually caused by the presence of nutrients in a test sample.

If not calculated properly, the LC50s or IC25s derived from data exhibiting hormesis can underestimate effluent toxicity. Environment Canada's guidance on calculating LC50s or IC25s requires labs to first attempt to fit one of several regression models, one of the recommended models is a log-logistic+hormesis model. However, if the parametric model assumptions are not met (i.e., normality and homoscedasticity), the LC50 or IC25 is calculated using a linear interpolation approach. If the later approach is used for data exhibiting hormesis, the values above the control (in this case, cystocarp counts) are adjusted down to the control values before the IC25 is calculated, as per Environment Canada's Guidance Document on Statistical Methods for Environmental Toxicity Tests (Report EPS 1/RM/46; Environment Canada 2010). In Cycle Seven, *Champia parvula* reproduction tests were corrected for apparent hormesis in Winter 2014 and Summer 2015.

3.1.3 Zones of Effluent Concentration

Under PPER, the 1% v/v effluent concentration zone represents the maximum extent of 1% effluent concentration (i.e., 100:1 dilution). The 1% zone is determined using a combination of tracer die studies and plume modeling.

Prior to the operation of the G12 Power Increase Project, a zone of effluent mixing was determined through modeling completed in March 2007 based on existing effluent discharge rates (Hayco 2007). Based on this study, the maximum extent of 1% effluent was defined as a radial distance of approximately 50 m from the pulpmill diffusers.

An additional modeling study was completed by EBA Engineering in 2010 to assess the potential effects of the G12 Power Increase Project, including the effect of increased effluent discharge rates, on the zone of effluent mixing. Post-G12 Power Increase Project, the maximum extent of 1% effluent (based on a worse-case scenario) was defined as a radial distance of approximately 120 m from port #36 of the pulpmill diffuser.

A maximum potential zone of sublethal effect was calculated for each test species from the geometric mean of the IC25 results and the extent of the post-G12 1% effluent concentration zone, as per Environment Canada (2010). The potential zone of sublethal effect is the maximum distance from the effluent discharge where a specified effect may be expressed for a test species and can be used to describe the “downstream” area where the effluent concentration exceeds the geometric mean of the endpoints. These maximum potential zones of sublethal effects were calculated as follows:

$$\text{Zone (m)} = \frac{\text{Extent of 1\% effluent zone(m)}}{\text{Geometric mean of IC25 results}}$$

This model assumes simple, linear dilution of effluent, which is not realistic for this situation, because Catalyst Paper, Powell River Division effluent is discharged through a multi-port diffuser that rapidly dilutes effluent into the marine environment upon release.

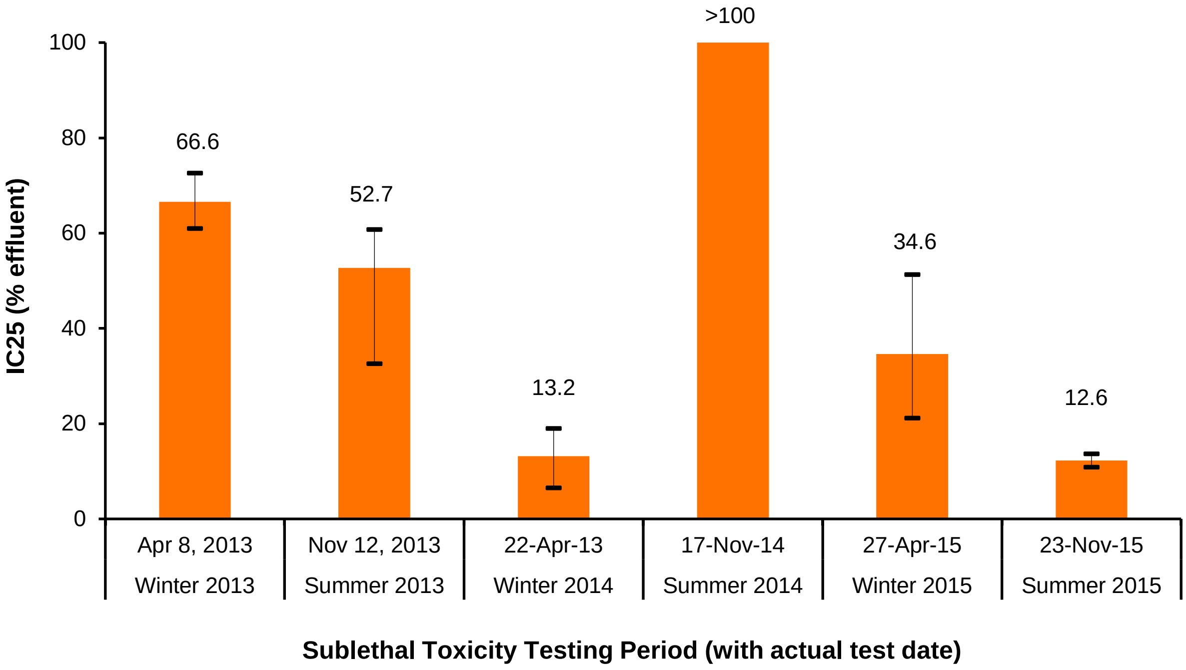
3.2 RESULTS AND DISCUSSION

A summary of the Cycle Seven sublethal toxicity results for the two test organisms are provided below. Appendix A1 provides detailed toxicity test results, including dose-response curves for all tests conducted.

3.2.1 Echinoderm Fertilization Test

The IC25s were highly variable in Cycle Seven, ranging from 12.6 % to >100% v/v effluent (geometric mean of 35.4% v/v) (Figure 3.1). The lowest fertilization rate, suggesting the greatest toxicity, occurred during the November 2015 test period (final Cycle Seven test period); however, there was no clear trend in the fertilization data during Cycle Seven. In Cycle Seven, the geometric mean of the fertilization rate was lower than the previous three cycles (suggesting greater toxicity), but greater than Cycles One, Two and Three (suggesting lower toxicity; Figure 3.3).

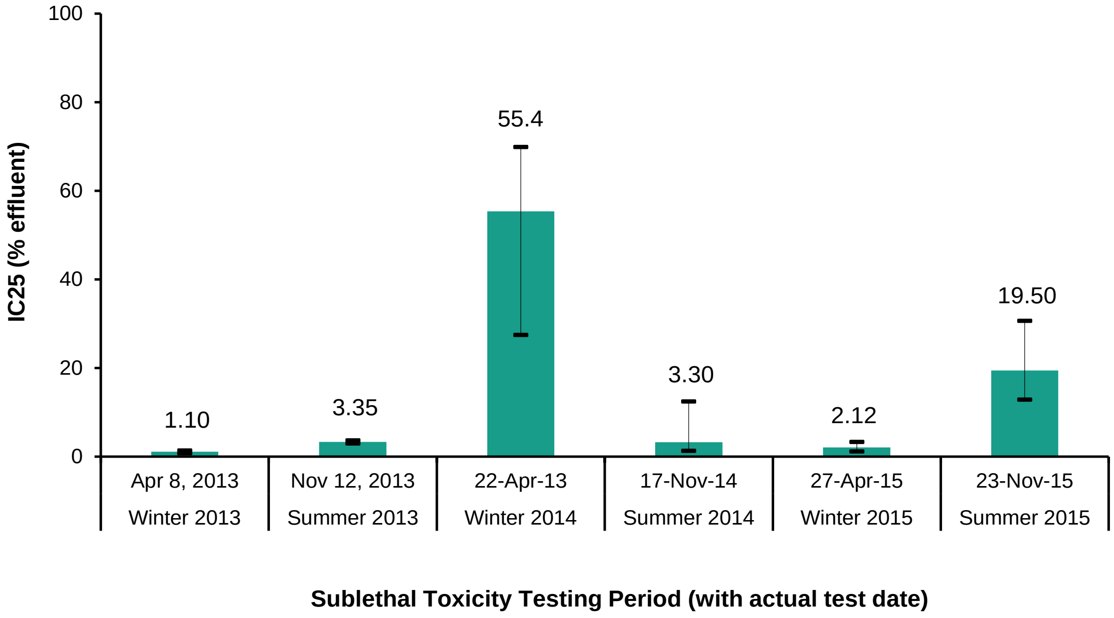
Figure 3.1 **Effect of exposure to Catalyst Paper, Powell River Division effluent on echinoderm fertilization, expressed as IC25 ±95% confidence limits, EEM Cycle Seven.**



3.2.2 *Champia parvula* Algal Reproduction Test

In Cycle Seven, the IC25 for algal reproduction ranged from 1.10% to 55.4% v/v, with a geometric mean concentration of 5.5% (Figure 3.2). No clear trend in algal reproduction toxicity was apparent in Cycle Seven. Overall, the Cycle Seven test results were similar to Cycle Six, with a geometric mean of 4.9%. Although, Cycle Seven and Six tests showed lower mean reproduction than previous cycles, suggesting greater toxicity (Figure 3.3).

Figure 3.2 **Effect of exposure to Catalyst Paper, Powell River Division effluent on algal reproduction, expressed as IC25 ±95% confidence limits, EEM Cycle Seven.**



3.2.3 Potential Zone of Sublethal Effect

In order to allow direct comparisons across all cycles, the zone of sublethal effect for Cycles One through Cycle Five was recalculated to the post-G12 1% effluent zone (i.e., 120 m) (Table 3.1).

In Cycle Seven, the zone of sublethal effect for echinoderm fertilization increased slightly from 1.86 m in Cycle Six to 3.39 m in Cycle Seven (Table 3.1). In contrast, the zone of sublethal effect for algal reproduction decreased slightly over the same period (24.7 m in Cycle Six to 21.8 m in Cycle Seven); however, the zone was larger relative to previous cycles.

Figure 3.4 presents the rate of effluent dilution for the Powell River pulpmill implied by the (Environment Canada 2010) zone-of-effect model. Using a conservative maximum extent of 1% effluent of 120 m, this model assumes that effluent would be diluted to 50% of release concentration 2.4 m from the diffuser, to 20% of release at 6 m from the diffuser, and to 5% of release concentration at 24 m from the diffuser. However, actual dilution of Powell River effluent occurs much more rapidly than this, mainly due to its discharge through a multi-port diffuser, which was designed to maximize initial dilution and dispersion of effluent in the marine receiving environment.

Table 3.1 Geometric mean and potential zone of sublethal effect, Catalyst Paper, Powell River Division, EEM Cycle One through Cycle Seven.

Sublethal Toxicity Test Species	IC25 or LC50 Geometric Mean (% v/v)							
	Cycle	Cycle	Cycle Three[1]		Cycle	Cycle	Cycle	Cycle
	One	Two	Kraft+TMP	TMP	Four	Five	Six	Seven
Topsmelt[2] Early Life Stage Growth IC25	>65%	>67%	>67%	>91%	>100%	>100%	-	-
Topsmelt[2] Early Life Stage Survival LC50	>65%	>67%	>67%	>91%	>100%	>100%	-	-
Echinoderm Fertilization IC25	26.5%	24.5%	23.9%	45.1%	47.8%	77.4%	64.4%	35.4%
Algal Reproduction IC25	14.0%	21.4%	7.4%	32.3%	12.1%	16.0%	4.9%	5.5%
	Maximum Potential Zone of Sublethal Effect[3] (m)							
Topsmelt[2] Early Life Stage Growth IC25	<46	<44	<45	<33	<0.5	<0.5	-	-
Topsmelt[2] Early Life Stage Survival LC50	<46	<44	<45	<33	<0.5	<0.5	-	-
Echinoderm Fertilization IC25	113	122	126	67	1.1	0.7	1.86	3.39
Algal Reproduction IC25	214	140	407	93	4.1	3.1	24.67	21.80

[1] Pulping process changed in November 2001 from Kraft and TMP to TMP only.

[2] *Menidia beryllina* was used as the fish test organism during Cycle One. Cycle Five geomeans and Potential Zones of Sublethal Effect for topsmelt growth and survival are based on three test periods. Testing for this species was no longer required after winter 2008.

[3] Based on 1% effluent zone of 3,000 m for Cycles One, Two, and Three, and a 1% effluent zone of 50 m for Cycles Four and Five. Cycles Six and Seven are based on 1 % effluent zone of 120 m.

[4] Echinoderm fertilization test results for summer 2006 were excluded from this calculation in the Cycle Four Interpretive Report because retest results were unavailable at the time the report was finalized. Values for Cycle Four presented here have been updated to include these results.

Figure 3.3 **Geometric means of IC25 and LC50 results from sublethal toxicity tests of Catalyst Paper, Powell River Division effluent for EEM Cycle One through Cycle Seven.**

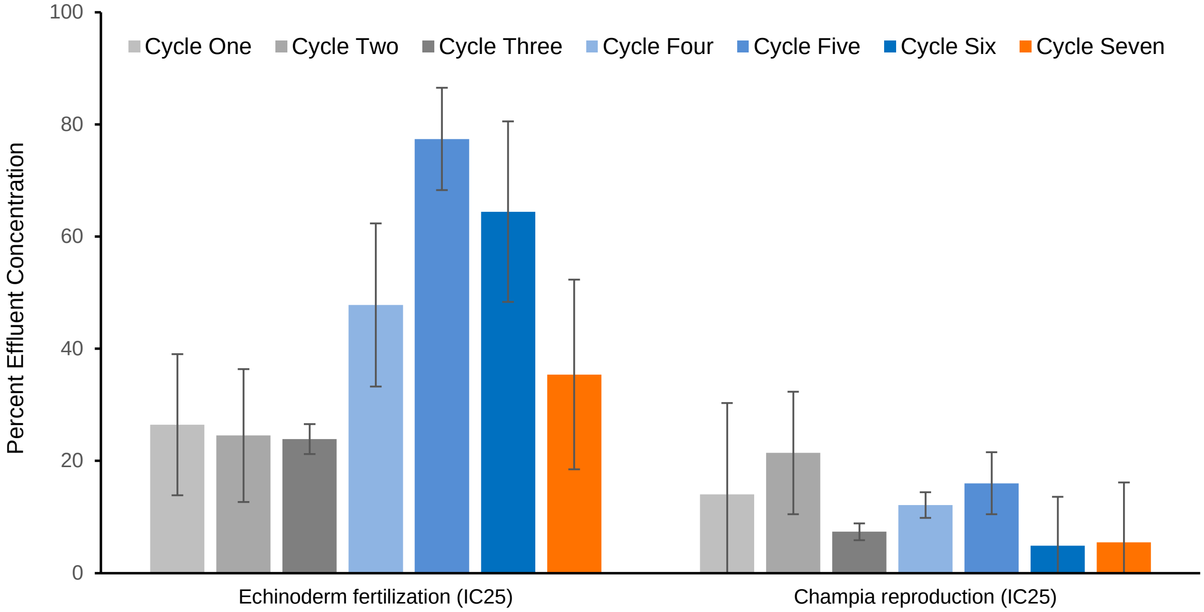
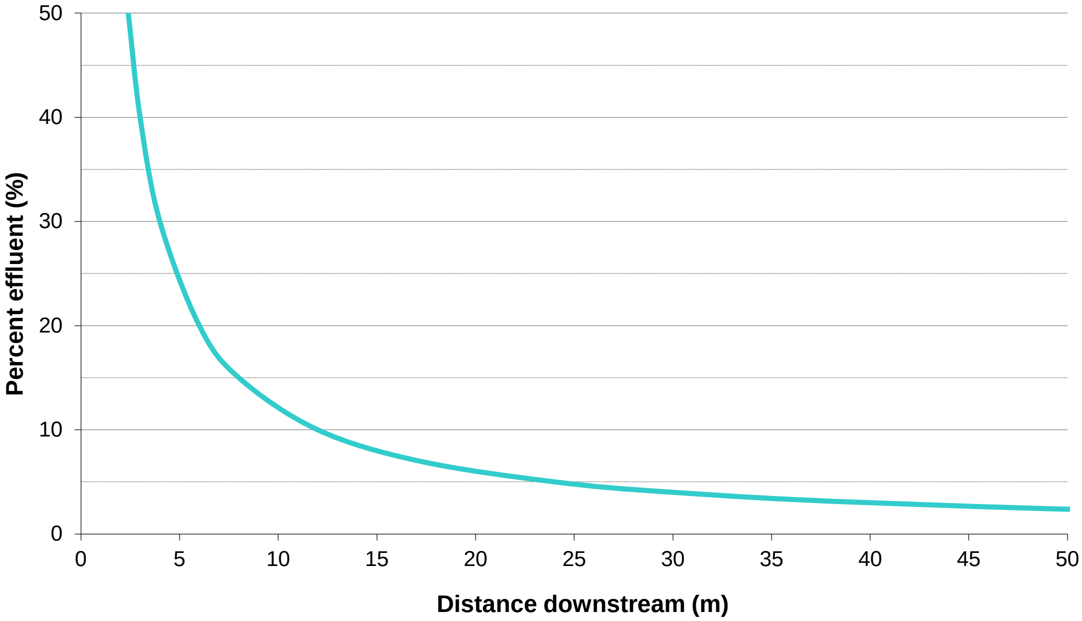


Figure 3.4 **Dilution of Powell River Pulpmill effluent in the receiving environment assumed by the Environment Canada (2010) maximum-zone-of-effect model.**



3.3 CONCLUSIONS

The effluent discharged from the Powell River pulpmill, as measured by sublethal toxicity results, indicated similar, or increased impacts in effluent quality relative to previous EEM cycles (Table 3.1, Figure 3.3). Algal reproduction was affected at a mean effluent concentration of 5.5%v/v effluent, while invertebrate fertilization was affected at a mean effluent concentration of 35.4%. Because of the rapid diffusion of effluent expected from the multi-port diffuser installed at the Power River Pulpmill, high effluent concentrations would not be expected to occur in the receiving environment around Powell River beyond the initial effluent mixing zone, immediately above the effluent diffuser. In addition, the addition of cooling water from the G12 Project occurs prior to final discharge (but is not included mill effluent toxicity test samples), further decreasing mill-related effluent concentrations in the receiving environment.

