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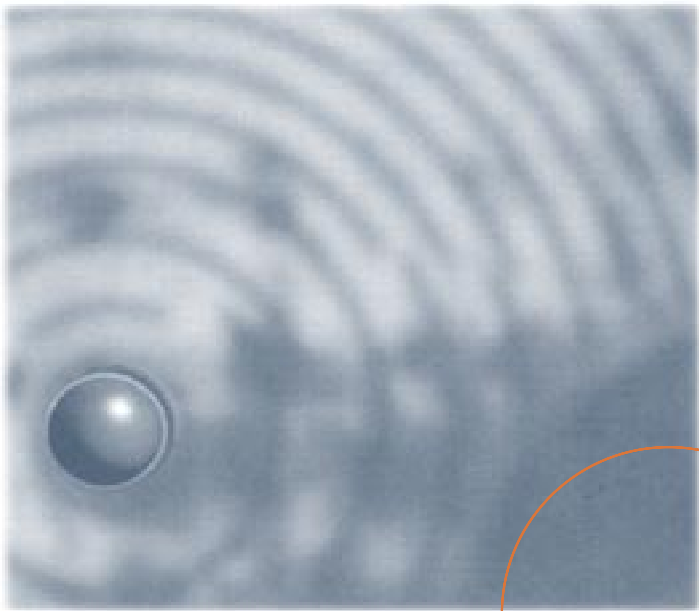
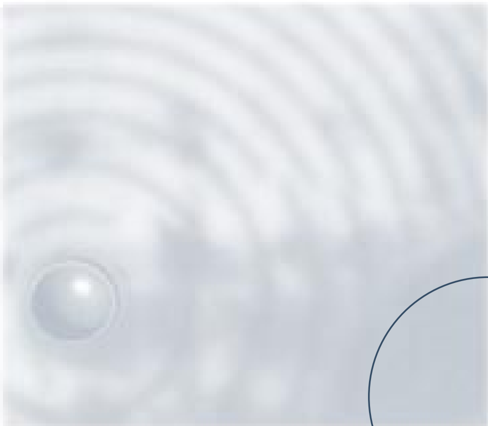


EEM

Environmental Effects Monitoring

A Report Synopsis

National Assessment of Pulp and Paper Environmental Effects Monitoring Data



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National Assessment of Pulp and Paper Environmental Effects Monitoring Data

NWRI Scientific Assessment Report Series No.2

Environment Canada   Environnement Canada

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Executive Summary

The *Pulp and Paper Effluent Regulations* (PPER) require Canada's pulp and paper mills to conduct Environmental Effects Monitoring (EEM) Program studies on their receiving environments in order to assess and monitor the potential effects of their effluents on fish, fish habitat, and the use of fisheries resources. The EEM studies focus mainly on benthic invertebrate community and fish population surveys. Where required supporting information pertaining to the sublethal toxicity of effluents, water, sediment and fish tissue quality, and tainting of fish is also collected. This report provides a summary of the key findings of a more detailed technical report entitled *National Assessment of the Pulp and Paper Environmental Effects Monitoring Data.*

For the purposes of this national assessment, benthic invertebrate community survey data were analysed with respect to study design, habitat type, effluent treatment type, and mill process type. On a national scale, the benthic invertebrate community surveys most commonly revealed a eutrophication response pattern, particularly in rivers, as a result of exposure to pulp mill effluent, likely due to its nutrient and organic content. Eutrophication is an "overfertilization" of the water, which can disrupt normal ecosystem functioning, produce harmful bacteria and algae, and lower the aesthetic value of an area. Although this response was generally mild to moderate, a few mills showed more pronounced eutrophication. The average pattern observed in marine/estuarine habitats was indicative of toxic or smothering effects, and the response in lakes fell somewhere in between those in rivers and marine/estuarine environments. With respect to magnitudes of effects measured, between 20 to 40% of the mills detected effects larger than two standard deviations.

Data from the fish population survey were analysed to determine the magnitude of effects on the key fish endpoints as influenced by gender, fish species, mill process type, effluent treatment type, and habitat. The predominant response patterns seen in fish across the country were a decrease in gonad weight and increases in liver weight, condition factor, and weight at age. These responses are believed to be indicative of some form of metabolic disruption or impairment of endocrine functioning in combination with a nutrient enrichment effect. Reductions in gonad size can result in impairment of reproductive capabilities, which in turn can lead to a loss of fish species. With respect to the magnitude of effects measured, 20% of the mills exceeded an effect size of 20 to 30% for gonad and liver weights, and 10% for condition factor.

Results from the benthic invertebrate community and fish population surveys were quantitatively integrated to further elucidate overall national response patterns. There was good agreement between results from the two surveys. The metabolic disruption/nutrient enrichment response observed in fish was closely related to the eutrophication response seen in benthos. Results also revealed that overall fish nutrient enrichment (without measurable metabolic disruption) may not be detected until the benthos reach a state of pronounced eutrophication. Under conditions of less pronounced eutrophication, the fish results indicated the presence of metabolic disruption effects even when the overall effect on invertebrates was simply one of eutrophication. Thus, the two core components of the EEM field survey complement each other by revealing different aspects of the effects associated with effluent exposure.

Sublethal toxicity data showed a national improvement in effluent quality at Canadian pulp and paper mills between Cycles 1 and 2. Decreases in effluent toxicity between Cycles 1 and 2 were, in part, attributed to the installation of secondary treatment systems at most mills across the country.

In general, pulp and paper mills are not impacting the ability of Canadians to use fish. In the two cases studied, pulp mill effluent was confirmed in one and suspect in the other to contribute to fish tainting. There are isolated cases where mills may be contributing to elevated levels of dioxins and furans in fish tissue. Environment Canada will continue to work with these mills on a site-specific basis.

In summary, effluent quality has vastly improved since the PPER were promulgated; however, effects on fish and fish habitat are still being seen. More monitoring is needed to assess the ecological importance of these observed effects, and Environment Canada will continue to work with industry and other stakeholders to better understand their significance.

Introduction

In 1992, the *Pulp and Paper Effluent Regulations* (PPER) under the *Fisheries Act* replaced a 1971 pulp and paper regulation. The PPER set discharge limits for total suspended solids (TSS) and biochemical oxygen demand (BOD). As well, they set a requirement that all discharged effluents should be non-acutely lethal to rainbow trout in 100% effluent. Compliance with the PPER entailed major changes in the way effluents were treated by mills, resulting in most cases in the installation of secondary (biological) treatment. With these amendments, mills were required to install secondary treatment systems as part of their effluent treatment processes. Although it was acknowledged that more stringent discharge limits would improve environmental protection, it was also recognized that these measures alone might not ensure adequate protection of the aquatic environment at every site. Consequently, the PPER included a requirement for an environmental effects monitoring (EEM) program.

The PPER requires Canada's pulp and paper mills to conduct studies on their receiving environments in order to assess and monitor effects potentially caused by their effluent. EEM's site-specific nature calls for iterative evaluations of the potential effects of effluent on fish, fish habitat, and the use of fisheries resources. The program is structured in a three-year sequence of monitoring and interpretation phases known as "cycles." At the beginning of each cycle, each mill is required to develop a site-specific monitoring program in collaboration with regional Environment Canada officials; at the end of each cycle, mills must submit interpretive reports summarizing their field work and interpreting the results. The structure of the EEM program ensures a certain level of national consistency in the way mills monitor the effects of their effluent on the environment.

The EEM program provides a long-term evaluation of effluent impacts on the aquatic environment, requiring a minimum of several cycles (15–20 years) to allow an assessment of the condition of the receiving environment and a true understanding of the significance of any impacts. Moreover, EEM provides quantitative and qualitative answers to clear, well-defined questions by measuring responses of organisms and populations to the presence of effluents in exposure and reference areas (Hodson et al., 1996). The program uses a tiered approach to monitoring, with initial studies carried out to characterize and assess the condition of the receiving environment followed by targeted studies once effects are found or reduced monitoring where effects are not occurring. This structure minimizes costs but allows the program to remain scientifically defensible and flexible.

