A A GIS-approach to compare intertidal diversity and contaminanat loading in the marine receiving environment of two pulp mills in British Columbia, Canada

By

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Abstract

Intertidal monitoring during 1992 and 1993 at mid to low intertidal rocky-shore beaches surrounding two marine-discharging pulp mills in British Columbia revealed a decline of biodiversity as the sites were closer located near the mill outlet. The present study reports spatial changes in species richness, trophic composition and algal composition of intertidal benthos over a gradient of effluent exposure. Those spatial trends are related to dioxin/furan loads in sediment, Dungeness crab (*cancer magister*) hepatopancreas and Pacific oyster (*Crassostrea gigas)* muscle, sampled in the same area but at slightly different locations. Local oceanographic conditions and non-pulp mill pollution sources in the vicinity of the two pulp mills are considered as confounding factors in assessing pulp mill effluent. Statistical analyses were used to assess trends in intertidal biodiversity. A GIS-approach, incorporating the most important known oceanographic features, is a very helpful additional tool to visualise the major relationships between intertidal biodiversity and contaminant loadings.

This study has discovered that in some regions cumulative contamination may exert a large and long-lasting effect on intertidal diversity and community structure even when current pollution has decreased. Feeding guilds deemed very useful tools to reflect shifts in the functioning of a given area. Deposit feeders were highly abundant on isolated patches close to the mill with abundant sources of organic material. Green algae deemed tolerant to pulp mill effluent whereas red algae were the most sensitive to bleached kraft pulp mill effluent. This study suggests that environmental impact is not always proportional to the volume of pulp and paper production and waste loading but highly depends on local oceanographic conditions and historic depositions.

There is a strong need for long-term monitoring to complete the accurate assessment or potential sublethal and ecosystem effects, and to understand the bioaccumulation dynamics of effluents on a site-specific basis. In the summer of 2004, intertidal monitoring will be repeated at the same sites, which aims to detect long-term changes in biodiversity and to evaluate the impact of historic contaminated sediment deposits. This paper serves as a preliminary study to propose a sampling regime and recommend appropriate analysis for interpreting the results.

Keywords: marine pulp mills, intertidal monitoring, TEQ, British Columbia, GIS

Introduction

Of the 25 pulp and paper mills in British Columbia, ten are currently discharging effluent into marine waters (British Columbia: Ministry of Water, Land and Air Protection, 2004). Besides the proximity of forest-covered mountains to sheltered ports, coastal pulp mills benefit from numerous coastal streams that provide the much-needed freshwater for the production process. Finished products can be shipped directly to world markets and the proximity of the sea, of course, is attractive for waste disposal.

This study aims to assess the marine environmental impact of two pulp mills; Skeena Cellulose Inc. (Prince Rupert) and NorskeCanada (Powell River), on the British Columbia coast.

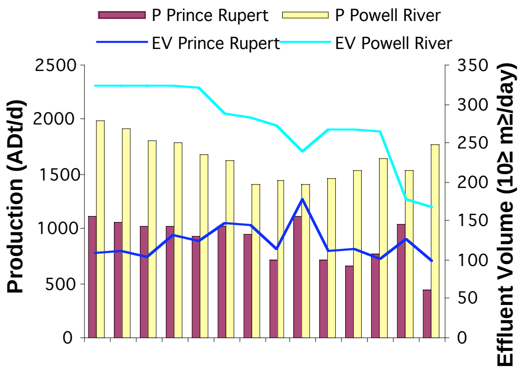
Skeena Cellulose Inc. pulp mill, located on Watson Island (Fig.3), has been closed since June 2001 due to poor economic conditions. The mill is expected to be operational again by the beginning of November 2004 (Patrick O'Brien, Hatfield Consultants, pers. comm., 2004). The original pulp mill was built in 1951 as a sulphite mill and was converted in 1976 to a kraft mill process. Initially, effluent discharged into Wainwright Basin but the diffuser was shifted to Porpoise Harbour in 1978. In the late 1970s, the Canadian government increased pressure to improve the quality of effluent which resulted in the instalment of a final effluent clarifier. Since 1991, primary and secondary treatment facilities have been in operation to reduce effluent and atmospheric emissions. All effluent is discharged since mid-1993 via the multi-port submarine diffuser, approximately 20m deep, to ensure a more efficient dispersion of mill effluent (Hatfield, 1994b).

NorskeCanada owns and operates a pulp and paper mill in *Powell River*, located at the north end of Malaspina Strait in the Strait of Georgia (Fig.3). Paper production began operation in 1912 using sulphite and mechanical pulp processes. A kraft mill, producing semi-bleached pulp, began operation in 1967 and the sulphite mill closed two years later. Thermomechanical pulp production started in 1975 but was converted in the early 1980's to a chemi-thermomechanical pulp process by means of sodium sulphite treatment of wood chips. In the early 1990's, the mill produced both semi-bleached and unbleached kraft pulp, chemi-thermomechanical and groundwood mechanical pulps. A kraft mill bleach plant modernization in 1991 eliminated the dioxins and furans in the final effluent. Prior to the instalment of a submarine outfall in 1993, the mill discharged effluent from two principal outfalls. Historically, effluent from the Powell River pulp mill has been recognized as a contributing factor to pollution in Malaspina Strait (Hatfield, 1994a). However, several improvements in the pulp mill's environmental standards over a period of years have greatly reduced the impact on this marine system.

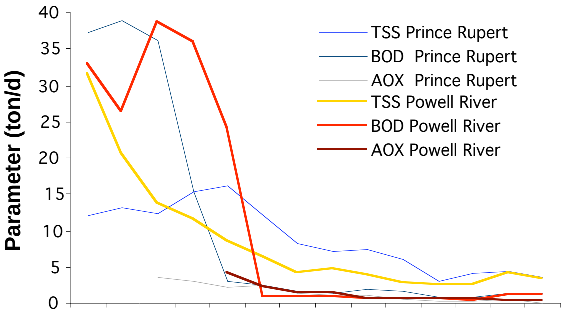
The deleterious effects of kraft pulping, also known as sulphate or chemical pulping, on receiving waters was historically reported as effects of toxicity (as measured by 96h trout bioassay), high biochemical oxygen demand (BOD), and total suspended solids (TSS) loadings. Prior to secondary treatment, deposits of fibres and effluent solids accumulated near pulp mill diffusers and became incorporated in sediments (Colodey A.G. 1987, Pomeroy, 1983). This results in short-term oxygen depletion when bacteria degrade the organic nutrients. A long-term loss of productive benthic habitat occurs via sediment deposits when the anaerobic fibre mat smothers benthic organisms and produce toxic hydrogen sulphide gas (Waldichuk, 1983). Extreme reductions in ambient dissolved oxygen, impacts on benthic and intertidal organisms, changes in water colour and primary productivity, have been demonstrated over years to cause environmental damage (Colodey and Wells, 1992).

