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ENVIRONMENT CANADA

CONSERVATION AND PROTECTION

ENVIRONMENTAL PROTECTION

[1]PACIFIC AND YUKON, AND [2]ATLANTIC REGION

EFFECTS OF PULP AND PAPER MILL EFFLUENTS AND THEIR CONSTITUENTS ON ESTUARINE AND MARINE ENVIRONMENTS IN CANADA: A BRIEF REVIEW

REGIONAL PROGRAM REPORT 90-08

by

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ABSTRACT

It is clear from this report and extensive reviews by McLeay (1987), and Sprague and Colodey (1989), that untreated pulp and paper mill effluents from Canadian mills are often acutely toxic at source. They have had, and in most cases continue to have, marked deleterious effects on receiving waters due to toxicity, and high BOD and TSS loadings. Impacts on benthic and intertidal organisms, contamination of biota by a wide range of organochlorine compounds, and changes in water colour, primary productivity and dissolved oxygen in the receiving waters, all have been demonstrated.

Where effluents have been treated successfully, water quality for dissolved oxygen levels has improved. However, even in these cases, long-term impacts of large accumulations of bark and effluent derived solids on inshore benthic habitats are expected. While sublethal effects of lowered dissolved oxygen levels and suspended solids on the water column and bottom communities are well known, the potential effects of major organochlorine contamination of water, sediments and biota are not fully understood, especially under natural conditions.

Site-specific assessments need to be updated in light of current biomonitoring techniques and changes in mill process and effluent treatment. The long-term effects of pulp mill generated organochlorine discharges on the receiving environment are largely unknown, but based on their properties, known persistence, results of laboratory toxicity studies, known bioaccumulation under natural conditions, and the findings of recent North American and Scandinavian studies which linked liver enzyme activation to reproductive changes in fish, such effects are a major concern.

There is no question as to the magnitude and seriousness of the biological impacts of pulp and paper mill effluents; they have been documented in Canadian waters for over three decades. Major new regulatory initiatives are completely justified to reduce the impacts of pulp and paper mill effluents and to allow for environmental recovery.

RESUME

D'après le rapport et des examens approfondis effectués par McLeay (1987) ainsi que par Sprague et Colodey (1989), il ne fait aucun doute que les effluents non traités des fabriques canadiennes de pâtes et papiers ont la plupart du temps une toxicité aigue à la source. Ils ont eu, et dans la plupart des cas, continuent d'avoir des effets nocifs marqués sur les eaux réceptrices en raison de leur toxicité ainsi que de leur forte charge en matières solides en suspension et en matières exerçant une DBO. Les effets sur le benthos et les organismes intertidaux, la contamination de la flore et de la faune par une grande variété de composés organochlorés ainsi que les changements dans la couleur, la productivité primaire et la teneur en oxygène dissous des eaux réceptrices ont tous été prouvés.

En ce qui concerne les teneurs en oxygène dissous, il semble que la qualité de l'eau s'améliore lorsque les effluents sont traités de façon efficace. Par contre, dans plusieurs cas, les effets à long terme sur les habitats benthiques côtiers de fortes accumulations d'écorces et de solides provenant des effluents suscitent des préoccupations. Les effets sublétaux de la diminution de la teneur en oxygène dissous et des solides en suspension sur la colonne d'eau et les communautés benthiques sont connues, mais les effets potentiels d'une importante contamination de l'eau, des sédiments, de la flore et de la faune par les composés organochlorés, notamment dans des conditions naturelles, ne sont pas encore tout à fait compris.

Pour les côtes de Pacifique et de l'Atlantique, il existe un certain nombre de cas où les effets des organochlorés (contamination, effets toxiques et perturbation des habitats) sur les organismes estuariens et marins de même que sur leurs communautés sont abondamment décrits. Bon nombre de ces cas doivent être mis à jour compte tenu des techniques actuelles de biosurveillance et des changements apportés aux procédés utilisés par les fabriques et au traitement des effluents.

Les études particulières à chaque site doinent être mis à jour à la lumière des présentes techniques de surveillance biologique et des changements de procédé dans les usines et du traitement des effluents.

Les effets à long terms des rejets d'organochlorés par les usines de pâtes sur le milieu récepteur sont fort peu connus, mais ils sont très préoccupants si l'on en juge par leurs propriétés, leur persistance reconnue, les résultats d'études de toxicité en laboratoire, leur bioaccumulation dans des conditions naturelles, et les résultats d'études récemment effectuées en Amérique du Nord et en Scandinavie, selon lesquels l'activation enzymatique est reliée aux changements dans la fonction reproductive du poisson.

L'ampleur et la gravité des effets biologiques des effluents des fabriques de pâtes et papiers ne font aucun doute; depuis plus de trois décennies, ces effets dans les eaux canadiennes ont été abondamment décrits. Pour réduire ces effets et permettre à l'environnement de se rétablir, de nouveaux projets de réglementation importants sont entièrement justifiés.

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1.0 INTRODUCTION

This summary document, based on numerous specific reports and reviews, (such as McLeay 1987, and Sprague and Colodey 1989), examines from a national perspective the serious environmental effects of pulp and paper mill effluents discharged to estuarine and marine waters in Canada.

The impact of each federally regulated parameter is addressed: Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and Toxicity. Known field impacts in Canadian marine waters are described briefly. In addition, the effects of organochlorine substances present in some effluents are described.

Where readily available, some information on freshwater impacts has been included to illustrate potential marine and estuarine impacts which should be evaluated.

1.1 Overview of Inputs and Impacts

Data for seven parameters from B.C. coastal mills in 1987 is summarized in Table 1. Data from Atlantic region mills for 1988 are in Table 2.

Pacific coastal waters received 336 t/d of BOD and 135 t/d of TSS in 1987, in effluents that at source were usually acutely toxic to fish. Atlantic coastal waters received 254 t/d of BOD and >127 t/d of TSS in 1988, in effluents that at source were either non-acutely toxic to fish or very toxic to fish.

The locations of the ten mills discharging to estuarine and marine areas on Canada's west coast are depicted in Figure 1. Measurable impact has been documented at every coastal mill, although the magnitude of these impacts varies considerably. Changes in mill process (e.g. sulfite recovery, or switching from sulfite to kraft) and changes in discharge mode (from surface

TABLE 1

EFFLUENT AND PRODUCTION DATA FOR B.C. COASTAL MILLS RANKED BY INCREASING PRODUCTION[1]

MILL LOCATION	BOD t/d*	TSS t/d	TSS kg/t	LC50 %	FLOW $m^3 \times 10^3/d$	TER[2]	PRODUCTION t/d
Port Alice[3]	85	4	8.7	33	175	530	462
Woodfibre	24	11	17.7	11	76	691	620
Port Mellon	16	7	10.8	24	117	488	647
Gold River	19	9	12.9	54	147	272	699
Harmac	22	9	8.6	75	265	353	1043
Port Edward	37	12	10.9	11	182	1655	1103
Port Alberni	9	10	7.7	64[4]	209	327	1294
Powell River	28	29	16.6	59	320	542	1751
Crofton	44	19	9.9	30	230	767	1910
Elk Falls	52	25	12.2	23	250	1087	2039
TOTAL	336	135	-	-	1971	6711	11568
RANGES	9-85	4-29	7.7-17.7	11-75	76-320	272-1655	462-2039