An EEM study includes the following components:

- a fish population survey to assess the health of fish;
- a benthic invertebrate community survey to assess fish habitat;
- a study of dioxins and furans in edible fish tissue and a tainting study as assessments of the usability of fisheries resources;
- sublethal toxicity testing to assess effluent quality; and
- supporting water and sediment quality variables to aid in the interpretation of biological data.

The benthic invertebrate community and fish population surveys utilize a select group of “effect” endpoints, which primarily drive future monitoring but also contribute to an understanding of the real nature of impacts (at the site level) from pulp and paper effluent discharges. In EEM, an “effect” is a statistically significant response in at least one of the select endpoints in comparisons between biological samples taken near a mill (exposure area) and samples taken from a reference area. The reference area is a sampling are a as similar as possible in all aspects to the exposure area (e.g., same habitat, water quality features, hydrological features, etc.), but without the presence of mill effluent. Unlike the field data, the supporting variables and sublethal toxicity data are not used to determine whether or not environmental “effects” are occurring at mill sites. Rather, they are meant to provide further information on parameters that may or may not have an influence on any observed effects.

The EEM effects endpoints used in the benthic invertebrate community and fish population surveys are as follows:

Benthic invertebrate community survey endpoints:
Total abundance
Taxon richness
Bray-Curtis index of dissimilarity
Simpson’s diversity (or evenness)

Fish population survey endpoints:
Gonad weight
Condition factor
Liver weight
Weight at age
Age

The purpose of this report is to provide a summary of the key outcomes of a more detailed technical report entitled *National Assessment of Pulp and Paper Environmental Effects Monitoring Data* (Lowell et al., 2003). The national EEM data assessment was primarily designed to assess the type and magnitude of effects occurring on fish populations and benthic invertebrate communities as a result of exposure to pulp and paper effluents across Canada. A series of core questions or priority areas of focus identified by Environment Canada scientists guided the assessment. The questions were fundamental to evaluate of the effectiveness of EEM monitoring in assessing the impacts of pulp and paper mill effluents on aquatic environments and to provide the necessary information to understand the ecological importance of these impacts.

In addition to the priority areas identified, the analysis of sublethal toxicity data was carried out to assess overall changes in effluent toxicity before and after the implementation of secondary treatment at most mills. Other components of the National EEM Program (i.e., dioxins and furans in edible fish tissue and tainting) were not the subject of analysis, due to the small number of mills that were required to complete such analyses.

Historical Overview of Pulp and Paper Mill Effluents

Pulp and paper products are made from three major types of fibres: wood, recycled fibres, and non-wood fibres (e.g., cotton, hemp, etc.), however, most pulp and paper products are wood-based. The kraft pulp is used for products such as writing paper, paper bags, and cardboard. Pulping procedures involving primarily chemical processes include those used at soda and sulphite mills. Mechanical pulping, which involves shredding or grinding wood chips and usually results in high-yield pulps, is most commonly used for newsprint and catalogue paper (Biermann, 1996). Finally, semi-chemical pulping combines chemical and mechanical methods (USEPA, 1998) and is commonly used for manufacturing corrugated cardboard.

Effluent treatment processes include primary, secondary, and in a few cases tertiary treatment. Primary treatment, in which solids are removed from water by allowing them to settle out, became widely used in the 1950s (Biermann, 1996). Today, most mills use at least a secondary treatment process as well, which involves reacting the effluent with oxygen and microorganisms to remove oxygen-consuming materials and decreases the effluent toxicity significantly (Biermann, 1996). Secondary treatment processes most commonly used in Canada are aerated stabilization basins and activated sludge.

Tertiary treatment processes, which are the most advanced types of treatment, follow secondary treatment and are often considered for the removal of colour (Biermann, 1996).

The pulp and paper industry, because of its diverse nature, can release a wide range of compounds into the aquatic environment. Research done on pulp and paper effluents has implicated fibre and suspended solids, colour and turbidity, and organic and nutrient enrichment loads as the three conventional pollutant factors with adverse environmental impacts (Owens, 1991). More specifically, BOD, TSS, and acute toxicity were among the major issues identified as being of concern. Dioxins and furans, which are highly persistent in the environment, have a strong affinity for sediments, and are bioaccumulative, were also a concern for communities living downstream from mills, particularly those with high fish consumption.

In 1992, the federal government passed the Pulp and Paper Regulatory Framework consisting of the *Pulp and Paper Effluent Regulations* (PPER) under the *Fisheries Act* and two regulations under the *Canadian Environmental Protection Act* (CEPA). The PPER revoked and replaced an earlier set of regulations passed in 1971. A major deficiency of the 1971 regulations, was that they were only legally binding on new mills built after the regulation's November 2, 1971 promulgation date. The new regulations were designed to ensure that all mills were subject to regulatory requirements. The PPER set discharge limits for BOD and TSS, and prohibit the discharge of effluent that is acutely lethal to rainbow trout. The CEPA regulations were designed to ensure that chlorinated dioxins and furans were not formed during pulp bleaching. The *Pulp and Paper Mill Effluent Chlorinated Dioxins and Furans Regulations* prohibit the release of measurable concentration of the 2,3,7,8 chlorinated dioxin and furan in effluent from mills that use chlorine or chlorine dioxide to bleach pulp. The *Pulp and Paper Mill Defoamer and Wood Chip Regulations*, impose quality requirements for defoamers used in chlorine bleaching processes and prohibit the manufacture of pulp from wood chips treated with polychlorinated phenols (OECD, 1999).

It was recognized that these measures alone might not ensure adequate protection of the aquatic ecosystem at every site. Consequently, the PPER included a requirement for an EEM program to provide an overview of the state of receiving environments around pulp and paper mills across Canada, to demonstrate whether or not the major improvements in effluent quality resulting from improvements in treatment processes were associated with similar improvements in the receiving environment, and to evaluate the long-term effects of pulp and paper mill effluents on Canadian aquatic ecosystems.

Implementation of these new regulations in combination with increasing environmental pressures, led to important improvements in the industry's treatment processes, dramatically improving the chemical composition and toxicity of the final effluent and significantly reducing the potential threat to the environment (Bothwell, 1992; Servos et al., 1996; Dubé and McLatchy, 2000). In the late 1990s, studies were beginning to document early signs of recovery in fish reproductive parameters at a number of mills that had modernized their processes (Munkittrick et al., 1997). Advanced pulp mill effluent treatment also resulted in significantly reduced incidences of toxic effects on or pronounced eutrophication in benthic invertebrate communities (Lowell et al., 1996, 2000; Felder et al., 1998; Chambers et al., 2000; Culp et al. 2000a,b; Lowell and Culp, 2002).

Despite these improvements, concerns remain about the long-term impacts of effluents on the aquatic environment. The chemical composition of each effluent varies drastically, making the assessment of their environmental impact a difficult task. Moreover, the complexity and natural variability of biological systems make it difficult to provide definitive answers with regard to the environmental impacts of effluents (Kovacs et al., 1995). However, the conceptual approaches used in the EEM program, based on site-specific design and applying standardized methods, have clearly shown that knowledge on the environmental effects of effluents can be gained. For the first time, this national assessment is providing answers on the effects of effluent based on geographically extensive scientific data collected in the receiving environment.

