Sixth National Assessment of Environmental Effects Monitoring Data from Pulp and Paper Mills Subject to the *Pulp and Paper Effluent Regulations*

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Executive Summary

In 1992, after extensive consultations, a new federal framework for pulp and paper effluents was completed. On May 7, 1992 the *Pulp and Paper Effluent Regulations* (PPER) were registered. The PPER govern the discharge of deleterious substances from pulp and paper mills into water frequented by fish, with the overall objective of water quality that sustains fish, fish habitat and the use of fisheries resources. Among many improvements, the PPER introduced enforceable effluent quality standards for all mills based on standards achievable using secondary wastewater treatment, a requirement that effluents not be acutely lethal to Rainbow Trout, and a requirement for all mills to conduct an environmental effects monitoring (EEM) program.

The EEM requirements in the PPER consist of sublethal toxicity (SLT) testing of mill final effluent and biological monitoring studies, to assess potential effects of mill effluent on the aquatic receiving environment and investigate the cause(s) of and solution(s) for environmental effects associated with mill effluent. Data from EEM studies have shown that, although there is little to no impact on the use of fisheries resources, some effluents continue to cause effects on fish and/or fish habitat. The national average pattern of effects for fish was typical of those conditions related to nutrient enrichment, co-occurring with metabolic disruption (reduced gonad size), and the national pattern of effects for fish habitat (benthic invertebrate communities) was typical of various degrees of eutrophication (i.e., nutrient enrichment conditions).

Most mills have now completed their 6th cycle of EEM monitoring and reporting, which covered the period from April 1, 2010 to March 31, 2013. During this 6th cycle, all operating mills subject to the PPER conducted SLT testing of their final effluent. A small number of mills conducted biological monitoring studies to assess effects in the receiving environment, while the majority of mills conducted biological monitoring studies to investigate causes and/or solutions for effects observed in previous cycles.

Although variable for individual mills, overall the effluents elicited SLT responses in half of all effluent tests conducted during previous cycles. In Cycle 6, effluents elicited SLT responses in 63% of all effluent tests, and a higher percentage of the tests involving invertebrate reproduction and fertilization inhibition showed SLT responses compared to previous cycles.

The cause of effects associated with eutrophication, for many mills, was well understood to be the nutrients in final effluent from the mill, and the nutrients linked to these effects included bioavailable phosphorus, total and dissolved phosphorus, nitrogen, and organic carbon. For other mills where confounding factors were present, the focus of investigation of cause studies was to determine if the mill's effluent caused the observed effects and/or the degree to which the mill's effluent contributed to the observed effects. The conclusions from investigation of cause studies involving confounding factors stated that, at some mills, effects observed in previous studies were caused by the mill's effluent, while at a few mills the observed effects were attributable to causes other than the mill's current effluent, such as municipal wastewater effluent or historical (pre-PPER) discharges.

The majority of studies conducted to identify solutions for effects associated with eutrophication involved either nutrient source assessments, or the analysis of nutrient management systems or both. Most of the solutions identified to eliminate eutrophic effects involved improving the wastewater treatment system, but a smaller number of changes to mill processes were also identified. Investigation studies for the effect of reduced gonad size in fish (metabolic disruption) concluded that the greatest potential for abating effects on fish reproduction in laboratory studies was the reduction of organics loading in final effluent. Therefore, the solutions identified for the two prevalent, prioritized effects of mill effluent, eutrophication and reduced gonad size in fish, have a common foundation: reduction of organics loading in final effluent.

Many mills implemented solutions identified by investigation studies. Results achieved from implementing solutions included reductions in final effluent residual phosphorus, nitrogen, biochemical oxygen demand (BOD) and total suspended solids (TSS), and in some laboratory studies the effect on egg production was eliminated once effluent BOD was lowered.

As more mills choose to implement solutions, more information on achievable results may become available. As mills that have implemented solutions conduct biological monitoring studies to re-assess effects in the receiving environment, the success of identified solutions in reducing effluent-related effects can be assessed.

Over time, mills will be re-assessing effects and, depending on the degree to which mills choose to implement identified solutions, the overall impact of mill effluent on the aquatic receiving environment could be quite different than previously observed.

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1. Introduction

In 1992, after extensive consultations, a new federal framework for pulp and paper effluents was completed. The 1992 *Pulp and Paper Effluent Regulations* (PPER) were registered on May 7, 1992. The PPER govern the discharge of deleterious substances from pulp and paper mills into water frequented by fish, with the overall objective of water quality that sustains fish, fish habitat and the use of fisheries resources. Among many improvements, the PPER introduced enforceable effluent quality standards for all mills based on standards achievable using secondary wastewater treatment, a requirement that effluents not be acutely lethal to Rainbow Trout, and a requirement for all mills to conduct an environmental effects monitoring (EEM) program.

EEM is a science-based performance measurement tool used to collect information from mills to assist in assessing the effectiveness of the PPER in achieving their objective. Designed to detect and measure changes in aquatic ecosystems (i.e., receiving environments), EEM goes beyond the final effluent measurement of chemicals in effluent; it examines the effectiveness of environmental protection measures directly in aquatic ecosystems. Long-term effects are assessed using regular cyclical monitoring and interpretation phases designed to assess and investigate the impacts on the same parameters and locations. In this way, both a spatial characterization of potential effects and a record through time to assess changes in receiving environments are obtained.

The EEM requirements[1] in the PPER consist of sublethal toxicity (SLT) testing of mill final effluent, biological monitoring studies conducted in the receiving environment, and investigations of the cause(s) of and solution(s) for confirmed environmental effects associated with mill effluent.[2]

Since the implementation of the EEM requirements in 1992, data from EEM studies have been analyzed[3] to discern national patterns. The data show that although there is little to no impact on the use of fisheries resources, some effluents continue to cause effects on fish and/or fish habitat. On a national basis, the prevalent effect on fish is associated with nutrient enrichment (of the receiving environment), sometimes combined with reduced fish gonad size (with possible disruption to reproduction). Specifically, fish exposed to mill effluent were fatter, grew faster, and had greater relative liver size but lower relative gonad size than unexposed fish. For fish habitat (benthic invertebrate communities), the prevalent effect is associated with eutrophication from nutrient enrichment, specifically increased invertebrate density, and changes in community structure and taxon richness (i.e., species diversity or number of species).

The purpose of this document is to report the results from EEM biological monitoring and SLT studies conducted in Cycle 6 (April 1, 2010 to March 31, 2013), and to summarize the results of all

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[1] For the regulatory EEM requirements, refer to sections 28 to 30 and Schedule IV.1 of the PPER, at http://laws.justice.gc.ca/eng/SOR-92-269/index.html.

[2] For more information on pulp and paper EEM studies, refer to the *2010 Pulp and Paper Environmental Effects Monitoring (EEM) Technical Guidance Document*.

[3] Previous National Assessments of pulp and paper EEM data are available from the EEM website http://www.ec.gc.ca/esee-eem/default.asp?lang=En&n=F55EEA87-1, and are listed in the reference section of this report.

investigation studies conducted during cycles 4, 5 and 6 (April 1, 2004 to March 31, 2013) to determine the causes of and identify solutions for environmental effects associated with pulp and paper mill effluent.

2. EEM Activity

Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Cycle 6
1992 to 1996	1996 to 2000	2000 to 2004	2004 to 2007	2007 to 2010	2010 to 2013

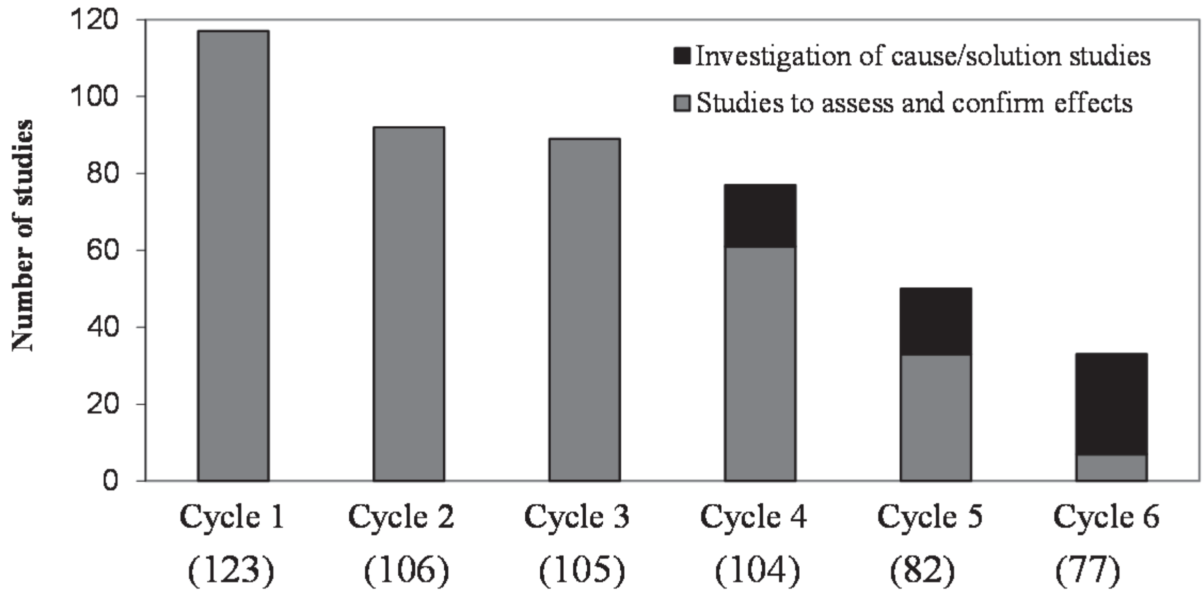
With a few exceptions, mills have completed their sixth cycle of EEM monitoring and reporting. The section below summarizes the EEM activity that has occurred in each cycle and describes the types of biological monitoring studies conducted in Cycle 6.