Contamination of biota by a wide range of chlorinated organic compounds has been more recently the focus of investigation. Adsorbable Organic Halides (AOX) is widely used to quantify total amount of halogens associated with organic compounds in effluent. Compounds known to be present in kraft mill effluent generally associated with chlorine bleaching operations include chlorinated phenols, catechols, guaiacols, dioxins/furans and resin acids. Chlorinated organics discharged in pulp mill effluent are generally bound to particulate matter. Sediment particles and biosolids are dispersed by tidal currents and deposited in sedimentation areas where contaminants are available for uptake by bottom dwelling organisms. The zone of influence from those compounds can extend for tens of kilometres from the outfall of the mill (Hatfield, 1994b). The Dioxin and Furan Trend Monitoring Program was prescribed by the federal government in 1990 following initial data collection from 1987 to 1989 which documented elevated dioxin and furan levels in edible fish and shellfish collected from sites near these mills (Dwernychuk et al., 1992). The federal government responded by issuing harvesting restrictions on various crabs, clam, prawn, shrimp, and oyster fisheries.

Well-designed and operated secondary treatment facilities are an effective way to reduce the toxicity of kraft mill effluent, largely by the decomposition of resin and fatty acids (Sprague & Colodey, 1989). Since 1991 and 1992, primary and secondary treatment plants are in full operation at respectively Prince Rupert and Powell River. A primary clarifier neutralises the liquid and removes the



<u>Fig 1</u>: Historical pulp and paper production (Air-Dried ton/day) as annual averages of pulp and paper production (P) and relating Effluent Volume (EV) for NorskeCanada, Powell River Division and Skeena Cellulose Inc., Prince Rupert (Hatfield Consultants Ltd.).



<u>Fig. 2</u>: Annual averages of process effluent quality variables (BOD = Biochemical Oxygen Demand, TSS = Total Suspended Solids, AOX = Adsorbable Organic Halides) collected by Skeena Cellulose Inc., Prince Rupert and NorskeCanada, Powell River Division (Hatfield Consultants Ltd.).

settleable solids as primary sludge. Thereafter, a biological treatment system (UNOX, VPSA) provides pure oxygen, anhydrous ammonia and phosphoric acid, essential for continuous growth of the micro-organisms which decompose organic substances in the waste (Hatfield, 1994a, 1994b). The liquid discharge from the bio-reactor flows to secondary clarifiers in which the bio-solids settle out. A proportion of the sludge is removed as waste sludge while the remaining bio-solids are recycled back to the bio-reactor. The final treated effluent flows to a foam trap before it is diffused into Porpoise Harbour (in the case of Prince Rupert) or Malaspina Strait (for Powell River).

Historical pulp and paper production and the overall improvement in final effluent quality as measured by TSS, BOD, AOX and toxicity are shown in Fig. 1 & 2. Since initiation of secondary treatment, marked declines in BOD have occurred and also TSS has decreased gradually for both mills. The substitution of chlorine dioxide for elemental chlorine in the bleaching process has resulted in decreased AOX levels in the mill effluent of Powell River in 1993. AOX levels in the Prince Rupert effluent dropped significantly from 1990 to 1993. Acute toxicity tests have shown 100% survival of rainbow trout since february 1992 (Hatfield, 1999) Dioxin/Furan Trend Monitoring Program, 1998). The process changes of the mills discharging to marine waters reduced their effluent polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F) loadings by over 97% between 1989 and 1994 (Hagen et al. 1997). All dioxin and furan (TEQ) concentrations were < 4 pg/L since 1993; well below the federal permit level of 20 pg/L. This has resulted in the reopening of a number of previously closed fisheries areas (Hagen et al. 1997). Nevertheless, locations with sawmills or wood treatment facilities at storage sites in the BC harbour, and near docks at pulp mills also contribute to the PCDD/Fs concentrations in the sediment (Yunker & Cretney, 2000). Use of pentachlorophenol (PCP) wood preservatives is responsible for this contamination.

The data used to compare the marine environmental impact of the Prince Rupert and Powell River pulp mill were obtained from the intertidal survey of Bard (1998) and the Environmental Effects Monitoring (EEM) Environment Canada.

First, the research of Bard in 1990-1993 provided information on the species diversity of 28 mid to low intertidal beaches in 4 regions along the coast of

British Columbia (Bard, 1998). A Biological Index for Intertidal Communities (Bioindex) was developed to correlate a beach‘s biodiversity with exposure to a constant level of mill effluent. In the summer of 2004, intertidal monitoring will be repeated at the same sites which aim to detect long-term changes in biodiversity and to evaluate the impact of historic contaminated sediment deposits. This paper serves as a preliminary study to propose a sampling regime and recommend appropriate analysis for interpreting the results.

Second, the EEM program, managed and coordinated by Environment Canada, is a scientific tool used to determine if industrial effluent adversely affects fish health, fish habitat and the human use of fisheries resources. The Canadian pulp and paper industry is currently required to conduct the EEM program under the *Pulp and Paper Effluent Regulations* (PPER) under the *Fisheries Act.* The basis for a proper design of monitoring efforts is a plume delineation study, which was carried out by the pre-design phase of the federal EEM program. Effluent dispersion has been examined through dye dispersion studies in Powell River (Hodgins and Knoll, 1991) and Prince Rupert (Hodgins and Knoll 1990). The pre-design document describes the historical water quality and provides data of tracers such as organochlorines both in sediment and in the hepatopancreas of the Dungeness crab (*cancer magister*). If effects of pulp mill effluents are found in the receiving environment, these tracers may be used to aid in the interpretation of biological monitoring results.