National EEM Data Assessment

Benthic Invertebrate Community Survey

The benthic invertebrate community survey helps to evaluate the condition of the aquatic food resources available to fish and assess the degree of habitat degradation. The measurement endpoints chosen for the benthic invertebrate community survey provide indications of changes in biodiversity. In Cycles 1 and 2 of the National EEM Program, the majority of mills reported statistically significant differences in the benthic invertebrate community structure between exposure and reference areas. Some of these differences may have been attributable to the confounding influence of non-mill-related factors, even though improvements were made to the study design following Cycle 1 to help rule out these confounders. In Cycle 2, mills reported an overall improvement in conditions across the country for benthic invertebrate communities in exposure areas. In many cases, the improvements in benthic conditions were attributed to improvements in effluent processing, especially the installation of secondary treatment, which led to significant decreases in the sublethal toxicity of the effluent. Although a small number of mills indicated a worsening of benthic conditions, many of those cases were due to changes in non-mill-related factors.

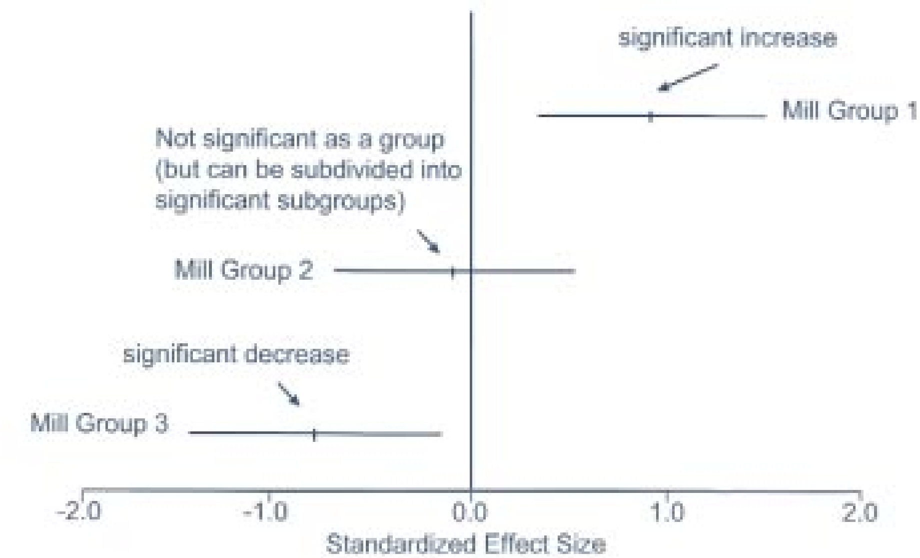
Benthic Invertebrate Community Survey Data Analysis

The benthic invertebrate community survey is one of the two core elements of the EEM program. Two main types of benthic invertebrate study designs were used in Cycle 2: 62 Control/Impact and 21 Gradient studies. The Control/Impact design involves one or more discrete groups of sampling stations exposed to mill effluent (typically downstream from the mill) and another group of sampling stations that are not exposed (often located upstream). The Gradient design involves the use of sampling stations distributed more continuously in a gradient from more exposed to less exposed areas — that is, progressing from areas close to the effluent discharge point to more distant areas where the effluent is much more dilute (for more details, see Environment Canada, 2002; Glozier et al., 2002; Lowell et al., 2002).

The national EEM data assessment was, in part, carried out using statistical comparisons of benthic invertebrate community endpoint values between exposure and reference areas based on the Control/Impact design. Analyses of Gradient design data were carried out using regressions of endpoint values against distance from the outfall. The results of the analyses based on the Control/Impact and the Gradient designs were then integrated using a detailed statistical analytical procedure termed meta-analysis, which facilitates the synthesis of a large number of independent studies (Gurevitch and Hedges, 1993; Rosenberg et al., 2000;). For the national EEM data assessment, meta-analyses gave a quantitative indication of the general conclusions that could be drawn concerning the nature of effluent-associated effects and provided some answers to questions that would be very difficult to address at the individual mill level, such as the influence of habitat type, effluent treatment type, and mill process type on effects observed in the field. As such, the national EEM assessment addresses a number of issues that have received little (if any) attention in the past.

The results from the meta-analyses are presented in the summary format shown in Figure 1. The x-axis represents the standardized effect size, and the vertical line represents no effect. The results for each mill grouping are presented as a 95% confidence interval (horizontal line segment), with the tick mark indicating the average effect size for that grouping of mills. Mill distributions (i.e., 95% confidence intervals) to the right of the zero effect line indicate that the average effect associated with effluent exposure was an increase in the measured endpoint. Similarly, mill distributions to the left of the zero effect line indicate an effluent-associated decrease in the measured endpoint. As long as the 95% confidence intervals do not overlap with the zero effect line at any point, the increase or decrease is considered statistically significant for the group as a whole, although the group may also contain subgroups exhibiting statistically significant effects.

Figure 1: *Meta-analysis summary figure*



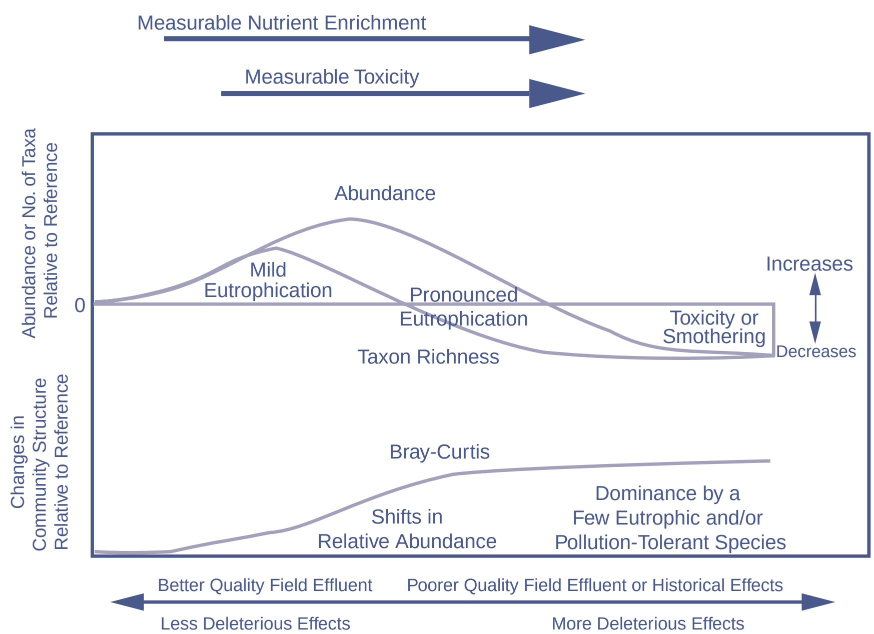
National Trends

Previous studies have provided insight into the expected effects of pulp mill effluent on benthic invertebrate communities (Lowell et al., 1995, 1996, 2000; Lowell and Culp, 1999, 2002; Culp et al., 2000a,b), and the overall nature of these interacting effects for the endpoints of abundance, taxon richness, and community structure is summarized in Figure 2. In the figure, the x-axis progresses from better quality effluent and less deleterious effects on the left to poorer quality effluent and more deleterious effects on the right. Historical effects (e.g., smothering effects of fibre mats generated over many years of mill operation) may also come into play.

Nutrient enrichment (or eutrophication) generally increases from left to right, along with increasing toxicity or smothering effects. In fact, nutrient enrichment can often be measured at lower effluent concentrations than toxicity, and toxic effects are often masked by eutrophication at low to medium concentrations. Mild eutrophication is typified by increases in both abundance and taxon richness. Progressing to the right, moderate eutrophication is typically associated with lessened increases in taxon richness, although further increases in abundance may still occur. More pronounced eutrophication is commonly associated with decreases in taxon richness, even while abundance is greater than that found in reference areas. Finally, decreases in both taxon richness and abundance are typically a sign of overall inhibitory effects, such as toxicity or smothering.