Starting in Cycle 1, SLT testing of final effluent has been conducted twice per year by all mills in production, or once per year if the mill deposited effluent on fewer than 120 days in a calendar year. Biological monitoring studies have been conducted once per cycle by all mills in production with a concentration of effluent greater than 1% in the area located beyond 100 m of a point of deposit of the effluent. In several situations, mills conducted biological monitoring studies jointly, including investigation studies.

The biological monitoring studies conducted in Cycle 1 were not sufficiently comprehensive to assess effects, but were used to establish initial results and develop technical guidance to improve future studies. Studies conducted in cycles 2 and 3 were used to assess and confirm effects observed in the receiving environment. In Cycle 4, the majority of mills continued to conduct biological monitoring to assess and confirm effects, while some mills that had confirmed effects in Cycle 3 conducted biological monitoring studies to investigate the magnitude, extent and cause of those confirmed effects.

During Cycle 5, mills continued to conduct biological monitoring studies to assess and confirm effects, and other mills either continued or began to investigate causes, while a few mills conducted investigation of solution studies. A small number of mills in Cycle 6 conducted studies to assess and confirm effects, while the majority of mills conducted studies to investigate causes and/or solutions. The total number of biological monitoring studies conducted per cycle declined because: 1) over the time frame of cycles 4 and 5, a number of mills ceased production and 2) during Cycle 6, many more mills participated in joint studies (Figure 2.1).

Figure 2.1 Biological monitoring studies conducted per cycle



Note: Total number of mills in operation shown in parentheses

The 77 pulp and paper mills in production and subject to the PPER during Cycle 6 conducted SLT testing on their final effluent and, if required, conducted biological monitoring studies to either assess effects or investigate confirmed effects.

Of the 77 mills, 29 were not required to conduct biological monitoring studies as per the Regulations—16 due to low effluent concentration in the receiving environment, three due to the confirmation of the absence of effects, and eight due to identifying solutions in the previous study.[4] Two mills are conducting monitoring studies on a delayed schedule due to previous mill shutdowns lasting more than eight months. The remaining mills (48) conducted 33 biological monitoring studies[5]: seven studies to assess effects (standard or alternative fish, fish tissue and/or benthic invertebrate community surveys), and 26 studies to investigate causes and/or solutions for confirmed effects (Figure 2.2).

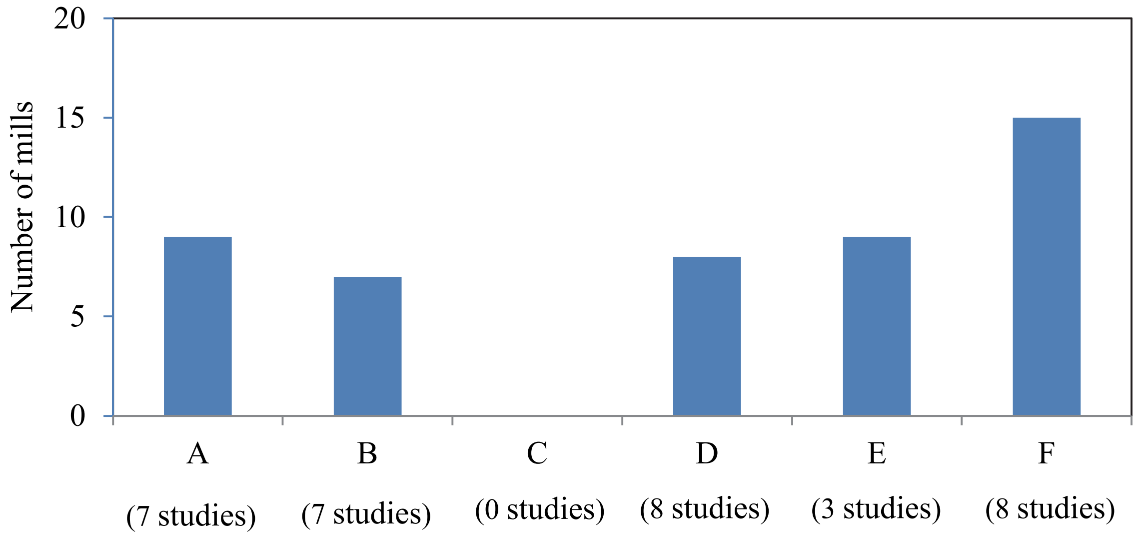
Mills that determined the causes of confirmed effects in Cycle 5 then conducted investigations in Cycle 6 to identify solutions to eliminate those effects. In some situations, mills conducted

[4] Biological monitoring studies are conducted once per cycle by all mills subject to the PPER that are in production and have a concentration of effluent greater than 1% in the area beyond 100 m from the point of deposit. Prior to the 2008 amendment, all mills in production conducted benthic invertebrate community biological monitoring studies, and those mills with a concentration of effluent greater than 1% in the area located beyond 250 m of a point of deposit of effluent also conducted fish biological monitoring studies. Mills confirming an absence of effects or identifying solutions for confirmed effects are required to submit their next report in six years.

[5] Several mills conducted studies jointly in conjunction with mills where similar effects exist.

studies jointly. The Cycle 6 National Investigation of Cause Project (National Study[6]) investigating the causes of and solutions for reduced gonad size in fish involved 20 mills. An overview of all investigation studies conducted to date (cycles 4, 5 and 6) to determine causes of and identify solutions for confirmed effects is provided in section 3.3.

Figure 2.2 Biological monitoring studies conducted by 48 mills in Cycle 6



A Standard and alternative monitoring studies to assess effects
B Investigation of cause studies for eutrophication
C Investigation of cause studies for reduced gonad size in fish
D Investigation of solution studies for eutrophication
E Investigation of solutions for effects on fish, including gonad reduction
F Investigation of solutions for both eutrophication and effects on fish