1 EP, P&Y Region 1987 Data

2 Toxicity Emission Rate Calculated by (100*1/LC50) *FLOW (see McLeay 1987)

3 Sulphite Mill

4 4/5 Tests Passed LC50 of 80%

* Tonnes/day

TABLE 2
EFFLUENT AND PRODUCTION DATA FOR THE ATLANTIC PROVINCES' COASTAL MILLS[1] RANKED BY INCREASING PRODUCTION

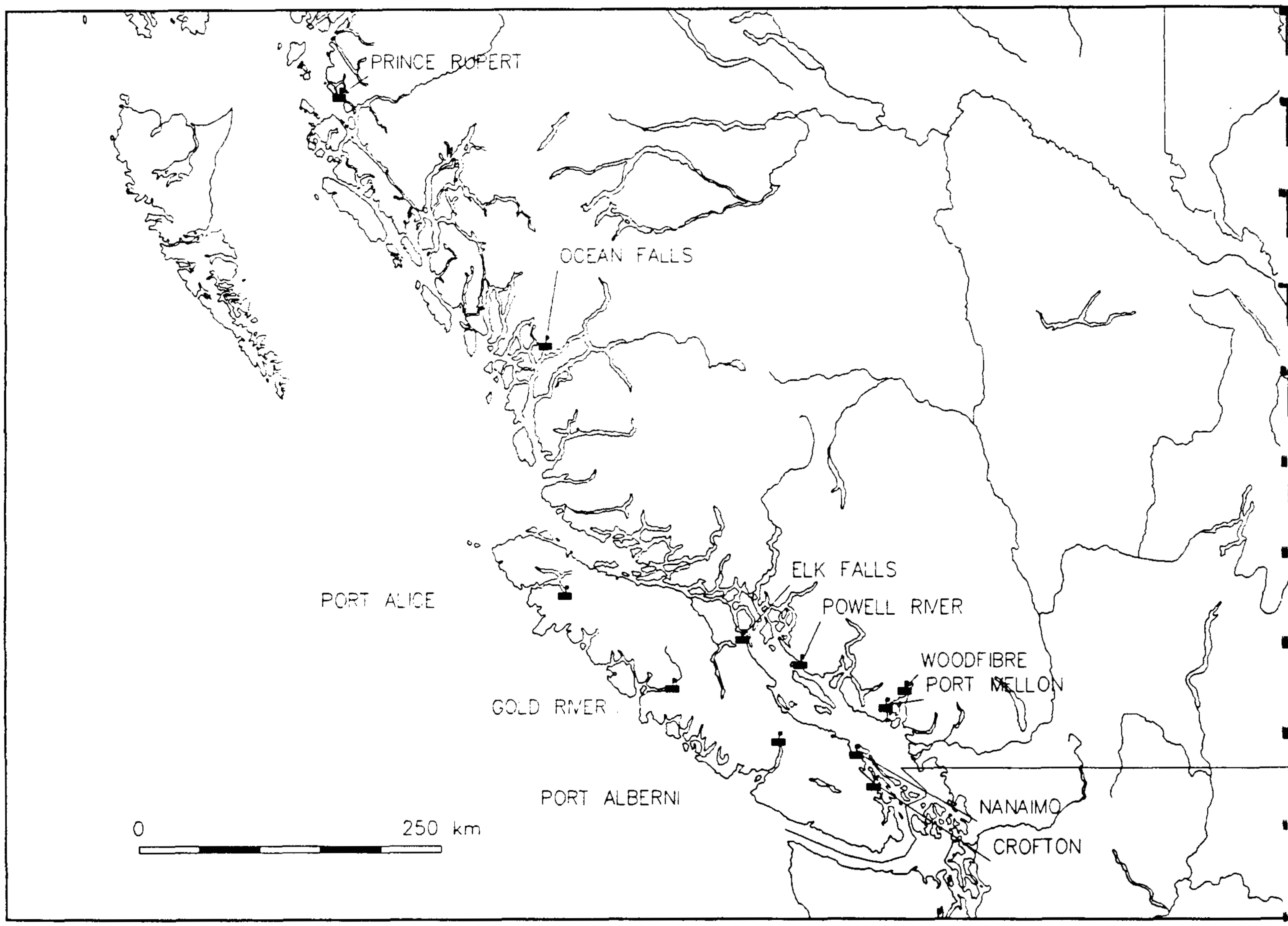
MILL LOCATION	BOD t/d	TSS t/d	TSS kg/t	AOX t/d	LC50 %	FLOW $m^3 \times 10^3$/d	TER[2]	PRODUCTION t/d
Hantsport, N.S. (CKF Inc.)	N/A	<1	--	N/A	>100	N/A	--	40
Saint John, N.B. (Irving Tissue)	N/A	<1	--	N/A	>100	N/A	N/A	50
Utopia, N.B.	17	2	6.7	N/A	12	6	50	300
Nelson, N.B.	2	1	3.3	N/A	2	7	350	300
East River, N.S.	4	4	12.9	N/A	19	3	16	310
Atholville, N.B.	20	3	8.8	2	20	60	300	340
Stephenville, Nfld.	7	3	6.7	N/A	9	33	370	450
Abercrombie, N.S.	5	3	5.3	1	>100	84	<84	570
Brooklyn, N.S.	29	7	11.5	N/A	30	41	137	610
Bathurst, N.B.	35	5	6.9	N/A	32	40	125	730
Saint John, N.B. (Irving Pulp & Paper)	19	10	13.3	2	6	77	1280	750
Corner Brook, Nfld.	17	30	39.0	N/A	20	94	450	770
Newcastle, N.B.	5	13	16.5	3	>100	65	<65	790
Saint John, N.B. (Rothesay Paper Inc.)	18	15	17.1	N/A	6	45	750	880
Point Tupper, N.S.	52	19	20.7	2	2	87	4350	920
Dalhousie, N.B.	24	12	12.9	N/A	20	61	305	930
TOTALS	254	127	--	10	--	703	8632	8740
RANGES	2-52	<1-30	3.3-39	1-3	2->100	3-94	16-4350	40-930

1 EP, Atlantic Region, 1988, Pulp and Paper Mills Sector Report

2 Toxicity Emission Rate Calculated by (100 x 1/LC50) x Flow (see McLeay 1987)

FIGURE 1

LOCATION OF MILLS DISCHARGING TO ESTUARINE AND MARINE AREAS ON CANADA'S WEST COAST



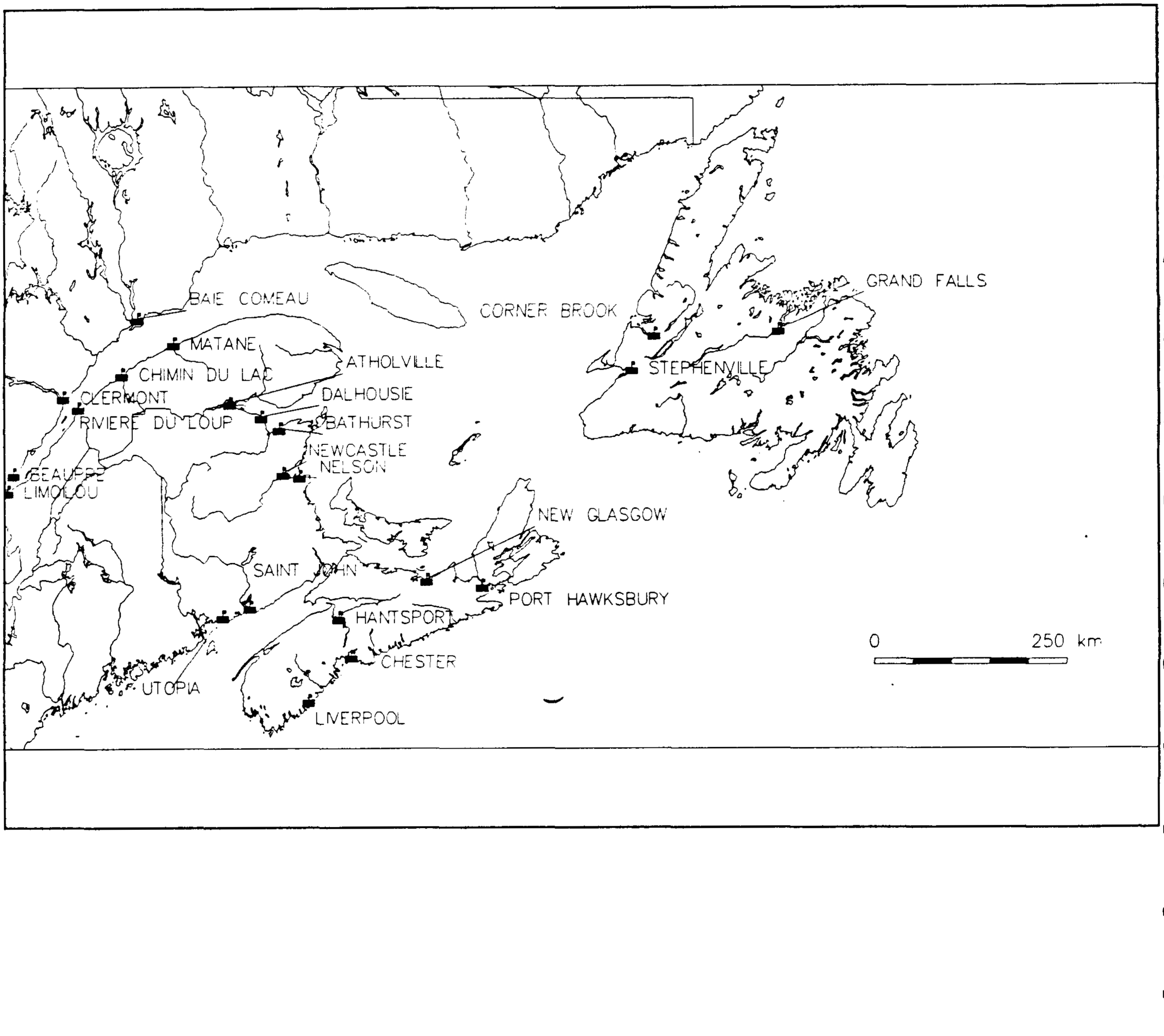
outfall to submerged diffuser) have led to environmental improvement at many locations on the coast. In contrast, other changes such as increased loading due to mill production increases, or reduced assimilative capacity via natural factors (such as reduced river runoff or tidal exchange) are threatening fishery resources at other sites.