Accordingly, the present study reports spatial changes in both species richness and composition of intertidal benthos in the early 1990’s over a gradient of effluent exposure. Those spatial trends are related with dioxin/furan loads in sediment and in Dungeness crab hepatopancreas sampled in the same area but at slightly different locations. Local oceanographic conditions and non-pulp mill pollution sources in the vicinity of the two pulp mills are considered as confounding factors in assessing pulp mill effluent. A GIS-approach, incorporating the most important oceanographic features, is a very helpful additional tool to visualise the major relationships between intertidal biodiversity and contaminant loadings.

Materials and methods

Study Areas

Skeena Cellulose Inc. pulp mill is located on Watson Island, within a channel system separating British Columbia mainland from Kaien Island, on which Prince Rupert is situated (Fig. 3). Mill effluent is discharged at a depth of approximately 18 metres in the centre of Porpoise Harbour, which is connected to Chatham Sound to the south and Wainwright Basin to the north. Shallow topography and large tidal amplitudes in the area result in significant amounts of shoreline being exposed at low tide. Tides in the Prince Rupert area are among the largest along the B.C. coast, with spring tides reaching 7.5 m in amplitude (Waldichuk, 1966). Stucchi and Orr (1993) determined that tidal forces accounted for 80% of the variance in currents observed in Prince Rupert Harbour. Strong and turbulent tidal flows cause the dilution of effluents to less than one percent of release concentrations within approximately 250 m of the diffuser to the south on an ebb tide and to the north during flood tides (Hodgings and Knoll, 1990). Effluents are widely dispersed north along Ridley Island to Digby Island on ebb tides and through Wainwright Basin and passages beyond on flood tides, although its further dissipation is physically limited in relatively sheltered Wainwright and Morse Basins. As a result, effluent likely moves slowly through the entire passage system, flushing back and forth with the tides throughout the Kaien

Island area. The Skeena River introduces large amounts of freshwater to the Kaien Island area, especially during spring and summer. There is only a small amount of freshwater runoff in the vicinity of the pulp mill, the largest single source being Wolf Creek (Waldichuk, 1962). Waters are somewhat stratified in the open waters of Chatham Sound, with lower salinity waters from the mouth of the Skeena River overlying more saline ocean waters. However, turbulent tidal flows result in a well-mixed vertical structure in the water column in areas surrounding the pulp mill (Hoos, 1975).

NorskeCanda, Powell River Division is situated at the north end of the Malaspina Strait in the Northern Strait of Georgia, between Jervis Inlet and Desolation Sound (Fig. 3). Malaspina Strait is a deep (>300m), steep sided channel separated from the Strait of Georgia by Texada Island. Prior to 1993, the mill discharged effluents from two principal outfalls: the tailrace and the deep diffuser. Since 1993, all effluent from the Powell River mill enters receiving waters via a submarine outfall, which extends approximately 800 m into strait; 35 diffuser ports along its length discharge effluent at depths of between 57.3 and 72.5 m below low water (Hatfield, 1994a). The top metre of the water column in summer normally contains a thin lens of brackish water. Below that layer and throughout the rest of the year, salinity is relatively constant both laterally and vertically, regardless of the season (Hatfield, 1994a). A thermocline develops in summer, between 25 and 45 m in depth, preventing the effluent from mixing upward and most of the effluent mixing occurs at depth. This thermocline moves with the seasons and may break down entirely in winter. Tides at Powell River are mainly diurnal, with a mean range of 3.35 m (Thomson, 1981). Flood tides move north up the strait and ebb tides flow south. Local currents in the area are driven predominantly by winds, tidal circulation, and seasonal freshwater movement into the region. The area is susceptible to relatively strong winds which blow predominantly from the southeast in winter and the northeast in summer. This results in good mixing and transport of surface waters and aids in the dispersion of mill effluents. To the north, effluent moves around Harwood Island to Savary Island (minimum dilution near 1000:1) and exits to the Strait of Georgia through Shearwater Passage. To the south, effluent disperses along Malaspina Strait (minimum dilution of approximately 2000:1 at Grief Point) to the entrance of Jervis Inlet.

Intertidal survey

Quadrat surveys were carried out at rocky-shore beach sites situated at increasing distances from the marine outfalls of the mills. 9 Prince Rupert sites were sampled in both 1992 and 1993 whereas the 7 sampling sites in the Powell River region were only assessed in 1993 (Fig. 3). The relatively remote Butze Rapids (11 km) and Fairview (14 km) for Prince Rupert and Hornby Island (38 km) for Powell River were selected as reference or low-exposure sites. The other sampling sites were labelled as moderate- or high-exposure zones, derived of oceanographic data, provided by the Department of Fisheries and Oceans (DFO), and two tracers; pulp fibres and organochlorines compounds, on the rocky intertidal shore.

During August of 1992 and 1993, sampling sites measuring 3m x 3m quadrats were established in the mid to low intertidal zone (0.5 to 1.0 m tide height) and species presence and/or abundance data were obtained during low tide with the help of volunteers from local environmental and community groups. The abundance of each species was counted using a 0.5 x 0.5 m quadrat frame, divided into a grid with strings spaced at 10 cm. The top species under each string intersection were recorded using a plump bob. In addition all the rocks in the quadrat were overturned to sum those covered species. The species cover was either put into five categories: >20 %, 6-19 %, 1-5 %, <1%, not present or simply represented as absence/presence measures.

The species were assigned to sensitivity categories (tolerant, intolerant, and sensitive) in a two-step procedure. First, effluent derived exposure categories were determined in 1990 and 1991 using the pulp mill fibres and organochlorine compounds of the effluent on the rocky intertidal shore. Those exposure categories were used to classify the indicator species; pollution “tolerant” species are those that survive in high-exposure sites; “sensitive” species first appear in the moderate-exposure sites and “intolerant” species first appear only at low-exposure sites.