The addition of effluent to the marine environment should not have resulted in any observable toxicity during Cycle Seven given the extremely small zone of sublethal effect near the diffuser. Using the EEM approach for estimating the zone of sublethal effect, potential effects were predicted to be possible up to a maximum of 21.8 m and 3.39 m from the effluent diffuser for algal reproduction and invertebrate fertilization respectively.

4.0 BENTHIC INVERTEBRATE SURVEY

Summary of the benthic invertebrate survey for Powell River EEM Cycle Seven, March 2015:

- Benthic invertebrate communities were sampled following a gradient sampling design of 13 stations extending northwest and southeast of the mill, with two replicate samples from each station analyzed for benthos with a third for sediment quality;
- Although statistically significant effects were observed for richness, evenness and diversity, these effects diminish with increasing distance from the diffuser (i.e., increasing distance from the historical fibre mat) and were not defined as biologically significant based on EEM critical effect sizes;
- Sediments near the diffuser, while improving, remain organically enriched; remaining stations exhibited sediment conditions indicative of natural conditions/ reference areas; and
- Given the improving state of the sediment quality near the Powell River pulpmill between Cycle Three and Cycle Seven and the large decrease in discharged mill effluent, it is evident that the enrichment in the area surrounding the pulpmill diffuser are from historical pulpmill discharges and not from current mill operations

4.1 INTRODUCTION

A subtidal benthic invertebrate community survey was undertaken in the vicinity of the Powell River pulpmill in March 2015 to meet federal environmental effects monitoring (EEM) Cycle Seven requirements. The objective of the invertebrate community survey is to confirm if there is an effect on benthos in relation to effluent discharge from the Powell River pulpmill and, if appropriate, the magnitude and extent of any observed effect. Specifically, the experimental question of the survey is whether benthic community metrics (density, taxa richness, diversity, and community composition) differ significantly with increasing distance from the pulpmill diffuser discharge point (Figure 4.1).

This section provides results of the EEM Cycle Seven benthic invertebrate community survey. Data are reported for benthic invertebrates and supporting environmental variables, as well as methodology changes, taxonomic analysis, QA/QC and comparisons to historical surveys (Cycles Two and Three and Six). This section follows the reporting guidelines recommended by Environment Canada for EEM Interpretive reports (Environment Canada 2010).

4.2 METHODS

4.2.1 Field Sampling

A radial gradient design survey was conducted in March 2015 identical to the survey undertaken in the EEM Cycle Six program. A total of thirteen stations were sampled in vicinity of the pulpmill primary discharge outfall (Outfall #1; Figure 4.1). Due to the small size of the 1% effluent concentration zone and its seasonal variability, sampling stations were arranged as a radial gradient design with increasing distance from the diffuser in both a northwest and southeast direction.

As per the *Pulp and Paper Technical Guidance for Aquatic Environmental Effects Monitoring* (Environment Canada 2010), two replicate samples were collected at each station for a total of 26 samples (2 replicates x 13 stations).

4.2.1.1 Station Selection

Stations were selected along gradients of exposure from Outfall #1 to a distance of approximately 7 km northwest and 6 km southeast. Locations of proposed sampling stations were consistent with those sampled in Cycle Six with the following changes:

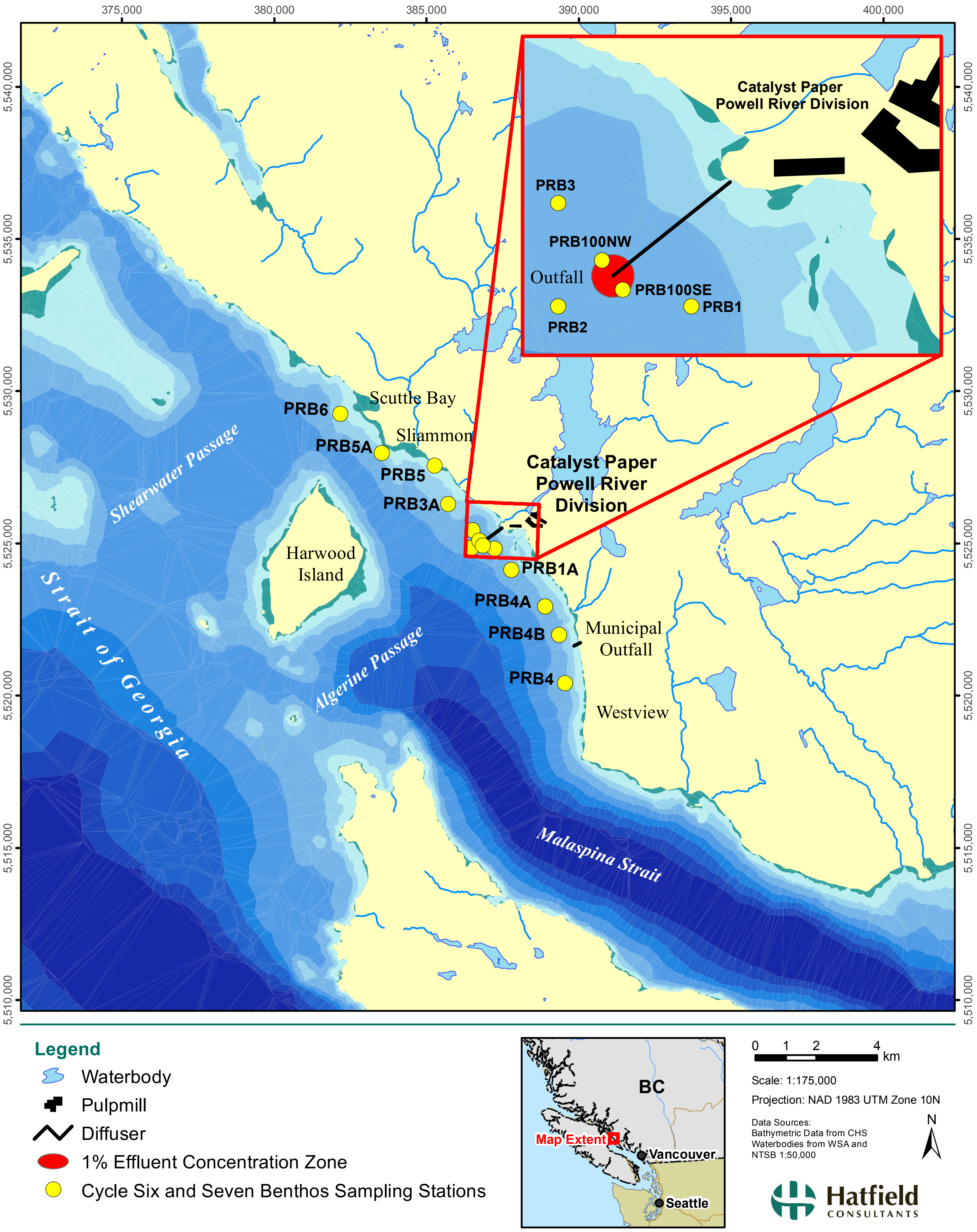
All stations were selected in consideration of known sediment transport patterns, particle size data, areas of contamination (e.g., log-booming grounds, mine tailings, sanitary shellfish closures) and current effluent dispersion patterns.

Table 4.1 summarizes the proposed sampling stations for the Powell River Cycle Seven program.

Table 4.1 Location, distance and depth of stations sampled during the benthic invertebrate survey, Powell River EEM Cycle Seven, March 30 to April 2, 2015.

Stations	ID	Easting	Northing	Distance (m)	Depth (m)	Date Sampled (yyyy/mm/dd)
Stations on Northwest Gradient						
Scuttle Bay	PRB6	382153	5529255	7,100	25	2015/03/31
Sliammon North	PRB5A	383434	5527934	4,600	54	2015/03/31
Sliammon South	PRB5	384844	5527170	3,000	39	2015/04/01
Powell River	PRB3A	385666	5526314	1,800	40	2015/04/01
Stations Nearest Diffuser						
North of Diffuser	PRB3	387203	5525628	320	47	2015/0401
Diffuser (NW100)	PRB100NW	386690	5525100	100	78	2015/03/30
Diffuser (SE100)	PRB100SE	386852	5524882	100	75	2015/03/30
South of Diffuser	PRB1	387678	5524652	280	47	2015/04/01
End of Diffuser	PRB2	387658	5524656	520	43	2015/04/01
Stations on Southeast Gradient						
North Westview	PRB4A	388892	5522951	2,700	61	2015/03/30
Breakwater	PRB1A	387678	5524652	1,200	38	2015/04/01
Westview WWTP	PRB4B	389359	5522066	4,000	52	2015/03/30
South Westview	PRB4	389580	5520379	5,900	64	2015/03/30

Figure 4.1 Location of benthic invertebrate sampling stations, Powell River EEM Cycle Seven, March 2015.



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4.2.1.2 Modifications to the Benthic Invertebrate Sampling Design

There were no changes in methodology relative to the EEM Cycle Seven Design Document (Hatfield 2014).

4.2.1.3 Sampling Procedure

Sampling Platform

Samples were collected from the MV *Lobo*, a custom-built, 10-m research vessel with dual, inboard diesel engines designed specifically for marine sediment and habitat-related work. The vessel was equipped with a hydraulic winch system, VHF radio, and all safety equipment required by Transport Canada. Station locations were determined using an on-board, differentially corrected Global Positioning System (GPS) integrated with digital nautical charts. Depth at sampling stations was recorded from the depth sounder.

Sample Collection

Sediment and benthos samples were collected using a stainless-steel, 30-cm Van Veen grab supplied by Searoamer Marine. The total surface area sampled by this dredge was 0.1 m^2 with a volume of 20 litres. Upon grab retrieval, the hinged doors were lifted and photographs of each benthic sample were collected. Small samples of sediment, to be analyzed for oxidation/reduction (redox) potential, total sulphides, total organic carbon and total nitrogen were removed by collecting two sediment volumes measuring 4 cm long by 4 cm wide by 2 cm deep from each grab sample. Following removal of the sediment samples, the grab was then opened and dumped into a large plastic tote, covered and labeled, taken to dock, and field sieved by Biologica Environmental Services (Biologica) using a stand equipped with 1 mm and 0.5-mm sieves.

An additional sediment grab was collected for particle size and chlorinated phenolic compounds. The top 2 cm of each grab were removed, composited, homogenized, and transferred to a 125-mL glass jar (one jar for each analysis). Chlorinated phenolics, serve as a tracer for long-term effluent exposure (historical, given its association with chlorine bleaching), particularly in the area of the mill.

Sample Sieving and Preservation

Following collection of all subsamples from each station, benthic invertebrate samples were immediately sieved onshore by Biologica. The contents of the sample were placed in a washtub with 0.5-mm stainless steel mesh screen on its bottom surface and sieved by placing the screened wash-pan in a specially designed holding shelf and gently washing the samples with seawater to allow the <0.5 mm fraction to pass through the mesh sieve. During this process, larger organisms were removed and placed in station labelled vials for identification. Following sieving, each subsample was placed in a 1-L plastic jar, appropriately labelled with the station and subsample number and preserved with 10% buffered formalin.

4.2.2 Taxonomic Analysis

Benthos samples were taken to the Biologica's laboratory in Victoria, BC, for sorting and taxonomic identification.

Invertebrate samples were sorted to 1-mm and 0.5-mm size fractions; all invertebrates retained in the 1-mm fraction were identified to the lowest possible taxonomic detail, typically species (Appendix A2).

Two samples from Powell River (PRB5-R2 and PRB5A-R2) were selected for resorting to determine sorting efficiency. As per EC recommendations, sub-sampling was done at the marine mill level, pooling the samples collected from the Powell River pulpmill, Port Alberni and Crofton, and selecting two random samples from each mill. Biologica re-sorted these random samples following the initial spot checks that are conducted on all sampled processed in the lab to meet efficiency requirements of >90%.

The precision and accuracy of Biologica's sub-sampling techniques were verified to ensure 20% precision and accuracy was measured; results are presented in Appendix A2.

4.2.3 Supporting Environmental Variables

4.2.3.1 Water Quality

Near-bottom water quality measurements were collected at each sampling station using a YSI-85 multi-parameter probe for the following variables.

- Dissolved oxygen (mg/L);
- Temperature (°C);
- pH; and
- Salinity (‰).

4.2.3.2 Sediment Quality

Two sediment samples were removed from each benthos replicate immediately upon collection. One sample (~30 ml) was measured immediately on board for:

- Total sulphides (mg/L); and
- Oxidation/reduction (redox) potential (Eh).

Redox potential and sulphides were analyzed in the field by Searoamer services using methods recommended by the BC Ministry of Environment's *Protocols for Marine Environmental Monitoring* (BCMOE 2002). Sulphide readings were taken using a ThermoOrion 290A plus pH/ion/mV meter and 9678BNWP probe; redox potential was analyzed using a VWR Symphony SP301 pH/ion/mV meter and a 9616BNWP probe by ThermoOrion.

The second sample was shipped to the ALS Environmental laboratory in Vancouver for the following analyses:

- Total organic carbon (%); and
- Total nitrogen (%).

An additional sample was taken from a separate 3rd grab and shipped to ALS for the following analyses:

- Particle size distribution; and
- Chlorinated phenolic compounds.

All containers and lids were labeled with the appropriate sample identification number. Matching sample identifications were applied to the primary data sheet for each station. Depth, geographic coordinates, photographs, and observations regarding sediment characteristics were recorded at each station.

4.2.4 Analytical Approach

4.2.4.1 Data Handling

Data were entered into an electronic spreadsheet by the consulting taxonomist, who checked for transcription errors. Taxonomic records were organized into adults (which included "adult" and "intermediate" classifications) and juveniles for Cycle Seven. Juvenile taxa were reported separately from adult taxa for all samples and stations as required.

Density

All count data were multiplied by the following density factor (DF) in order to estimate the number of organisms per m^2, as required for electronic reporting for the national database (Appendix A2):

$$DF = \frac{1\ m^2}{\text{(grab sample area – area of subsamples taken for sediment chemistry)}}$$

$$DF = \frac{1}{[0.1\ m^2\text{(grab sample area)} - 3 \times 0.0004\ m^2\text{(redox)} - 1 \times 0.0004\ m^2\text{(TOC/TN)}]}$$

$$DF = 10.13$$

Individual densities were reported per replicate and station densities were calculated using the average of all replicates.

Total adult taxonomic richness (i.e., to family level and to lowest possible taxonomic level) was also calculated for each sample.

4.2.4.2 Biotic Indices

Three biotic indices were calculated to describe benthic community composition for each area, and compared among stations. These indices were calculated using average taxon density data for each station. Descriptions of each biotic index area are presented below and further described in the EEM Technical Guidance Document (Environment Canada 2010).

Evenness Index

Evenness can be quantified for each station as presented in Smith and Wilson (1996). The index takes into consideration the abundance of each taxon in proportion to total abundance, and the taxonomic richness at the station. Evenness is calculated as:

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

where: E = Evenness;

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

S = number of taxa in the sample.

Simpson's Diversity Index

Simpson's diversity can be calculated for each station as presented in Krebs (1985). The 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 is calculated as:

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

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.