3. EEM Study Results

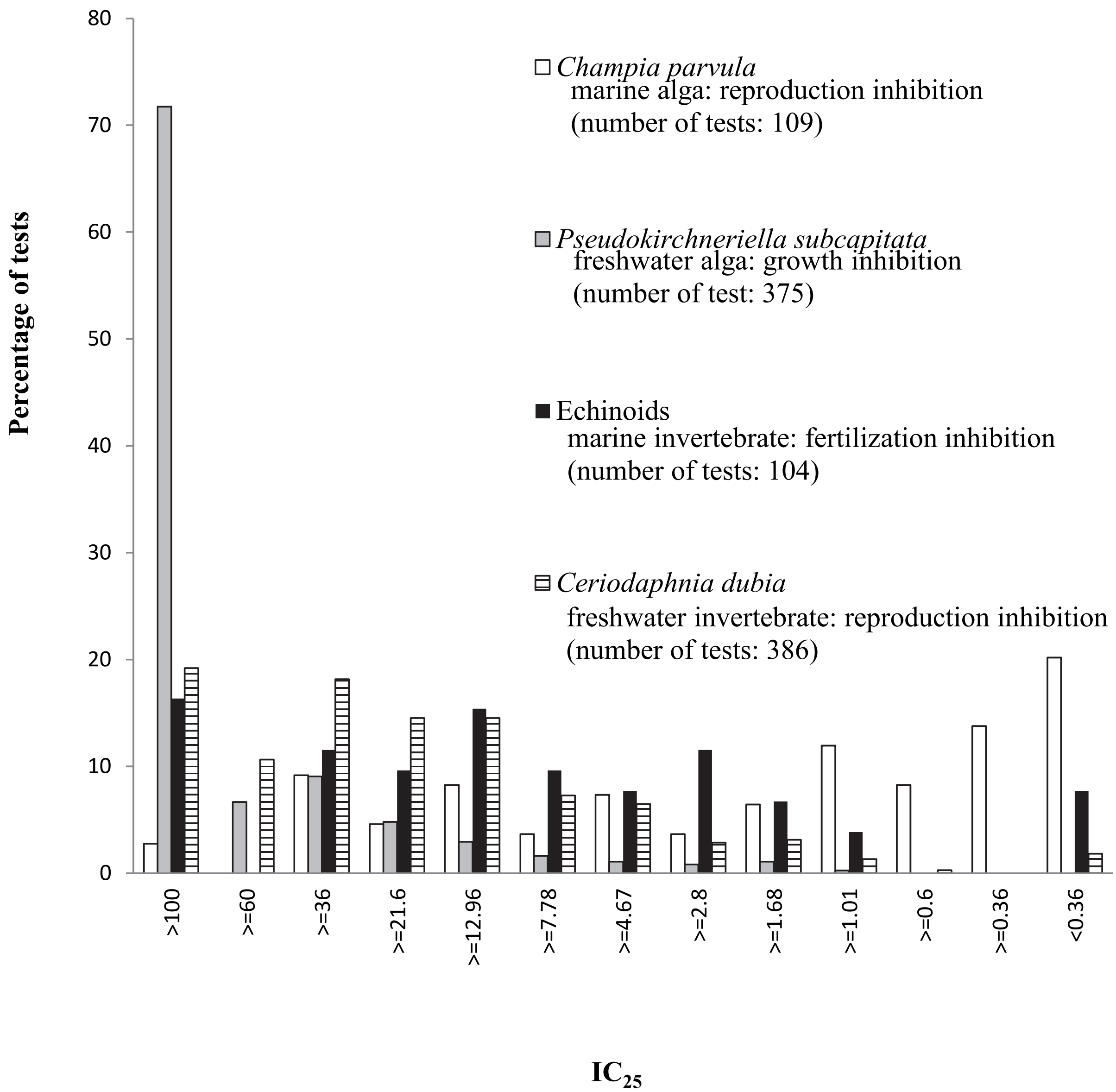
3.1 Sublethal Toxicity Testing Results

Mills are required to conduct SLT testing on final effluent twice per calendar year. Tests are conducted to assess non-lethal effects on reproduction, growth and fertilization. The endpoint used to measure the SLT of effluent is the inhibiting concentration that produces a 25% effect (IC_{25}), i.e., the effluent concentration that causes a reduction in performance (e.g., lower growth or reproduction) of 25% relative to the performance of control organisms. If a 100% concentration of effluent does not cause at least a 25% inhibition, the effluent is reported as showing no SLT for that test (i.e., reported as an $IC_{25} > 100\%$).

[6] The National Study is a collaborative multi-cycle initiative undertaken by industry, academic and government researchers to determine the causes of and solutions for reduced gonad size in fish.

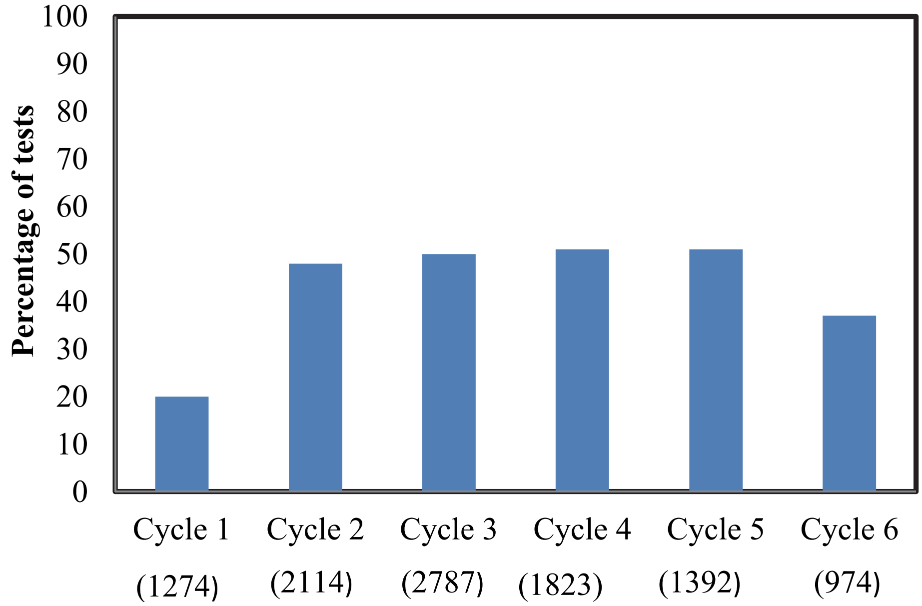
In Cycle 6, all 77 operating mills subject to the PPER conducted SLT testing of their final effluent. No tests were conducted on fish species, because the requirement to conduct a fish test was removed by the 2008 PPER amendments. Cycle 6 growth inhibition tests on the freshwater alga species reported no SLT in 72% of tests; however, in many of these tests, effluent stimulated algal growth, signalling that the effluent could potentially be a source of nutrient enrichment in the receiving environment. Cycle 6 reproduction and fertilization inhibition tests on invertebrates and the marine alga species reported no SLT in less than 20% of the tests (Figure 3.1).

Figure 3.1 Sublethal toxicity of pulp and paper mill final effluent at 77 mills during Cycle 6



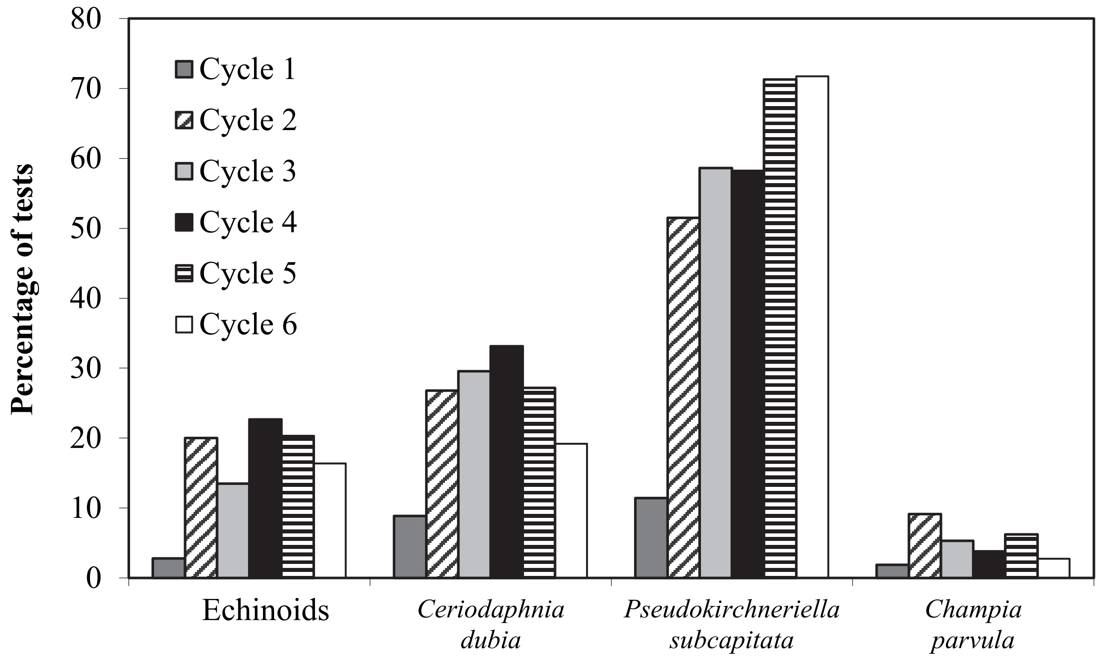
Previous results showed that the SLT of effluents declined between Cycle 1 and Cycle 2 (Figure 3.2). The improvement in effluent quality following Cycle 1 has been attributed to upgrades in effluent treatment in response to the PPER. Although variable for individual mills, overall the effluents continued to elicit SLT responses in half of all effluent tests conducted during cycles 2 to 5. In Cycle 6, effluents elicited SLT responses in 63% of all effluent tests. Some of the increase in overall SLT could be the result of the discontinuation of tests conducted on fish species (more than 80% of the SLT tests conducted on fish species during Cycle 5 reported no SLT), but there was also an increase in overall toxicity in tests conducted with *Ceriodaphnia dubia* (a freshwater invertebrate) and Echinoids (marine invertebrates) during Cycle 6 (Figure 3.3).

Figure 3.2 Percentage of tests per cycle showing no sublethal toxicity at 100% effluent concentration



Note: Total number of tests per cycle shown in parentheses. Chart represents all SLT testing conducted on algae, invertebrates and fish.