Contaminant survey

Since 1989, Skeena Cellulose Inc., Prince Rupert and NorskeCanada, Powell River Division, have been required by the DFO and Environment Canada to undertake a Dioxin/Furan trend monitoring program in the vicinity of the pulp mills. Data from 1987 to 1995 for polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/F) concentrations in surficial sediment, crab hepatopancreas and oyster muscle were obtained from Environment Canada, Pacific and Yukon Region, Environmental Protection Branch.

Sediment samples were collected using a 23 cm stainless steel Ponar sediment grab for three individual replicate samples for each site. For each replicate, the top 2 cm of sediment was removed and used for chemical and particle size analysis. Sediment samples were analyzed for particle size, loss on ignition, and chlorinated phenols/guaiacols/catechols (_g/kg dry weight), and for dioxins and furans (pg/g dry weight) (Dwernychuk et al., 1992).

Sampling for male Dungeness crab (*Cancer magister*) was undertaken using standard commercial crab traps. Crustaceans are particularly useful as bio-monitors because they have limited ability to metabolize chlorinated contaminants and their PCDD and PCDF congener patterns often mirror those of the surface sediments (Yunker & Cretney, 2000). Dungeness crab is a bottom dwelling forager preferring depositional zones and it is widespread distributed throughout coastal B.C. But the mobility of these species, the inability to age crabs accurately and the considerable variation in size and appearance should be considered when using them as an indicator species for contaminant uptake monitoring.

Pacific oysters (*Crassostrea gigas*) are relatively short-lived water column feeders and appear more sensitive to changes in environmental levels of dioxins and furans, as opposed to bottom feeders which are exposed to contaminated sediment from previous discharges. Pacific oysters were collected by hand but sex was not determined in the field

Analysis of intertidal monitoring

We tested 13 variables representing species richness (total number of taxa, total taxa of animals, total taxa of algae), species sensitivity (proportion of tolerant, sensitive and intolerant species), trophic composition (number taxa of suspension feeders, surface deposit feeders, herbivores and carnivores/omnivores) and the algal composition (number taxa of chlorophyta, phaeophyta and rhodophyta). In addition to the classification of species sensitivity by Bard (1998), the taxa were divided into trophic and algal composition to determine the functional changes in communities resulting from a disturbance gradient. Species were classified into feeding guilds (suspension feeders, surface deposit feeders, herbivores or omnivores/carnivores) using literature descriptions of feeding behaviour (Kozloff, 1983; Snively, 1978). The algal composition was identified according to taxonomic division, as being Chlorophyta, Phaephyta and Rhodophyta (Integrated Taxonomy Information System database, Canadian Biodiversity Information Facility, 2004).

A total of 138 algae and invertebrates were identified in the Prince Rupert and Powell River region together, of which 16 were not identified to species or genus level and hence not incorporated in the statistical analysis.

A linear regression was performed to detect changes in intertidal biodiversity, represented by the 13 different parameters mentioned above, as the distance of the sites increases with respect to the mill. Note that in the case of Powell River, only 1993 survey results are available, complicating the comparison with results of Prince Rupert, which was surveyed in both the years 1992 and 1993. To obtain comparable regression results, the Prince Rupert analysis was repeated only for the 1993 data. Proportions were arcsine transformed to obtain the best regression fit. Statistical regressions were performed using the software Statistica © (Release 4.0, Statsoft, Inc.1993).

To describe similarities of sampling occasions (sites and years) in terms of intertidal species composition, a dataset of 129 identified species in 16 beaches surrounding B.C. kraft mills in 2 regions was subjected to multivariate analysis.

A Two Way Indicator Species Analysis (TWINSPAN) (Hill, 1979) was used to cluster the sampling occasions in terms of benthic communities. Relative abundances were converted into two pseudospecies classes: absence (0) and presence (1) prior to analysis.

A DCA (Detrended Correspondence Analysis) was applied on the species samples for the determination of the length of the gradient, which was larger than 2, assuming a unimodal respons model and a CA (Correspondence Analysis) was carried out which arranged each sampling unit in relation to one or more coordinate axes such that their relative positions to the axes and to each other provided maximum information about their ecological similarities.

An Indicator Species Analysis (INSPAN) was used to identify species' association to clustered groups of sampling occasions obtained in TWINSPAN. The statistical significance of indicator species was tested using the Monte Carlo permutation test. INSPAN is accomplished by calculating indicator values for species association to a certain group. The relative frequency and abundance of a species is combined to develop an index which is maximal (100%) when individuals of a species are found in a single group of sites and when the species occurs in all sites for that defined group (Dufrene M. and Legendre P., 1997). These multivariate analyses were all conducted using PC-ORD for Windows (version 4.0).

Comparison with contaminant data

The absence of contaminant measurements in sediment or invertebrates at the same beaches where intertidal monitoring was carried out didn't permit a correlation between intertidal community structure and the contaminant loading at the same sites. However, as sediment and Dungeness crab were collected concurrently during some years, this data set provides a unique opportunity to investigate the influence of environmental, mill-process-related effect on both the sediment and the Dungeness crab. The trend in both intertidal and contaminant data can be visually compared by ranking the sites geographically according to the distance from the mill.

Total-TEQ values, a measure of the total toxicity, were used to represent the sum of all dioxin and furan congener TEQ values for each crab and sediment sample. Those TEQS were calculated by multiplying the concentration of each congener with its respective Toxicity Equivalency Factors (TEF) value to normalize the concentration to the level that would be produced by an equivalent amount of 2,3,7,8-T4CDD (the most toxic congener). Toxicity factors used in this report follow the international standards of the 1998 World Health Organization 2,3,7,8-toxic equivalent factor for fish (Van den Bergh, 1998). To present the “below detection” concentrations of dioxins and furans for purposes of TEQ calculations, the detection limit of the congener was used.

In addition, a lipid-normalised TEQ was calculated by dividing the tissue by percent lipid. TEQ measurements in sediment were carbon normalised.

GIS

Geographic Information systems (GISs) are valuable mapping tools for use in the analysis of environmental monitoring data. The automated functions of GIS programs such as ArcView allow rapid quantification of distance, area, and other variables; and more complex operations can be executed with the ArcView extensions. To present the results of this study in an easy and interpretable way, all of the maps were made with ArcView 8.3 (Ormsby, 2001).