Bray-Curtis Dissimilarity Coefficients

The Bray-Curtis dissimilarity coefficient is a distance measurement that reaches a maximum value of "1" for two sites that are entirely different and a minimum of "0" for two sites that possess identical descriptors (Bray and Curtis 1957). Bray–Curtis dissimilarity coefficients were calculated to compare the degree of similarity between individual stations and a reference median. Dissimilarity coefficients for the reference median and individual stations were calculated using SYSTAT 10 (SPSS Inc. 2000). The Bray-Curtis index is calculated as:

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

where: B-C = Bray-Curtis distance between sites 1 and 2;

y_{i1} = count for species i at site 1;

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

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

Given the Powell River EEM survey used a gradient design, no true reference stations were available for calculation of a reference median for comparison. Therefore, the reference median was calculated for Bray-Curtis comparisons using two furthest stations from the mill (i.e., PRB6 and PRB4).

4.2.4.3 Statistical Analysis

Analyses were conducted using Excel 2014 and R version 2.14.1.

Regressions

Linear regression was used to determine if significant linear relationships existed among benthic community metrics and exposure gradients. In this study, the exposure gradient was defined in two ways: as absolute distance from the pulpmill diffuser; and a carbon:nitrogen (C/N) ratio, which provides an indication of the ratio of organic matter present in sediments that was derived from terrestrial sources (such as pulpmill solids) or marine sources (Macdonald and Crecelius 1994). Supporting environmental variables also were examined against these exposure gradients using regression analysis.

Residual plots from regressions were evaluated to ensure that assumptions of the regression model were met. If data met these assumptions, regressions were conducted using $\log_{10}$-transformed variables to determine if the fit of the model improved. If the fit had improved, results for $\log_{10}$-transformed variables were reported but if that fit did not improve, results from untransformed variables were reported. If $\log_{10}$-transformed data still failed to meet assumptions of model, regressions were conducted using ranked data.

All tests were conducted at a significance level of $\alpha = 0.10$.

Determination of Effects

Results of regression analyses were used to determine whether there are effects on benthic invertebrates along the exposure gradient, where a statistical effect was defined as a statistically significant relationship between a metric and distance or a metric and an effluent exposure indicator.

The magnitude and direction of observed effects were calculated and compared to the EEM effect criterion for a biologically (rather than simply statistically) significant effect of ±2 standard deviations from the reference mean for suitable “reference” stations (i.e., the two gradient stations furthest from the mill and were also used as reference stations in Cycle Three).

In this gradient-based study, which used a regression-based rather than analysis-of-variance-based approach to assess effect, a relationship between a benthic invertebrate community metric and distance from the pulpmill diffuser with a correlation coefficient (r^2) of at least $|0.50|$ was considered to be biologically significant, which was equivalent to ±2 times the standard deviation of the reference mean (Environment Canada 2010).

Correlations

Spearman’s rank correlations were used to evaluate the relationships between benthic community metrics and supporting environmental variables. Correlations greater than r_s of $|0.503|$ for $n = 13$ (number of stations) ($\alpha = 0.10$) were indicative of statistically significant relationships. Moderate correlations were defined as those ranging from $|0.50|$ to $|0.75|$. Strong correlations were defined as those ranging from $|0.75|$ to $|1.00|$.

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.

Power Analysis

Post-hoc power analysis was conducted to verify the ability of regression analyses to detect an effect, which was defined as a relationship with a correlation coefficient (r) of at least |0.707| (Environment Canada 2010, Cohen 1988). Regression analyses were considered to have sufficient power when P≥ 0.90. Analyses were only completed for insignificant relationships to verify that the design had sufficient statistical power.

Power analysis was conducted using G*POWER (Faul and Erdfelder 1992).

4.3 RESULTS

Results of the benthic invertebrate community survey are presented below (Table 4.2 and Figure 4.2 to Figure 4.4); raw benthic data are presented in Appendix A2.

Table 4.2 Benthic invertebrate community statistics, Powell River EEM Cycle Seven, March 2015[1].

Station	Diffuser Distance (m)	Mean Density (#/m^2)	Total Richness (# families)	Simpson's Diversity	Evenness	Bray-Curtis
Stations on Northwest Gradient						
PRB6	7,100	11,330	49	0.780	0.093	0.240
PRB5A	4,600	12,900	57	0.841	0.110	0.795
PRB5	3,000	11,015	48	0.832	0.124	0.277
PRB3A	1,800	12,905	49	0.896	0.197	0.337
Stations Nearest Diffuser						
PRB3	320	3,870	35	0.929	0.401	0.611
PRB100NW	100	1,650	23	0.827	0.252	0.692
PRB100SE	100	5,885	38	0.859	0.186	0.486
PRB1	280	6,665	51	0.936	0.306	0.631
PRB2	520	6,915	43	0.870	0.179	0.503
Stations on Southeast Gradient						
PRB4A	2,700	2,300	41	0.928	0.338	0.632
PRB1A	1,200	6,730	39	0.872	0.200	0.557
PRB4B	4,000	2,220	42	0.868	0.180	0.607
PRB4	5,900	3,705	50	0.880	0.167	0.403

[1] Adult organisms only (which includes intermediates).

4.3.1 Density and Taxa Richness

Benthic invertebrate density was highly variable among and within stations, with densities notably higher in northwest stations compared to near-field and southeast stations (Figure 4.2). Station densities ranged from 1,650 organisms/m^2 at PRB100NW (within the predicted zone of 1% effluent), to 12,905 organisms/m^2 at PRB3A (northwest of the diffuser). Within the predicted zone of 1% effluent dispersion (i.e., stations PRB100NW and PRB100SE), densities were 1,650 and 5,885 organisms/m^2, respectively. In Cycle Seven northwest stations had densities higher than those observed at the same stations in Cycle Six while near-field and southwest stations had similar or lower densities. In addition, the two stations closest to the diffuser (PRB100NW and PRB100SE) had densities below the Cycle Seven program median density of 6,776 organisms/m^2 (Table 4.2).

Taxa richness varied among stations, ranging from a low of 23 taxa at PRB100NW to a high of 51 taxa at PRB1, and generally increased with distance from the diffuser (Table 4.2, Figure 4.3). In Cycle Seven all stations had a total richness near or slightly lower than those observed at the same stations in Cycle Six.

Lower densities and taxa richness of juvenile invertebrates versus adults were observed at all stations (Table 4.3); however, densities and richness were higher than those observed in Cycle Six, with spatial patterns of density and richness similar to those observed for adult organisms.

4.3.2 Evenness Index and Simpsons Diversity

Evenness ranged from 0.093 at station PRB6 to 0.401 at station PRB3 and generally increased in a northwest to southeast gradient (Figure 4.4). These results contrast with those of Cycle Six, where evenness was lowest at the two stations closest to the diffuser and generally increased with absolute distance an C:N ratio.

Simpson’s diversity index ranged from 0.780 at station PRB6 to 0.936 at station PRB1 and was generally consistent among stations (Figure 4.5) and similar to those observed in Cycle Six.

4.3.3 Bray-Curtis Index

Using the two furthest stations from the pulpmill as a reference median (PRB6 and PRB4), dissimilarity was highest at stations PRB5A with the invertebrate community becoming increasing dissimilar along a northwest to southeast gradient (Figure 4.6).

Figure 4.2 **Mean density (organisms/m^2) per station, Powell River EEM Cycle Seven, March 2015.**

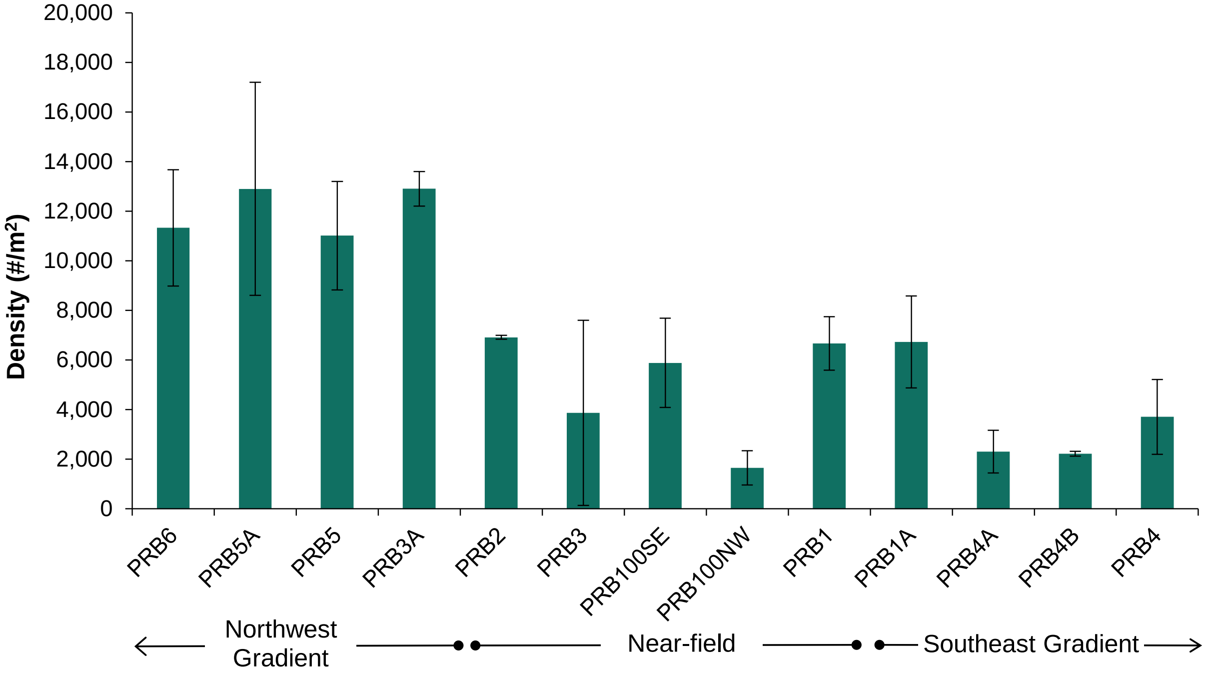

Figure 4.3 **Total taxa richness per station, Powell River EEM Cycle Seven, March 2015.**

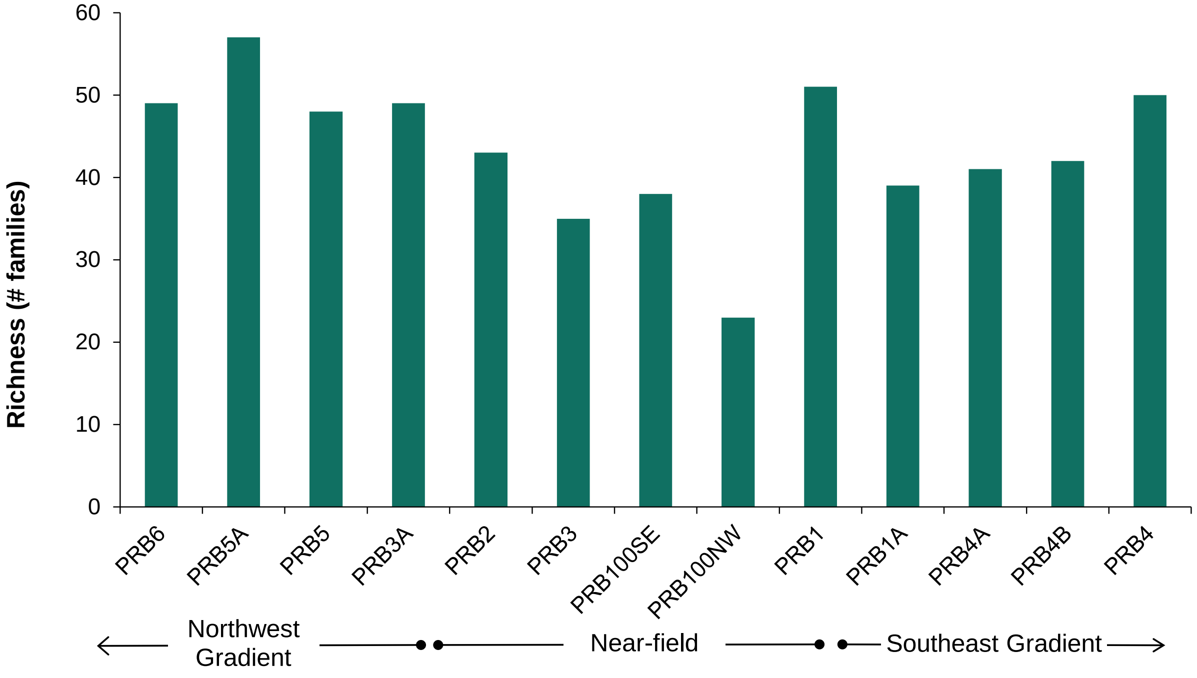

Figure 4.4 Benthic invertebrate community evenness, Powell River EEM Cycle Seven, March 2015.

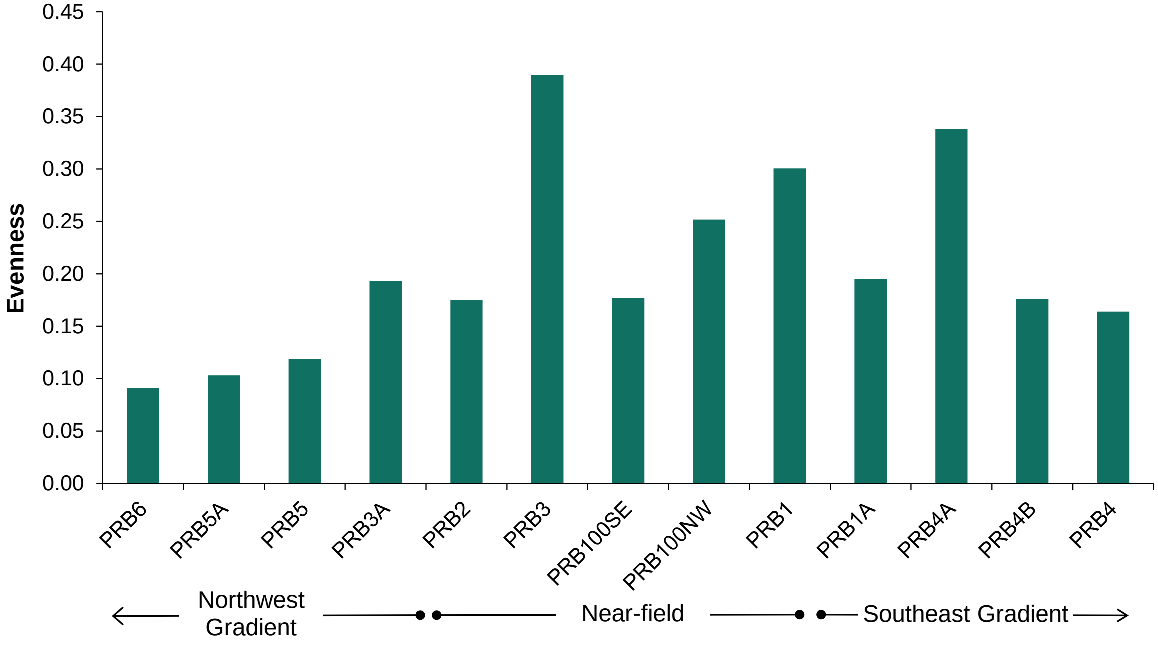

Figure 4.5 Benthic invertebrate community diversity (Simpson’s index), Powell River EEM Cycle Seven, March 2015.

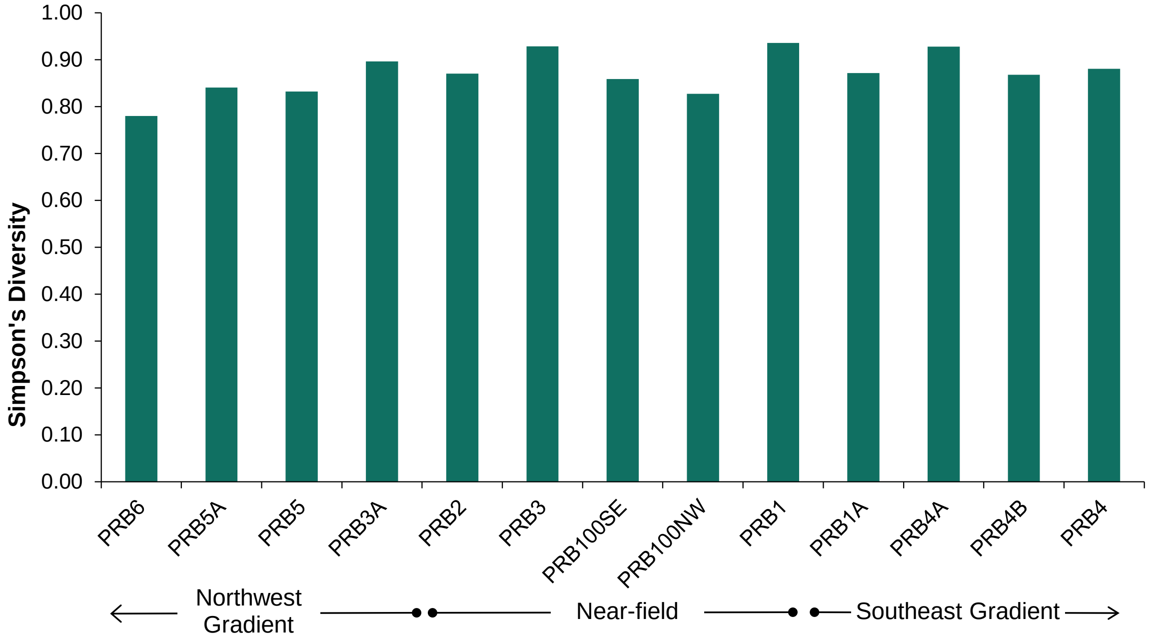

Figure 4.6 Benthic invertebrate community Bray-Curtis Index, Powell River EEM Cycle Seven, March 2015.