In the EEM program, changes in invertebrate community composition are measured by changes in the Bray-Curtis index of dissimilarity. The value of this index increases as poorer quality effluent leads to greater changes in community composition. This point is illustrated at the bottom of Figure 2, although it should be noted that changes in community composition are not always tied to changes in total abundance and taxon richness. There are many different ways in which benthic communities may be affected in the field; due to complex direct and indirect effects, effluent exposure may lead to pronounced effects on community composition without large effects on abundance or taxon richness, and vice versa.

Figure 2: *Predicted response patterns (modified from Lowell et al., 2000; see also Culp et al., 2000a)*



The average overall effects on benthic invertebrate communities associated with exposure to effluent are illustrated in Figure 3. These means represent the averages across the country for all habitat types and, as for the following figures, focus on mills using a Control/Impact study design. Essentially, total abundance was well to the right of the zero effect (or vertical) line, meaning that the most common effect associated with exposure to effluent was an increase in invertebrate numbers. This is a well-known eutrophication-type response to exposure to pulp mill effluent (Hall et al., 1991; Dubé and Culp, 1996; Chambers et al., 2000; Culp et al., 2000a,b; Lowell et al., 2000; Lowell and Culp, 2002) and is due to the nutrient enrichment effects of the phosphorus, nitrogen, and organic content of the effluent.

Figure 3: *Grand mean of benthic invertebrate endpoints for Control/Impact study designs*

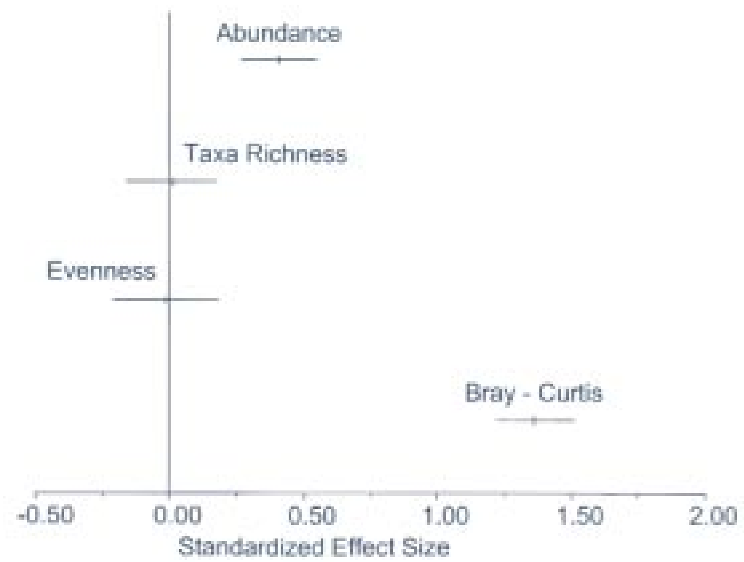


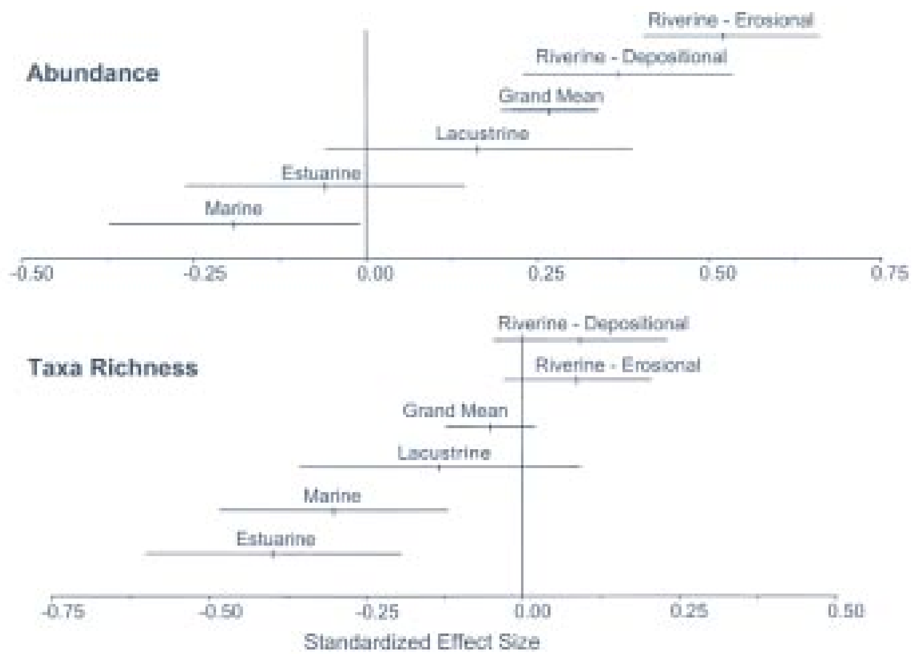
Figure 3 shows that in contrast to abundance, the taxon richness grand mean was close to zero. This reflects a more even distribution of mills with increases, mills with decreases, and mills with no significant change in number of taxa. The abundance and taxon richness distributions, taken together, indicate that the most common effect across the country was an increase in abundance and either an increase or no change in taxon richness, indicative of mild eutrophication (see Lowell et al., 2003). The smaller number of mills with increases in abundance and decreases in taxon richness were showing typical signs of more pronounced eutrophication. The evenness grand mean was close to zero, also reflecting a more even distribution of mills with increases, decreases, or no significant change in evenness. On the other hand, the Bray-Curtis grand mean was highly significantly positive. This shows that there were clear changes in benthic invertebrate community composition in exposure areas across the country. Because of the way in which the index is calculated, any changes in community composition in exposure areas result in positive (not negative) Bray-Curtis values, with larger effects yielding larger Bray-Curtis values. This endpoint is very sensitive and as such tends to yield more responses. Effects detected by the Bray-Curtis index therefore tend to be highly significant.

Effluent-associated effects on benthic invertebrate communities varied significantly among different habitat types. The main habitat types were riverine (rivers) — erosional or depositional; lacustrine (lakes); and marine/estuarine. Abundance was significantly increased in both erosional and depositional riverine habitats, whereas the distribution of mill responses for taxon richness mostly ranged from increases to no significant change (Figure 4). This combination of responses is indicative of an average effect of mild eutrophication in riverine exposure areas. In contrast, both abundance and taxon richness decreased in marine/estuarine habitats, a response indicative of a toxicity or smothering effect. This inhibitory response in marine/estuarine habitats is likely due to a combination of factors, including the deterioration of habitat at several of the marine mills due to the long-term deposition of fibre mats. In erosional riverine habitats, the data suggested that evenness was reduced in exposure areas, which may reflect the sensitivity of organisms in these habitats to even mild eutrophication. In contrast, evenness was almost significantly increased in marine/estuarine exposure areas, suggesting that toxicity/smothering effects may have led to the loss of more rare taxa, leaving behind a smaller number of more evenly distributed, pollution-tolerant taxa.

The largest exposure area effects for the habitat subgroups were observed for the sensitive Bray-Curtis endpoint. By far the largest exposure-associated changes in community composition were measured in lacustrine habitats, in contrast with other endpoints, where the measured lake effects were more intermediate. This illustrates that, under different environmental conditions, effluent-related effects may be manifested in different ways, and it underscores the value of measuring changes in community structure using multiple endpoints to reduce the probability of missing important effects.