Digital geographic data for surface features were obtained as ArcView shapefiles from the National Topographic Database (NTDB), Natural Resources Canada (NRCan). The 1:50,000 digital map files with land and water features were projected by the NAD 1983 Zone 10N coordinates for the Powell River region and the NAD 1983 Zone 9N for the Prince Rupert region. The spreadsheets with the point data of the sampling stations can be easily imported and processed in GIS programmes such as ArcView. Therefore all the available datasets were uniformly stored in Excel spreadsheets and imported as dbf files. Each sampling station was characterized by a unique identification code including the name of the region and the sampling number. The exact location of the effluent diffuser, estimated effluent concentration zones and modelled dispersion zones, the 10 m and 100 m contour lines, the fisheries closures and the surface currents were digitized from the Pre-Design documents (Hatfield, 1994a, 1994b) and imported into ArcMap.

Results

Intertidal survey

General spatial patterns: Fig. 3 represents the geographic position of all the Prince Rupert and Powell River sampling sites with their related species richness, species sensitivity, trophic composition and algal composition according to the Bard survey (1992-1993). Although effluent did not concentrate in waters in the immediate vicinity of the Skeena Cellulose Inc. pulp mill diffuser at any time, the maximum potential extent of effluent of 1% or greater concentration has been defined conservatively as a circle of 500 m radius from the diffuser. The near-field exposure sites are continually exposed to effluent, which flushes back and forth on the tides. The expected far-field dispersion of effluent corresponds to the maximum measurable extent of effluent dispersion as suggested by the dye study (Hodgins & Knoll, 1990) and by dioxin and furan monitoring data. Effluent dispersion patterns in the Powell River area as modeled by Hodgins and Stronach (1991) show the dilution contours for different concentrations. Their model “GF8” demonstrated that effluent may be carried in either direction, depending on the direction of wind-induced currents at the effluent trapping depth. In the model effluent was found to dissipate further and to dilute more quickly to the southeast of the mill than to the north. PISCES IV dives in 1987 confirmed the presence of fibre accumulations near the Powell River mill (Colodey, 1987). The fibre mat was estimated to be 10 to 30 cm thick and covered with patches of white bacterial slime. Fig. 3 shows the fibre bed area as extending 1 km west and approximately 0.6 km east of the outfall, reaching a maximum of 1.1 km.

Fig. 3: Summary of the intertidal survey results and the major geographic conditions in the Prince Rupert region and the Powell River Region.

Table 1: Regression analysis of the effect of distance from the mill on 13 variables representing species richness, species composition and trophic composition for each site in 1993 and for the pooled 1992 and 1993 samples for the Prince Rupert region.

	Prince Rupert 92-93			Prince Rupert 93			Powell River 93		
Dependent Variable	**R?**	**F(1,11)**	**p**	**R?**	**F(1,5)**	**p**	**R?**	**F(1,5)**	**p**
total species	0.88	91.31	**< 0.0001**	0.93	63.32	**0.0005**	0.79	19.35	**0.0070**
total animals	0.90	99.45	**< 0.0001**	0.87	32.46	**0.0023**	0.92	31.75	**0.0025**
total algae	0.64	19.35	**0.0011**	0.62	8.18	**0.0354**	0.53	5.57	0.0646
proportion tolerant species	0.58	15.07	**0.0026**	0.4	3.31	0.1283	0.12	0.65	0.4556
proportion sensitive species	0.07	0.77	0.3998	0.1	2.02	0.5031	0.24	1.58	0.2625
proportion intolerant species	0.79	40.21	**< 0.0001**	0.57	6.62	**0.0499**	0.41	3.54	0.1185
proportion chlorophyta	0.32	5.34	**0.0412**	0.25	1.64	0.2566	0.10	0.55	0.4901
proportion phaophyta	0.01	0.10	0.7610	0.06	0.33	0.5882	0.01	0.01	0.9214
proportion rhodophyta	0.09	1.11	0.3143	0.05	0.27	0.6285	0.06	0.31	0.5989
proportion suspension feeders	0.02	0.23	0.6382	0.18	1.07	0.3471	0.33	2.45	0.1785
proportion deposit feeders	0.58	15.39	**0.0024**	0.5	5.1	0.0736	0.01	0.02	0.8937
proportion herbivores	0.10	1.21	0.2948	0.02	0.1	0.7688	0.11	0.63	0.4632
proportion carnivores/omnivores	0.26	3.84	0.0757	0.22	1.44	0.2835	0.49	4.85	0.0789

The total number of taxa, animals and algae per site is represented by respectively the size of the tart pie, the feeding guild bar and the algal composition bar. A total of 71 species in 7 sampling sites in 1992 and 75 species in 6 sampling sites in 1993 were found in the Prince Rupert region while 99 species in 7 sampling occasions were found in the Powell River region. Annelids, molluscs, arthropods, and rhodophytes represented 60-70% of the observed taxa. The taxa which were present over all sites in both areas are acorn barnacles (*Balanus sp.*), shore crabs (*Hemigrapsus sp.*) and sea lettuce (*Ulva sp.*).

Table 1 summarises the regression results for the effect of distance from the mill on 13 variables, reflecting intertidal community structure. The total number of species and animals increased significantly as distance from the mill increased, for both the Prince Rupert and Powell River regions. There was also a significant increase in the total number of algae and the proportion of intolerant species as the distance from the mill increased for the Prince Rupert sites but the significance was on the cusp for all Prince Rupert sites. A spatial trend in the proportion of tolerant species, chlorophyta and deposit feeders was observed for the Prince Rupert sites although this trend is not visible for the Powell River sites, neither for the 1993 sampled sites in Prince Rupert. The linear regression proved no significant spatial trend in the proportion of sensitive species, phaeophyta, rhodophyta, suspension feeders, herbivores and carnivores/omnivores for neither region.