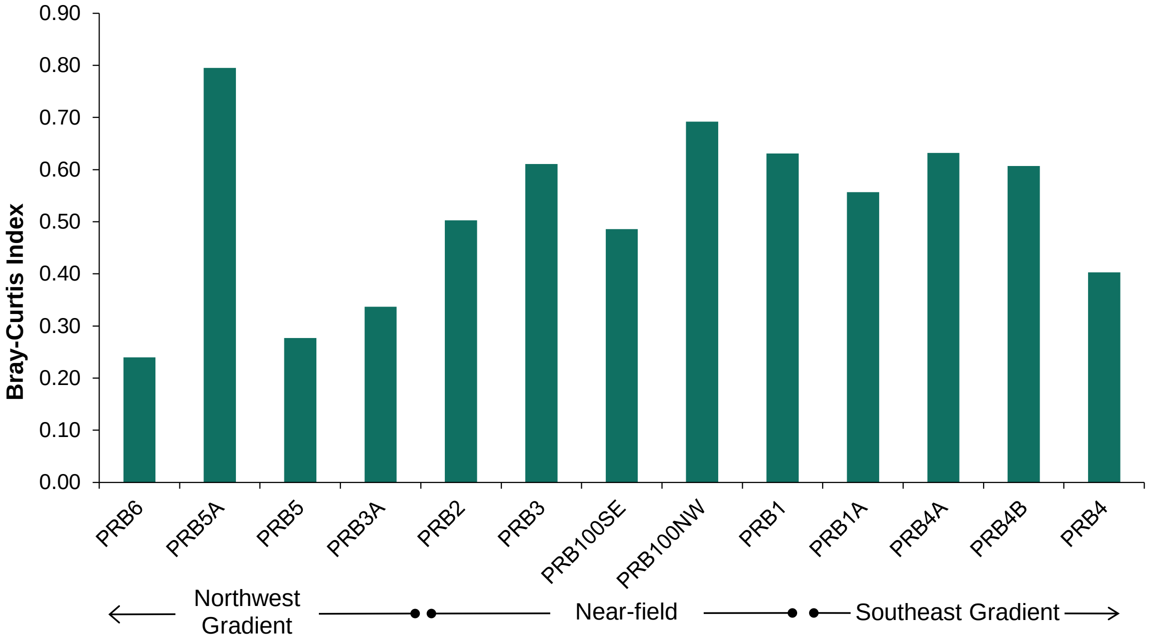

Table 4.3 Juvenile invertebrate density and taxa richness, Powell River EEM Cycle Seven, March 2015.

Station	Diffuser Distance (m)	Mean Density (#/m^2)	Total Richness (# families)
Stations on Northwest Gradient			
PRB6	7,100	6,860	18
PRB5A	4,600	9,335	41
PRB5	3,000	5,555	23
PRB3A	1,800	4,010	19
Stations Nearest Diffuser			
PRB3	320	1,060	16
PRB100NW	100	280	7
PRB100SE	100	1,360	18
PRB1	280	1,190	20
PRB2	520	725	17
Stations on Southeast Gradient			
PRB4A	2,700	795	13
PRB1A	1,200	1,525	19
PRB4B	4,000	1,175	16
PRB4	5,900	975	23

4.3.4 Community Composition

Table 4.4 presents the most abundant adult taxa for each station with taxa listed in decreasing order of density for the entire Cycle Seven Program; these taxa comprised approximately 75% of the total density. In Cycle Seven, the Phironid, *Phoronis psammophila*, was the most abundant taxon and comprised 11.6% of the total density across all stations; however, this taxon was only dominant at several northwest and southeast gradient stations and was either absent or comprised a very small proportion of the near-field benthic community. This differed from Cycle Six where the sedentary polychaete, *Mediomastus californiensis* was the most abundant taxa (11.6%), and *Phoronis psammophila* comprised only 4.7% of the total density; however, similar to Cycle Seven, *Phoronis psammophila* not dominant in the near-field area. In Cycle Seven, *Mediomastus californiensis* was the second most abundant taxon (9.2%) and, similar to Cycle Six, was dominant in both gradient and near-field stations.

Polychaete worms comprised the largest portion of organisms in all stations, with the exception of PRB6, PRB5, PRB3A (northwest gradient stations) and PRB4B (which were all dominated by either the phironids, *Phoronis psammophila or Phoronopsis harmeri*), and comprised four of the five most abundant taxa. 15 sedentary and nine errant polychaete taxa comprised 40.0% and 15.5% of the total abundance, respectively (Table 4.4). The three most abundant, non-polychaete taxa were Phoronids (horseshoe worms), the mollusk, *Axinopsida serricata*, and the crustacean *Euphilomedes producta*, which comprised 14.6, 2.0 and 1.5% of the total density of all stations (Table 4.4). As mentioned previously, the horseshoe worms were generally found in gradient stations further from the diffuser while the mollusk and crustacean were found in both gradient and nearfield stations.

Other abundant taxa exhibited variable, yet low, proportions among stations sampled for Powell River, ranging from 0.5 to 2.5% (Table 4.4); many of these taxa were found at nearly all stations (both near-field and gradient). However, several taxa including polychaete worms of the families Thyasiridae and Lumbrineridae were abundant in near-field stations and either absent or found in low numbers at other stations.

4.3.4.1 Cluster Analysis

A dendrogram clustering stations together according to their densities and taxa was calculated using the Bray-Curtis dissimilarity index (Figure 4.7). Similar to Cycle Six, there were two major clusters visible in Cycle Seven with a clear distinction between stations northwest and southeast of the diffuser.

Two of the three most impacted stations, with respect to sediment conditions indicative of the historic fibre mat (PRB2 and PRB3), clustered with other near-field stations while PRB1 clustered with northwest gradient stations; these three stations were also the closest stations to the diffuser during Cycle Three. Stations in the northwest gradient formed another distinct sub-cluster with the exception of PRB5A. Stations in the southeast gradient and it close proximity with the municipal discharge also grouped together based on gradient direction. Distances between individual stations ranged from approximately 0.25 to 0.70.

Table 4.4 Total and mean densities of the most abundant taxa in the Powell River EEM Cycle Seven benthic invertebrate community survey (76% of total abundance), March 2015.

Group	Family	Taxon Name	PRB6	PRB5A	PRB5	PRB3A	PRB3	PRB100NW	PRB100SE	PRB1	PRB2	PRB1A	PRB4A	PRB4B	PRB4	Total Average Densities	Percent of Total	Cumulative Percent
			7,100 m	4,600 m	3,000 m	1,800 m	320 m	100 m	100 m	280 m	520 m	1,200 m	2,700 m	4,000 m	5,900 m			
PHOR	Phoronidae	*Phoronis psammophila*	**2,150**	0	**3,975**	**2,365**	0	0	245	40	40	125	**285**	**705**	**270**	10,200	11.6	11.6
POSE	Capitellidae	*Mediomastus californiensis*	370	**1,880**	**575**	585	**300**	**280**	**1,185**	**710**	**920**	**605**	40	20	**645**	8,115	9.2	20.8
POSE	Capitellidae	*Decamastus nr. gracilis*	**750**	10	**645**	**1,065**	100	**300**	**495**	60	**790**	**840**	**245**	75	**235**	5,610	6.4	27.2
POER	Syllidae	*Exogone lourei*	80	**840**	475	**905**	200	0	280	90	160	**1,300**	90	**125**	170	4,715	5.4	32.5
POSE	Oweniidae	*Owenia fusiformis*	485	0	340	**1,440**	0	0	**620**	0	**1,200**	140	0	0	**360**	4,585	5.2	37.7
POSE	Oweniidae	*Galathowenia oculata*	**1,210**	0	**905**	**800**	40	40	**430**	0	165	60	0	15	**295**	3,960	4.5	42.2
POSE	Capitellidae	*Mediomastus sp.*	0	**3,800**	0	0	0	0	0	0	0	0	0	0	120	3,920	4.4	46.7
PHOR	Phoronidae	*Phoronopsis harmeri*	**2,690**	0	0	0	0	0	0	0	0	0	0	0	0	2,690	3.1	49.7
POER	Lumbrineridae	*Lumbrineris luti*	120	0	280	340	**440**	**240**	105	0	170	220	**115**	95	10	2,135	2.4	52.1
MOBI	Thyasiridae	*Axinopsida serricata*	280	0	180	240	**300**	**280**	35	0	120	80	**125**	45	110	1,795	2.0	54.2
POER	Syllidae	*Typosyllis heterochaeta*	0	**470**	80	140	80	0	210	65	40	105	10	**110**	40	1,350	1.5	55.7
CROS	Philomedidae	*Euphilomedes producta*	0	0	200	520	160	**100**	0	0	240	90	25	0	10	1,345	1.5	57.2
POER	Pholoidae	*Pholoides asperus*	0	180	50	160	0	0	40	**730**	0	65	0	0	50	1,275	1.4	58.7
POSE	Chaetopteridae	*Spiochaetopterus costarum*	260	80	**520**	50	40	0	40	80	40	0	10	**135**	0	1,255	1.4	60.1
POSE	Maldanidae	*Euclymene nr. zonalis*	0	0	60	80	210	0	160	40	**245**	195	60	70	70	1,190	1.4	61.5
MOGA	Columbellidae	*Astyris gausapata*	205	0	200	160	80	0	40	175	40	0	70	50	30	1,050	1.2	62.7
POER	Glyceridae	*Glycera nana*	60	80	70	130	55	25	25	40	190	120	75	70	60	1,000	1.1	63.8
POSE	Spionidae	*Boccardiella hamata*	0	0	200	400	**240**	0	0	0	40	0	0	0	110	990	1.1	64.9
POER	Lumbrineridae	*Lumbrineris cruzensis*	40	0	20	30	150	80	50	65	**260**	155	75	10	30	965	1.1	66.0
POSE	Spionidae	*Boccardia pugettensis*	0	0	120	240	100	40	80	80	0	100	60	**80**	45	945	1.1	67.1
POSE	Spionidae	*Prionospio multibranchiata*	480	0	0	80	80	0	0	195	0	40	10	0	45	930	1.1	68.1
POSE	Spionidae	*Prionospio lighti*	**680**	0	40	40	40	0	40	40	0	0	0	0	30	910	1.0	69.2
POER	Syllidae	*Sphaerosyllis californiensis*	0	**850**	0	0	0	0	0	0	0	0	0	0	0	850	1.0	70.1
POSE	Maldanidae	*Euclymeninae indet.*	0	210	80	25	0	40	160	40	40	**200**	0	0	10	805	0.9	71.0
MOBI	Pholadidae	*Xylophaga washingtona*	0	0	0	0	**600**	0	0	40	0	40	50	0	20	750	0.9	71.9
POSE	Terebellidae	*Polycirrus sp. A*	10	0	0	40	200	0	20	120	160	40	40	30	80	740	0.8	72.7
POER	Syllidae	*Opisthodonta uraga*	0	260	0	40	0	0	140	**260**	0	0	0	0	0	700	0.8	73.5
POER	Dorvilleidae	*Protodorvillea gracilis*	0	140	0	0	0	40	**305**	120	40	40	0	0	0	685	0.8	74.3
POSE	Trichobranchidae	*Terebellides californica*	0	0	0	40	0	0	0	0	120	160	**250**	85	10	665	0.8	75.1
POSE	Terebellidae	*Polycirrus sp. complex*	60	200	0	0	0	80	60	90	40	80	10	0	30	650	0.7	75.8

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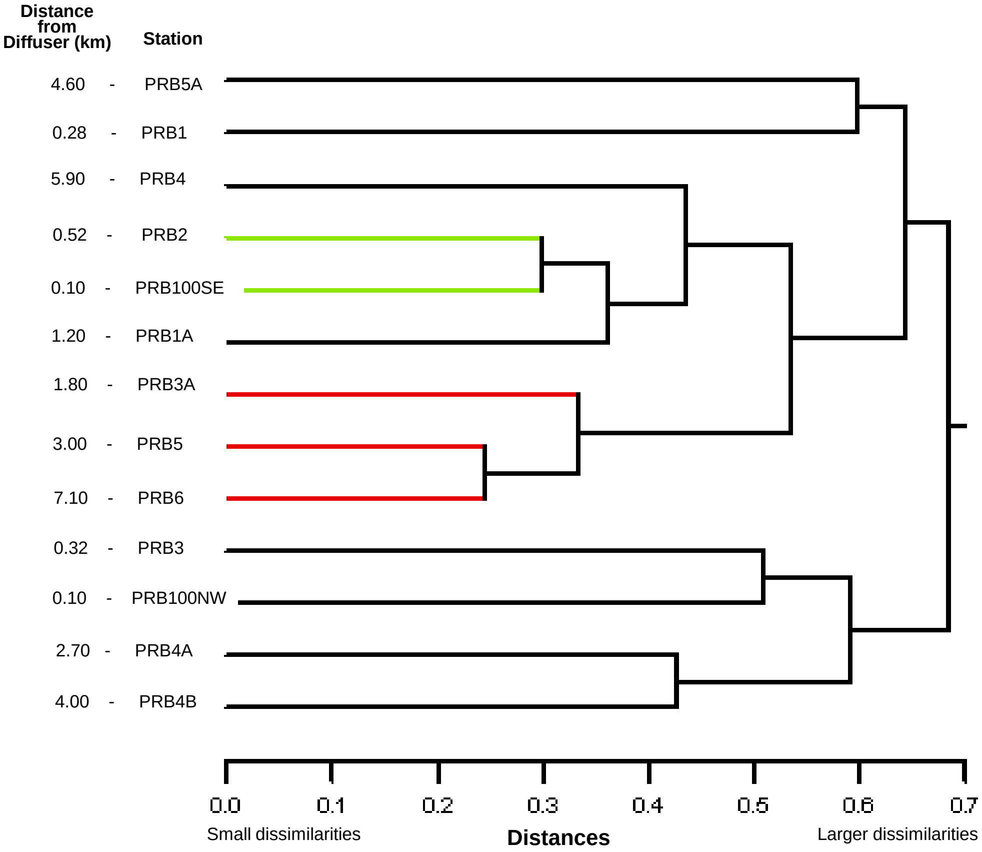
Figure 4.7 **Dendrogram describing similarities in benthic community composition, Powell River EEM Cycle Seven, March 2015.**



4.3.5 Statistical Analysis

4.3.5.1 Regression Analysis

A summary of the relationships between benthic invertebrate metrics and absolute distance from the diffuser and C/N ratio are provided in Table 4.5 and Table 4.6. Scatter plots of each regression are presented in Figure 4.8 and Figure 4.9.

No significant relationship was observed between absolute distance from the pulpmill diffuser and density or Bray-Curtis Index (Table 4.5); however, a significant relationship was observed between absolute distance and taxa richness (p=0.040), evenness (p=0.009) and between absolute distance and Simpson's Diversity (p=0.090). When the pulpmill exposure gradient was defined using the C:N ratio, an indicator of terrestrial organic inputs and related to absolute distance from the diffuser, a significant relationship was observed for evenness (p=0.30) (Table 4.6).

The EEM effects criterion was defined as a biologically significant relationship with a correlation coefficient (r) of at least |0.707|, which is equivalent to ±2SD of the reference mean (Environment Canada 2010). Based on this criterion, no benthic metrics showed a gradient effect with either absolute distance or C:N. (Table 4.6 and Table 4.5).

4.3.5.2 Power Analysis

The statistical power of the gradient regressions was 0.96, above the recommended level of P=0.90, indicating sufficient power to detect the target effect size for this survey (Appendix A4).

Table 4.5 Relationships between benthic invertebrate metrics and absolute distance from the pulpmill diffuser, Powell River EEM Cycle Seven, March 2015.

