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ENVIRONMENTAL RESPONSE TO DECREASED DIOXIN AND FURAN LOADINGS FROM BRITISH COLUMBIA COASTAL PULP MILLS

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Abstract: Dioxin/furan contamination resulted in shellfish harvesting restrictions covering up to 1200 km^2 of the British Columbia coast between 1988 and 1995. Process changes made by pulp mills discharging to marine waters reduced their dioxin and furan loadings by over 97% between 1989 and 1994. A dioxin and furan trend monitoring program conducted at sites adjacent to pulp mill outfalls documented the following average declines in dioxin and furan toxicity equivalents (TEQs) between 1990 and 1995: sediment (61%), Dungeness crab hepato-pancreas (80%), Dungeness crab muscle (85%), oyster (93%), prawn (92%), and shrimp (87%). In 1995, harvesting restrictions due to dioxin/furan contamination were removed for 486 km^2 of affected area.

Keywords: Dioxin, furan, PCDD, PCDF, pulpmill, crab, oyster, prawn, shrimp, fisheries restrictions.

1.0 Introduction

Ten pulp mills discharge secondary-treated effluent to the marine waters of British Columbia, Canada (Figure 1). The sulphite mill at Port Alice on the north coast of Vancouver Island uses chlorine in its process, but dioxins and furans measured in the receiving environment of Neroutsos Inlet have not been elevated to levels of concern.

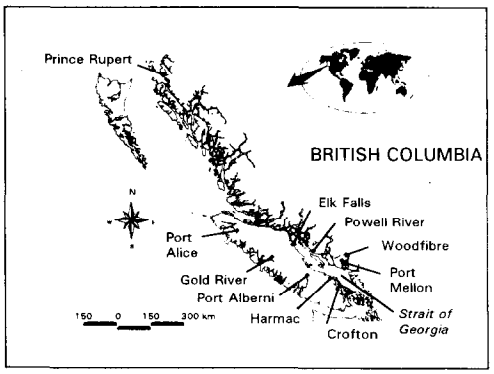

Figure 1: British Columbia pulp mills discharging to marine waters.

The Port Alberni mill, at the head of Alberni Inlet on the south coast of Vancouver Island, used chlorine in its operations until November 1993 when the kraft mill was shut down. Pulp is now produced from groundwood and chemo-thermomechanical mills, using some hydrogen peroxide bleaching.

The other eight mills are all bleached kraft pulp mills. Three of these mills discharge to relatively sheltered, low-energy fjord environments. Four mills discharge to more exposed, higher energy coastal areas, although these mills are all located on the sheltered interior waters of the Strait of Georgia. The eighth mill, at Prince Rupert on the north coast, discharges to a tidally flushed channel system. The mill environmental impacts have been previously described.[1]

Initial monitoring from 1987 to 1989 documented elevated dioxin and furan levels in edible fish and shellfish collected from sites near these mills. The federal government responded by issuing harvesting restrictions on various crab, clam, prawn, shrimp, and oyster fisheries; implementing a monitoring program in conjunction with the pulp and paper industry; and introducing legislation to control dioxin and furan discharges. Industry responded by implementing mill process changes that dramatically reduced effluent dioxin and furan loadings by over 97% between 1989 and 1994.[2]

This paper presents an overview of the environmental improvements documented by the annual Dioxin and Furan Trend Monitoring Program conducted by coastal pulp mills as directed by the Department of the Environment (DOE) and the Department of Fisheries and Oceans (DFO). The program includes all coastal mills except the sulphite mill at Port Alice. Original data are described in consultant reports (e.g., Dwernychuk, et al.,[3,4,5,6,7,8] IRC Inc.,[9] and G3 Consulting Ltd.[10])

2.0 Dioxin and Furan Trend Monitoring Program

The Dioxin and Furan Trend Monitoring Program was prescribed by the federal government in 1990 following initial data collection from 1987 to 1989. Sampling locations, species, and numbers of samples in composites are specified annually by DOE following consultation with DFO. The participating mills are responsible for collection and analyses. Analysis is for the 17 dioxin and furan congeners chlorinated at the 2, 3, 7, and 8 positions (PCDDs and PCDFs). The results, submitted to DOE, are evaluated and forwarded to DFO for incorporation of fisheries utilization information, and thence to Health Canada (HC) for a health hazard assessment. Fishery restrictions are reviewed annually by DFO, based in part on the HC assessment.