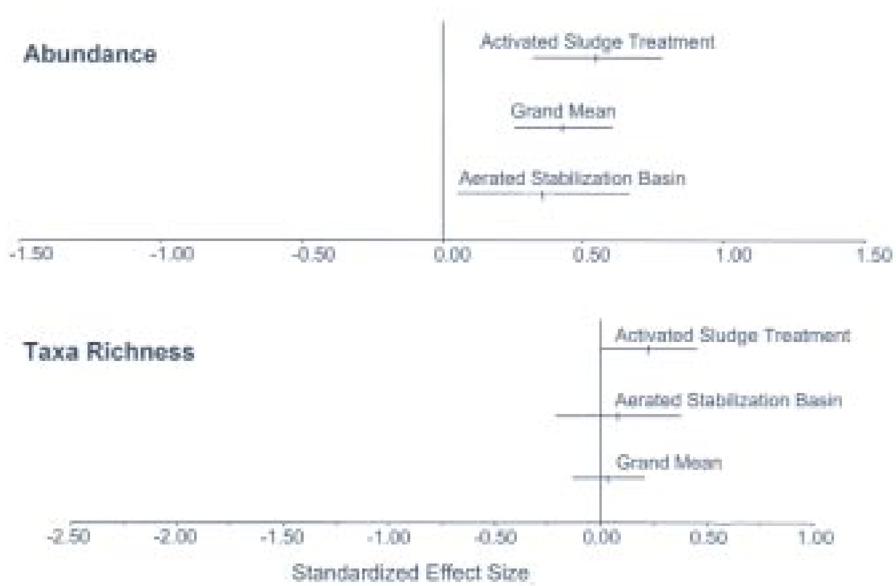
Pulp mills in Canada use a wide variety of effluent treatment and mill process types. Mills were grouped into broad categories in order to determine whether certain effluent treatment and mill process types were associated with greater or lesser effects in the environment or whether the different groupings are more or less equivalent in terms of their environmental effects. The two most common mill process types were kraft and thermomechanical, and the two most common effluent treatment types were activated sludge treatment and aerated stabilization basin. Since these represented the majority of the mills, the patterns observed in the meta-analyses apply on a national scale.

Figure 4: *Abundance and taxon richness by habitat (Control/Impact mills + Gradient mills)*



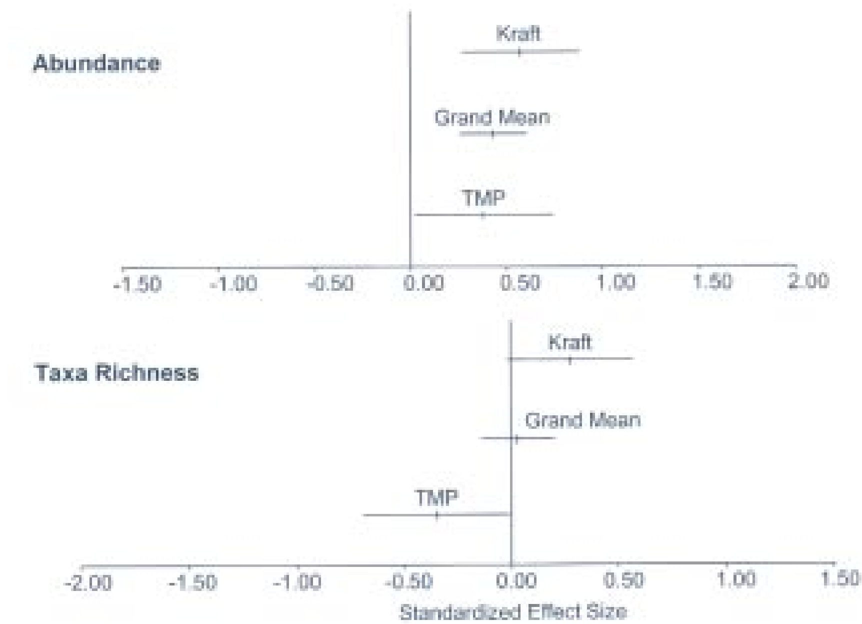
The abundance/taxon richness response patterns for the two prevalent effluent treatment types were similar and reflected the mild eutrophication effect that was most commonly observed for benthic invertebrate communities in Cycle 2 (Figure 5). The two major effluent treatment types were also quite similar in terms of effects on evenness and were not significantly different from zero. Overall, the magnitudes of effects were larger for the Bray-Curtis endpoint, and these measured changes in community composition were fairly similar between the two treatment types.

Figure 5: *Abundance and taxon richness by effluent treatment (Control/Impact mills)*



Exposure area abundance was significantly increased for the two most common mill process types (Figure 6). The two types differed for the taxon richness endpoint, with the results suggesting a milder eutrophication response for kraft mills and a more pronounced eutrophication response for thermomechanical mills on a national scale. The two mill process types had fairly similar responses for the evenness endpoint. The results indicated that individual mills that had either significant increases or decreases in evenness could not be distinguished on the basis of mill process type. The magnitude of effect was greater for the Bray-Curtis endpoint, but the two mill process types did not significantly differ.

Figure 6: *Abundance and taxon richness by mill process (Control/Impact mills) Kraft = kraft mills; TMP = thermomechanical pulp mills.*



Although apparently less pronounced than in previous years, effects of pulp mill effluent on benthic invertebrate communities are still widely present. For the invertebrate community survey endpoints, between 20 to 40% of the mills detected effects larger than two standard deviations. The most predominant response pattern observed in benthic invertebrate communities across the country was one of mild to moderate eutrophication, particularly in riverine habitats, although more pronounced eutrophication was observed at a few mills. In contrast, the average response pattern observed in marine/estuarine habitats was more indicative of toxic or smothering effects. The benthic invertebrate response in lakes was intermediate between those in riverine and marine/estuarine habitats. These response patterns were national averages, and exceptions occurred in each of the habitat subgroups. Further monitoring and accompanying research will help provide a better understanding of the extent and ecological significance of these effects.

Fish Population Survey

The fish population survey monitors and compares fish in the receiving water where mills discharge effluent to those from a reference site. This survey uses fish growth, reproduction, condition, and survival to assess the overall health of fish and can be a warning of fish species being at risk.

There were a number of problems associated with fish monitoring studies during Cycle 1. For instance, only 8% of mills (9 of 115 studies) successfully caught the required minimum number of fish (20 males and 20 females of two fish species) in the exposure and reference areas (Environment Canada, 1997), 50% were marginally or partially successful, and 42% were unsuccessful (not enough fish of either species or sex). The most common problems encountered in Cycle 1 were too few fish, uncertainty regarding their exposure to effluents, lack of suitable reference sites, and the presence of other effluents. Cycle 2 surveys proved to be more successful, as over 82% of the studies that attempted to use fish were able to gather sufficient interpretable data.

As with the benthic invertebrate community survey, not all effects found in Cycle 2 were necessarily mill-related effects. There were sites where concerns with the study design resulted in questionable responses. Moreover, measured effects may not always be ecologically relevant for that specific site and that current time, at least in some respects. For instance, if the fish population is sustaining itself, this may indicate that the population can survive despite the presence of poor quality effluent, although this may require access to non-impacted waters during certain parts of the life cycle (McMaster et al. 1991; Munkittrick et al. 1997, 1998).

Fish Population Survey Data Analysis

The results presented in this national assessment of effects on fish are focused on the analysis of the electronic data that mills submitted to Environment Canada. These data were used to conduct a variety of statistical analyses, and, where possible, the results were compared with the mills' interpretive reports. Generally, there was good agreement between the results submitted by mills and the analyses carried out on the electronic data.