Based on the TWINSPAN ordination, 6 clusters of sampling events were distinguished together with the indicator species responsible for the cluster divisions (Fig. 4a). The grouping of sampling sites and years separated primarily the beaches surrounding the 2 different pulp mills. Also the reference sites were not clustered together but as a part of the distinct geographic areas. The porcelain crab (*Petrolisthes eriomerus)* is the indicator species for the Powell River region. It occurs at all the Powell River sites but never at the Prince Rupert sites. Where loose rocks rest tightly on an accumulation of sand or rather fine gravel, there will probably be porcelain crabs (Kozloff, 1983).

Prince Rupert: The TWINSPAN in the Prince Rupert area separates first Grain Ridley and the two reference sites (Butze and Fairview), independent from the year in which sampling occurred, from the resulting sites. The low exposure control sites at Butze and Fairview hosted an average of 45 and 49 species respectively. Large kelp beds, sponges, nudibranchs, green sea urchins, six-rayed stars, solitary tunicates and a large variety of annelids were noted among other species. The cockscomb blenny (Anoplarchus purpurescens), commonly found under rocks (Kozloff, 1983), is the TWINSPAN indicator species for these respectively low and intermediate exposure sites. While this species was present in both survey years in Butze and Fairview, it only appeared in 1992 in Grain Ridley. Grain Ridley exhibited 32 species of which 15 were algae.

As the next division clearly separates the sites sampled in different years, community structure of both sites seems to change concurrently in time. The bent nose clam *Macoma nasuta*, was present in 1992 but not found in 1993.

The resulting Prince Rupert sites beaches were classified together, except for Ridley Trail in both survey years because of the presence of the six-rayed sea star *Lepasterias hexactis* at both sampling years in Ridley Trail. This site, 5 km from the outfall, hosted 29 species of which 11 were algae. Large and dense beds of kelp were found along the shore, as well as large populations of pill bugs (Gnorimosphaeroma oregonensis), rockweed isopods (Idotea Wosnesenskii) and amphipods. Pill bugs are most likely to be found living under mussels, among barnacles, or in cavities in wood. Large populations of it are usually an indication that salinity is at least a little below that of full-strength sea water (Kozloff 1983).

The 5 sites located in between 5 kilometres from the mill showed closely associated species communities. The sites Across Mill, Lighthouse and Wolf Creek were highly depleted, showing respectively a mean of only 7, 11 and 10 species. Those sites had high accumulations of pulp fibers and were contaminated with organochlorines (Bard, 1998), thus ranked as having high exposure to pulp mill effluent. The sites Wainwright Basin and Inverness were tested positive for organochlorines but did not have washed-up pulp chips, as such ranked as mediate-exposure sites. A total of respectively 21 and 23 species were found at those sites with a higher proportion of algae (9 species) in Wainwright Basin than in Inverness (6 species). Practices of log handling and log storage in the vicinity of Inverness was physically present as washed up wood and fibres at the Inverness beach site.

As only one site (Wainwright Basin) was separated at the next TWINSPAN division, the clustering was discontinued at this stage because an INSPAN cannot be performed for only one group.

Powell River: The first grouping of the Powell River sites is found between the majority of sites close to the mill and the reference site (Hornby Island). The exception is Texada Highway, which is closer ranked to the reference site than to the other Powell River sites. Brown Bryozoa (*Eurystomella sp.*) is the indicator species of these more remote areas and it is never present at sites closer located near the mill.

No Powell River sites were evaluated to be high-exposure sites according to oceanographic data from DFO and wood chips and organochlorine tracers on the beaches. As such, the sites surrounding the Powell River mill on both sides and on nearby Texada Island had no gross species depletions. No fibrous mass was observed at any of the sites which may explain why no populations of pill bugs or Isopods were noted. The Texada Ferry site directly across the water from the mill hosted the lowest diversity at 22 species. This site along with Westview and Site A were

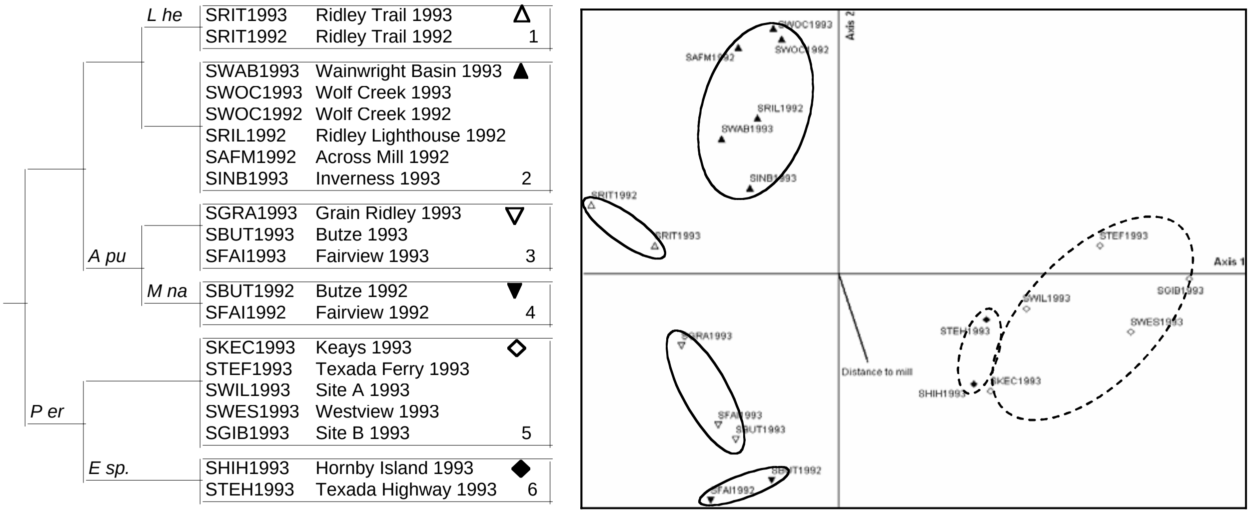


Fig. 4: **a.** Ordination of 128 species in 28 sampling sites according to TWINSPAN, resulting in 6 sample clusters. The indicator species *P er = Petrolisthes eriomerus, A pu = Anoplarchus purpurescens E sp. = Eurystomella sp, L he = Lepasterias hexactis, M na = Macoma nasuta*.**b.** CA ordination plot along the first two axes. The discrimination between the 6 sampling groups is based on TWINSPAN. Position of the sampling groups is indicated by the ellipses (full lines represent Prince Rupert sites, dotted lines represent Powell River sites). Sampling sites are presented as 8 letter codes with the first 4 letters referring to the site name and the last 4 letters to the sampling year. Full names are displayed in Fig. 4 a.

moderate exposed to mill effluent. Westview and Site B hosted 30 species each, however the resident species of Site B had a higher proportion of intolerant species and the proportion of animals on the total species number was also larger at this site than at Westview.