Dioxins and furans discharged in pulp mill effluent are generally bound to particulate matter.[11,12] Sediment particles and biosolids are dispersed by tidal currents and deposited in sedimentation areas where contaminants are available for uptake by bottom dwelling organisms such as crab. More than 200 sediment samples from over 70 different sites have been collected and analysed since 1990.

More than 1200 tissue samples from clam, crab, oyster, prawn, shrimp, other invertebrates, salmonids, and bottomfish have been collected and analysed from over 200 different sites since 1987. Initially, many species were screened for dioxin and furan contamination. After data evaluation, the Dungeness crab was selected as a key species. The Dungeness crab generally bioconcentrates higher levels of dioxins and furans in its hepatopancreas than other crab species, and higher levels than expected on a lipid-normalized basis.[13] It is a bottom dwelling forager preferring depositional zones, which enhances its exposure to potentially dioxin-contaminated sediment. Its long life, fecundity, widespread distribution, and relatively stationary habit make it an ideal indicator species for contaminant uptake monitoring. The hepatopancreas from legal-sized male Dungeness crab (minimum 165 mm carapace width) is the preferred sample medium and was targetted in the sampling program.

Dioxin and furan analyses are conducted via ultra-trace high resolution gas chromatography/high resolution mass spectrometry, although some data generated in the 1980's were low resolution. Quality assurance and quality control (QA/QC) procedures including the number of blanks, duplicate samples, and the level of surrogate recovery are specified by DOE.[14] Dioxin and furan toxicity equivalent (TEQ) is calculated using I-TEFs for the 17 dioxins and furans chlorinated at the 2,3,7,8 positions.[15] A value of 0 (zero) is assumed for congeners that are not detected in the analysis.

Sediment was usually collected with a stainless steel Smith-MacIntyre grab. The top 2 cm were analysed, and results are not normalized for total organic carbon content. Shellfish tissue was usually collected in February or March. Fresh weight tissue was analysed, and results are not normalized for lipid content.

3.0 Dioxin and Furan Trends in the Coastal Environment

The following discussion of dioxin and furan trends focuses on two subsets of data for sediment, crab hepatopancreas, crab muscle, oyster, prawn, and shrimp: (1) all sites for which data can be paired between years before and after regulations were implemented in 1992, and (2) representative sites near each pulp mill outfall that were sampled each year.

The most defensible trends are those derived from as many sites as possible for which data are comparable. TEQs were calculated for sites sampled both in 1990 and in 1993 for crab muscle, oyster, and prawn; 1990 and 1995 for crab hepatopancreas and sediment; and 1989 and 1993 for shrimp (shrimp were not successfully captured in 1990) (Table 1). The percent change between the pre-regulation sample and the post-regulation sample was calculated for each site. The average for all sites is given in Table 1. While some sites were sampled earlier than 1990, more pairs are available using 1990 data.

Table 1: Year of pre- and post-regulation sampling, and number of sites used to derive average percent change in TEQs in the British Columbia marine environment.

Sample medium	Pre-regulation sample	Post-regulation sample	Number of sites	Average % TEQ decline
Sediment	1990	1995	25	61
Crab muscle	1990	1993	7	85
Crab hepatopancreas	1990	1995	38	80
Oyster	1990	1993	9	93
Prawn	1990	1993	5	92
Shrimp	1989	1993	5	87

Pulp mill outfall sites are considered representative of the worst-case environmental impact of pulp mill effluent, and were generally sampled each year. These sites were selected and results presented in Figures 2 - 7 so that a year-by-year trend can be displayed in the figures. The 1995 tissue results are currently being evaluated by Health Canada and therefore are not available for public release at this time.