Effect Endpoint	p-value for F-test	Regression Equation1	Effect?	Direction of Effect	r2	Critical Effect1
Density	0.330	Dens =5530.2+512.2*Dist	No	-	0.005	No
Richness	**0.040**	Rich =38.28+2.13*Dist	**Yes**	↑ with distance	0.270	No
Evenness	**0.009**	Even = 11.84-0.69*Rank Dist	**Yes**	↓ with distance	0.430	No
Diversity	**0.090**	Dive = 0.89-0.009*Dive	**Yes**	↓ with distance	0.160	No
Bray-Curtis	0.220	Bray-Curtis = 0.58-0.026*Dist	No	-	0.060	No

Bolded entries represent statistically significant relationships (α=0.10)

R^2 = coefficient of determination.

[1] Critically significant regression effect $r^2 \geq 0.50$

Table 4.6 Relationships between benthic invertebrate metrics and C/N ratio, Powell River EEM Cycle Seven EEM, March 2015.

Effect Endpoint	p-value for F-test	Regression Equation1	Effect?	Direction of Effect	r2	Critical Effect1
Density	0.590	Dens =8017.3-37.71* C:N	No	-	0.000	No
Richness	0.200	Rich =1.95+0.70*C:N	No	-	0.070	No
Rank Evenness	**0.030**	Rank Even=2.8+0.60*Ranked C:N	**Yes**	↑ with distance	0.300	No
Diversity	0.120	Dive = 0.83+.0001*Dive	No	-	0.130	No
Bray-Curtis	0.340	Bray-Curtis = 0.43+0.002*C:N	No	-	0.001	No

Bolded entries represent statistically significant relationships (α=0.10)

R^2 = coefficient of determination.

[1] Critically significant regression effect $r^2 \geq 0.50$

Figure 4.8 **Benthic invertebrate scatter plots by distance, Powell River EEM Cycle Seven, March 2015.**

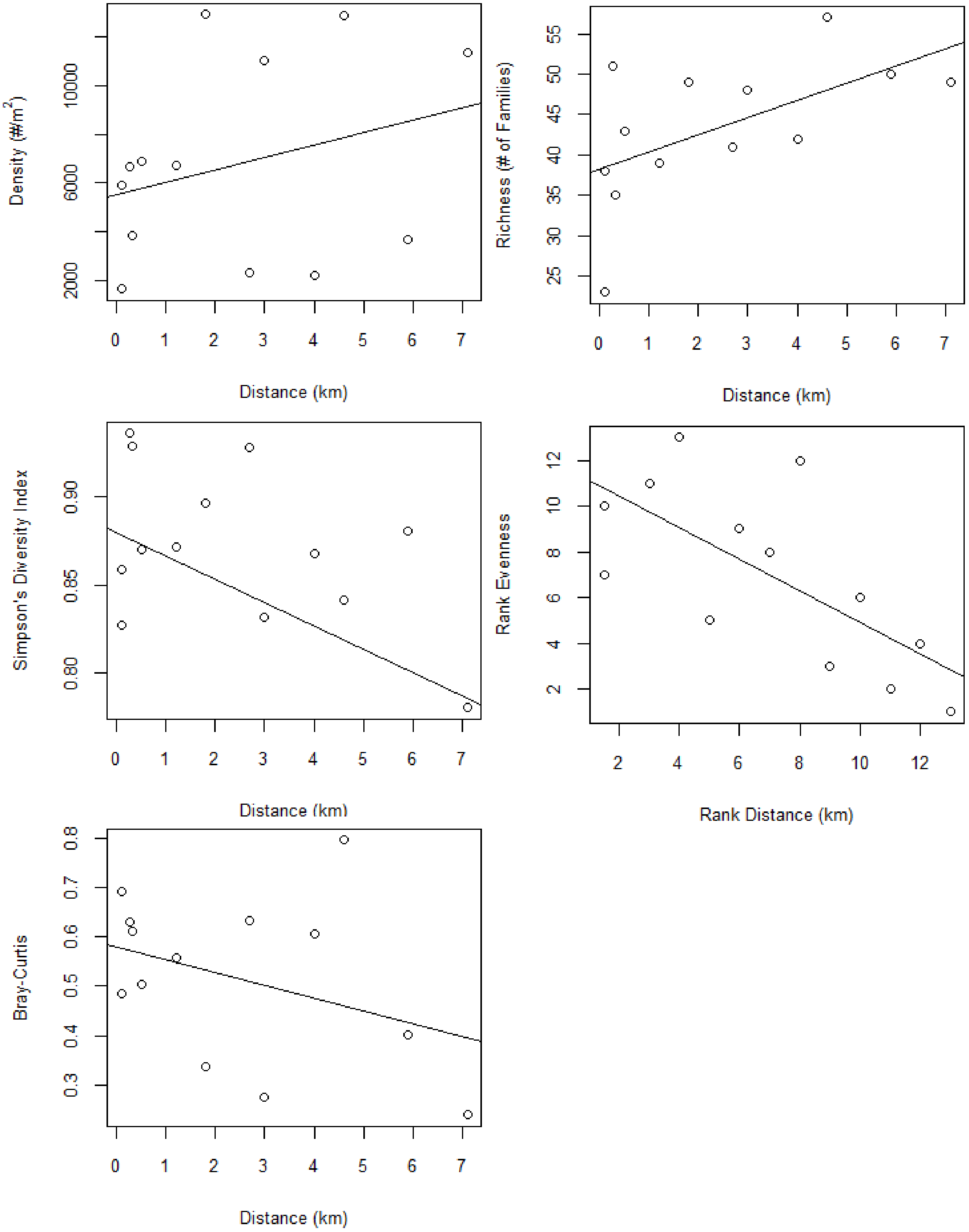
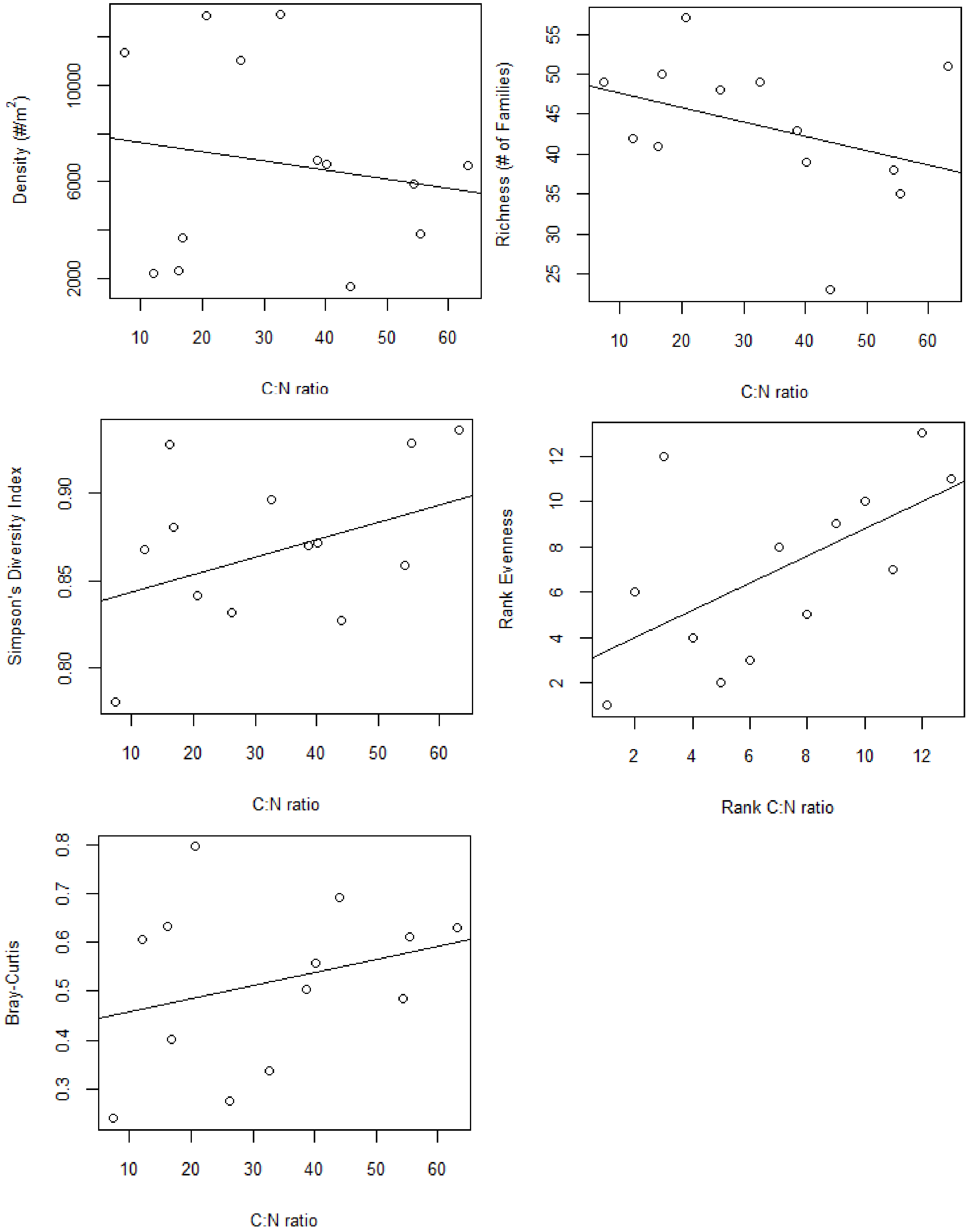


Figure 4.9 **Benthic invertebrate scatter plots by C/N ratio, Powell River EEM Cycle Seven, March 2015.**



4.3.6 QA/QC Verifications

All QA/QC reports are presented in Appendix A2. The estimated sorting efficiency based on the resorted samples was 98.07%, which passed the required >90% efficiency.

QA/QC results for the accuracy of the splitting technique showed a sub-sampling error ranging from 7.3 to 11.7% across the three marine mills (one to two stations from each of the three mills for a total of 4 stations), with an average sub-sampling error of 9.2%, which is within the 20% error allowed. Of the two randomly selected samples from Powell River, average sub-sampling error was 7.3%.

4.4 SUPPORTING EVIRONMENTAL VARIABLES

4.4.1 Water Quality

In situ water samples were taken at near-bottom depths (~2 m off the bottom) at each station. Table 4.7 presents water variables measured in the field during the benthic invertebrate survey, taken at near-bottom depths.

Table 4.7 Near-bottom water quality at stations sampled for the Powell River EEM Cycle Seven benthic invertebrate survey, March 2015.

Station	Sample Depth (m)	DO (mg/L)	Temp (°C)	Salinity (%)
Stations on Northwest Gradient				
PRB6	47	6.1	9.2	29.3
PRB5A	56	6.0	9.2	29.9
PRB5	41	7.3	9.2	29.1
PRB3A	43	6.7	9.2	30.0
Stations Nearest Diffuser				
PRB3	41	6.7	9.3	29.6
PRB100NW	60	6.6	9.3	29.6
PRB100SE	60	7.0	9.2	29.1
PRB1	38	6.9	9.3	29.6
PRB2	60	6.7	9.3	29.6
Stations on Southeast Gradient				
PRB4A	60	6.3	9.7	29.6
PRB1A	50	6.6	9.2	29.4
PRB4B	54	6.6	9.3	29.6
PRB4	60	6.5	9.3	29.6

Temperatures for all stations were similar ranging from 9.2ºC at PRB4B to 9.7 ºC at PRB3. Little variation was also observed in dissolved oxygen (DO) concentrations and salinity, ranging from 6.0 to 7.3 mg/L and 29.1 to 30.0%, respectively. In situ measurements did not appear to correlate with distance from the diffuser. Trends in water quality measurements across stations were relatively different compared to Cycle Six, with near-bottom tempers, on average, 2℃ warmer and salinity on average 2% greater; In situ measurements were more similar to Cycle Three results.

4.4.2 Sediment

Sediment sub-samples were collected from benthic grabs and from one additional grab at each station at the same depths as the benthic samples and analyzed for particle size, total organic carbon, total nitrogen, chlorinated phenolics, redox potential and total sulphides. Results of the sediment quality survey are presented below; raw data are presented in Appendix A3.

4.4.2.1 Particle Size and Moisture Content

Particle size distributions of composited sediment collected at stations near Powell River are presented in Figure 4.10. Photographs of representative sediment samples are presented in Figure 4.11 to Figure 4.14. Sediments at all stations were comprised predominantly of sand ranging from 33.0% at PRB5A to 96.1% at PRB6 and to a lesser extent by silt ranging from 6.2% at PRB100100SE to 46.2% at PRB5A. The proportion of clay was low at all stations with the exception of PRB5A (20.8%). Gravel was also low at all stations, although higher proportions were found in near-field and southwest stations compared to northwest stations. In general, the proportion of harder substrates with increased gravel content and decreased silts and clays increased in a northwest to southwest gradient. In addition

In Cycle Seven, substrate composition was generally similar to Cycle Six (Hatfield 2013) although the proportion of softer substrates (i.e., silt and clay) increased slightly in northwest stations and decreased slightly in near-field and southeast stations. Organic debris and wood chips were not as prevalent during Cycle Seven and were only observed in near-field stations and in relative small proportions. In addition, substrates in both Cycle Six and Seven were notable coarser and denser relative to Cycle Three making it increasing difficult to retrieve consistently full grabs. Dense coarse substrates prevent bottom grabs from fully closing causing sediment to spill out during retrieval.

Figure 4.10 Particle size distribution of sediments, Powell River EEM Cycle Six, March 2012.

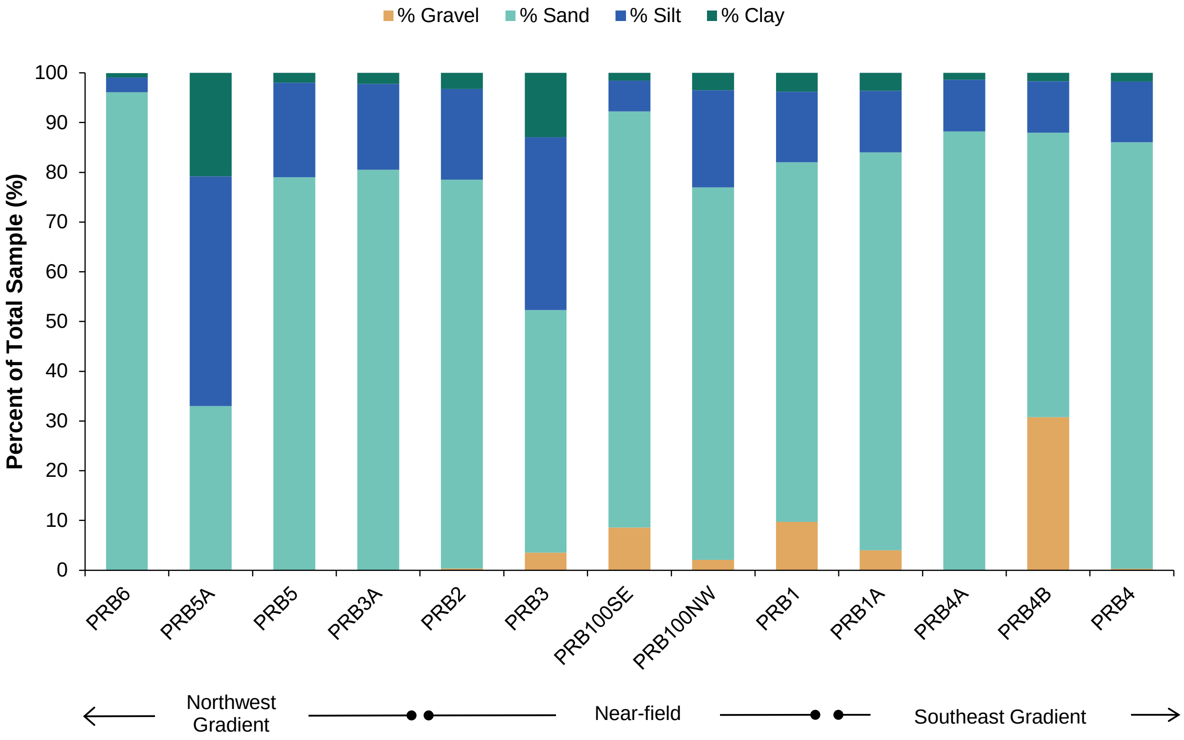


Figure 4.11 **Substrate at PRB1 (note wood fibre in sediment), Powell River EEM, March 2015.**

Figure 4.12 **Substrate at PRB100SE (sand and gravel content), Powell River EEM, March 2015.**

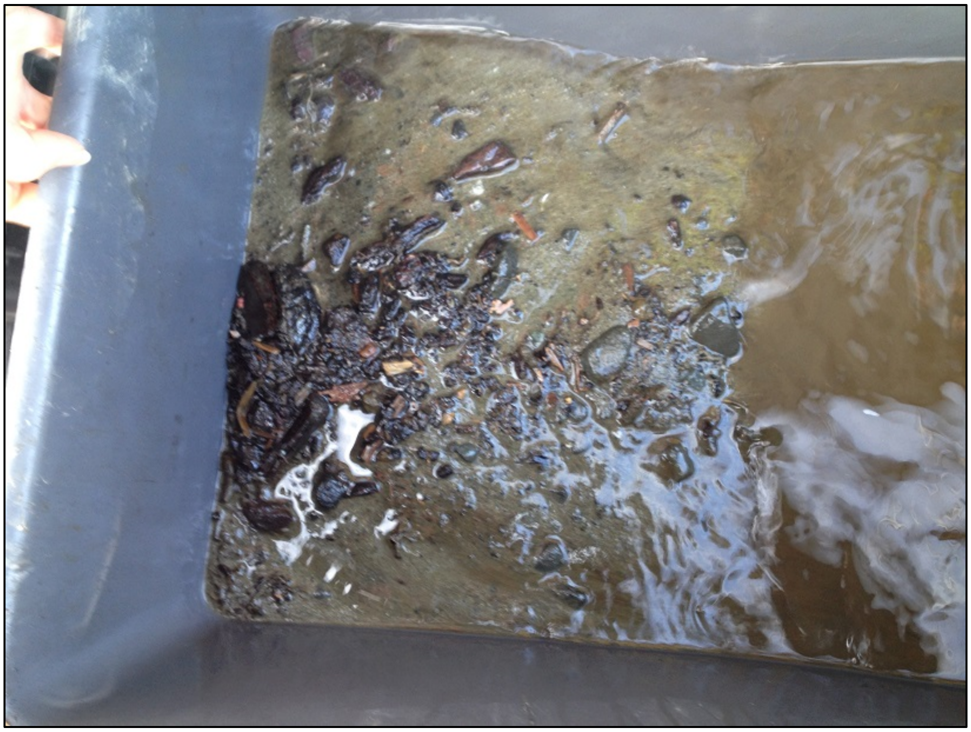


Figure 4.13 Substrate at PRB6 (note sandy substrate and absence of wood fibre), Powell River EEM, March 2015.