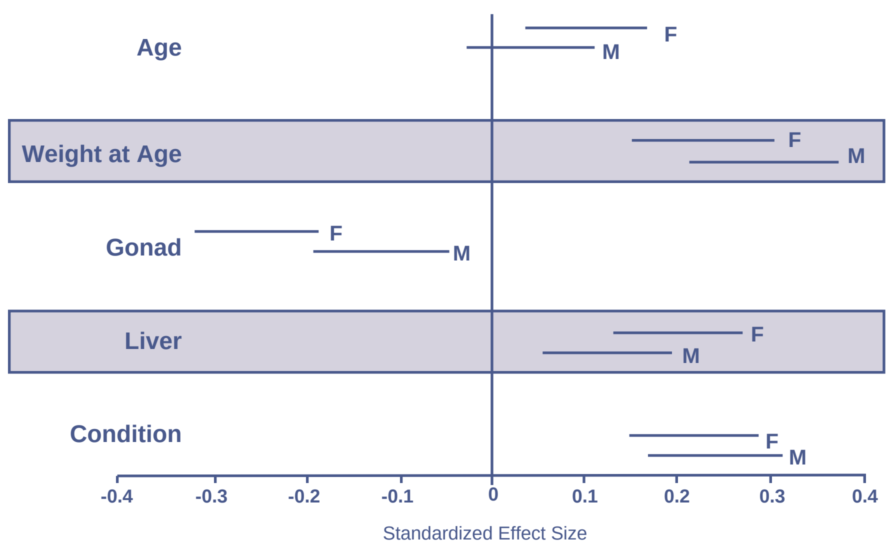
National Trends

The range in magnitude of effects was determined by calculating percent changes in each endpoint for exposure areas relative to reference areas. For example, the percent changes ranged from a decrease of 27% to an increase of 24% for condition factor, from a decrease of 90% to an increase of 286% for gonad weight, and from a decrease of 88% to an increase of 73% for liver weight. For the fish population survey endpoints, about 20% of the mills exceeded an effect size of 20 to 30% for gonad and liver weights, and 10% for condition factor. Therefore, these represent some of the largest effects measured.

Meta-analyses were conducted using the key fish endpoints, and effects were evaluated relative to the presence of several potential influencing factors, including gender, fish species, mill process type, effluent treatment type, and habitat of the receiving environment.

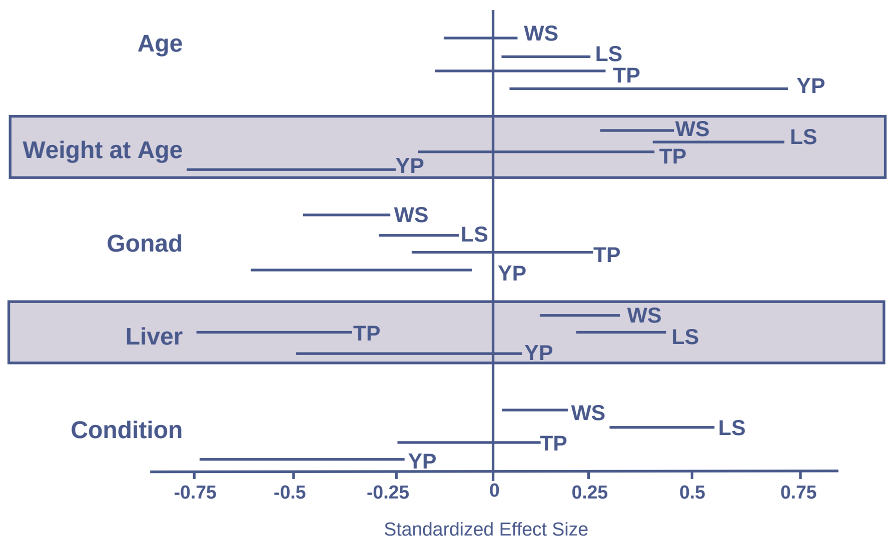
Both male and female fish showed similar responses for all but one of the endpoints, indicating that gender did not strongly influence fish results (Figure 7). Fish from the exposure area exhibited significant decreases in gonad weight, with the magnitude of effects being greater for females than for males. Condition, liver weight, and weight at age were all significantly increased in the exposure areas for both males and females. Moreover, female fish taken from exposure areas were significantly older, possibly due to the loss of juveniles, greater survival of older fish, or delayed maturity in female fish. A similar, although non-significant, effect on age was seen for males.

Figure 7: *Effect of gender on the five key fish endpoints*
M = male; F = female.



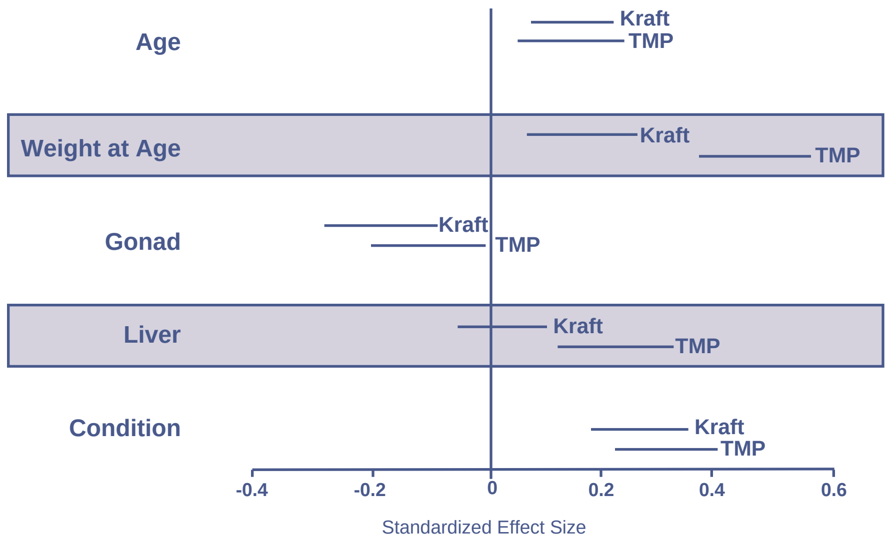
Response to effluent exposure was evaluated for 19 fish species. Figure 8 illustrates the meta-analysis results for the four most common species (white sucker, longnose sucker, yellow perch, trout-perch) for each of the five key endpoints. Nationally, the two most common species (white sucker and longnose sucker) showed a significant increase in liver weight, condition factor, and weight at age and a decrease in gonad weight. These responses were consistent with the overall national response pattern seen for all species combined. The longnose sucker also exhibited a significant age increase in exposure areas, again consistent with the national response pattern; the average age structure for white suckers, however, was not significantly different in exposure versus reference areas. Yellow perch showed significant decreases in condition factor, gonad weight, and weight at age, as well as a similar, although non-significant, decrease in liver weight. The responses exhibited by yellow perch were consistent with what is typically found in situations of food limitation.

Figure 8: *Effect of species on the five key fish endpoints*
WS = white sucker; LS = longnose sucker; TP = trout-perch; YP = yellow perch.



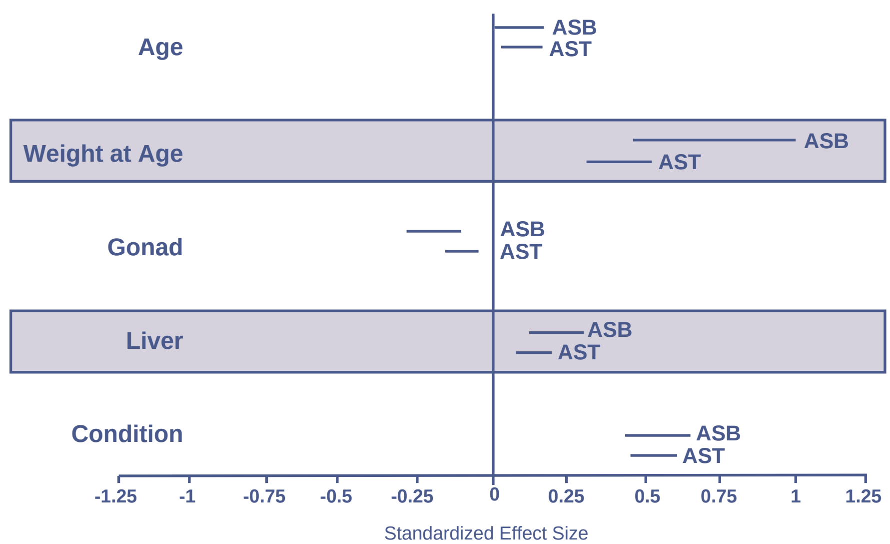
The response pattern was fairly similar between the two most common mill process types, thermomechanical and kraft. Fish consistently exhibited a decrease in gonad weight and an increase in age, weight at age, liver weight, and condition for both thermomechanical and kraft mills, although the effect on liver was not significant for kraft mills (Figure 9).