Figure 3.3 Percentage of tests per species / per cycle showing no sublethal toxicity at 100% effluent concentration



Species	**Number of tests conducted per species per cycle**					
	Cycle 1	**Cycle 2**	**Cycle 3**	**Cycle 4**	**Cycle 5**	**Cycle 6**
Echinoids	108	175	215	150	128	104
Ceriodaphnia dubia	361	514	707	471	418	386
Pseudokirchneriella subcapitata	236	532	703	481	413	375
Champia parvula	106	175	227	158	129	109

3.2 Cycle 6 Biological Monitoring Studies Conducted to Assess Effects

Biological monitoring studies to assess effects are conducted in three components: fish health, fish habitat, and human usability of fisheries resources. In general terms, if biological monitoring data collected in an area exposed to mill effluent are statistically different from data collected in a similar area not exposed to mill effluent, the mill's effluent has an effect on fish health and/or habitat. For human usability of fisheries resources, fish tissue data from the exposure area are assessed against an established threshold for tissue concentrations of chlorinated dioxins and furans.

Eleven mills conducted nine[7] biological monitoring studies to assess fish and fish habitat effects in Cycle 6 (Table 3.1). The mills conducted these studies for different purposes. Seven mills were re-assessing effects after a period of reduced monitoring, due to previously confirming an absence of effluent-related effects. Two mills were assessing effects as part of an investigation of cause study to determine if previously confirmed effects were caused by the mill's effluent or other nearby pollutant sources, and two mills were continuing to assess effects that had remained unconfirmed in previous studies. In addition to the above nine studies, two mills conducted studies to assess effects in fish tissue.

3.2.1 Effects on Fish and Fish Habitat (Benthic Invertebrate Communities)

To assess fish health, six fish population surveys were conducted: three standard lethal surveys (one involving wild mussels) and three alternative surveys (one non-lethal, one using caged bivalves, and one tracking movement of Sockeye Salmon). All but one of the fish surveys observed an effect in at least one of the core endpoints, and the size of some of the observed effects was above the critical effect size[8] (CES).

To assess fish habitat, there were seven benthic invertebrate community surveys conducted, three with a control-impact design and four using a gradient design. All but one benthic invertebrate survey observed an effect in at least one of the core endpoints, and in some instances the magnitude of the effect(s) was above the CES.

Conclusions from the studies varied (Table 3.1). Some studies concluded that, after a period of reduced monitoring, effects were observed in the receiving environment; the next step will be to confirm these results. Other studies concluded that the effects confirmed in previous studies were caused by mill effluent; the next step will be to conduct studies to investigate solutions. A few studies determined that the effects observed in the exposure area were attributable to causes other than the mill effluent (i.e., municipal wastewater effluent).

[7] Three mills conducted one biological monitoring study jointly.
[8] A critical effect size (CES) is a threshold above which an effect may be indicative of a higher risk to the environment.

Table 3.1 Summary of the biological monitoring studies conducted to assess effects on fish and/or fish habitat (benthic invertebrate communities) in Cycle 6

Study	Study Purpose	Component	Study Design	Effects Observed in Cycle 6	Study Conclusions
1	Re-assessing /confirming effects	Benthic	gradient	Effect on Bray-Curtis index	Effects confirmed in exposure area
		Fish	standard	Effects on gonad, liver, weight at age, condition and age	
2	Re-assessing effects	Benthic	standard	Effect on Bray-Curtis index	Effects observed in exposure area. Re-assess and confirm effects in next cycle.
		Fish	standard	Effect on gonad, liver, condition, and age	
3	Re-assessing effects	Benthic	radial gradient design	Effect on taxon richness and Bray-Curtis index both above CES	Effects observed in exposure area. Re-assess and confirm effects in next cycle.
4	Assessing effects	Benthic	standard	Effect above CES in taxon richness, density, Evenness and Bray-Curtis index	Benthic effects observed in exposure area caused by mill effluent. No measureable effect of mill effluent on fish; observed fish effects caused by nearby municipal wastewater treatment plant effluent.
		Fish	non-lethal	No measureable effect of the mill effluent on fish	
5	Investigation of cause study	Benthic	gradient design	Effect on density, taxa richness and Bray-Curtis Index (B-C above CES)	Benthic effects observed in exposure area; related to historical mill discharges. Fish effects observed in exposure area not attributed to mill effluent.
		Fish	standard, wild blue mussels	Effect on condition and size at age	
6	Re-assessing effects; joint study involving three mills	Benthic	standard study and a reference condition approach	No benthic effects	No benthic effects confirmed in exposure area
7	Re-assessing effects	Benthic	gradient	Effect in density and an effect above CES on Bray-Curtis index	Benthic effects in exposure area attributed to historical impacts; not current mill effluent
8	Assessing effects	Fish	alternative to standard fish survey (due to site-specific conditions) assessing Sockeye Salmon movement in exposure area	Alternative assessment (no EEM endpoints) EEM effects endpoints not measured due to site-specific conditions	Study found that there were improvements in near-bottom dissolved oxygen levels, and that historical impacts of the effluent no longer pose a risk to Sockeye Salmon in that area
9	Investigation of cause study	Fish	caged bivalve study	Effect in size at age, weight and gonad effect above CES	Effects confirmed in previous studies are caused by mill effluent

3.2.2 Effects on Fish Tissue

An effect on fish tissue means concentrations of chlorinated dioxins and furans, expressed as toxic equivalents (TEQs) of 2,3,7,8-tetrachlorodibenzo-para-dioxin, exceed 15 picograms per gram (pg/g) wet weight in muscle or 30 pg/g wet weight in liver or hepatopancreas of fish taken in the exposure area. In Cycle 6, two coastal mills conducted studies to assess effects on fish tissue; both studies observed an effect on fish tissue.

One study captured Dungeness Crabs from eight sampling locations located at varying distances from the mill's discharge point, and found that TEQ concentrations did not appear to vary consistently with distance from the mill. The two highest values were recorded at the two furthest sampling locations from the mill. TEQ values continued to decline at some locations, while values at other locations appeared to have stabilized at near-record lows. Total TEQ concentrations in crab hepatopancreas ranged from 49.9 pg/g to 10.7 pg/g. Some of these concentrations were the lowest values recorded since the onset of monitoring, while other concentrations were within the lower range of those reported in recent years, and considerably lower than concentrations reported in the early to mid-1990s (when concentrations were as high as 186 pg/g).

The other study found that concentrations of dioxins and furans appear to be exhibiting a decreasing trend in Dungeness Crabs and dogfish captured in the exposure area. Total TEQ values of dioxins and furans in hepatopancreas samples of Dungeness Crabs from three of the eight sampling locations and in dogfish liver exceeded the effect threshold (30.0 pg/g liver), but an exceedance was not observed in dogfish muscle tissue.

3.3 Investigation Studies for Confirmed Effects

To confirm that effects observed in the receiving environment are not simply the result of a one-time study, biological monitoring studies to assess effects are repeated in consecutive cycles. If the same effect on the fish population, benthic invertebrate community or fish tissue occurs in studies from consecutive cycles, the effect is considered confirmed.

To investigate confirmed effects, mills describe the magnitude and geographical extent of the effects, investigate their causes, and identify possible solutions to eliminate them. To describe the magnitude and extent of confirmed effects, mills conduct additional sampling downstream in the exposure area. Mills that had included this additional sampling while monitoring to assess effects had the information needed to describe the magnitude and geographic extent of confirmed effects, and could proceed with investigation of cause studies. Mills that had not already conducted additional monitoring needed to describe the magnitude and extent of their confirmed effects before beginning their investigation of cause studies. The goal of an investigation of cause study is to determine the cause of the observed effects. The goal of an investigation of solution study is to identify possible solutions to eliminate the observed effects.

Priority was given, by the Smart Regulation Initiative,[9] to the investigation of causes and solutions for two nationally prevalent effects, eutrophication (nutrient enrichment) and reduced gonad size in fish. In 2008 the Forest Products Association of Canada (FPAC) developed a Best Management Practices Guide for Nutrient Management in Effluent Treatment[10] to assist mills in investigating and reducing eutrophication effects; and a National Investigation of Cause Project[11] (National Study) to investigate the causes of reduced gonad size in fish was initiated. As of Cycle 6, 66 mills had conducted 60 investigation studies (some studies were conducted jointly by two or more mills). Table 3.2 lists the number and type of investigation studies conducted over cycles 4, 5 and 6. The following sections, along with Table A-1 in the appendix, summarize the study methodologies used and the results found.