The control site in Hornby Island, located at 40 kilometres from the pulp mill, had a total number of 90 species and 29 algae were observed of which red algae predominated. Hornby hosted a community almost exclusively composed of intolerant species with a small proportion of sensitive species. Brittle sea stars (*Ophiopholis aculeata*), leather stars (*Dermasterias imbricate*), ringed nudibranchs (*Diaulula sandiegensis*), lined and mossy chitons (*Tonicella lineate* and *Mopalia sp.*), anemones (*Tealia sp.*) and 4 intertidal fish species were noted (*Gobiesox maeondricus, Oligocottus maculosus, Anoplarchus purpurescens and Xiphister mucosus).*

Correspondence Analysis: The correspondence analysis (CA) shows pronounced differences in the intertidal invertebrate composition between Prince Rupert and Powell River (Fig. 4b), conform the TWINSPAN results. The CA reveals a partial separation of the two areas along the first CA axis (Eigenvalue: 0.342). The second axis (Eigenvalue: 0.240) separates the Powell River communities but this grouping along the second axis is less pronounced for the Prince Rupert region. Based on their position in the CA plots, the communities among the replicate beaches between two years show a high degree of biological similarity. Neither axis one or two was correlated with the distance from the mill or the survey year (correlation factor is respectively 0.313 and -0.566). Overall, the CA indicates that for the similarity of the intertidal communities, the difference between both areas is far more important than the distance to the pulp mill. In Prince Rupert, the groups of communities are more diversified than in Powell River, as indicated by the larger area on the graph. The species associated with the grouped clusters identified using TWINSPAN are found using INSPAN.

Cluster	Sensitivity Bard	Scientific Name	Taxonomy	Indval	Mean	St.dev.	p
1	T*	*Gnorimosphaeroma oregonensis*	Isopoda, Crustacea	50	26.8	13.08	0.027
3	S	*Paranemertes peregrina*	Nemerta	66.7	29.6	12.58	0.026
3	S	*Lophopanopeus bellus*	Decapoda, Crustacea	66.7	29.6	12.58	0.026
3	I	*Crepidula lingulata*	Gactropoda, Mollusca	66.7	29.6	12.58	0.026
3	T	*Littorina sp.*	Gastropoda, Mollusca	38.5	27.6	7.68	0.042
4	I	*Hemipodus borealis*	Errantia, Polychaeta	100	30	13.57	0.015
4	I	*Tealia crassicornis*	Anthozoa, Cnidaria	100	30	13.57	0.015
4	I	*Macoma nasuta*	Bivalvia. Mollusca	100	30	13.57	0.015
4	I	*Katharina tunicata*	Polyplacophora, Mollusca	75	28	13.4	0.033
6	T	*Enteromorpha sp.*	Chlorophyta	35.3	26.4	3.96	0.007
6	I	*Gigartina sp.*	Rhodophyta	100	30.1	13.96	0.02
6	I	*Ceramium sp.*	Rhodophyta	100	30.1	13.96	0.02
6	I	*Corallina vancouverienns*	Rhodophyta	100	30.1	13.96	0.02
6	I	*Petrolisthes eriomerus*	Decapoda, Crustacea	50	26.3	13.12	0.029
6	I	*Alia carinata*	Gastropoda, Mollusca	83.3	28.7	14.4	0.03
6	S	*Leathesia difformis*	Phaeophyta	55.6	26	14.22	0.038
6	S	*Sargassum muticum*	Phaeophyta	83.3	28.1	14.28	0.037

Table 2: Indicator species and their indicator values for the hierarchical classification (cluster 1-6) of benthic communities at different sampling occasions.

INSPAN: Indicator species were identified with the Monte Carlo permutation test for clusters 1, 3, 4 and 6 of the hierarchical classification of the sampling sites. Species obtaining their highest indicator values were identified for sampling clusters 4 and 6. Those species have a narrower ecological niche as their indicator value increases as groups are more finely divided. Table 2 summarizes the indicator species with their indicator value and the correspondence of the sensitivity categories according to Bard (1998).

No indicator species were found in cluster 2 and 5 and only one indicator species is known for cluster 1, indicating that the majority of species occurring at those clustered sites also occur farther away from the mill. In contrast, several species were identified as associated or restricted to cluster 3, 4 and 6 and most of these species were considered to be mill pollution sensitive or intolerant (Bard, 1998). The large number of indicator species in the fairly remote sites supports the conclusion that these existing benthic communities are more diverse than those communities at sites closer to the mill.

Contaminant survey

In contrast with the simultaneous crab and sediment sampling, no direct comparison with the intertidal survey is possible. Ranking the sampling sites in accordance to the closest distance to the mill outfall however, gives the opportunity to visually observe trends (Fig. 5).

Prince Rupert

Fig. 5 shows the decreasing species number as the distance to the mill increases, both southwards in the direction of Chatham Sound and northwards towards Prince Rupert Harbour. However, the decreasing TEQ as the distance to the mill increases is not as clear because of the lack of sampling sites at equal distances along the spatial gradient, leaving the uncertainty about a possible mill-effect or other confounding factors.