Figure 9: *Effect of mill process type on the five key fish endpoints*
Kraft = kraft mills; TMP = thermomechanical pulp mills.



The response pattern was also fairly similar between the two most common effluent treatment types, activated sludge treatment and aerated stabilization basin (Figure 10). Again, the response pattern was characterized by increased weight at age, liver weight, and condition and decreased gonad weight. Age was increased in both types of effluents, although this difference was not significant for aerated stabilization basin treatment.

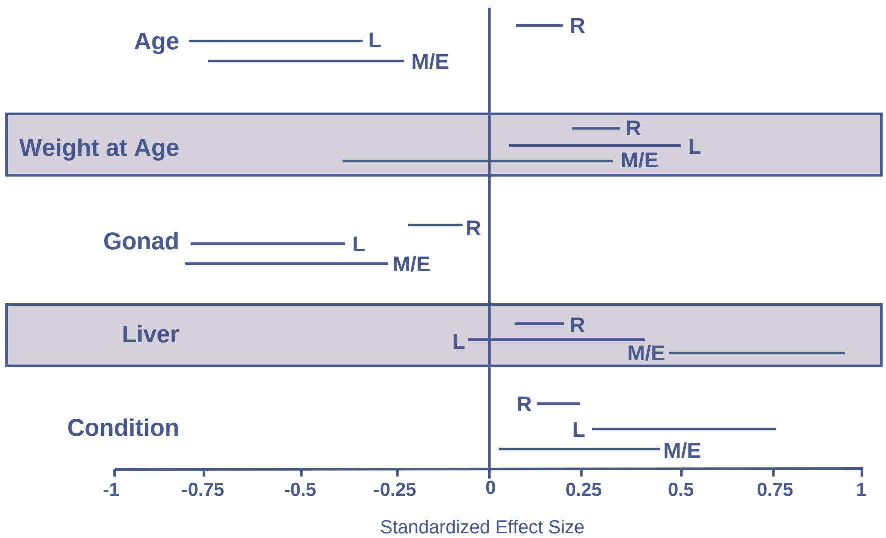
Figure 10: *Effect of treatment type on the five key fish endpoints*
ASB = aerated stabilization basin; AST = activated sludge treatment.



As for the benthic invertebrate analyses, the receiving areas were broken down into three habitat types: riverine, lacustrine, and marine/estuarine (Figure 11). All three habitat types showed a decrease in gonad weight, especially lakes and marine/estuarine sites.

Condition factor was significantly increased for all three habitat types, liver weight was significantly increased for rivers and marine/estuarine sites, and weight at age was significantly increased for rivers and lakes. Age was significantly increased for rivers and significantly decreased in lakes and marine/estuarine receiving areas. In summary, rivers had significant changes in all five response variables, while lakes and marine/estuarine habitats had significant changes in four of the five variables.

Figure 11: *Effect of habitat on the five key fish endpoints.*
R = river; L = lake; M/E = marine/estuarine.



The predominant response pattern seen in fish across the country (decrease in gonad weight and increases in liver weight, condition, and weight at age) is believed to be indicative of some form of metabolic disruption in combination with a nutrient enrichment effect. Although the mechanism of such responses and their ecological importance remain unclear, these patterns of effects on a national scale may be related to some form of disruption of endocrine functioning, which is key to growth and reproductive development (Munkittrick, 2001). Together with this metabolic disruption effect, an increase in liver weight and condition factor is often an indication of an increase in food availability or nutrient enrichment. The general pattern observed in Cycle 2 is consistent with what was observed in Cycle 1. Further research and continued EEM studies are required to understand these phenomena and to confirm the type, spatial extent, and ecological importance of these effects.

Overall National Response Patterns for Benthic Invertebrate Community and Fish Population Surveys

The results from the benthic invertebrate community and fish population surveys were quantitatively integrated using meta-analysis and mutivariate analysis to elucidate overall national response patterns. Good agreement was seen between the results for the two surveys. As expected, cases where fish exhibited a combined metabolic disruption/nutrient enrichment response were closely related to cases where benthic invertebrates were showing signs of eutrophication. Moreover, the results revealed that overall fish nutrient enrichment (without measurable metabolic disruption) may not be detected until the benthos reach a state of pronounced eutrophication. The results of these analyses showed that the two core components of the EEM field survey complement each other, each giving specific information on various aspects of the impact of effluent exposure.

The endpoints were each originally selected to measure a unique aspect of the way in which fish populations or benthic communities might respond to pulp mill effluent. The integrated analyses showed that this was achieved and confirmed that the core EEM endpoints are not redundant or repetitive. Each endpoint has value for describing a different (and partially independent) aspect of the nature of effluent effects. The elimination of any of the endpoints would run the risk of missing an important component of effluent effects.

The impact of pulp and paper mill effluent on the use of fisheries resources is evaluated through tainting tests, designed to determine if the taste of the fish is affected, and analyses for dioxins and furans in edible portions of fish.

Only two mills conducted a tainting study as part of Cycle 2. In one case the mill was identified as the cause of the taint, and measures are currently under way to mitigate this problem. In the other case, it was confirmed that tainting was an issue in the exposure area but the cause could not be isolated, though the mill effluent is suspected to be the source.

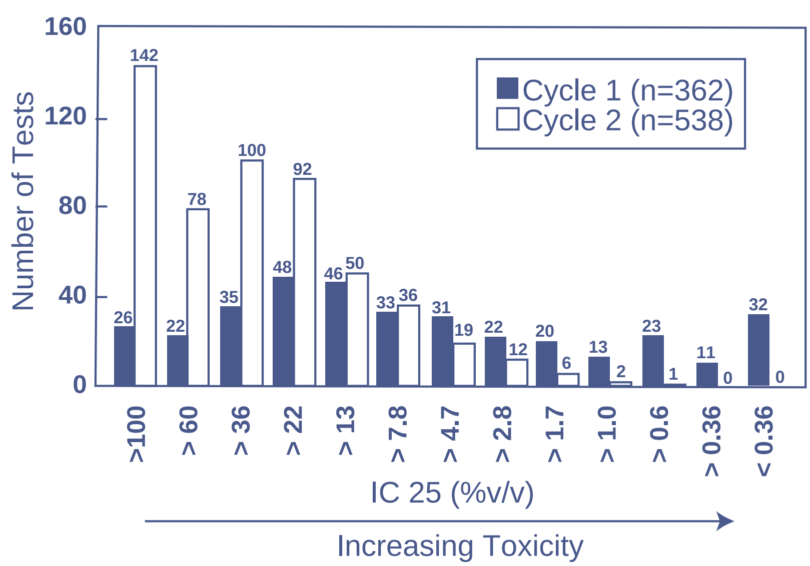
In Cycle 1, mills that were using chlorine bleaching or had used chlorine bleaching in the past were required to conduct a tissue analysis of edible portions of fish for chlorinated dioxin and furan congeners. Where results were below fish consumption guidelines in these evaluations, the mill was exempted from these analyses in future cycles. Cycle 1 results indicated that levels of dioxins and furans in edible fish tissue were low. As a result, in Cycle 2, only ten mills conducted fish tissue analyses for dioxins and furans, six of which had levels of dioxins and furans in fish tissue that exceeded Health Canada fish consumption guidelines. Continued monitoring is needed to determine the source of the dioxins and furans at these six sites.

Sublethal Toxicity

Sublethal toxicity tests allow mills to monitor the quality of their effluent and complement the field components of EEM studies. Within EEM, the results of sublethal tests on effluent or receiving water can be used to measure changes in toxicity over time, including those that are a result of changes in mill process or effluent treatment; evaluate the potential for effects in the receiving water; and estimate, in multiple-discharge situations, the relative contributions from various sources to any observed effects in the receiving environment.