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[9] The Smart Regulation Initiative for Environmental Effects Monitoring report and Environment Canada's response to the reports are available upon request by email at EEM-ESEE@ec.gc.ca .

[10] Available at http://www.fpac.ca/index.php/en/publications-viewer/488/.

[11] The National Study is a collaborative initiative undertaken by industry, academic and government researchers to determine the cause of reduced gonad size in fish. Eight mills participated in this joint investigation study in cycles 4 and 5, and 20 mills participated in the Cycle 6 study.

Table 3.2 Number of types of investigation studies conducted per cycle

Type of Study	Cycle 4	Cycle 5	Cycle 6	Total
Investigation of Cause				
eutrophication	14(16)	6(6)	7(7)	27(29)
reduced gonad size in fish	2(12)	2(11)	-	4(23)
Investigation of Solutions				
eutrophication	-	9(11)	8(8)	17(19)
effects on fish, including gonad size	-	-	3(9)	3(9)
eutrophication and effects on fish, including gonad size	-	-	8(15)	8(15)

Note: The number of mills conducting studies are indicated in parentheses.

3.3.1 Investigation of Cause Studies for Effects Associated with Eutrophication

<u>Studies Conducted for Eutrophic Effects</u>

For many mills, the cause of the effects associated with eutrophication was well understood to be nutrients in the mill final effluent. In these situations, mills simply stated the cause and progressed directly to investigate possible solutions to eliminate the effects. For other mills where confounding factors were present, the focus of investigation of cause studies was to determine if the mill's effluent caused the observed effects and/or the degree to which the mill's effluent contributes to the observed effects. A wide variety of studies were conducted to investigate causes of effects associated with eutrophication, including the following:

- Fish population and benthic invertebrate community surveys were used to investigate the link between observed eutrophic effects and mill effluent. These surveys were designed to sample fish and/or invertebrates in the vicinity of mill effluent, as well as other nearby confounding discharges, such as municipal sewage. In other cases, the sampling stations were placed in such a way as to discriminate between the effects caused by current mill effluent and historic deposits, such as bark and/or fibre mats. Some fish surveys used caged bivalves in the sampling location to determine the relative contribution to observed effects of each effluent. One study, in addition to the fish survey, conducted stomach content and histopathological analyses on the fish.
- Water and/or sediment quality parameters were used to investigate effects, either on their own or in conjunction with benthic and/or fish surveys. Parameters were measured to evaluate nutrients in the receiving environment and included total phosphorus (TP), nitrite, total nitrogen, total Kjeldahl nitrogen, ammonia, total organic carbon (TOC), suspended sediment, and total dissolved solids. Specific to sediment, parameters included sulphides, carbon to nitrogen ratio, bacteria, and sediment redox potential. The distribution of salinity, temperature and dissolved oxygen was studied, and short-term sediment traps were employed to measure total mass and organic content.
- Stable isotopes were used to trace the sources of organic matter in benthic habitats and organisms as well as fish. Other studies evaluated stable isotopes in sediment cores or used isotopes to determine depositional rates and timelines.

- Periphyton studies compared biomass values to water quality objectives or compared taxonomies between sampling locations. One study investigated periphyton accrual on nutrient-diffusing artificial substrates.
- Effluent parameters were studied to determine nutrient inputs from mill effluent to the receiving environment. Some of the parameters measured included total suspended solids (TSS), sulphur compounds, total phosphate, nitrite, nitrate, Kjeldahl nitrogen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved organic carbon (DOC) and TOC. In some studies, effluent parameters were evaluated before and after nutrient amendments were made to the wastewater treatment system.
- Water quality modelling techniques were used to predict the nutrient reductions from mill effluent required to produce recommended receiving environment nutrient concentrations; or an assimilative capacity study was conducted to clarify the degree to which phosphorus from the mill effluent may be contributing to enrichment effects.
- Methodologies were used to isolate the effects caused by mill effluent, for example:
    - A mesocosm study, using periphyton and epibenthic invertebrates exposed to various effluent concentrations, was used to determine effluent-related effects.
    - A laboratory SLT study using various effluent concentrations and fractions was conducted using a benthic invertebrate species[12] to determine the effluent's contribution to toxicity effects observed in the receiving environment.
    - A microcosm experiment using multiple concurrent exposures to varying concentrations of mill effluent was used to assess mill-specific effects, isolated from historic and confounding influences.
    - Visual assessments of mill effluent and other point-source exposure sites were conducted using remote underwater vehicles. Historical fibre mats were delineated to determine their relative contribution to organic enrichment. Benthic surveys using transplant devices filled with reference-area sediment or stone substrates were employed to investigate causes for and relative contributions to effects.
- Re-assessment of existing EEM biological data and other information was used to determine causes of observed non-priority effects.[13]

<u>Causes Determined for Eutrophic Effects</u>
The majority of investigation of cause studies for effects associated with eutrophication concluded that some form of nutrient enrichment from mill effluent was causing the observed effects. Some of the nutrients identified included bioavailable phosphorus, effluent biosolids, total and dissolved phosphorus, nitrogen and organic carbon.

Some studies were able to determine the relative contribution of mill and other nearby confounding influences to observed effects. A mesocosm study determined that mill effluent could affect water quality and benthic communities in the receiving environment. Benthic surveys confirmed that observed effects were strongly related to mill effluent exposure, as opposed to substrate. A microcosm experiment concluded that mill effluent did affect sediment and benthic communities at environmentally relevant concentrations. SLT laboratory studies

[12] The species used was *Hyalella azteca* and the SLT test used was EPS 1/RM/33.
[13] See section 1.5.3 of the *Pulp and Paper Technical Guidance for EEM* document for a description of prioritized and non-prioritized effects.

determined that solids in mill effluent may contribute to observed smothering/toxicity effects, but results observed for effluent fractions without solids suggested that there were causes of toxicity in addition to potential effects attributed to solids alone.

Other investigation of cause studies concluded that the current mill effluent was not the major cause of the eutrophic effects. Instead, influences from the decomposition of historical fibre mats, habitat differences and municipal wastewater discharges were identified as causes for observed effects.

In addition, two studies for eutrophic effects in fish did not determine a cause for the observed effects, but concluded that future research may shed more light on causative agents in mill effluents that affect energy usage in fish.

3.3.2 Investigation of Solution Studies for Effects Associated with Eutrophication

Solution Studies Conducted for Eutrophic Effects

The majority of studies conducted to identify solutions to eliminate effects associated with eutrophication involved either nutrient source assessments or the analysis of nutrient management systems or both.

Nutrient source studies involved the assessment of current and historical mill operations data to identify the major contributors to mill process–generated nutrients. By using mill process data and surveys undertaken in the mill, concentrations and variations of phosphorus and nitrogen forms in mill streams and effluents could be determined. The contribution, in terms of total phosphorus from other sources (such as wood chips and solids such as lime mud and ash) was also analyzed in a number of studies.

The analysis of nutrient management systems most often involved identifying gaps in existing nutrient management processes and procedures, by making comparisons to FPAC's *Best Management Practices Guide for Nutrient Management in Effluent Treatment*. By assessing variables in daily biotreatment operations databases and focusing on inputs of waste, addition of chemicals, and control tests, the overall performance of the effluent treatment system could be determined and key initiatives could be identified to move the system to a state of quality treatability. Common variables measured included total phosphorus, added phosphorus (often phosphoric acid), residual phosphorus in effluent, suspended solids, TOC and sludge volume index. Nutrient management studies often included the assessment of monitoring protocols, analytical methodologies, equipment, and personnel training needs.

Some studies went beyond studying nutrient source and management and evaluated phosphorus removal technologies, or determined seasonal changes by sampling nutrients monthly in the river upstream of the outfall as well as filtered and unfiltered effluent. A few studies investigated the impact of dredging aeration stabilization basins on the nutrient concentration in final effluent.

Solutions Identified for Eutrophic Effects

Most of the solutions identified to eliminate effects associated with eutrophication involved improving the wastewater treatment system. A smaller number of identified solutions involved changes to mill processes. Solutions related to wastewater treatment system procedures, processes and equipment included the following:

- improved monitoring within the system
- improved supplemental nutrient addition efficiency
- equipment maintenance and verification
- improved procedures and planning
- physical changes to the wastewater system
- personnel training and additional research

Many solution studies identified improvements to the monitoring of wastewater treatment systems and processes. Suggested improvements included the following:

- addition of new or upgraded monitoring locations
- increased monitoring frequency
- addition of testing programs for other parameters, such as nitrites, nitrates, total phosphorus, microbes and nutrients in the influent from the mill

In order to increase the accuracy of supplemental nutrient additions, improvements to chemical databases (especially the ratio between COD and BOD, and testing methods and procedures) were suggested. One study suggested that COD and BOD results be discussed during daily production meetings.