Mill locations in the Atlantic Provinces are shown in Figure 2. Measurable impacts have been documented at eight mills. Most of the mills are older ones, that in their original design, did not provide much treatment for their effluents prior to discharge (Waldichuk 1988a). However, total daily discharge loadings from Atlantic mills have been reduced 60% for BOD and 51% for TSS from 1969 to 1984 (Eaton et al. 1986). This has been achieved through a combination of process changes, in-plant controls and the addition of external treatment, mainly with aerated stabilization basins (Waldichuk 1988a).

Along the St. Lawrence River and Estuary, 29 mills were in operation in 1982 and collectively discharged about 703 t/d of BOD and 336 t/d of TSS, a decrease from levels discharged in 1973: 891 t/d BOD and 684 t/d TSS (Statistics Canada 1986). In the Saguenay Fjord, pulp wastes have been detected through measures of enhanced organic material in the sediments and have provided a historical record of the industry's activities (Smith 1988, In: MEQ in Canada 1989). Evidence of impact of these mills was not available for this summary.

FIGURE 2

LOCATIONS OF PULP AND PAPER MILLS IN THE FOUR ATLANTIC PROVINCES



2.0 BIOCHEMICAL OXYGEN DEMAND

2.1 BOD Loading

Pulp and paper mill effluent is a complex mixture of many substances including carbohydrates, lignins, organic acids and alcohols. Oxygen is consumed when bacteria degrades these materials. BOD is a measure of this oxygen demand. The majority of effluent oxygen demand can be met either in a mill treatment system, or if the effluent is not treated, the demand will be met by consumption of oxygen from receiving waters. Each day, ten B.C. mills discharge over 330 tonnes of oxygen demanding wastes to coastal waters in 2 million cubic metres of effluent (Table 1). Despite reductions of up to 56% between 1975 and 1980 at B.C. coastal mills (Kay 1989), the BOD loading from all but one pulp mill exceeds the BOD loading of municipal sewage from B.C.'s second largest coastal city, Victoria. Sixteen mills in the Atlantic Provinces discharge 254 t/day to estuarine and marine environments (Table 2). Only one B.C. coastal mill has secondary treatment for about half its effluent, while eight Atlantic mills (six coastal, two inland) have secondary treatment.

2.2 Fate

The impact of mill effluent BOD on dissolved oxygen levels is moderated by the assimilative capacity of the receiving environment at each location. For example, at Elk Falls, B.C., where effluent is rapidly mixed and dispersed by strong currents in Discovery Passage, there is little or no change in dissolved oxygen levels, even at the outfall. At the other extreme, where effluent is discharged into relatively quiescent coastal estuarine inlets which have restricted circulation (Port Alice, Port Alberni, Gold River, L'Etang Estuary), wide-scale, low dissolved oxygen levels are chronic and become serious during certain times of the year, especially when inlet flushing rates are reduced due to low river runoff. Unfortunately, this is also a time of fisheries sensitivity due to migrating salmon stocks.

The Lake Utopia (semi-chemi-mechanical) Paper Mill, discharging into the L'Etang Estuary near St. George, in southwestern New Brunswick, caused serious dissolved oxygen depletion in the upper estuary throughout the 1970's and 1980's. Although mill production levels decreased from 250 t/d to 200t/d, dissolved oxygen conditions in the receiving water remained the same (often severely depleted) from 1975 to 1985 (Wildish et al. 1986). Recent modifications to convert the upper retention ponds to fresh water have resulted in reduced hydrogen sulphide production in the upper estuary, and perhaps reduced BOD in lower parts.

Mill effluent not only exerts an oxygen demand, it can also reduce oxygen supply in receiving waters. Effluent colour can shade phytoplankton, thus reducing re-oxygenation via photosynthesis, and thereby reduce primary productivity in the estuary (Parker and Siebert 1972). This has been demonstrated near mills at Crofton, Port Alberni, Powell River (Anderson 1983) and at Port Mellon and Woodfibre (Stockner et al. 1975).

It is important to note that some significant improvements have been made to BOD loadings by some mills. For example, prior to the installation of secondary treatment at the Fraser's Inc. mill in Edmunston, New Brunswick, and the Georgia-Pacific mill in Woodland, Maine, depressed levels of dissolved oxygen in the Saint John River and the St. Croix River, respectively, were observed. Since the implementation of secondary treatment at these mills (1980 for Edmundston, 1977 for Woodland), significant increases in receiving water oxygen levels have been measured (Dafoe et al. 1987, Eaton 1989).

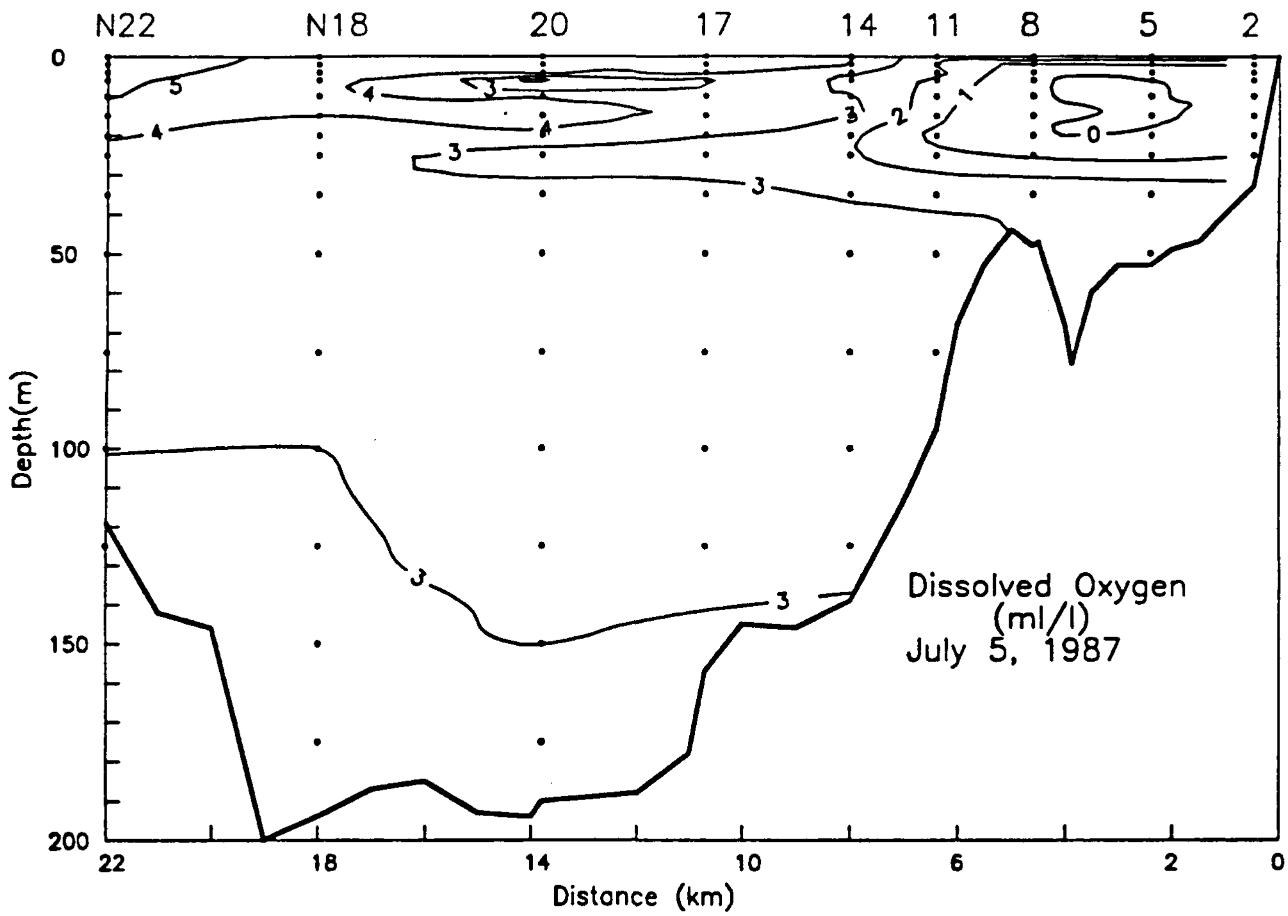
2.3 Biological Effects of Reduced Dissolved Oxygen