The EEM sublethal toxicity data show that there has been a national improvement in effluent quality at Canadian pulp and paper mills between Cycles 1 and 2. This improvement is largely due to the installation of secondary treatment systems at most mills during this period. Figure 12 illustrates the important decreases in effluent toxicity between Cycles 1 and 2, using *Ceriodaphnia dubia* (an invertebrate species) as an example.

Figure 12: *Summary of Ceriodaphnia dubia reproduction test results for Cycles 1 and 2*



Overall Conclusions

The Canadian pulp and paper industry has invested billions of dollars towards research and technology aimed at reducing its emissions and improving the quality of their effluent. Today, most pulp and paper mills in Canada are equipped with at least primary and secondary treatment systems. Although mills have been successful in dramatically reducing the toxicity of their effluents, EEM data show that impacts continue in the aquatic environment.

On a national scale, the benthic invertebrate community surveys most commonly revealed a eutrophication response pattern as a result of exposure to pulp mill effluent. This nutrient enrichment effect, which was usually mild to moderate (but sometimes pronounced), was likely due to the phosphorus, nitrogen, and organic content of the effluent. EEM studies showed that study design and habitat type had some influence on the results. For example, riverine habitats showed mild eutrophication, marine/estuarine habitats showed signs of toxic or smothering effects, and lakes showed more intermediate responses.

Effects were also observed on fish downstream of pulp mill effluent, with the overall response pattern being one of combined metabolic disruption and nutrient enrichment. The national trend for fish was towards a decrease in gonad weight and an increase in liver weight, condition factor, and weight at age. Other response patterns were also observed, however, including ones expected under conditions of food limitation.

The integration of the results from the benthic invertebrate community and fish population surveys showed good agreement. That is, the combined metabolic disruption/nutrient enrichment observed in fish reflected the eutrophication results seen in benthos. The results also showed that a predominantly nutrient enrichment effect in fish (without measurable metabolic disruption) may not be detected until the benthos reach a state of pronounced eutrophication. This integration also showed that these two main components of the EEM field survey complement each other by revealing different aspects of the effects associated with effluent exposure.

The national EEM data assessment has revealed some important response patterns in the aquatic environments around pulp and paper mills. Although effluent quality has vastly improved since the 1992 Pulp and Paper Effluent Regulations were promulgated, mills continue to have an impact on fish and their habitat (as measured by the benthic invertebrate community survey). More monitoring is needed to assess the spatial extent and ecological importance of these observed effects, and Environment Canada will continue to work with industry and other stakeholders to better understand their importance. As well, the results of the national assessment verified that each of the effect endpoints being used in the EEM program provides ecologically relevant and useful monitoring information. These results are an excellent starting point and underline the importance of continued EEM.

Glossary

Activated sludge treatment – A treatment process for waste by-products, such as ink and fibre particles from recycled waste paper, whereby decomposing bacteria are purposely added to the sludge and the mixture is then agitated to dissolve oxygen. The remaining sludge is either landfilled or dried and burned.

Aerated stabilization basin – A treatment pond usually one to two metres deep, constructed to allow sunlight, microorganisms, and oxygen to interact to break down organic material. Aerated stabilization basins have improved oxygen transfer into the water by use of aerators.

Benthic invertebrate community – The interacting populations of small animals (excluding fish and other vertebrates), living on or at the bottom of a water body, on which fish may feed. Measuring changes in invertebrate communities helps to understand changes in aquatic habitats and provides an evaluation of the aquatic food resources available to fish.

Bray-Curtis index – An index that measures the degree of difference in community structure (especially community composition) between sites. This measure helps to evaluate the amount of dissimilarity between benthic invertebrate communities at different sites.

Condition factor – A measure of the physical condition of fish that describes the relationship between body weight and body length. Essentially, the condition factor measures how “fat” fish are at each area.

Control/Impact design – A study design consisting of no less than one reference area, usually upstream from the mill or situated in a different watershed, and a series of downstream exposure areas. This study design was most commonly used in rivers.

Depositional – Usually a section of a riverine habitat where the flow of water tends to be slower and therefore where sediment tends to deposit. The bottom substrate in these areas tends to be softer and more granular in nature.

Effect – In the context of the EEM program, an effect is a statistically significant difference between measurements taken from the exposure area and from the reference area.

Endocrine – The endocrine system controls a number of internal body functions via hormonal secretions, which are transported throughout the body in the blood.

Endpoint – A particular measurement that is used as an indicator of potentially important effluent effects on receiving water biota. Examples of endpoints are gonad weight, liver weight, condition factor, and weight at age for fish or abundance, taxon richness, Simpson's diversity index, and Bray-Curtis index for benthos.

Erosional – Usually a section of a riverine habitat where the flow of water tends to be faster and turbulent. In these areas, sediments are usually carried downstream. Generally, the bottom substrate in these sections tends to be made up of larger sediments, rocks, and boulders.

Eutrophication – The process of overfertilization of a body of water by nutrients that often results in excessive production of organic biomass and is typified by large numbers of organisms and, when pronounced, few species. Eutrophication can be a natural process, or it can be accelerated by an increase of nutrient loading to a water body by human activity.

Exposure area – A sampling area where fish and benthic invertebrates are exposed to pulp and paper mill effluent. This area may extend through a number of receiving environments and contain a variety of habitat types.

Gradient design – Generally, sampling is done along a gradient of decreasing effluent concentration, starting with exposure areas close to the mill and progressing towards less exposed areas farther from the mill. This study design was sometimes used in situations where rapid effluent dilution was a factor.

Kraft pulp mill – A mill that uses a full chemical wood pulping process to produce papers that are generally coarse, noted particularly for their strength, and, in unbleached grades, used primarily as wrappers or packaging materials.

Metabolic disruption – Metabolism is a mechanism used by the body whereby complex substances are synthesized from simple ones or by which complex substances are broken down. The disruption of this system can occur from exposure to deleterious substances in the environment and can cause important imbalances in the maturation, sexual behaviour, growth, etc. of the organism.

Nutrient enrichment – The effect of adding large quantities of organic and inorganic nutrients to the environment.

Reference area – A sampling area that has no effluent exposure from the pulp and paper mill in question and natural habitat features that are similar to those of the exposure areas, including anthropogenic impacts.

Simpson's diversity index – A measure of the character of a community that takes into account both the abundance patterns and the taxonomic richness of the benthic invertebrate community. It is calculated by determining, for each taxonomic group, the proportion of individuals that it contributes to the total sample.

Smothering – The overaccumulation of organic matter derived from pulp mill effluent at the bottom of a water body, impeding the functioning of organisms and sometimes causing death.

Sublethal toxicity – In the context of EEM, sublethal toxicity tests usually measure the proportion of organisms affected by their exposure to specific concentrations of pulp mill effluent. A sublethal toxicity test measures what is detrimental to the organism, but below the level that directly causes death within the test period.

Taxon richness – The total number of different taxonomic categories collected at a sampling station.

Taxon – Organisms are classified into categories based on similarities and evolutionary relationships between them. Each of these categories (e.g., species, genus, family, phylum, etc.) is called a taxon (plural taxa).

Thermomechanical pulp mill – A mill that uses a two-step process to produce pulp. First, wood chips are disintegrated by passing them through a special refiner pressurized with steam and refined through a series of chemical reactions at elevated temperatures. In the second stage, the refiners are set to the ambient temperature to treat the fibres so that they are ready for paper making. Thermomechanical pulp is generally very strong and is used to make coated or uncoated papers, such as papers for magazines, catalogues, directories, books, etc.

Total abundance – The total number of individuals of all taxonomic categories collected at the sampling station, expressed per unit area.

Weight at age – A measurement of the rate of growth of fish described by the relationship of size (weight) to age. Over the entire life span of a fish, the rate of increase in size usually declines as fish approach death.

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