Solutions for improving supplemental nutrient-addition efficiency focused on ways to optimize the use of supplemental nutrients, with the goal of maintaining the lowest nutrient residual possible while maintaining efficient BOD and TSS removal and not causing aquatic toxicity. In some cases this optimization meant creating or renewing the nutrient addition strategy and basing it on grade changes and/or monitored parameters such as the amount of phosphorus present in mill streams, influent COD, ammonia and ortho-phosphate residuals. Other solutions identified involved extending the time period when no supplemental nutrients are added, or conversely adding a food source for the system's microbes during periods of extended shutdowns. Changes to the supplements used were suggested, such as switching from ammonium polyphosphate to a nutrient source containing only phosphate, or separating the addition of nitrogen and phosphorus by installing a separate phosphoric acid addition system. Changes to the way nutrients are added to the system were suggested, such as adding automated, continuous flow-adjustment capabilities or recycling treated effluent back into the first cell of the aeration stabilization basin to reuse nutrient residuals.

A review of all analytical methods associated with nutrient management was the most common solution identified to improve procedures and planning related to the wastewater treatment system. Developing a planning document to assist with more effective, prompt responses to changes in the bacterial flora of the treatment system was suggested. Setting targets for nitrogen and phosphorus levels was identified as a solution for ensuring best management practices are maintained. Another solution was to establish a method for the environmental manager to assess the nutrient content of each new product used in the production process.

Solutions for optimizing the wastewater treatment system included the maintenance and verification of equipment. The development of predictive preventive maintenance programs and flow-control verification requirements for nutrient dosage equipment was suggested, such as establishing a weekly procedure for manually verifying flow metering pumps and verifying the accuracy and repeatability of the flow delivered. Other solutions included maintaining good equipment calibration and upgrading equipment so that nutrient control systems were active and maintained seven days a week.

Solutions involving physical changes to the wastewater treatment system were identified. Dredging the aeration stabilization basin on a regular basis to maintain available volumes above 50% was identified as a solution for reducing solids in final effluent. Regulating the load arriving at the wastewater treatment system, improving settling in primary settling tanks, and maintaining an optimal temperature during winter were solutions identified to assist with biotreatment optimization. The addition of a second aeration basin in series or parallel was identified in one study as a solution for increasing hydraulic retention time in the aeration zone. The addition of post-treatment technologies was evaluated as a potential solution; these technologies included phosphorus removal or physical-chemical treatment processes such as enhanced coagulation/flocculation/settling technologies, active sand filtration and conventional clarification, and filtration methods. One study suggested that an anaerobic system could pre-treat the wastewater, removing approximately 80% of the COD and turning it into biogas to generate power on-site. The study pointed out that COD removal would result in reduced supplemental nutrients, polymer and sludge, and therefore less COD and nutrients entering the receiving environment.

Other identified solutions involved personnel training and further research. The training of analysts and technicians working with the wastewater system was a common recommendation, as was the revision of procedures and work instructions. Recommendations for further research included the following:

- Pinch and mass balance analyses
- comparison of healthy ranges of phosphorus within a cell to overall treatment performance in order to verify an end-of-pipe target and acceptable ranges within the system
- further investigation of the species of phosphorus present in mill streams
- evaluation of the use of products that induce high BOD
- investigation of the contribution of boiler ash to total phosphorus in mill streams
- investigation of alternative settling aids that contain negligible quaternary ammonia cations

In addition, a smaller number of solutions relating to mill processes were identified. Some of these solutions focused on continued efforts to minimize discharge of organic material from the mill to biotreatment. Examples of process changes that would decrease BOD load include improved brownstock washing, increased reuse of condensates, improved sludge dewatering, and improved spill control and spill-pond reclaim. Improving the reliability of online conductivity instrumentation was identified as a means of further optimizing the wastewater treatment system by reducing the volume and duration of high-strength spills (shock loads). Installing a pulp fibre recovery system and/or a pressure diffusion washer would reduce BOD loading to biotreatment. To reduce the load of nutrients going into biotreatment, further monitoring of the phosphorus content of wood chips was recommended to facilitate the choice to pulp only low-phosphorus chips. Use of make-up lime with lower phosphorus content was also recommended.

3.3.3 Investigation Studies for Reduced Gonad Size in Fish

The collaborative initiative undertaken by industry, academic and government researchers to determine the cause of reduced gonad size in fish (the National Study) initially focused on selecting the most appropriate laboratory tests for conducting investigations into this effect. The work included an assessment of wild fish from a river receiving mill effluent and a series of laboratory tests with four species of fish, coupled with extensive chemical analyses of the effluents used in the tests. Laboratory tests ranged in duration from a few days to over six months, and covered an assortment of reproductive indicators in fish, from the biochemical level to egg production.

The Cycle 4 National Study final report (Kovacs et al. 2007) concluded that the egg production endpoint in laboratory tests appeared to have the greatest potential for assessing an effluent's ability to affect fish reproduction, as effluent-related effects on this endpoint were found to be similar in three species of fish. The study results also suggested that the effect of a mill effluent on egg production might be reliably assessed in a shorter time frame than previously thought, further supporting the indication that the egg production endpoint may be a good tool for future investigation of cause and solution studies. Variability in the responses of Fathead Minnow to effluent, and in the results of chemical analyses, indicated that effluent quality from a given mill can vary over time, demonstrating the complexity of identifying causative agents and the need for more studies. The report concluded that the final selection of diagnostic tools for investigation studies would only be possible by completing similar studies at other mill sites.

The Cycle 5 National Study final report (Martel et al. 2010) describes similar studies conducted at two other mills. Temporal effluent variability with respect to fish reproduction was studied, and laboratory tests were conducted to confirm hypotheses on the causes and sources of the variability. Laboratory tests ranged in duration from a few days to several weeks, and covered an assessment of reproductive endpoints in fish from the biochemical level to egg production. Wild fish from a river receiving mill effluent were assessed, and final effluent quality was characterized by measuring a gas chromatographic profiling index, BOD and organic compounds of concern (e.g., methyl-2-cyclopentenones).

The short-term ($\leq$ 7 days) tests found that the response of egg production to effluent exposure was the most sensitive endpoint in two fish species. Longer-term tests (approximately 30 days) also found that egg production was the most sensitive endpoint and that effluent-related effects on egg production occurred at lower concentrations than in short-term tests. The National Study found that Fathead Minnow egg production tracked changes in effluent quality as it related to production upsets, mill restarts, and conditions affecting biotreatment performance. Additional laboratory tests with five fish species confirmed the potential contribution of black liquor for causing final mill effluent-related effects on fish reproduction.

The work conducted for the National Study during cycles 4 and 5 identified egg production in short-term tests as the diagnostic tool having the most potential for future investigation studies into the causes and solutions for confirmed effects related to mill effluent. It was acknowledged that the exact relationship between effluent effects on egg production in short-term tests using laboratory fish species and gonad size in different species of wild fish is presently unclear. However, the report concluded that, because the effects on egg production were significant, investigation of cause and solution studies using such a test would have environmental benefits.

The Cycle 5 report also identified leads for future studies investigating the potential solutions for confirmed effects. These leads involved minimizing organics losses and upsets to biological treatment.

The Cycle 6 National Study (Martel et al. 2012) applied the egg production and effluent chemical characterization tools developed in the previous two cycles to a variety of effluents, in order to investigate leads for solutions related to the minimization of losses of organic matter and upsets to biological treatment. Twenty mills participated in the National Study, and the effluent of each of these mills was assessed on at least three occasions each. Thus, an assessment of effluent quality in relation to fish reproduction across the sector and at any one mill was possible. The 20 participating mills were grouped into four categories: kraft (eight), mechanical pulping (five thermomechanical, one bleached chemi-thermomechanical), recycled/paper/board (four) and complex using sulphite pulping (two).

A strong relationship between kraft mill final effluent BOD_5[14] and Fathead Minnow egg production was observed. Egg production was consistently reduced in all cases where the BOD_5 was > 25 mg/L. Over 90% of the kraft mill data supported the conclusion that final effluents with a BOD_5 < 25 mg/L do not affect egg production in laboratory tests. In cases where a mill's effluent BOD_5 was lowered over the course of the Cycle 6 National Study, through internal spill control and reduction initiatives or biotreatment optimization, the effect on egg production was eliminated.

All of the effluents collected from the mechanical pulp mills had BOD_5 levels of < 20 mg/L and four of the six mill effluents exhibited no effects on egg production. Effluents from the two other mills, a thermomechanical and the single bleached chemi-thermomechanical, consistently reduced egg production independent of BOD_5 levels. The thermomechanical mill effluent affecting egg production had not done so in previous tests, and given that mill production and treatment efficiency had not changed, the National Study suggested that other factors, such as polymer and additive usage, could be contributing to the reduction in egg laying. No suggestions for why the lone bleached chemi-thermomechanical mill effluent was affecting egg production were given, but further research on these types of mills was encouraged.