Figure 4.14 Substrate at PRB4 (note sand composition and worm casings), Powell River EEM, March 2015.

4.4.2.2 Total Organic Carbon and C:N Ratio

TOC, TN, and C/N ratios at each station are presented in Table 4.8; raw data for each replicate grab are presented in Appendix A3.

TOC content in sediments was generally highest at near-field stations; however, TOC content at station PRB100SE remained comparatively low and more representative of the closest gradient stations (Table 4.8). The highest TOC value (12.7%) was recorded at the historical near-field station PRB3. In addition, TOC content at PRB5A was comparatively high and more representative of near-field stations; however, notable proportions of decomposed glass-sponges were observed in these grab samples and likely attributed to the higher TOC content. TOC values among near-field stations ranged from 2.3 to 12.7%. TOC decreased rapidly in the remaining gradient stations ranging from 0.16% at PRB6 (furthest station from the diffuser) to 0.69% at station PRB4 (Table 4.8). Since Cycle Three, TOC content has continually decreased at stations closest to the diffuser, and has remained low at all others (Figure 4.15).

TN content in sediments followed similar patterns as TOC; samples containing the highest TOC also exhibited the highest TN. TN ranged from 0.04 to 0.23% at sites closest to the mill and from 0.02 to 0.327% (station PRB5A containing decomposed glass-sponges) at the remaining gradient stations (Figure 4.10).

C/N ratios for stations within the historical near-field area ranged from 44.12 to 63.08 with the remaining gradient stations ranging from 7.27 to 40.16 (Table 4.9 and Figure 4.10). All stations exhibited high C/N ratios relative to expected background concentrations of near 6.0 for marine mills, suggesting terrestrial carbon sources are present in sediments (Macdonald et al. 1991), especially in the vicinity of the diffuser where C/N ratios were in excess of 30. Evidence of the historical fibre mat in the immediate area around the Powell River diffuser remains even though TOC content continues to decrease (Figure 4.10). However, nearly all stations decreased C/N ratio relative to Cycle Six, suggesting continued improved of sediment quality.

Table 4.8 Mean organic carbon and nitrogen concentrations, C/N ratio, and oxidative-state variables in sediments, Powell River Cycle Seven, March 2015.

Stations	ID	Total Organic Carbon (%)	Total Nitrogen (%)	C/N Ratio	Redox Potential (mV)	Total Sulphides (µmol)
Stations on Northwest Gradient						
Scuttle Bay	PRB6	0.16	0.022	7.27	158.90	196.55
Sliammon North	PRB5A	6.77	0.327	20.70	336.50	19.37
Sliammon South	PRB5	1.49	0.057	26.14	334.07	49.53
Powell River	PRB3A	2.09	0.064	32.66	272.20	126.17
Stations out from Diffuser						
North of Diffuser	PRB3	12.7	0.23	55.459	-70.60	384.33
Diffuser (NW100)	PRB100NW	5.03	0.11	44.123	-61.57	381.00
Diffuser (SE100)	PRB100SE	2.34	0.04	54.419	306.63	56.57
South of Diffuser	PRB1	4.1	0.07	63.077	33.67	71.17
End of Diffuser	PRB2	3.72	0.10	38.75	197.60	29.83
Stations on Southeast Gradient						
North Westview	PRB4A	0.65	0.040	16.25	236.13	89.03
Breakwater	PRB1A	2.45	0.061	40.164	175.97	60.37
Westview WWTP	PRB4B	0.71	0.059	12.034	364.10	136.77
South Westview	PRB4	0.690	0.041	16.829	578.33	42.53

Figure 4.15 **Mean organic carbon, total nitrogen and C/N ratios in sediments, Powell River EEM Cycle Seven, March 2015.**

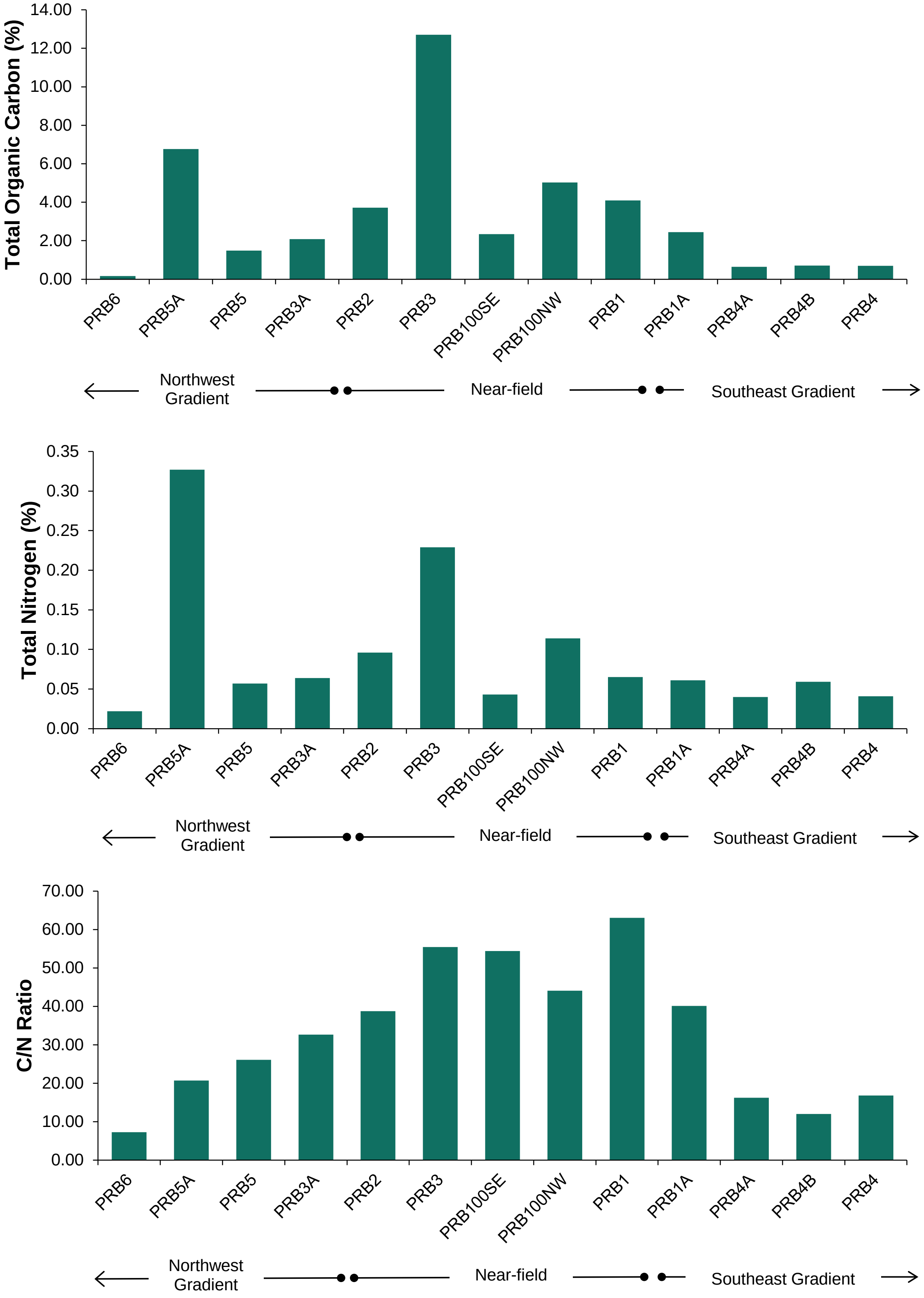
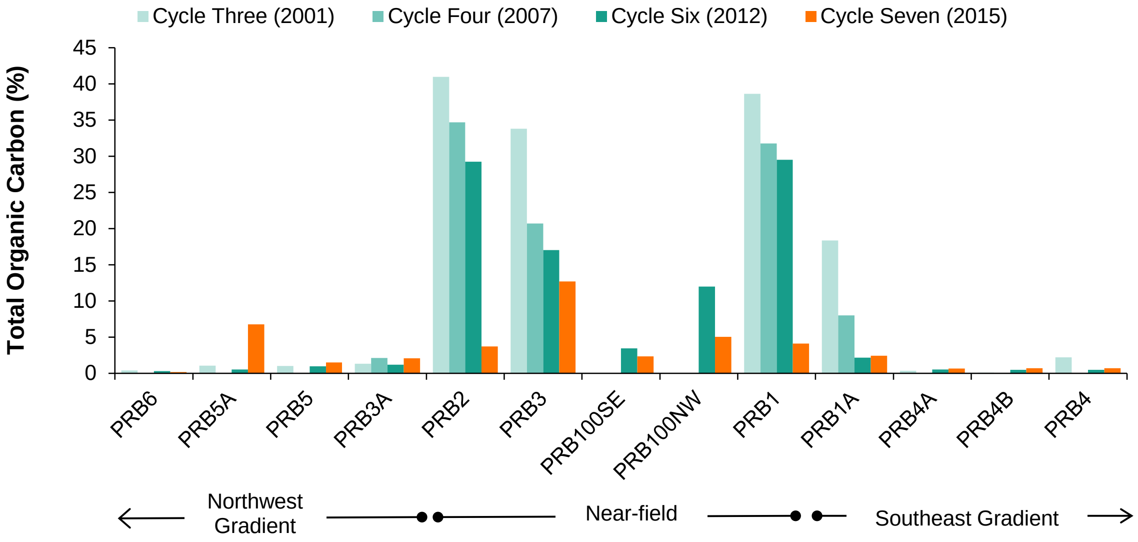


Figure 4.16 Percent total organic carbon in sediments, Powell River EEM Cycle Three, Cycle Four, Cycle Six and Cycle Seven.

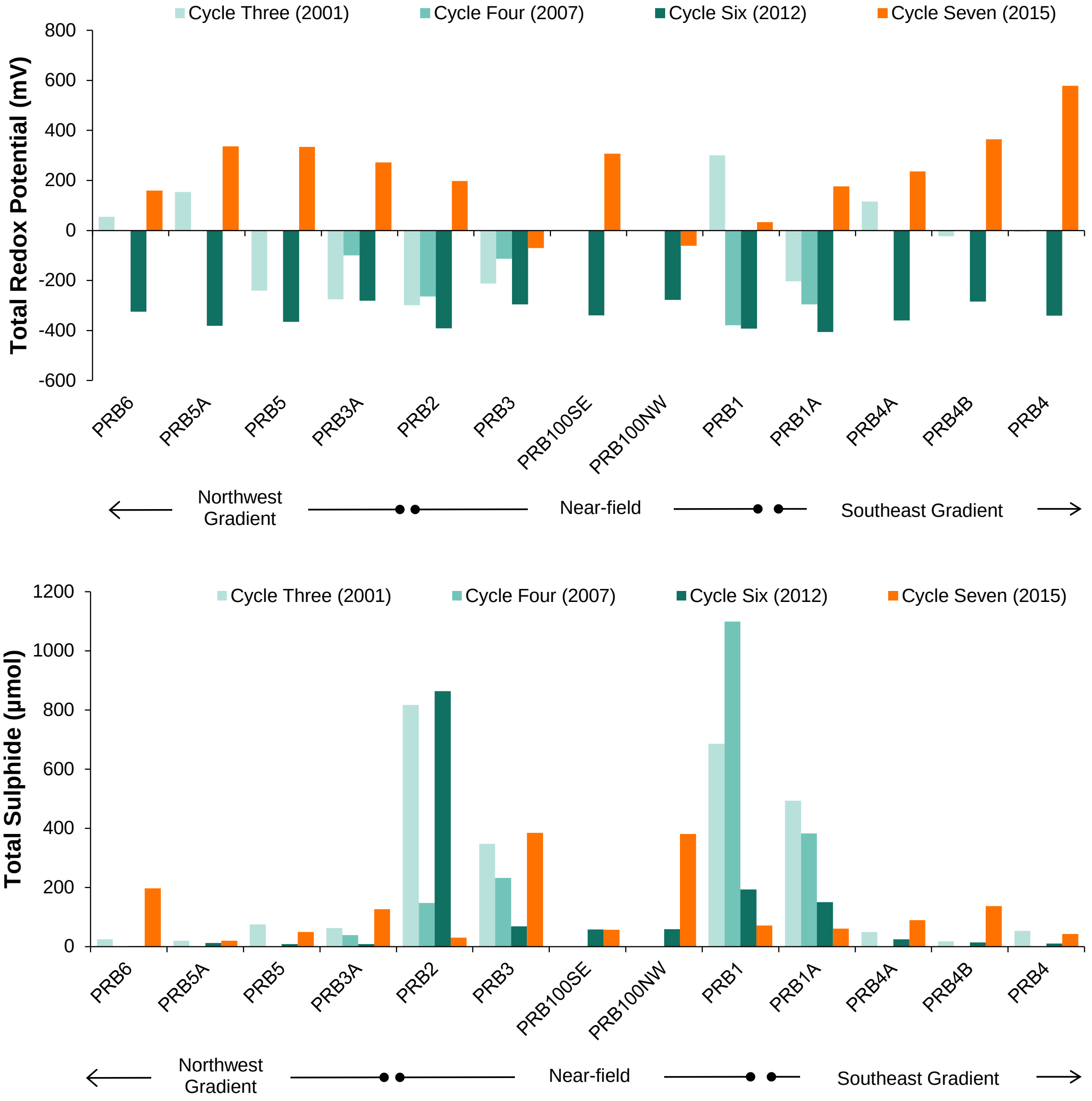


4.4.2.3 Oxidative State

Redox potential was positive (i.e., indicative of oxidizing conditions) at all stations in Cycle Seven, with the exception of stations PRB3 and PRB100NW (which were slightly reducing), and ranged from -61 mV at PBR3 to 578 mV at PBR4 (Table 4.8 and Figure 4.17). This was in stark contrast with Cycle Six where all stations were highly reducing; however, concerns were raised about the reliability of the Cycle Six redox and sulphide results. The transition to an oxidizing environment observed in Cycle Seven is consistent with the improved sediment chemistry results and aligns with the generally improving redox conditions observed between Cycle Three and Cycle Four (Figure 4.17).

Total sulphide (TS) values were highest at near-field stations PRB3 (384 µmol) and PRB100NW (381 µmol) and were low at remaining stations, with the exception of PRB6 (Figure 4.17). In Cycle Seven, TS increased at all stations relative to Cycle Six, with the exception of PRB2, PRB1 and PRB1A; however historical near-stations PRB2 and PRB1 showed considerable improvement relative to earlier cycles.

Figure 4.17 Mean sediment redox potential and total sulphides in sediments, Powell River EEM Cycle Three, Cycle Four, Cycle Six and Cycle Seven.