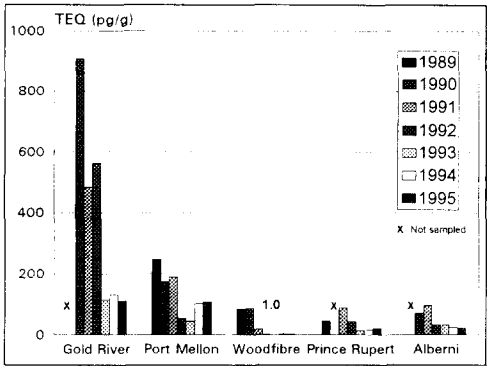

Figure 2: Dioxin and furan TEQs in sediment at pulp mill outfall sites on fjords and the channel at Prince Rupert.

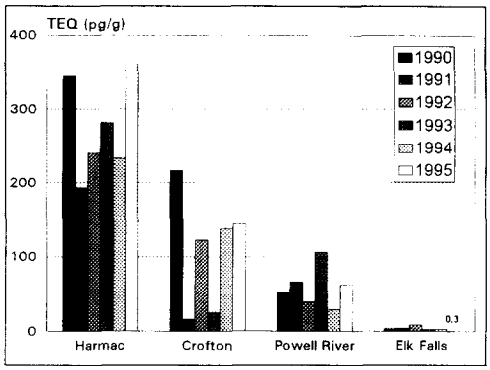

Figure 3: Dioxin and furan TEQs in sediment at pulp mill outfall sites located on relatively exposed coasts.

3.1 Sediment

Although sediments have been collected from 70 different sites during the program, only 25 of these sites were sampled in 1990 and again in 1995. TEQs declined at 19 of the sites; the average decline was 61%. Values in 1995 samples ranged from 2% to 166% of 1990 levels. An increasing trend of dioxins and furans in sediment has occurred at many open-coast sites since 1993. Reasons for this increasing trend are unknown. More intensive sampling using non-composited samples is planned for 1996 to check sample variability and further explain this trend.

Outfall Sites: All nine pulp mills included in the program discharge via submerged diffusers. A sedimentation site near each diffuser was sampled each year. The TEQ values from fjord sites display definite downward trends (Figure 2). The more exposed, open coast sites showed more variable results (Figure 3).

Reasons for the contrast between fjord and more exposed coast sites include varying degrees of effluent mixing and dispersion by tidal currents, sediment resuspension and transport, burial by river sediment load, particle size composition, and organic content. For example, Discovery Passage (Elk Falls) has very high tidal currents (5 - 7 knots) and consequently has relatively coarse sediments. As a result of discharging into this high-energy environment, the sediment TEQ levels adjacent to the Elk Falls mill are very low (3 pg/g); however, there are widespread, discontinuous areas of dioxin and furan contamination associated with this mill. In contrast, dioxin and furan levels in sediment surrounding the Woodfibre mill in Howe Sound have dropped very rapidly, probably due to burial of contaminated sediment by high sediment inputs from the Squamish River.

Bioturbation, or the biological mixing of sediments, is another factor in how long the sediments will take to recover from contamination. Even if the contaminant source is eliminated, bioturbation will act to prolong exposure of biota to contaminated sediment. The half-life of sediment contamination is partially dependent on the thickness of the mixing layer and the sedimentation rate, and may be about 10 years at a typical B.C. coastal fjord site.[16]

3.2 Dungeness Crab (*Cancer magister*) Hepatopancreas

Dungeness crab hepatopancreas was sampled at 38 sites in both 1990 and 1995. Dioxin and furan TEQs declined at 35 of these sites; the average decline was 80%. Values in 1995 samples ranged from 1% to 277% of 1990