Lethal and sublethal responses of fish to decreases in dissolved oxygen include changes in behaviour, growth, swimming, respiration, fecundity, disease resistance, and feeding (Davis 1975, Birtwell 1989). These demonstrated sublethal effects are more difficult to document in wild populations, but may be more widespread and significant than dramatic, serious events like fish kills, which may only rarely be documented. It also should be noted that the toxicity of kraft mill effluent increases when dissolved oxygen levels decrease (Marier 1973, Sprague 1985). Specific examples of effects related to BOD loading are given below.

2.3.1 Port Alice, British Columbia. Following recovery of sulfite liquor in 1977, the zone of serious BOD impact in Neroutsos Inlet was reduced from 20 km from the mill, to about 2 km (Kay 1989). However, during September and October 1985, the zone of potentially lethal (to salmon) dissolved oxygen concentrations (DO <3 mg/L) extended over 5 km up and down-inlet from the pulp mill and included water depths from 0-20 m at some locations (Birtwell 1989). This situation has persisted to present, as illustrated in Figure 3 for July 1987 (from Stucchi 1990). Measured dissolved oxygen levels fell below 1 mg/L in 1985 (Colodey and Pomeroy 1986), and were thus inadequate for even some species of invertebrates (Miller et al. 1988). Non-salmonid mortalities, including herring and ratfish occurred (Colodey and Pomeroy 1986). Salmonid mortalities and stressed salmon were also demonstrated in 1985 using in situ juvenile chinook salmon bioassays (Kruzynski, DFO,pers. comm. in Birtwell 1989). Distribution of migrating salmon caught by DFO test-fishing nets was positively correlated to ambient dissolved oxygen concentrations (Colodey and Pomeroy 1986). The changes in maturation of these salmon were described by Birtwell (1989), who concluded that poor water quality blocked and hindered first-run salmon from entering their natal streams. He notes that late-run fish entered the creek to spawn during increasing dissolved oxygen levels in inlet waters and higher stream flows following strong winds and heavy rainfall.

In 1986 there were fourteen reported fish kills in Neroutsos Inlet ranging from 26 ratfish up to 10,000 dead herring, or on another occasion 90% of all intertidal life in a 10 km distance. In five cases, mortalities are clearly related to low ambient dissolved oxygen (dissolved oxygen less than 1 mg/L), while others may have been due to various factors such as effluent toxicity, or upwelling of hydrogen sulfide gas from the decomposition of deposited fibres and wood wastes (Colodey unpubl. file reports). Stucchi (1990) reviewed the physical oceanography, dissolved oxygen and BOD loading in Neroutsos Inlet and concluded that a substantial reduction in the daily BOD loading is required before Davis (1975) Level B dissolved oxygen levels can

FIGURE 3 - AREA OF HYPOXIC WATER IN NEROUTSOS INLET, B.C.
(FROM STUCCHI 1990)



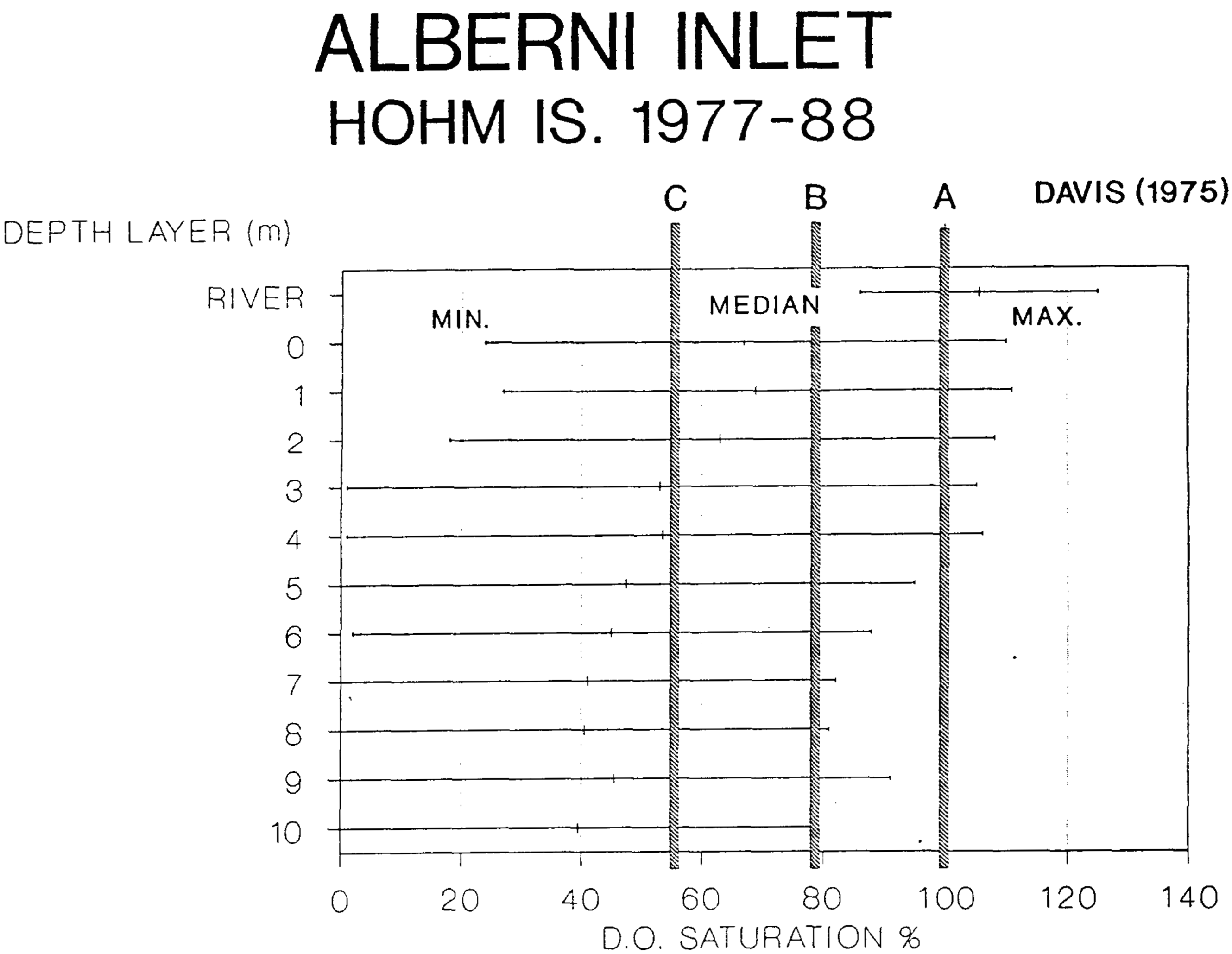
even be approached. (At Level B the average member of a species starts to exhibit symptoms of oxygen distress.) Improved treatment facilities to achieve 80% reduction in BOD are currently in the pilot stage of development at Port Alice.