4.4.2.4 Chlorinated Phenolic Compounds

Table 4.9 presents concentrations of chlorinated phenolic compounds (CPCs) in composited sediments collected from benthic invertebrate stations in March 2015. Seven stations, including two near-field stations, were below detection limits for all chlorinated phenolic compounds while the remaining stations ranged from 0.007 mg/kg at station PRB100SE to 0.067 mg/kg at station PRB3 (Table 4.9). Tetrachlorocatechol and 3,4,4-tetrachlorocatechol, which have been associated with either historical chlorinated pulpmill effluent or its historical use as a wood preservative, were the only two CPCs detected during Cycle Seven with both compounds detected in both near-field and far-field stations. All stations have shown a general decrease in total chlorinated phenolic compounds since Cycle Three (Figure 4.18). Station PRB3 has had the highest total concentration since Cycle Two, mainly attributed to relatively high concentrations of catechols and guaicols (Figure 4.18 and Table 4.9).

Figure 4.18 Summary of total chlorinated phenolic concentrations in sediments, Powell River EEM Cycle One (1997) to Cycle Seven (2015).

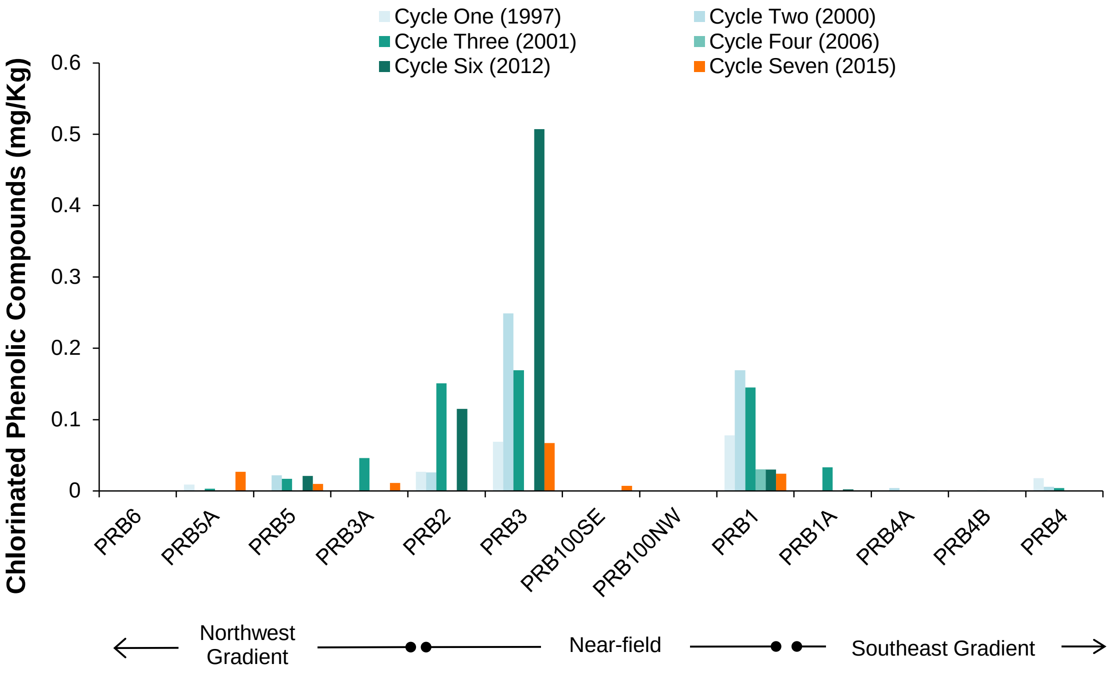


Table 4.9 **Chlorinated phenolic compounds in sediments (mg/kg dry weight), Powell River EEM Cycle Seven, March 2015.**

	PRB100SE	PRB100NW	PRB1	PRB3	PRB2	PRB1A	PRB3A	PRB4A	PRB5	PRB4B	PRB5A	PRB4	PRB6
	100 SE of	100 NW of	South of	North of	End of	Break-	Powell	North	Sliammon	Westview	Sliammon	South	Scuttle
Parameter	Diffuser	Diffuser	Diffuser	Diffuser	Diffuser	water	River	Westview	South	WWTP	North	Westview	Bay
Pentachlorophenol	<0.0030	<0.0040	<0.0050	<0.020	<0.0040	<0.0040	<0.0070	<0.0020	<0.0030	<0.0020	<0.0070	<0.0020	<0.0050
Tetrachlorocatechol	**0.0071**	<0.030	**0.0168**	**0.051**	<0.0090	<0.020	**0.0107**	<0.0050	**0.01**	<0.0050	**0.0189**	<0.0050	<0.0080
Tetrachloroguaiacol	<0.0050	<0.0050	<0.0060	<0.0080	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,3,4,5-Tetrachlorophenol	<0.0020	<0.0020	<0.0020	<0.0050	<0.0020	<0.0020	<0.0040	<0.0020	<0.0020	<0.0020	<0.0040	<0.0020	<0.0020
2,3,4,6-Tetrachlorophenol	<0.0020	<0.0030	<0.0020	<0.0040	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
2,3,5,6-Tetrachlorophenol	<0.0020	<0.0020	<0.0020	<0.0030	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
3,4,5-Trichlorocatechol	<0.0050	<0.0050	**0.0067**	**0.0157**	<0.0050	<0.0070	<0.0050	<0.0050	<0.0050	<0.0050	**0.008**	<0.0050	<0.0050
3,4,5-Trichloroguaiacol	<0.0050	<0.0050	<0.0060	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050	<0.0050
2,3,4-Trichlorophenol	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0030	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0040
2,3,5-Trichlorophenol	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
2,3,6-Trichlorophenol	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020
2,4,5-Trichlorophenol	<0.0020	<0.0020	<0.0020	<0.0080	<0.0020	<0.0020	<0.0030	<0.0020	<0.0020	<0.0020	<0.0030	<0.0020	<0.0020
2,4,6-Trichlorophenol	<0.0020	<0.0020	<0.0040	<0.0070	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0020	<0.0030	<0.0020	<0.0020
STATION TOTAL[1]	***0.007***	***ND***	***0.024***	***0.067***	***ND***	***ND***	***0.011***	***ND***	***0.010***	***ND***	***0.027***	***ND***	***ND***
Cycle Six Total	*ND*	*ND*	*0.030*	*0.507*	*0.115*	*0.002*	*ND*	*ND*	*0.021*	*ND*	*ND*	*ND*	*ND*
Cycle Four Total	*ns*	*ns*	*0.030*	*ND*	*ND*	*ND*	*ND*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Cycle Three Total	*ns*	*ns*	*0.145*	*0.169*	*0.151*	*0.033*	*0.046*	*0.001*	*0.017*	*0.001*	*0.003*	*0.004*	*0.000*
Cycle Two Total[2]	*ns*	*ns*	*0.169*	*0.249*	*0.026*	*ns*	*ns*	*0.004*	*0.022*	*ns*	*ns*	*0.006*	*0.001*
Cycle One Total[3]	*ns*	*ns*	*0.078*	*0.069*	*0.027*	*ns*	*ns*	*ns*	*ns*	*ns*	*0.009*	*0.018*	*ns*

Back of table

4.4.3 Statistical Assessment of Supporting Data

Based on spearman rank correlations, total organic carbon, redox potential, % gravel, and dissolved oxygen exhibited significant correlations with distance from the pulpmill diffuser (p-values ≤0.10; Table 4.10). TOC, percent gravel and dissolved oxygen decreased with distance from the diffuser while redox potential increased with distance; all correlations exhibited a moderate strength of effect (i.e., $0.5<r_s<0.75$). No data transformation were required to meet the assumptions of the test.

Table 4.10 Relationships between supporting environmental variables and absolute distance from the pulpmill diffuser, Powell River EEM Cycle Seven, March 2015.

Effect Endpoint	Correlation Coefficients		Direction of Effect	Strength of Correlation[1]
	r_s	Correlation		
Sediment Quality				
Total Organic Carbon	**-0.611**	Yes	Decreasing with distance	**Moderate**
Total Nitrogen	-0.432	No	-	None
Total Sulphides	-0.217	No	-	None
Redox Potential	**0.569**	Yes	Increasing with distance	**Moderate**
Chlorophenols	-0.209	No	-	None
% Gravel	**-0.541**	Yes	Decreasing with distance	**Moderate**
% Sand	0.261	No	-	None
% Silt	-0.239	No	-	None
% Clay	-0.347	No	-	None
Water Quality				
Depth	-0.167	No	-	None
Dissolved Oxygen	**-0.620**	**Yes**	Decreasing with distance	**Moderate**
Temperature	-0.125	No	-	None
Salinity	0.188	No	-	None

Bolded entries represent statistically significant relationships ($\alpha = 0.10$).

*p < 0.10; **p<0.01

rs = Spearman's correlation coefficient (non-parametric correlations).

[1] Strength evaluated using Spearman rank correlation coefficient: weak correlation (rs < 0.5), moderate correlation (i.e., 0.5 < rs < 0.75), strong correlation (i.e., rs > 0.75)

Correlations between benthic metrics and supporting environmental variables are presented in Table 4.11; significant correlations ($r \geq |0.484|$ for n=12) are discussed below.

Based on Spearman's rank correlations, evenness was the only benthic metric that was correlated with C/N ratio, while evenness and taxa richness were correlated with absolute distance from the diffuser (Table 4.11). Evenness and taxa richness were also correlated with oxidative-state variables; however, evenness was correlated with a reducing environment (i.e., negatively correlated with redox potential and positively correlated with total sulphides) while taxa richness was correlated with non-reducing environments. Mean adult density was negatively correlated with percent gravel and depth.

Bray-Curtis was positively correlated with total organic carbon, total nitrogen, and percent clay indicating that the most dissimilar stations to the reference stations with respect to benthic invertebrate communities were found in environments with high organic matter and nutrients.

Table 4.11 Spearman's rank correlations (r_s) between benthic community metrics and supporting environmental variables, Powell River Cycle Seven, March 2015.

Variable	Density	Richness	Simpson's Diversity	Evenness	Bray-Curtis
C:N	-0.082	-0.341	0.379	**0.599***	0.280
Distance	0.305	**0.601***	-0.256	**-0.691****	-0.344
%Gravel	**-0.531***	-0.374	0.260	0.418	0.254
%Sand	0.066	0.006	-0.099	-0.17	**-0.604***
%Silt	0.181	0.014	0.060	0.143	0.445
%Clay	0.170	0.083	0.280	0.275	**0.544***
Total.Nitrogen	0.099	-0.058	0.137	0.258	**0.593***
TOC	0.027	-0.19	0.165	0.363	**0.593***
Sulphides	-0.379	**-0.517***	0.071	**0.511***	0.066
Redox	0.088	0.435	-0.170	**-0.577***	-0.231
Chlorophenols	0.412	0.251	0.317	0.167	0.179
Depth	**-0.529***	-0.461	-0.08	0.094	0.334
DO	-0.021	-0.182	0.14	0.315	-0.154
Temp	**-0.533***	-0.36	0.27	0.232	0.340
Salinity	0.061	0.154	0.175	-0.046	0.257

Bolded values represent significant correlations where $r_s \geq |0.484|$ for n=12.

*p < 0.10; **p<0.01

Moderate correlations: $|0.5|<r_s<|0.75|$; Strong correlations: $r_s>|0.75|$.

4.5 DISCUSSION

4.5.1 Comparisons with Previous Cycles

Relative to Cycle Six, mean invertebrate densities in Cycle Seven were higher in northwest stations, similar in near-field stations and generally lower in southeast stations (Table 4.12). Overall, invertebrates densities within the historical near-field area continue to improve and are more similar to those observed in the far-field areas.

Benthic community data from Cycle One are not presented in Table 4.12, given sampling methodologies and benthic processing and enumeration techniques were not comparable with subsequent cycles. Generally, all Cycle One stations in the vicinity of Powell River exhibited lower densities relative to the reference area (Qualicum Beach). Within exposed stations, mean density at near-field stations was slightly lower relative to far-field and far-far-field stations (Hatfield 1995).

Taxa richness has varied considerably over time, with many stations experiencing decreasing richness between Cycles Two and Three, slight increases in Cycle Six, followed by slight decrease at most stations in Cycle Seven (Table 4.12). In Cycle Seven taxa richness at most stations were similar to those observed in Cycle Three.

In Cycle Six it was noted that stations near the WWTP (PRB4A, PRB4B and PRB4) experienced considerable decreases in taxa richness over time; however, generally increased in mean density. This trend continued in Cycle Seven, although taxa richness at these stations decreased only slightly compared to previous cycles although, many of those stations experienced their lowest richness values since monitoring began.

Table 4.12 Mean density and richness of benthic invertebrate communities in Malaspina Straight, Powell River EEM Cycles Two (1999), Three (2001), Six (2012) and Seven (2015).

Station	Station Name	Mean Density (N/m^2)				Taxa Richness (# families)			
		Cycle Two	Cycle Three	Cycle Six	Cycle Seven	Cycle Two	Cycle Three	Cycle Six	Cycle Seven
Stations on Northwest Gradient									
PRB6	Scuttle Bay	2,926	3,468	5,535	11,330	76	65	77	49
PRB5A	Sliammon North	NS	2,876	9,420	12,900	NS	74	82	57
PRB5	Sliammon South	2,922	2,649	8,795	11,015	88	63	68	48
PRB3A	Powell River	NS	4,300	9,755	12,905	NS	89	63	49
Stations Nearest Diffuser									
PRB3	North of diffuser	1,830	5,890	8,375	3,870	71	47	45	35
PRB100NW	100 m northwest	NS	NS	4,755	1,650	NS	NS	40	23
PRB100SE	100 m southeast	NS	NS	7,885	5,885	NS	NS	45	38
PRB1	South of diffuser	777	1,405	5,315	6,665	59	32	36	51
PRB2	End of diffuser	1,670	4,455	3,525	6,915	64	44	45	43
Stations on Southeast Gradient									
PRB4A	North Westview	2,587	2,829	3,460	2,300	81	69	43	41
PRB1A	Breakwater	NS	9,526	4,720	6,730	NS	51	49	39
PRB4B	Westview WWTP	NS	1,166	11,020	2,220	NS	35	81	42
PRB4	South Westview	2,017	4,629	4,385	3,705	80	79	61	50

NS = not sampled.

As noted in Cycle Six, a noticeable difference in community composition was also observed between Cycle Three and Cycle Six (Section 4.3.4). Given the long time frame between benthic field studies (11 years) and the nature of the species present, this was not unexpected (T. Macdonald, Biologica Environmental Services Pers. comm. 2013). However, community composition was relatively similar between Cycle Six and Cycle Seven, which again is not unexpected give the now short time frame between the two most recent surveys. Many of the dominant species present in both Cycle Three, Cycle Six and Cycle Seven were opportunistic species that can have highly fluctuating densities (T. Macdonald, Biologica Environmental Services, pers. comm. 2013). In addition, there were 200 new taxa (i.e., new species or higher order organisms) identified in Cycle Seven, a large increase in the overall number taxa in the area. Similar to Cycle Six, many of these were epifaunal taxa (e.g., hyroids, sponges, ascians and polychaetes) that inhabit harder, sandy substrates, more common beyond the extent of the historical fibre mat.

4.5.2 Sediment Quality and Degree of Impact

The Pulp and Paper EEM Technical Guidance Document (Environment Canada 2010) provided guidelines for classifying impacted sediments (Table 4.13). Based on these criteria, sediment quality at stations along Malaspina Straight was classified according to percent TOC, redox potential and sulphide concentrations (Table 4.14). In Cycle Seven, data from nearly all stations indicated a normal grade of impact for redox potential (i.e., sediment at all stations was non-reducing) and low to normal grades for total sulphides; sediment at PRB1 indicated a low impact for redox potential while sediment at PRB3 and PRB100NW was moderately impacted (Table 4.14). Percent TOC at stations in the near-field area indicated low grade of impact, with the exception of PRB3 which was modernly impacted, in terms of TOC. Stations in the southeast gradient indicated a low grade of impact while stations in the northwest varied from low to moderately impacted (Table 4.14).

At all stations, a general improvement in sediment quality has been observed over time, most notably between Cycle Three, and Cycle Six and Seven. Concerns were raised in Cycle Six regarding the change in redox sample analyses personnel which indicated a gross impact, and decline over time; however, in Cycle Seven redox notably improved at all stations relative to Cycle Six and previous cycles. The degree of organic enrichment in sediments, indicated by TOC impacts, has remained similar or shown some improvement across cycles. Improvements in sulphide concentrations in Cycle Six and Cycle Seven indicate that sediment quality has reached "normal" conditions at nearly all sites and, with respect to sulphides, has largely recovered from effects of historical pulpmill discharges. Similar results were observed for the oxidative state of sediments near the diffuser, which in Cycle Seven, reached also reach "normal" conditions and nearly all stations.