The BOD_5 levels for the recycled mills varied between 2 and 6 mg/L for three of the mills and 45 and 86 mg/L for the 4th mill (due to unusually high solids content). Of all 18 effluent samples collected from these mills, only four depressed egg production, three of which could be related to biotreatment upsets. There was no relationship between BOD_5 and egg production, and thus the National Study concluded that the potential of these effluents to cause reproductive effects in fish, under normal operating conditions, appears to be low.

All of the effluents collected from the two mills using sulphite pulping caused significant depressions in egg production. The BOD_5 levels ranged from 17 to 24 mg/L at one mill and 16 to 65 mg/L at the other mill. Given the limited amount of data, the National Study could not predict whether a relationship between BOD_5 and egg production exists or whether further reductions in BOD_5 would be sufficient to remove the effect on egg production.

[14] BOD_5 is the amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter, and is a measure of the organic content of wastewater.

The National Study concluded that the greatest potential for abating effects on fish reproduction in laboratory studies was the reduction of organics loading in final effluent, and that, through the optimization of biological treatment, spill minimization and reduced BOD_5 throughout all processes, improvements in effluent quality were achievable. The threshold level of 25 mg/L for BOD_5 in final effluent was shown to be robust and in many cases resulted in the elimination of effects on egg production in the laboratory.

Another investigation of cause study for reduced gonad size in fish was conducted by two mills separate from the National Study. This study conducted toxicity source and identification evaluations to isolate the waste stream(s) within the mill that were potentially causing effects on fish reproduction. Laboratory fish were exposed to six separate waste streams and untreated reference water. Fractionation methods developed to identify the class of chemicals that might cause depression of plasma sex steroids in Mummichog were refined by iteratively applying them to biologically active waste streams. The effect of final effluent on adult Mummichog egg production was also assessed.

At one mill, the source of compounds causing reproductive and other effects on laboratory fish was identified as the reverse osmosis feed stream (5th effect condensate). Causative compounds were present in the reverse osmosis concentrate, which is removed and burned, but not in the reverse osmosis permeate that enters the final effluent. For the other mill, fish exposed to 3% and 100% final effluent had significantly lower final condition factors compared with controls, but there were no significant differences in all other parameters measured (for example, gonad somatic index, hormone levels, egg production). Changes at the mill included a production change from newsprint to high-quality super-calendared paper, reducing BOD input to the treatment plant, increased aeration capacity in the treatment plant, and a switch to magnesium hydroxide as the alkali source in the peroxide bleaching process. Treated effluent (reverse osmosis and a moving bed bioreactor at one mill and standard secondary treatment at the other) from both mills is combined and discharged at one main outfall. The joint study concluded that current effluent from both mills has low potential to cause reproductive effects to fish within the receiving environment due to changes in production and wastewater treatment.

3.3.4 Investigation Studies for Fish Tissue Effects

One mill has investigated a confirmed effect on fish tissue. The study traced sources of organic matter and contaminants in crab habitat (sediment survey) and crabs (crab tissue survey), and established a sedimentation timeline (sediment coring survey). Recently deposited sediments showed relatively low dioxin/furan concentrations and had similar stable isotope signatures to sediments deposited prior to the opening of the mill. Sediments deposited after the mill opened, but prior to the implementation of secondary treatment of effluent, exhibited different isotope signatures and contained higher concentrations of dioxins and furans. The age of adult crabs ranged between 4 and 10 years, increasing the likelihood that the crabs fed on historical contaminants at some point in their life cycle. Slow sedimentation rates have resulted in slow burial of fibre and other contaminants related to historical effluent discharges. Historical deposits are therefore still accessible to potential crab prey (e.g., clams), and crabs may take up contaminants from organisms feeding on these historical deposits.

In terms of solutions, it was suggested that crab tissue dioxin/furan concentrations will likely continue to decline as contaminated sediments become buried, although low levels of dioxins and furans may persist beyond this time due to bioturbation[15] and decomposition of deceased contaminated biota. The study speculated that contaminated strata are likely already buried below biologically active layers in sheltered or depositional areas; however, in exposed or erosional areas, contaminated strata will not be buried for many more years.

4. Solutions Implemented and Results Achieved

Many mills implemented solutions identified by investigation studies. The majority of solutions implemented for effects associated with eutrophication involved the wastewater treatment system and included changes in nutrient additions, improved procedures for monitoring and testing, equipment addition, upgrade or repair, dredging and personnel training.

Changes in nutrient addition involved the increase of supplemental nutrients during periods of shutdown or cold weather and/or the reduction or complete cessation of supplemental nutrient addition during periods of normal operation. Due to the recalculation of the BOD/COD correlation, a mill found that the predicted BOD may have been overestimated by 15% and could therefore reduce the nutrient dosage used. Another mill has continued the recycling of some final effluent to reuse ortho-phosphate within the aerated stabilization basin beyond the summer season, thereby reducing the need for incremental phosphorus addition during winter. For another mill, switching to a low-phosphorus fertilizer, and only fertilizing between October and April when lower water temperatures require nutrient addition, has maintained efficient effluent treatment. Several mills have implemented the use of whey from cheese to serve as a nutrient source for the bacterial flora of the lagoon during prolonged shutdowns.

Many mills implemented the improvements to monitoring and testing procedures identified by investigation studies. Examples of improved monitoring included the following:

- increasing the testing of COD to twice a day, 7 days a week
- increasing the frequency of nutrient testing from once a week to 5 days a week
- adding testing programs for nitrate/nitrites residuals and lagoon BOD, TSS, dissolved oxygen and pH
- incorporating a sludge volume index threshold above which analysis would be conducted to determine the cause of poor settling

The addition of supplemental nutrients was optimized by increasing the number and quality of sampling locations to improve the monitoring of nutrient residuals and treatment efficiency. Monitoring and laboratory testing procedures were validated, and standard operating procedures were updated. Daily tracking of the nutrient dosage was implemented to ensure nutrient addition rates were optimizing supplemental nutrient additions. Discussion of in-house COD and third-party BOD results was incorporated into daily morning production meetings and, in one case, a sensor was installed in the inlet of the lagoon to provide a daily measurement of COD; the mill's production rate is adjusted according to this daily measurement.

[15] Bioturbation is the stirring or mixing of sediment or soil by organisms, especially by burrowing or boring.

Equipment additions, upgrades or repairs were mostly related to improving aeration. Fine bubble aeration systems were repaired, more efficient aerators replaced existing less effective aerators, and pre-aeration equipment was installed, all to increase dissolved oxygen within the treatment system. Curtains or membranes were installed and/or repaired to improve hydraulic retention times in lagoons, allowing for more effective removal of suspended solids and BOD. To stimulate consumption of ammonia released by sludge, recirculation pumps were installed. A pump for the ammonia feed system was installed so that small feed rate adjustments could be implemented and, in one case, construction had started on a new anaerobic pre-treatment system. Other solutions implemented for the wastewater treatment system included the following:

- dredging the aeration stabilization basin or lagoon, with a two-year dredging frequency planned for the future
- adding a pH control at the entrance or output of the lagoon by the addition of sulfuric acid
- training of analysts and technicians

In one case the pH control strategy was abandoned after a year, because it showed no significant effect on the toxicity of the final effluent, and one mill removed a curtain because it was creating an imbalance between the two cells and increased effluent toxicity.

Solutions involving changes in mill processes were also implemented for effects associated with eutrophication, and were focussed on reducing the amount of BOD and/or COD going to the wastewater treatment system. Mill process changes included the following:

- changing the management of white water
- installing a pressurized diffuser from the digester and existing air diffuser to improve the washing of brown stock and reduce the loss of black liquor[16]
- starting up a second stage of oxygen delignification to decrease residual lignin[17] and black liquor carryover to the bleach plant
- installing a water conservation system resulting in the elimination of sewering of waste generator acid to the effluent treatment system
- installing a pressure diffusion washer
- redirecting a condensate stream from sewer to the condensate steam stripper treatment process
- improving operation of the primary clarifier and sludge dewatering

In studies where the results achieved were reported, most often the residual phosphorus and nitrogen content of effluent was reduced, in some cases by 50%. Reductions in final effluent BOD and TSS levels were also reported. In some mills, the implementation of solutions resulted in reducing the amount of supplemental nutrients added to the wastewater treatment system with no reduction in treatment efficiency, as BOD removal rates remained at more than 95%.