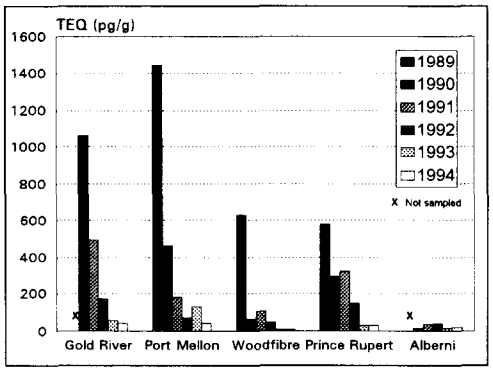

Figure 4: Dioxin and furan TEQs in Dungeness crab hepatopancreas at pulp mill outfall sites on fjords and the channel at Prince Rupert.

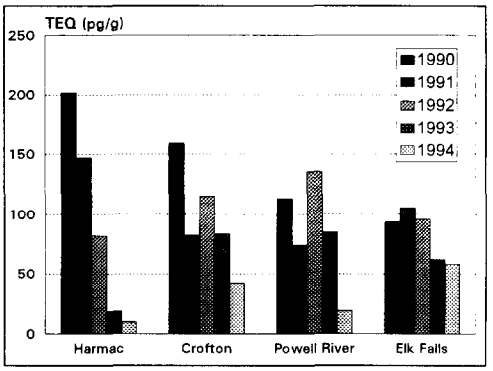

Figure 5: Dioxin and furan TEQs in Dungeness crab hepato-pancreas at pulp mill outfall sites on relatively exposed coasts.

levels. The three increases (16.2 pg/g in 1990 increased to 44.8 pg/g in 1995; 78.6 increased to 134.1 pg/g; and 80.2 increased to 100.7 pg/g) tended to reflect higher lipid levels in the later samples.

Outfall Sites: Dungeness crab have been sampled each year near the nine mill outfalls. These sites do not necessarily coincide with the outfall sediment sites, but they exhibit similar trends. Sites where crab hepatopancreas had high dioxin and furan TEQs in 1989/1990 (600 - 1,400 pg/g) are in fjords, and levels have dropped dramatically at these sites (Figure 4). Sites with low TEQs (≤200 pg/g) in 1990 are on relatively exposed coasts and while TEQs declined, the declines were not as dramatic (Figure 5). The exception is the site at the head of Alberni Inlet adjacent to the Alberni pulp mill discharge. TEQs in crab hepatopancreas captured at this fjord site have been variable, but have always been comparatively low and have ranged between 40.7 (in 1992) and 15.5 (in 1993) pg/g. Reasons for the contrast between fjords and more exposed coasts parallel those expressed for sediment. Yunker and Cretney,[17] found distinct differences in crab hepatopancres TEQ trends depending on whether the habitat were in quiescent versus tidally well-flushed areas.

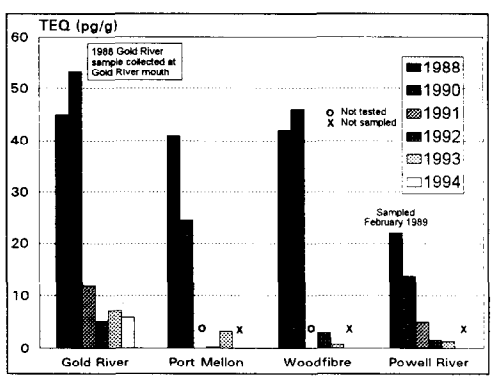

Figure 6: Crab muscle TEQs from samples collected near outfalls at Gold River, Howe Sound, and Powell River.

3.3 Dungeness Crab (*Cancer magister*) Muscle

Dungeness crab muscle samples have not been analysed as frequently as hepatopancreas samples because muscle tends to have lower lipid and TEQ levels than hepatopancreas. Dioxin and furan contamination of muscle tissue was of concern in Muchalat Inlet (Gold River), Howe Sound, at Powell River , and at Prince Rupert due to high levels that resulted in complete crab fisheries closures in these areas. Crab muscle contamination dropped rapidly after 1991 and had declined to near detection limits by 1993 at most sites after which muscle sampling was suspended.