2.3.2 Port Alberni, British Columbia. The situation at Port Alberni has been studied for many years since the modelling and BOD evaluation of the proposed sulfite mill by Tully in 1949. Waldichuk (1974) has reviewed the response of Alberni Inlet to increasing BOD loading as kraft mill production increased. He notes that there was no oxygen problem when the mill was producing 220 short tons per day of unbleached kraft pulp because of the low volume of waste. Dissolved oxygen problems were encountered when BOD loading rose in conjunction with increases in mill production. Although total production is now about 1300 tonnes per day, it should be noted that BOD loading has decreased from about 40 t/d in 1970, to present averages of about 9 t/d, due to installation of an aerated stabilization basin in 1970 which treats about half the mill effluent. However, despite partial secondary treatment, weekly loadings of 14,500 kg/d were exceeded on three occasions in 1985 (Dyer 1986).

In situ bioassays at Alberni Inlet have demonstrated that acutely lethal conditions occur due to low dissolved oxygen levels and to effluent toxicity (Birtwell and Harbo 1980, Birtwell and Kruzynski 1989). Use of the water column by juvenile and adult salmonids is restricted, at Alberni Inlet, to the upper water layers (with highest effluent concentration) due to the low levels of oxygen in deeper waters. Recent studies on the impact of mill BOD (Colodey et al. 1988, Birch 1989) have concluded that the Alberni Inlet is receiving more oxygen demanding wastes than can be balanced by oxygenation processes, leading to a polluted situation with low ambient dissolved oxygen. Mill studies corroborated the observations of declining dissolved oxygen levels within the inlet (Hodgins 1989a). Davis' Level A criteria are not even met in the surface water layer for 50% of the data points collected from 1977-1988 as shown in Figure 4 (Colodey et al. 1988). Below 2 m median conditions were such that a large portion of the population would suffer a severe deleterious effect if exposed beyond a few hours (Davis 1975, Level C).

FIGURE 4

FREQUENCY OF DISSOLVED OXYGEN VALUES BELOW LEVELS A, B AND C (DAVIS, 1975) IN ALBERNI INLET, B.C.



from Colodey et al.1988

Pre-mill data collected at Holm Island in 1941 (Pacific Oceanographic Group 1957) indicate that minimum dissolved oxygen saturation in the upper (0-2 m) and lower (4-10 m) water layers were much higher (88% and 20 % saturation respectively), than present minimum levels (20 % saturation in the upper and 1% saturation in lower layer). This demonstrates that the magnitude of the present very low dissolved oxygen conditions is not a "natural" occurrence of this inlet, although natural factors such as river flow and tidal exchange alter the degree of impact caused by the mill effluent.

2.3.3 Gold River, British Columbia. Effluent from the bleached kraft mill at Gold River is discharged to Muchalat Inlet, which is very deep and has restricted circulation. The dissolved oxygen minima in the upper 20 m water layer often coincides with effluent concentration maxima at each station sampled (Colodey 1986, 1988 unpubl. data). This lowered dissolved oxygen layer (1.5-3.0 mg/L) can extend up into shallower depths (e.g. 2 m), thus lowering the amount of usable fish habitat within the inlet (Colodey 1989 unpubl. data). Oxygen conditions within the inlet could be further stressed with the recent addition of a CTMP plant at the site, which could increase TSS by 72 % and BOD by 24%.

2.3.4 L'Etang Estuary, New Brunswick. Following the opening of Lake Utopia Paper Limited in 1970, the benthic changes in the Lower L'Etang Estuary associated with mill discharges stabilized by 1972-1975 (Wildish et al. 1986). Water quality in the Lower L'Etang is adequate for aquacultural purposes as presently practiced. The multiple effects of aquaculture and effluent loading have resulted in some eutrophication, reduced diversity, and phytoplankton blooms and die-backs. The Upper L'Etang, however, became incapable of supporting benthos and fish shortly after mill start-up, due to the organic loading and resulting anoxia (Poole et al. 1978, Wildish 1983). Extensive descriptions exist of the major effects on the upper part of this small estuary, including the development of anoxic or hypoxic bottom waters, hydrogen sulfide production, the rapid elimination or gradual disappearance of indigenous species, and colonisation by hypoxic-tolerant benthic organisms. Not to be forgotten are the long-term impacts of mill effluent on the bacteriological water quality, in terms of shellfish harvesting standards and contamination with Klebsiella spp. (Blaise and Legault 1973, Baxter 1972, Menon 1973). The Lower L'Etang is closed to all bivalve shellfish harvesting.

2.3.5 Other Locations in British Columbia. At other sites localised, minor depressions in dissolved oxygen have been noted in the vicinity of effluent outfalls at Crofton (Colodey 1989 unpubl. data, Colodey and Tyers 1987, Sullivan 1980), Port Mellon (Cross 1989), and Woodfibre (Western Pulp 1988). No dissolved oxygen depressions have been noted near the outfalls at Harmac (Sullivan 1980, Colodey 1989 & 1986 unpubl. data), or Powell River (Sullivan 1980, Colodey 1983 unpubl. data). Dissolved oxygen levels at Porpoise Harbour have improved since the sulfite mill was shut down (1976) and the diffuser brought on-line (1978) for kraft mill effluent (Kay 1989).

2.3.6 Other Locations in the Atlantic Provinces. The Bathurst mill at the mouth of the Nepisiguit River, New Brunswick, reduces surface water dissolved oxygen concentrations when effluents are temporarily backed up by rising tides and low river flows. No significant oxygen depletion occurs when the tide is falling and effluents are flushed out into the harbour (I.E.C. Beak Consultants Ltd. 1985).

At Cornerbrook, Newfoundland, dissolved oxygen was reduced to 75% saturation up to 2 km from the Cornerbrook Pulp and Paper Limited mill located on the Humber Arm (Moores 1989).

3.0 TOTAL SUSPENDED SOLIDS

3.1 Loading

Suspended solids associated with pulp and paper mill effluent are largely composed of cellulose fibres, wood chips, and bark fines, although a smaller portion of the solids can be inorganic constituents such as boiler ash and calcium carbonate. The range of TSS loading for B.C. coastal mills is from 4 to 29 tonnes per day (EP P&Y 1987 unpubl. data) (Table 1). Atlantic mills have loadings ranging from <1 to 30 tonnes per day (Table 2). Mill efficiency with regard to fibre loss can be evaluated when TSS loading is divided by production. Values for B.C. coastal mills range from 7.7 to 17.7 kg TSS per tonne of pulp produced, whereas Atlantic region mills range from 3.3 to 39 kg TSS per tonne of pulp produced.

3.2 Fate

Waldichuk (1988b) recently summarised the effects of wood wastes on marine benthic organism and habitats. He noted that deposition of fibres can lead to conditions where benthic flora and fauna are totally eliminated. He concluded that wood fibres not only degrade benthic habitat but also lead to depletion of dissolved oxygen and production of toxic hydrogen sulfide. The long-term oxygen demand of mill effluent is related to its organic solids which are deposited on the seabed at many locations in British Columbia waters. At Port Alberni, for example, an elevation in oxygen demand was demonstrated for degraded sediments which covered about 40% of the harbour bottom and accounted for about 10% to 55% of the total oxygen demand in the inner harbour (Hodgins 1989b, Stucchi pers. comm.). Hodgins states that: "... if the solids mat were to decrease in size through better retention and disposal of solids, then ultimately the benthic BOD would decrease. Studies reported in the literature indicate that this would not be a rapid recovery process."

Suspended solids loading causes the loss of productive benthic habitat when discharged solids settle and smother benthic organisms. A typical black, anaerobic deposit is often sampled near the outfall of most coastal mills. These deposits are often in the form of a jelly-like fibre mat which can be from several centimetres to 15 meters in depth (Pomeroy 1983). The release of methane gas, hydrogen sulphide gas (Waldichuk 1983, 1988b), and acids (Miller et al. 1979) along with organic contaminants (Section 5 below) are a serious threat to the receiving environment. The release of nutrients to the water column (Pearson 1982), although beneficial, is over-shadowed by benthic habitat degradation and oxygen demand (which has been measured to be as much as 3.6 $g/m^2/d$; Stein and Denison 1966). Figure 5A is a photo of a typical fibre mat area taken from the PISCES IV submersible, while Figure 5B shows the loss of benthic habitat by coarse wood material from log-booming operations at Port Alberni. Sediment oxygen demand under log-booming areas in the Coos River Estuary and areas with bark and wood debris in Alaska have been measured to be 2 - 4 $g/m^2/d$ (Schaumberg 1973, Jones & Stokes Inc. 1989).