[16] Black liquor is the spent cooking liquor from the kraft process when digesting pulpwood into paper pulp, removing lignin, hemicelluloses and other extractives from wood to free cellulose fibers.
[17] Lignin is a complex chemical compound most commonly derived from wood and is an integral part of the secondary cell walls of plants.

5. Conclusions

Sublethal Toxicity Testing and Biological Monitoring Studies to Assess Effects

Final effluents elicited SLT responses more often in Cycle 6 compared to previous cycles (63% of tests compared to 50%). There was an increase in overall toxicity in tests conducted with *Ceriodaphnia dubia* (freshwater invertebrate) and Echinoids.

The conclusions from the biological monitoring studies conducted to assess and confirm effects varied. Two studies concluded that, after a period of reduced monitoring, effects still exist in the receiving environment; the next step will be to confirm the results. Other studies concluded that the effects confirmed in previous studies were caused by mill effluent; the next step will be to conduct studies to investigate solutions. Other studies determined that the effects observed in the exposure area were attributable to causes other than the mill effluent (i.e., municipal wastewater effluent). The two coastal mills that conducted studies to assess effects on fish tissue in Cycle 6 observed an effect on fish tissue.

Investigation Studies for Eutrophic Effects

For many mills, the cause of effects associated with eutrophication was well understood to be nutrients in mill effluent discharged to the receiving environment. In these situations, mills simply stated the cause and moved forward to investigate possible solutions to eliminate the effects. Some of the nutrients identified included bioavailable phosphorus, effluent biosolids, total and dissolved phosphorus, nitrogen and organic carbon.

For other mills where confounding factors were present, such as nearby municipal wastewater discharges, the focus of investigation of cause studies was to determine if the mill's effluent caused the observed effects and, if so, the degree to which the mill's effluent contributed to the effects. Benthic studies confirmed that effects were strongly related to mill effluent exposure, as opposed to substrate. Mesocosm studies determined that mill effluent could affect water quality and benthic communities in the receiving environment, while microcosm experiments found that mill effluent did affect sediment and benthic communities at environmentally relevant concentrations. Laboratory studies determined that solids in mill effluent may contribute to smothering/toxicity effects, but effluent fractions without solids also elicited toxicity effects. In a few instances, studies concluded that the current mill effluent was not the major cause of the eutrophic effects. Instead, influences from the decomposition of historical fibre mats, habitat or municipal wastewater discharges were identified as the cause of the observed effects.

Solutions identified to eliminate effects associated with eutrophication involved improving the wastewater treatment system and changes to mill processes. Solutions related to wastewater treatment system procedures, processes and equipment included the following:

- improved monitoring within the system
- improved supplemental nutrient input addition
- equipment maintenance and verification
- improved procedures and planning
- changes to the wastewater system itself

- personnel training and additional research

Investigation Studies for Reduced Gonad Size in Fish

For the effect of reduced gonad size in fish, the National Study applied the diagnostic tools that it developed to effluents from 20 mills, and found that the threshold level of 25 mg/L for BOD_5 in final effluent was robust and in many cases resulted in the elimination of reproductive effects on fish in the laboratory. The National Study concluded that the greatest potential for abating effects on fish reproduction in laboratory studies was the reduction of organics loading in final effluent, and that improvements in effluent quality were achievable through the optimization of biological treatment, spill minimization and reduced BOD_5 throughout all processes.

Investigation Studies for Fish Tissue Effects

The one investigation study conducted for fish tissue effects determined that sediments deposited after the mill opened, but prior to the implementation of secondary treatment of effluent, contained higher concentrations of dioxins and furans. These historical deposits are still accessible, and crabs may take up contaminants from prey organisms feeding on these historical deposits. The study suggested that crab tissue dioxin and furans concentrations will likely continue to decline as contaminated sediments become buried.

Solution Implementation and Achievable Results

The solutions identified for the two prevalent, prioritized effects of mill effluent, eutrophication and reduced gonad size in fish, have a common foundation: reduction of organics loading in final effluent.

Many mills implemented solutions identified in investigation studies. The majority of solutions implemented for effects associated with eutrophication involved the wastewater treatment system, and included changes in nutrient additions, improved procedures for monitoring and testing, equipment addition, upgrade or repair, dredging and personnel training.

In studies where the results achieved from implementing solutions were reported, most often it was residual phosphorus and nitrogen content of final effluent there were reduced, in some cases by 50%; reductions in final effluent BOD and TSS levels were also reported. The implementation of solutions often resulted in the reduction of supplemental nutrients with no reduction in treatment efficiency. In cases where a mill's effluent BOD_5 was lowered over the course of the National Study, through internal spill control and reduction initiatives or biotreatment optimization, the effect on egg production in the laboratory was eliminated.

As more mills choose to implement solutions, more information on achievable results may become available. As mills that have implemented solutions conduct biological monitoring studies to re-assess effects in the receiving environment, the success of identified solutions in reducing effluent-related effects can be assessed. Over time, mills will be re-assessing effects, and depending on the degree to which mills choose to implement identified solutions, the overall impact of mill effluent on the aquatic receiving environment could be quite different than previously observed.

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7. Appendix

Table A-1 Number and type of investigation studies conducted, causes determined, and solutions identified during cycles 4, 5 and 6 (number of mills in parentheses)

Type of investigation of cause studies conducted	Number of studies (mills)
Benthic invertebrate community survey	15 (16)
Fish population survey	7 (7)
Receiving environment water and sediment quality monitoring	14 (13)
Periphyton analysis	8 (8)
Organic source determination using stable isotopes	4 (4)
Effluent nutrient characterization	8 (7)
Re-assessment of existing data and information	18 (18)
Specific methodologies: mesocosm microcosm benthic artificial substrates toxicity testing determination of depositional rates water quality modelling subtidal visual assessment fibre mat delineation in-situ temperature recording devices assessment of mill process changes	1 (1) 1 (1) 2 (2) 1 (1) 3 (3) 2 (2) 2 (1) 1 (1) 1 (1) 1 (1)
Cycle 4 National Investigation of Cause Project	1 (8)
Cycle 5 National Investigation of Cause Project	1 (8)
Toxicity source evaluation and toxicity identification evaluation	1 (2)
In-vitro assays of condensate extracts	1 (2)
Dioxin/furan concentration in crabs, prey species and sediments	1 (1)
Causes determined	**Number of studies (mills)**
Mill effluent	6 (6)
Nutrients in mill effluent	12 (13)
Phosphorus in mill effluent	4 (4)
Organics in mill effluent	18 (32)
Historical (pre-PPER) mill effluent	4 (4)
Nearby municipal wastewater treatment effluent	4 (4)
Other non-effluent-related causes	4 (6)
Causes not determined	3 (3)
Type of investigation of solutions studies conducted	**Number of studies (mills)**
Comparison to *Best Management Practices Guide for Nutrient Management in Effluent Treatment* (FPAC 2008)	17 (17)
Nutrient management study	9 (9)
Nutrient source study	9 (9)
Supplemental nutrient optimization study	5 (5)
Wastewater treatment plant (WWTP) optimization study	5 (5)

Assessment of personnel training needs	1 (1)
Evaluation of phosphorus removal technologies	1 (1)
Cycle 6 National Investigation of Cause Project	1 (20)
Correlation of effect reduction with mill and treatment upgrades	1 (2)
Solutions not required, effects not related to current mill effluent	4 (6)
Solutions identified	**Number of studies (mills)**
Improve[18] WWTP monitoring	18 (18)
Improve WWTP testing and analytical procedures	11 (11)
Optimize[19] WWTP efficiency	8 (8)
Optimize supplemental nutrient addition	13 (13)
Dredge aeration stabilization basin	4 (4)
Change type of supplemental nutrient	2 (2)
Extend period of no supplemental nutrient addition	1 (1)
Reduce discharge of organics from mill to WWTP	11 (11)
Train analysts and technicians	6 (6)
Communicate testing results daily	1 (1)
Improve equipment maintenance and validation procedures	5 (5)
Reduce volume and duration of high-strength spills (shock loads)	3 (3)
Maintain optimal temperatures for biomass health during winter	1 (1)
Recycle portion of treated effluent to reuse nutrients	1 (1)
Add food source for biomass during extended shutdowns	1 (1)
Reduce hydraulic retention time with second aeration basin	1 (1)
Add anaerobic system to pre-treat portion of wastewater	2 (2)
Add phosphorus removal technologies (tertiary treatment)	1 (1)
Conduct further studies	10 (10)
Cycle 6 National Investigation of Cause Project: reduce organics in final effluent	1 (20)

[18] Improvement solutions identified included increasing monitoring frequencies, addition of parameters, and addition of sampling locations and/or equipment.
[19] Optimization solutions identified included changes to increase the effectiveness of a system.

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