Table 4.13 Environment Canada criteria for classifying impacts of organic carbon concentrations and oxidative state in marine sediments (Environment Canada 2010).

Degree of Impact	% TOC	Redox Potential (mV)	Sulphides (µmol)
Normal	Normal (0 to 0.5%)	> 100	< 300
Low impact or enrichment	Slight increase (0.5 to 5%)	0 to 100	300 to 1,300
Moderate to high impact	Moderate increase (5 to 20%)	-100 to 0	1,300 to 6,000
Gross impact	High TOC (>20%)	< -100	> 6,000

Table 4.14 Evaluation of sediment variables at each station based on Environment Canada impact criteria, Powell River EEM Cycles Two, Three, Four, Six and Seven.

Station	Total Organic Carbon					Redox Potential[1]					Total Sulphides[1]				
	Cycle Two	Cycle Three	Cycle Four	Cycle Six	Cycle Seven	Cycle Two[2]	Cycle Three	Cycle Four	Cycle Six	Cycle Seven	Cycle Two[2]	Cycle Three	Cycle Four	Cycle Six	Cycle Seven
PRB1	Gross	Gross	Gross	Gross	Low	Gross	Normal	Gross	Gross	Low	Moderate	Low	Low	Normal	Normal
PRB1A	ns	Moderate	Normal	Low	Low	ns	Gross	Gross	Gross	Normal	ns	Low	Low	Normal	Normal
PRB2	High	Gross	Gross	Gross	Low	High	Gross	Gross	Gross	Normal	Low	Low	Normal	Low	Normal
PRB3	High	Gross	Gross	Moderate	Moderate	Gross	Gross	Gross	Gross	Moderate	Moderate	Low	Normal	Normal	Low
PRB3A	ns	Low	Low	Low	Low	ns	Gross	Moderate	Gross	Normal	ns	Normal	Normal	Normal	Normal
PRB4	Moderate	Low	ns	Normal	Low	High	Moderate	ns	Gross	Normal	Moderate	Normal	ns	Normal	Normal
PRN4A	Low	Low	ns	Low	Low	Moderate	Normal	ns	Gross	Normal	ns	Normal	ns	Normal	Normal
PRB4B	ns	Normal	ns	Normal	Low	ns	Moderate	ns	Gross	Normal	ns	Normal	ns	Normal	Normal
PRB5	ns	Low	ns	Low	Moderate	Low	Gross	ns	Gross	Normal	Low	Normal	ns	Normal	Normal
PRB5A	ns	Low	ns	Low	Moderate	ns	Normal	ns	Gross	Normal	ns	Normal	ns	Normal	Normal
PRB6	Normal	Normal	ns	Normal	Normal	Moderate	Low	ns	Gross	Normal	Normal	Normal	ns	Normal	Normal
PRB100NW	ns	ns	ns	Moderate	Low	ns	ns	ns	Gross	Moderate	ns	ns	ns	Normal	Low
PRB100SE	ns	ns	ns	Moderate	Low	ns	ns	ns	Gross	Normal	ns	ns	ns	Normal	Normal

[1] Redox potential and total sulphides were not measured in Cycle one.

[2] Sediment samples analyzed by a different laboratory than cycles Four and Five.

ns = not sampled.

4.5.3 Effects Along the Exposure Gradient

Although stations closest to the Powell River diffuser continue to show significant effects, these effects diminish with increasing distance from the diffuser (i.e., increasing distance from the historical fibre mat) and, in Cycle Seven no longer exceed the CES along either the distance or C/N ratio exposure gradients. A spatially condensed study design, with more stations near the diffuser and fewer distant (far-field) station, likely contributed to the significant effects observed in Cycle Six and not observed in Cycles Two and Three. The reduced effluent discharge and continued improvement in sediment conditions observed in Cycle Seven, likely reduced the magnitude of the effects.

Table 4.15 Summary of benthic invertebrate endpoint analyses, Powell River EEM Cycle Seven.

Effect Endpoint	Effect?	Direction	Magnitude	Exceeds CES?
Distance				
Density	No	-	-	-
Taxa Richness	Yes	↑ with distance	$r^2 = 0.270$	No
Evenness	Yes	↓ with distance	$r^2 = 0.430$	No
Diversity	Yes	↓ with distance	$r^2 = 0.160$	No
Bray-Curtis	No	-	-	-
C/N Ratio				
Density	No	-	-	-
Taxa Richness	No	-	-	No
Rank Evenness	Yes	↑ with distance	$r^2 = 0.300$	No
Diversity	No	-	-	No
Bray-Curtis	No	-	-	-

Deposit-feeding taxa that are commonly found in organic enriched and or polluted areas such as municipal and industrial outfalls (Musale and Desai 2011; Simboura and Zenetos 2002; Eleftheriou and Basford 1989) continue to be present within the historical near-field are; however, many of these species (e.g., *Prionospio sp*., and *Pholoe sp*.) comprised <1% of the total abundance, and in Cycle Seven showed declining abundancies relative to previous cycles. Two abundant species found at nearly all stations were the deposit-feeding polychaete *Mediomastus californiensis*, which often is found in remediated areas with improving sediment oxygen concentrations and finer sandy sediments (Gallagher and Keay 1998; Flint and Kalke 1986) and the herbivore polychaete *Exogone lourie,* which is also used as an indicator of recovery (Vanderhorst et. al 1980). Gradient stations continue to also be dominated by an opportunistic species of phoronid *Phoronis psammophila;* which is a filter-feeding species of horseshoe worm that prefers sandy substrates with minimal silt content (Simboura and Zenetos 2002).

Stations PRB100SE and PRB100NW are within the current 1% dilution zone, as identified in Hatfield (2010b), and are representative of current conditions near the diffuser. Relatively high abundance of *Axinopsida serricata,* a small, free-burrowing, deposit-feeding bivalve, was observed at PRB100NW. Several studies have found that *A. serricata* was one of the most abundant species of benthic invertebrate in areas were organic enrichment was declining (Stull et al. 1986, Swartz et al. 1986). In addition, relatively high abundancies of the suspension-feeding polychaete *Owenia fusiformis* were found at PRB100SE. This species is not known to be an opportunistic species and occurs frequently with other species that characterize areas not exposed to pollution (Flaten et al. 2002).

Sediments closest to the diffuser continue to exhibit higher TOC, increased sulphides and vary in their oxidative state relative to gradient stations, although significant improvements in near-field sediment quality have been observed over time. Given large improvements in effluent quality, in terms of significant decreases in discharged volumes of BOD and TSS, and the consistent declines in TOC in sediments over time, the cause of the effect is clearly historical (i.e., a result of the historical fibre mat, defined in Hatfield [2007]).

4.5.3.1 Conclusions

Based on the results of the Cycle Seven benthic invertebrate survey including the supporting sediment and water quality surveys, the following conclusions are made:

- Although significant effects were observed along the absolute distance exposure gradient for taxa richness, evenness and Simpson's diversity, the magnitude of these effects was within the critical effect size (i.e., were not biological significant according to EEM guidance);
- No effects were observed on invertebrate density or the Bray-Curtis dissimilarity index along the absolute distance exposure gradient;
- Evenness was the only benthic metric that exhibited a significant effect along the C/N exposure gradient, with a magnitude that was not biologically significant;
- Overall, benthic conditions near the Powell River pulpmill improved relative to previous cycles, evident in the general increase in invertebrate densities at most stations and the increased similarity between near-field and gradient stations. In addition, the increase in the relative abundance of species associated with ecosystem recovery in the near-field area provide evidence of improving sediment conditions;
- While an overall improvement in the condition of sediments is evident from Cycle One to Cycle Seven, sediments closer to the diffuser and within Cycle Three near-field area continue to exhibit a mild organic enrichment and increase sulphides relative to far-field stations;
- Concentrations of pulpmill-specific contaminants in sediment (i.e., chlorinated organic compounds) are low and continue to decline;
- Given the significant decreases in discharged volumes of BOD and TSS and the improving state of the sediment quality near the Powell River Pulpmill between Cycle Three and Cycle Seven, it is evident that the mild enrichment in the area surrounding the pulpmill diffuser are from historical pulpmill discharges.

5.0 CONCLUSIONS

Based on the results of the Powell River EEM Cycle Seven program, the following conclusion can be made.

Sublethal toxicity testing showed variability in sublethal response over Cycle Seven, with average effects of effluent of 5.5% on algal reproduction and 35.4% on echinoderm reproduction. Due the rapid diffusion of effluent discharge from the multi-port diffuser installed at the Power River Pulpmill, the potential for sublethal effects of effluent extends only to the immediate vicinity of the outfall, to a maximum extent of 21.8 m from the effluent diffuser.

Benthic invertebrate communities exhibited differences in taxa richness, evenness and Simpson's diversity along a gradient of effluent exposures that were statistically significant but not biologically significant based on EEM guidance. Taxa richness and evenness generally increased with distance from the diffuser, while evenness and Simpson's diversity generally decreased. Similar community composition (calculated as Bray-Curtis index) was observed along exposure gradients. Continued improvements in sediment conditions near the diffuser (i.e., declining organic content and increasing oxidative state) likely contributed to the reduction in the magnitude of observed effects.

While an overall improvement in the condition of sediments is evident from Cycle One to Cycle Seven, sediments closest to the diffuser and within Cycle Three near-field area continue to exhibit a mild organic enrichment relative to far-field stations, although no longer exhibit anoxic conditions. Given large improvements in effluent quality, in terms of significant decreases in discharged volumes of biological oxygen demand and suspended solids, and the consistent declines in organic content of sediments over time, the cause of the mild enrichment is clearly historical.

6.0 REFERENCES

Barkowski S. 2010. Personal communication (letter to Director, Environmental Protection, Environment Canada Pacific and Yukon Region, regarding January 28, 2010 untreated effluent release [#902835]). Catalyst Paper Powell River Division, Powell River, BC. 2 pp + attachments. February 19, 2010.

BCMOE (BC Ministry of Environment) (formerly WLAP). 2002. Protocols for Marine Environmental Monitoring. BC Ministry of Environment (formerly Water, Land and Air Protection), September 5, 2002, 29 pp.

Bray JR, Curtis JT. 1957. Ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325-349.

Cohen J. 1988. Statistical Power Analysis for the Behavioral Sciences. Second Edition. Lawrence Erlbaum Associates. Hillsdale, New Jersey.

Dwernychuk LW, Young LU, Allan JA, Davies M. 1997. Dioxin/furan trend monitoring program, 1997 (sediment/crab/fish). Prepared for MB Paper, Powell River Division, by Hatfield Consultants Ltd., September 1997.

Eleftheriou A, Basford DJ. 1989. The macrobenthic infauna of the offshore northern North Sea. J. Mar. Biol. Ass. U.K. 69(1) 193-284.

Environment Canada. 2010. Pulp and Paper Technical Guidance for Aquatic Environmental Effects Monitoring. Environment Canada. 2010.

Environment Canada. 1997. Biological Test Method: Fertilization Assay Using Echinoids (Sea Urchins and Sand Dollars). Report EPS 1/RM/27 (December 1992, and November 1997 amendments).

Faul F, Erdfelder E. 1992. GPOWER: a priori, post hoc, and compromise power analyses for MS-DOS [Computer Program]. Bonn, Germany: Bonn University.

Flint RW, Kalke RD. 1986. Biological enhancement of estuarine benthic community structure. Mar. Ecol. Prog. Ser. 31(1) 23-33.

Gallagher ED, and Keay KE. 1998. Organism-sediment-contaminant interactions in Boston Harbour. MIT Sea Grant Publications. 98(1): 170pp.

Government of Canada. 2004. Regulations amending the Pulp and Paper Effluent Regulations. Canada Gazette Part II, Vol. 138, No. 10. SOR/2004-109. May 2004. p. 598-658.

Government of Canada. 2008. Regulations Amending the Pulp and Paper Effluent Regulations. Registered July 28, 2008. Canada Gazette Part II, Vol. 142, No. 16 SOR/DORS/2008-239 published August 6, 2008.

Hatfield. 2014. Powell River environmental effects monitoring (EEM) cycle seven design. Prepared for Catalyst Paper Ltd., Powell River Division. Powell River, BC.

Hatfield. 2013. Powell River environmental effects monitoring (EEM) cycle six interpretive report. Prepared for Catalyst Paper Corporation, Powell River Division, by Hatfield Consultants, March 2013.

Hatfield. 2013. G12 receiving environment monitoring report. Prepared for Catalyst Paper Ltd., Powell River Division. Powell River, BC.

Hatfield. 2012. Powell River environmental effects monitoring (EEM) cycle six design. Prepared for Catalyst Paper Ltd., Powell River Division. Powell River, BC.

Hatfield. 2010. Screening assessment of potential environmental effects on increased thermal discharge from the G12 power increase project. Prepared for Catalyst Paper Ltd., Powell River Division. Power River, BC.

Hatfield. 2007. Powell River environmental effects monitoring (EEM) cycle four interpretive report. Prepared for Catalyst Paper Corporation, Powell River Division, by Hatfield Consultants, March 2007.

Hatfield. 2004. Powell River environmental effects monitoring (EEM) cycle three interpretive report. Prepared for NorskeCanada, Powell River Division, by Hatfield Consultants Ltd., March 2004.

Hatfield. 2001. Pacifica Papers Inc., Powell River operations, environmental effects monitoring (EEM) cycle three design document. Prepared for Pacifica Papers Inc., Powell River Division, by Hatfield Consultants Ltd., West Vancouver, BC. February 2001.

Hatfield. 2000. Pacifica Papers Inc., Powell River operations, environmental effects monitoring (EEM) cycle two interpretive report, 1997 to 2000. 2 Volumes. Prepared for Pacifica Papers Inc., Powell River Operations, by Hatfield Consultants Ltd., March 2000.

Hatfield. 1997. Powell River environmental effects monitoring (EEM) Cycle One interpretive report. Prepared for MacMillan Bloedel Limited, Powell River Division, by Hatfield Consultants Ltd., April 1997.

Hatfield. 1994. Powell River environmental effects monitoring (EEM) pre-design reference document. Prepared for MacMillan Bloedel Limited, Powell River Division, by Hatfield Consultants Ltd., June 1994.

[Hayco] Hay & Company Consultants. 2002. Powell River Pulp Mill Effluent Outfall Plume Modelling. Prepared for Norske Canada, Powell River Division, by Hay & Company Consultants, Vancouver, BC.

Hayco. 2007. Diffuser Performance at the Catalyst Paper Powell River Outfall. Hay & Company Consultants, Vancouver, BC. March 2007.

Macdonald RW, Crecelius EA. 1994. Marine sediments in the Strait of Georgia, Juan de Fuca Strait and Puget Sound: what can they tell us about contamination? [In:] R.C.H. Wilson, R.J. Beamish, F. Aikens and J. Bell. (eds.) Review of the marine environment and biota of the Strait of Georgia, Puget Sound and Juan de Fuca Strait. Can. Tech. Rpt. Fish. Aquat. Sci. 1948: 101-129.

Musale AS, Desai DV. 2011. Distribution and abundance of macrobenthic polychaetes along the South Indian coast. Environ. Monit. Assess. 178(1-4) 423-436.

Simboura N, Zenetos A. 2002. Benthic indicators to use in ecological quality of Mediterranean soft bottom marine ecosystems, including a new biotic index. Mediterranean Marine Science. 3(1) 77-111.

SPSS. 2012. SYSTAT 10. Statistics I. SPSS Inc. United States of America. 663 pp.

Stull JK, Haydock CI, Smith RW, Montagne DE. 1986. Long-term changes in the benthic community on the coastal shelf of Palos Verdes, Sothern California. Mar. Biol. 91: 539-551.

Swartz RC, Cole FA, Schults DW, Deben WA. 1986. Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Mar. Ecol. Prog. Ser. 3(1): 1-13.

Tiley MH, Bocking RC. 2009. Contaminant levels in marine bivalves collected from Sliammon First Nations traditional territory beaches and recommended consumption limits. Prepared by LGL Limited, Sidney, BC for the Tla'amin Community Health Services, Powell River, BC. March 2009.

[U.S. EPA] United States Environmental Protection Agency. 2002. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Water to Marine and Estuarine Organisms, Third Edition. EPA-821/R/02-014. October 2002.

U.S. EPA. 1995. Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to West Coast Marine and Estuarine Organisms, First Edition. EPA/600/R-95/136. August 1995.

APPENDICES

Appendix A1

Sublethal Toxicity Testing Results and Calculations

Appendix A2

Benthic Invertebrate Data and QA/QC Reports

Appendix A3

Sediment Chemistry