Present zones of measurable impact range from about 0.5 km to 5.0 km from the mills, covering several square kilometres at most mills. For example, benthic degradation at B.C. coastal mills ranges from 1 to 8 square kilometres. Insufficient data are available to determine the rate at which solids deposition is encroaching on the benthic habitat, although it has been suggested that at some locations mats are in equilibrium (e.g. Harmac: Ellis and Ostrovsky 1983). In one instance where fibre accumulations have been adequately sampled, we can conclude that their size is relatively stable and fluctuates from year to year (e.g. Crofton: Colodey and Tyers 1987).

In the Atlantic Provinces, the results of a monitoring program on the Humber Arm, Newfoundland, indicated that the major impact from the Cornerbrook mill effluents was the smothering of benthos by wood fibre for a distance of 2 km north and northeast of the point of discharge (LeDrew and Bennett 1989, Moores 1989). This mill had the highest fibre loss per tonne of pulp produced (39 kg), when east and west coast marine and estuarine mills are considered. The active deposition in the Arm of coarse wood material, from log drives and debarking, is now stopped (LeDrew and Bennett 1989).

PLATE 1 Appearance of typical fibre deposit - Northumberland Channel off Harmac pulpmill

PLATE 2 Wood debris and development of white bacterial slime found under sorting and storage areas - Alberni Inlet in vicinity of Port Alberni pulpmill

Similarly, sediment cores taken in Liverpool Harbour, Nova Scotia, indicated that Organic Sediment Index values were elevated at stations up to 1 km from the outfall of the Bowater Mersey mill (Beak 1971). A major benthic deposit of wood fibre has been present off the Stora Mill at Port Hawkesbury, Cape Breton, for at least twenty years (Machell et al. 1978; M. Bewers, pers. comm.).

As in British Columbia waters, it is expected that effects on benthos, even after deposition stops, will occur over many decades.

3.3 Biological Effects of Effluent Solids

Resource species, as well as smaller invertebrates used as food sources, may be replaced by fewer kinds of less desirable, pollution-tolerant species when organic deposits change the characteristics of the sediment. Changes to invertebrate species diversity and abundance in response to increasing sediment organic content have been described for Porpoise Harbour, Port Alberni, Port Mellon, Port Alice, Harmac and Ocean Falls by McGreer (1984). Degraded sediment from Port Alberni and Port Mellon are toxic to amphipod crustaceans in laboratory bioassays (Chapman and Barlow 1984). Fish kills have been caused by upwelling of toxic gases from benthic deposits at Powell River (B.C. MOE; B. Moore, pers. comm.). Even at Elk Falls, where strong currents disperse the effluent, there are degraded sediments (wood chips and indication of pulp). Near the outfall, benthic species response is reduced abundance and diversity in comparison to the reference location (Morrow Engineering 1985).

The recovery rate following cessation or reduction of solids deposition is a function of site-specific sedimentation rates and larval supply, both of which are mediated by local current regimes. It may be decades until natural sediments cover the historical inputs (up to 15 m thick) which have accumulated at many sites, such as at Ocean Falls in British Columbia (Pomeroy 1983, Fournier and Levings 1982).

Reduction in TSS loading, through improved levels of effluent treatment is required to prevent further habitat degradation and begin the recovery period as quickly as possible. Since a large portion of hydrophobic organic chemicals (like dioxins) are associated with suspended solids (Muir et al. 1985, Servos and Muir 1989), solids control could also be expected to limit the release of particulate associated contaminants. Settling suspended particulate matter (SPM) is of great importance for the introduction of these contaminants to a variety of organisms, where uptake is mainly by ingestion of SPM (Broman et al. 1989).

4.0 TOXICITY: ACUTE LETHALITY

4.1 Loading

Acute bioassay tests are used, in accordance with federal regulations, to evaluate the lethality of the mixture of toxic compounds found in mill effluents.

One review (Sprague and Colodey 1989, using data from McLeay 1987) calculated that untreated kraft mill effluent had a 96 h LC50 of 16% (killed 50% of the test fish when exposed to 16% effluent for 96 h). Only one B.C. coastal mill has secondary treatment for about half its effluent, and as a result B.C. marine discharge mills *in toto* have rather toxic effluents (median LC50 = 32%, Table 1), in relation to B.C. freshwater discharge mills where secondary treatment is required (all LC50 = 100%). On the east coast, mills have final effluent toxicities ranging from 96 h LC50's of 2% to >100% (Table 2). It can be seen that one east coast mill accounts for 50% of the region's toxic effluent emmissions (as expressed as TER in Table 2).

In the early 1980's, three mills in northern New Brunswick were studied extensively. "Consolidated-Bathurst effluent samples, mixed from four sewers in proportion to flow, were found to have 96 h LC50's to Atlantic salmon parr of 32-56%, 10-32% and 0-10%. Miramichi Pulp and Paper effluent samples had LC50's of 56-100% and greater than 100%. Effluent samples from Atholville Pulp had LC50's of 10-18% and 10-32%" (Boudreau et al. 1988).

Well designed and operated secondary treatment facilities are an effective way to eliminate effluent toxicity of kraft mill effluent, largely by the decomposition of resin and fatty acids (Sprague and Colodey 1989). Secondary treatment (especially activated sludge) can also be expected to reduce the loading of some chlorinated organic compounds (Gergov et al. 1988, Fleming et al. 1990, *inter alios*).

In the Atlantic Region by 1984, eight mills of thirteen being modernized, produced effluents which met the toxicity requirements of the Pulp and Paper Effluent Regulations, and were non-acutely toxic to test fish (Waldichuk 1988a).

4.2 Biological Effects of Effluent Toxicity

The aquatic toxicity of pulp and paper mill effluents has been extensively reviewed by McLeay (1987) and Sprague and Colodey (1989). Recently, in situ field bioassays at Port Alberni and Port Mellon, British Columbia, demonstrated toxicity of partially treated and untreated BKME to several species of salmon (Birtwell and Kruzynski 1989). The reader is also referred to Section 5.3 for more information on effluent toxicity, particularly as it relates to organochlorine substances and sublethal effects.

Even when effluent passes the acute bioassay test (at least 50% of the fish survive) and is deemed "non-acutely toxic", it is possible that it can cause other detrimental effects. Examples from the freshwater environment illustrate the point. A study near the Proctor and Gamble bleached kraft mill at Grand Prairie (Alberta), which discharged treated non-toxic effluent, showed that downstream fish had accumulated chlorinated effluent compounds and had liver damage when compared to upstream fish (AEC 1987). A recently published study by Munkittrick (1989) demonstrated that fish exposed to bleached kraft mill effluent had elevated liver enzyme activity, coupled with reduced steroid hormone levels. These metabolic changes were associated with reduced sexual development in male and female whitefish. In another instance, plasma testosterone levels in trout were decreased by exposure to BKME in a lab study (Lindstrom-Seppa and Oikari 1989a). Liver enzyme activation has also been demonstrated in fish exposed to BKME on the Fraser River (Servizi et al. 1990), Thunder Bay (Smith and Rokosh 1989), St. Maurice River (Hodson et al. 1990), Finland (Lindstrom-Seppa and Oikari 1989b, 1990), and Sweden (Andersson et al. 1988).

The above discussions on toxicity have focused primarily on the toxicity of whole effluents to fish. However, all ecosystem components must be protected from effluent toxicity. In this regard, Anderson (1983) has demonstrated that copepods, which are an important part of the food web, are more sensitive to kraft mill effluent (LC50 = 12%) than juvenile salmonids (LC50 = 25%). The toxic effect of bleached kraft mill effluent constituents has also been demonstrated using sea urchins (Cherr et al. 1989).