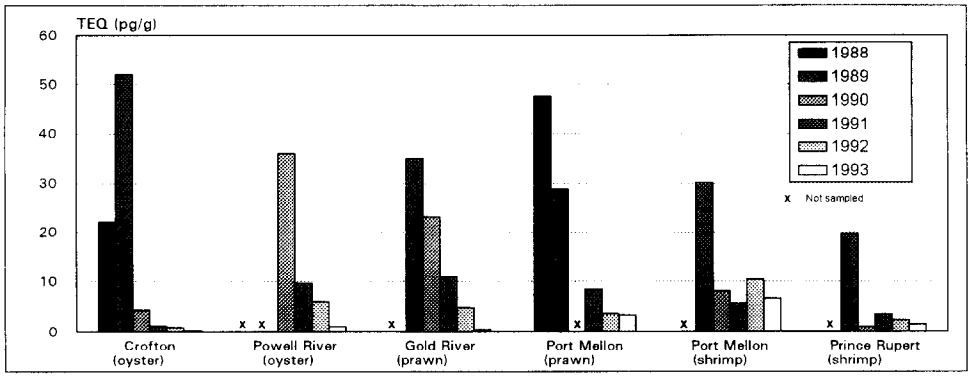

Figure 7: Oyster, prawn, and shrimp TEQs near selected pulp mill outfalls.

Dungeness crab muscle samples were collected at seven sites in both 1990 and 1993. Dioxin and furan TEQs declined at six of these sites; the average decline was 85%. Samples collected in 1993 ranged from 2% to 106% of 1990 levels.

Outfall Sites: Four of the seven crab muscle collection sites are adjacent to pulp mill diffusers. Monitoring at these sites started in 1988, and TEQs declined an average of 92% from 1988 to 1993 (Figure 6).

3.4 Oyster (*Crassostrea gigas*), Prawn (*Pandalus platyceros*), and Shrimp (*P. borealis, P. dispar*) Muscle

Oyster, prawn, and shrimp are relatively short-lived water column feeders. These organisms appear more sensitive to changes in environmental levels of dioxins and furans, as opposed to bottom feeders such as crab which are exposed to contaminated sediment from previous discharges. Whole oyster (Powell River, Crofton), shrimp tail muscle (Howe Sound, Prince Rupert), and prawn tail muscle (Gold River, Howe Sound) samples collected in 1987 and 1988 had elevated dioxin and furan levels and as a result fisheries restrictions were introduced by DFO in 1988 and 1989. Levels declined to near detection limits by 1993 (Figure 7), after which sampling was suspended in these areas and dioxin-mediated harvesting restrictions were lifted.

Whole oyster samples were collected by hand at nine sites in both 1990 and 1993. The average decline in oyster TEQs from these sites was 93%; the range was 85% to 97%. Annual results for the two outfall sites where oyster were collected are shown in Figure 7.

Prawn were not captured in Howe Sound in 1990. Samples were collected by trawling from five Gold River sites in 1990 and in 1993. The average decline in prawn tail muscle TEQs from these sites was 92%. Annual results for two outfall sites (Figure 7) clearly show a declining trend for prawn.

Shrimp samples were collected by trawling at five sites in both 1989 and 1993. Tail muscle TEQs declined at four sites, the average decline was 87%. One site at Prince Rupert had a 24% increase from 1.7 to 2.1 pg/g TEQ, but the change is not statisically significant given the low TEQs from this site. A decreasing trend is clearly shown by results from shrimp samples collected near mill outfalls (Figure 7).

4.0 Fisheries Restrictions

Dioxin/furan fish and shellfish contaminant data are referred to Health Canada for a human health hazard assessment. The HC assessment and subsequent decisions by DFO regarding fisheries restrictions are based on a number of factors, including the TEQ, species utilization/consumption patterns, and the type of fishery.