Pulp mill effluent chlorate levels rise when chlorine dioxide is substituted for chlorine gas (Munro et al. 1990). Effluent chlorate has been shown to be toxic to brown algae (Fucus vesiculosus) at 10-20 ug/L when ambient nitrate levels were low (Lehtinen et al. 1988). It should be noted that several chlorate spills (up to 45% concentration) have occurred during the past year at Pacific coast marine pulp mills during loading or unloading operations (EP spills database). As mills increase their use of chlorate for chlorine dioxide generation, more care will have to be used to limit its entry into the aquatic ecosystem, through proper handling and treatment system design. Chlorine dioxide, itself, is two to four times more toxic than total residual chlorine to freshwater fish with a 96 h LC50 of 20 ug/L for juvenile fathead minnows (Wilde et al. 1983). However, effects of chlorine dioxide on marine organisms occur only at relatively high concentrations: kelp germination and sea urchin malformations at 250 mg/L (Hose et al. 1989).

Wu and Levings (1980) demonstrated that blue mussels and barnacles suffered reproductive impairment and slower growth rates when transplanted near the Port Mellon kraft mill outfall. The authors note that the results of their study correlated well with a previous study at the location which found low densities of barnacles and mussels near the outfall (Levings and McDaniel 1976).

In the Atlantic Provinces, three mills in New Brunswick (Bathurst, Newcastle, Atholville) created extensive effluent plumes in the receiving estuaries. During rising tides, the Nepisiguit River had concentrations ranging from 1 to 10% effluent across most of its width and greater concentrations near the sewers. Under similar tidal conditions, the Miramichi River had 1 % effluent across its entire width. The Restigouche River, however, had areas on its north side where effluent could not be detected at any part of the tidal cycle (Boudreau et al. 1988). Behavioural studies in the laboratory with Atlantic salmon parr showed that effluents from the three mills at high concentrations (10% and 100%) increased their locomotor activity. Behavioural responses (changes in activity) occurred at 1% effluent concentrations for all mills, and concern was expressed that salmon migration might be affected in the receiving estuaries (Boudreau et al. 1988). In a follow-up 1985 study by I.E.C. Beak at the Consolidated-Bathurst mill in Bathurst, New Brunswick, it was shown that juvenile Atlantic Salmon would avoid mill effluent at a concentration of 3.5%. Under low flow river conditions, a plug of effluent at, or above that concentration was predicted to form in the freshwater layer at hightide and to flow downstream until low tide was reached (I.E.C. Beak 1985).

5.0 IMPACT OF ORGANOCHLORINE SUBSTANCES

5.1 Loading

The impacts and toxicity of pulp mill related organochlorine substances have been recently reviewed (Colodey 1989, Sprague and Colodey 1989). About 200 low molecular weight chlorinated compounds have been identified in kraft bleach plant wastes (Reeve and Earl 1988, Suntio et al. 1988, McKague et al. 1989). This represents only a portion of the total number of chlorinated compounds represented as AOX (Adsorbable Organohalogens). A single large kraft mill may discharge around 4 tonnes of organically bound chlorine or about 50 t/d chlorinated organic substances (Sprague and Colodey 1989). AOX data for B.C. coastal mills (Table 3) indicates organically bound chlorine loadings of 1-26 t/d, compared to limited data from Atlantic Region mills which indicate that they discharge from 1-5 t/d (Table 2). The untreated effluents from these mills have the potential for introducing over 33,000 tonnes of organically bound chlorine into the receiving waters annually. This could represent over 400,000 tonnes of chlorinated organic compounds, assuming a conversion factor of thirteen from organically bound chlorine (AOX) to chlorinated organic compounds (Sprague and Colodey 1989).

5.2 Fate

Once discharged into the environment, these compounds can become sorbed to particles (Broman et al. 1989, Servos and Muir 1989), dispersed and contaminate a large area. Chlorinated organics from pulp mills on the Fraser River were detected in water and fish in the Fraser Estuary up to 750 km downstream (Carey and Hart 1988, Rogers et al. 1988a, Rogers et al. 1988b, Servizi et al. 1988). The linear dispersion distances of dioxins, chloroguaiacols and chlorocatecols from B.C. coastal mills is shown in Table 4. Just as dispersion distance depends on site-specific variables, recovery of contaminated sediments by burial with clean sediment will also be related to local sedimentation and erosion rates, and the degree to which the sediments are modified by biological communities (bioturbation). It has been

TABLE 3 - AOX DATA FOR BC COASTAL MILLS

Mill	AOX (kg/adt)[1]	Loading (t/d)[2]
Crofton	4.4-7.1	8.4-13.7
Elk Falls	6.0	12.2
Port Mellon	5.8	3.8
Harmac	5.5-7.1	5.7-7.4
Port Alberni	5.8	7.5
Powell River	9.0-14.9	15.8-26.1
Prince Rupert	0.5-3.1	0.5-3.5
Port Alice	5.2	2.4
Woodfibre	3.7	2.3
Gold River	6.2	4.3
	TOTAL	62.9-83.2

1 CPPA Data, Sept. 15, 1989

2 1987 Production Data

TABLE 4

DISTANCES (KM) FROM MILL OUTFALLS WHERE TRICHLOROGUAIACOL (TCG), TETRA-CHLOROGUAIACOL (TECG), TRICHLOROCATECOL (TCC), TETRACHLOROCATECOL (TECC), AND 2,3,7,8-TETRACHLORODIBENZO-DIOXIN (2,3,7,8-TCDD) HAVE BEEN DETECTED IN SEDIMENT AND BIOTA (DATA FROM DWERNYCHUK 1989)[1]

Location	TCG	TeCG	TCC	TeCC	2,3,7,8-TCDD			
	Sediment		Sediment		Sediment	Crab	Shrimp	Mussels
Prince Rupert	>6	>6	>6	>6	>6	>6	2	<1
Woodfibre	5	10	8	10	4	>16	<1	<1
Port Mellon	6	8	5	>10	>10	>22	1	<1

1 ">" means the contaminant was found at the furthest distance sampled.

demonstrated that levels of 2,3,7,8-TCDD (dioxin) in contaminated sediment from Newark Bay, N.J., have declined considerably over the past 25 years. However, some areas with low net sediment accumulation and active sediment mixing have the highest contaminant concentration in surficial sediments (Bopp et al. 1988). These sediments would therefore be available as a biological contact surface.

Other studies predict that food-chain uptake is the main bioaccumulation route for polychlorinated dibenzo-p-dioxins in aquatic environments, especially when water concentrations are low (Muir and Servos 1988, Servos and Muir 1988, Muir and Yarechewski 1988, Muir et al. 1988). Such food-chain models are recommended as the preferred method for calculating site-specific dioxin body burdens (Dudley and Wagner 1989). Although 2,3,7,8-TCDD fate has been studied in freshwater model ecosystems (Isensee and Jones 1975, Corbet et al. 1983, inter alios), results are not available for marine and estuarine systems. Freshwater studies indicate that bioaccumulation of 2,3,7,8-TCDD occurred primarily through the food chain and secondarily through contact with contaminated sediment, when rainbow trout were exposed in the laboratory. The water-exposure route did not appear to make a significant contribution in this case (Batterman 1989).

The environmental fate and biological effects of these compounds is further complicated because some higher molecular weight compounds (e.g. chloroguaiacols) can be degraded and transformed into other more toxic compounds (e.g. chloroveratroles: Neilson et al. 1984, Neilson 1989, Paasivirta 1987). Chloroveratroles and chloroanisoles bioaccumulate and have been linked to tainting in some species of fish (Paasivirta 1988). The tainting potential of 2,4-dichlorophenol is reflected in the 0.2 ug/L guideline set in the Canadian Water Quality Guidelines (CCREM 1987), a concern given the shift to lower chlorinated compounds during ClO_2 substitution (cf. Flemming et al. 1990). For example, the final effluent levels of 2,4-dichlorophenol at the Terrace Bay mill in Ontario would require 100-fold dilution in order to meet the CCREM guidelines (07/24/89 sampling date- DOE data).