Harvest restrictions may involve closure of all fishing in an area, or may be tissue-specific as in the case of crab hepatopancreas. Areas with unacceptable levels of crab hepatopancreas contamination but acceptable muscle concentration are closed to commercial harvesting but may remain open for non-commercial harvesting. Normally in such cases an advisory is issued to non-commercial harvesters recommending safe levels for consumption of hepatopancreas tissue.

Generally, when dioxin and furan TEQ levels in Dungeness crab hepatopancreas exceed 30 pg/g the area is closed to commercial fisheries and an advisory is issued to non-commercial fishers. When levels generally exceed 15 pg/g in crab, oyster, prawn, or shrimp muscle, the fishery is closed to both commercial and non-commercial fishing.

4.1 DFO Fisheries Evaluation Criteria

Criteria to guide decisions to lift fisheries restrictions include the following:[18]

- data are assessed on a species- and area-specific basis;
- lifting of restrictions may be partial (e.g., total closure to all crab fishing may be replaced with a commercial closure, coupled with an advisory on hepatopancreas consumption by non-commercial harvesters);
- re-openings must encompass at least one-half of the closed area or a discrete portion of the habitat;
- re-openings require a minimum of two years of "clean" data (i.e., probable daily intake by human consumers does not exceed tolerable daily intake, using 30 pg/g in crab hepatopancreas and 15 pg/g in muscle as a general guide) and for which TEQ levels do not appear to be increasing; statistical tests may be applied;
- independent audit and/or confirmatory samples may be collected;
- data must meet QA/QC requirements; and
- areas may remain closed for other reasons (e.g. sewage contamination).

4.2 Fisheries Re-openings

In February 1995, all dioxin/furan contamination closures for harvesting of oyster, prawn, and shrimp were lifted. However, in some cases, harvest restrictions continue due to sewage contamination or paralytic shellfish poisoning (PSP) related closures. The February 1995 lifting of prawn, shrimp and oyster fishery restrictions affected 236 km^2.

Declining contaminant concentrations in crab muscle resulted in a re-opening to non-commercial fishers of 165 km^2 of area previously closed to all crab harvesting at Gold River, Howe Sound, and Powell River. Advisories on hepatopancreas consumption were issued for these areas. In February 1995, based on 1993 data, all existing crab fisheries closed due to elevated hepatopancreas TEQ levels remained closed to commercial harvesters and an additional

65 km^2 was closed in areas not previously sampled. Since all reopened oyster, prawn, and shrimp areas overlapped with continuing crab closure areas, the total area remaining under closure was approximately 1200 km^2.

In August 1995, for the first time since fishery restrictions were implemented, the total area subject to dioxin-mediated shellfish closure was reduced. Based on 1994 data, all restrictions were lifted in 40% (486 km^2) of the previously closed area, with commercial fisheries being re-opened subject to stock management plans. Commercial fisheries are closed and crab hepatopancreas consumption advisories remain in place for non-commercial fishers in the remaining 715 km^2 area, of which only 100 km^2 is closed to all crab harvesting because both muscle and hepatopancreas remain contaminated.

5.0 Conclusions

The reason for the rapid decline in dioxin and furan levels in crabs, even in areas where sediment values remain relatively high and variable, is not entirely clear. It may indicate that contaminant uptake in crab is related to their consumption of relatively uncontaminated prey species such as mussels, in preference to other species which are more exposed to sediment. The rapid TEQ decline in oyster, prawn, and shrimp which resulted in fisheries re-openings tends to support this conclusion because they are not deposit feeders.

Federal regulatory initiatives and a substantial capital investment by the B.C. pulp and paper industry to enable compliance have resulted in lower levels of dioxin and furan contamination in the marine environment and a reduction in fisheries harvesting restrictions. This improved environmental quality can be viewed as the "environmental dividend" of the investments, and as an indicator of the effectiveness of regulations which significantly limit dioxin and furan levels in effluent discharges.

Future dioxin and furan monitoring will likely focus on assessing environmental quality levels after human health concerns of consumers cease to be an issue.[19]

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