A study of the fate of organochlorine compounds from the 750 ton/d bleached kraft mill at Saint John, NB (Bacon 1978, Bacon 1980, Bacon 1983) showed the presence of dichlorophenols, trichlorophenols, trichloroguaiacols and tetrachloroguaiacols in sediments, clam (Mya arenaria) extracts, tomcod and flounder liver, and confirmed the earlier results of Brownlee and Strachan 1977. Pentachlorophenol was markedly present in all animals examined, and may have been related to the use of wood preservatives. A wide range of concentrations (not given) were detected, all at presumably sublethal levels. Flounder, smelt and tomcod accumulated the compounds, in liver and fat (flounder), viscera (tomcod) and liver (smelt), respectively. Resin acids and fatty acids were only detected in clams and tomcod from one location.

5.3 Biological Effects of Effluent Organochlorine Compounds

The biological effects of chlorinated compounds found in pulp and paper effluents on marine and estuarine biota are not well known. Lab studies on the uptake and depuration of chlorinated phenols and guaiacols in mussels agreed with field results which indicated the presence of these contaminants in biota from Saint John Harbour and the Northumberland Strait near New Glasgow. The uptake and depuration of these compounds were also studied using a small estuarine fish (Fundulus heteroclitus). Histological damage was demonstrated when fish were exposed to either 0.5 ppm trichlorophenol (TCP), or trichloroguaiacol (TCG) or 2.5 % bleachery effluent. Liver damage was only completely reversible in fish exposed to TCP and TCG, but not in fish exposed to 2.5 % bleachery effluent (Bacon 1980).

Artificial stream studies using well-treated (14 d aerated lagoon) bleached kraft mill effluent consistently demonstrated lower survival in effluent exposed rainbow trout (NCASI 1989 p. 97; cf. Flemming et al. 1990). Natural colonization of streams by Mountain Whitefish was also much lower in stream channels receiving effluent (NCASI 1989 p. 122). It is estimated that these streams were receiving effluents having AOX (adsorbable organohalide) levels of 3 to 4 kg/t (Flemming et al. 1990).

Recent studies on Fraser River juvenile chinook salmon exposed to treated BKME support the importance of the food chain uptake of dioxin, demonstrate liver enzyme activation (EROD induction 2.5 times control levels) and tentatively identify liver granulomas, as healing bacterial kidney disease (Servizi et al. 1990; J. Servizi, pers. comm.). Fish growth and seawater acclimation were not affected by effluent exposure. Lab exposure of fish to treated BKME led to contaminant uptake (chlorophenols, chloroguaiacols, EOCL= extractable organochlorine) in proportion to effluent exposure. Field studies (Rogers et al. 1989) indicated similar levels of organochlorine contamination in feral fish, but much higher levels of EROD induction (55 times control).

The effect of BKME on fish in the St. Maurice River (Quebec) show a similar pattern of response to effluent exposure as Fraser River fish. Liver AHH enzyme activity was elevated in exposed white suckers 5-10 fold at sites up to 95 km downstream. Changes in enzyme induction match changes in liver somatic index (LSI), hematocrit, serum glucose, serum protein and fin-ray asymmetry, and were all clearly related to effluent exposure. A decrease in gonad somatic index (GSI), for both sexes at the 95 km site indicate that sexual maturation was retarded, a suggestion supported by changes in serum hormone levels measured for both sexes. Too few northern pike were sampled to be conclusive, but they seem to demonstrate a similar pattern for AHH induction and LSI as white suckers. Similar reproductive changes, either to organs or hormone levels were described by Munkittrick (1989), and Lindstrom-Seppa and Oikari (1989a) in Section 4.2 above. Andersson et al. 1988 and Sandstrom et al. 1988 respectively, found gradients in liver enzyme activity and reduced gonad size and development at a Swedish bleached kraft mill. Hodson et al. 1990 conclude that Scandinavian studies of the effects of BKME on fish are applicable in Canada, at least in some cases (J. Carey, pers. comm.).

Some data is available on marine species. One study has examined the effects of blue crabs consuming radio-labelled 2,3,7,8-TCDD (dioxin) contaminated clams (Cristini et al. 1989). It was determined that the digestive gland (hepatopancreas) of the crab accumulated the highest concentrations of TCDD, which is consistent with data from B.C. organochlorine surveys (Dwernychuk 1988, EP unpubl. data). Some 2,3,7,8-TCDD was detected in the fecal material which the authors interpreted as excretion, but may be a result of incomplete assimilation. In a separate experiment, crab were fed dioxin and furan contaminated (137 ppt) clams from Newark, N.J. (Cristini et al. 1989). The physiology of these crabs was disrupted in that they had fewer molts and slower limb regeneration compared to crabs from the control area.

A clam transplant study (Cristini and Cooper 1988) was used to evaluate the bioavailability and physiological effect of dioxins and furans on the clam (Mya arenaria). Exposed clams (Elizabeth and Newark, NJ) accumulated dioxins and furans, had reduced length, width, and shell-meat ratios, exhibited significant lesions in the digestive tract and hepatopancreas, and had lowered adenylate energy charge. The authors concluded that the environmental exposure to dioxins and furans could alter physiological processes. A later study demonstrated shell-thinning and a variety of lesions of the gill, kidney and digestive gland; (Cooper et al. 1989).

The fecundity of crustacean copepods was reduced when they were exposed to 37-54 ug/l tetrachloroguaiacol, whereas the 96 h LC50 of this compound was a thousand-fold higher (39 mg/L) (Renberg et al. 1980).

The subtle nature of the mode of action of some chlorinated compounds is perhaps best illustrated by the delayed mortality to rainbow trout fry exposed to 38 part per quadrillion 2,3,7,8-TCDD: fish died after a 28 day depuration phase which followed the 28 day exposure phase (Mehrle et al. 1988). Other examples of delayed mortality in fish exposed to 2,3,7,8-TCDD are cited by Muir and Yarechewski (1988).

The bioaccumulation of some of these compounds (dioxins and furans) to levels higher than public health standards has resulted in the restrictive use or closure of over 67,000 hectares of productive fisheries and wildlife habitat in British Columbia. Although half-lives for some dioxin and furan congeners have been calculated for some species of freshwater fish like fathead minnows, trout (Niimi and Oliver 1986, Muir and Yarechewski 1988, Muir et al. 1989), carp (Kuehl et al. 1987) and yellow perch (Kleeman et al. 1986), similar data for marine species of fish and invertebrates are unavailable. It is known that invertebrates accumulate dioxins and furans in marine environments with little or no selectivity due to metabolism, and that fish can metabolize non-2,3,7,8 congeners greater than 2,3,7,8 congeners (Norstrom and MacDonald 1989).

The impact of chlorinated organic compounds like dioxins are not limited to aquatic organisms. Great Blue Herons (Ardea herodias) have been shown to be a valuable indicator of organic contaminants, like PCB, HCB, DDE, TCDD and TCDF in British Columbia. (Whitehead 1989). Concern was raised about the possibility that TCDD was implicated in the failure to fledge young at the Crofton heron colony in 1987 (Elliott et al. 1989). A laboratory study has since shown that eggs contaminated with higher levels of dioxins exhibited reduced growth, edema, liver enzyme (EROD) activation and other morphological and physiological changes (Hart et al. 1990, Bellward et al. 1990).

The prudent approach is to limit the entry of chlorinated compounds into the environment by instituting effluent controls on the chlorinated compounds as a class of substances and by minimizing TSS loadings, since the fate and biological effects of these compounds are largely unknown.

6.0 RECOMMENDATIONS

Studies are needed to quantify the responses and describe the health of fish exposed to BKME in the marine and estuarine environments, using current diagnostic health and ecotoxicological techniques.

The sublethal effects of effluents and organochlorines can be partly assessed by new laboratory tests proposed under the changes to the federal regulations. However, hazard assessments and environmental effects monitoring at each mill site are needed to complete the accurate assessment of potential sublethal effects and bioaccumulation dynamics of organochlorine compounds. There is a clear need to eliminate acute toxicity of effluents, especially in situations where the effluent is discharged to areas of shallow water or constricted areas through which migrating fish must pass.

In conjunction with field biomonitoring and hazard assessments, long-term bioassays are needed for assessing the effects of specific chlorinated compounds alone and in combination with pulp and paper effluents.

As chlorine dioxide substitution rates increase, there is a need to track Canadian mill effluent chlorate levels. The release of chlorate into the environment should be minimized by treatment system design and through proper chemical handling procedures at mill sites. There is a concurrent need to evaluate chlorate toxicity with local algal species as well as with standard test species.

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