Few data available for sediment TEQ suggest that the highest value occurs at SK-SS3, in the immediate vicinity of the mill's outfall in Porpoise Harbour followed by site SK-SS1 in Morse Basin. The more remote sites, SK-SS13 and SK-SS14, exhibit very low sediment TEQ. Sediments were fractionated by size into four categories: clay (< 4 _m), silt (0.063 mm - 4 _m), sand (2 mm - 0.063 mm), and gravel (> 2 mm). Organochlorine compounds may preferentially adsorb onto clay and silt fractions of sediment. Consequently, sediments exposed to similar levels of effluent, but with different particle size distribution profiles, may adsorb differing amounts of organochlorines. The proportional sediment particles for the 4 sampling sites show higher fractions of gravel in Wainwright and Morse basin, possibly as a

Fig. 5: Summary of the comparison between intertidal diversity, expressed as the number of species and contaminant loading in sediment, crab and oyster, resulting in the crab and oyster closures.

result of the sedimentation of the Skeena River and Wolf Creek in those locations with restricted circulation.

The crab samples however are abundant along the spatial gradient for 1992, displaying a three-fold TEQ at SK-SC3, compared to the sediment TEQ at the outfalls position. Even a higher crab TEQ value occurs in Wainwright Basin but no comparison can be made with the sediment TEQ at this location. Two sites in Morse Basin, SK-SC1 and SK-SC7, display about a three-fold value as compared to the sediment TEQ in the middle of Morse Basin. Lowest northward sediment TEQ is measured closest to Porpoise Harbour at SK-SC1A and SK-SS14. The crab TEQ near Ridley Trail; SKSC5 and Grain Ridley; SKSC8 exhibit very low values whereas crab TEQ is higher more to the north at SK-SS13. Those elevated TEQ values explain the fisheries closures showed in Fig. 5.

Powell River

The linear gradient along the Powell River coast clearly shows the declining species number as the distance from the mill increases. The only exception is Texada Ferry but the location at Texada Island at the prolongation of the pipeline can influence this number. Hornby Island is not included because of the remote location and no TEQ values were available close by.

Sediment TEQ values for 1992 are only available at three sites in between 8.8 km northwards of the mill. The most remote site exhibits the lowest TEQ, whereas the site at 2.7 km displays the highest value, not much more than the site close to the mill's outfall.

The TEQ values for crab are highly variable, exhibiting the highest TEQ at the immediate vicinity of the mill, declining towards the northwest (PR-C2) and southeast (PR-C5). Farther northwest, TEQ increases again at PR-C1 and displays the PR-C5 but exhibit a higher value at the most remote site PR-C14.

lowest value at PR-C15; km away from the mill. Farther southeast, TEQ decreases at

In contrast, the oysters along the spatial gradient seem to show a decreasing TEQ value as they are sampled farther away from the mill with lower values at the southeast compared to the northwest.

For both mills, the TEQ for Dungeness crab hepatopancreas and sediment has declined from 1990 to 1996 (Fig. 6) at the sites nearest the marine outfall. Prince Rupert had the highest TEQ in the earliest years of sampling but generally has shown the largest decrease over time in both sediment and crab TEQ. The sediment TEQ for both mills has similar values since 1993. No crab was collected close to the marine outfall of Prince Rupert in 1994. The crab TEQ values from 1995 and 1996 however are comparable. Those annual TEQ reductions explain the effectiveness of mill process changes in reducing the environmental impact of pulp and paper mill operations.

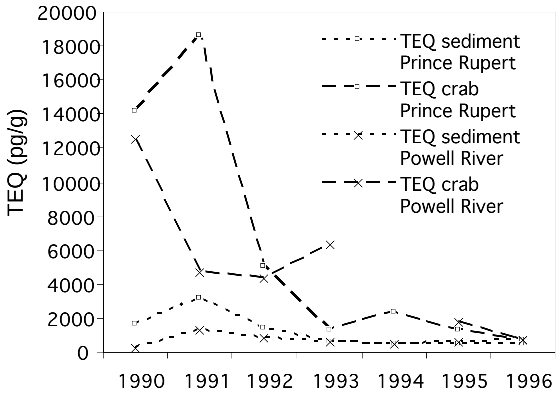


Fig. 6: Year-to-year changes in TEQ for sediment and Dungeness crab hepatopancreas (pg/g) at representative locations close to the pulp mills Prince Rupert and Powell River.

Discussion

Prince Rupert

The depleted communities at beaches nearest the mill support earlier reports (Drinnan 1977; Wilkes & Dwernychuk, 1991) that document the evidence of changes in the community structure of benthic macroinvertebrates adjacent to the Skeena Cellulose Inc. pulp mill.

Wolf Creek showed a lower biodiversity as compared to Lighthouse that is closer located to the mill outfall. Due to the low tidal flushing at the Wolf Creek site a large volume of organochlorine compounds and pulp fibres remained on the beach that smothered other organisms (Bard, 1998). Important to notice is the historic contamination in Wainwright Basin which can also attribute to these findings. Studies in Wainwright Basin in 1976 to 1977 when the sulphite mill was discharging showed that the basin became anoxic during the summer period (Hoos, 1975). This was accompanied by frequent fish kills and other problems such as the loss of intertidal macroalgae. A severe dissolved oxygen deficit in Porpoise Harbour has not been recorded since the current mill discharge was redirected to this location (Wilkes & Dwernychuk, 1991). Sediments at Wolf Creek continue to exhibit a high degree of contamination from the old sulphite process, as shown by the crab TEQ value which is higher at Wolf Creek than near the mill‘s outfall. By comparison, the area also exhibits the lowest count of subtidal benthic macroinvertebrates found in the 1991 study of Wilkes and Dwernychuk (1991). Moreover, Capitella Capitata which has been used as an indicator of organic enrichment due to pulp mill discharges was also found in large numbers in Porpoise Harbor sediments in 1983 (Hatfield, 1994b). A final confounding factor biasing the intertidal diversity at the Wolf Creek site is the influence of the Wolf Creek freshwater source. Surface waters near the mill clearly exhibited lower Total Suspended Solids (TSS) and salinity while bottom waters tended to be more saline (Hatfield, 1994b). Very low surface salinities and sediment deposits can greatly influence intertidal biota (Chapman and Wang, 2001), confounding the assessment of the mills' impact.

Although Wainwright Basin was ranked as moderate exposure sites, the previously mentioned factors of lower tidal action and historic contamination also explain why this site was clustered together with the high exposure sites.

Inverness and Ridley Trail are located at nearly equal distances from the mill outfall, however, the first site exhibit a lower biodiversity as indicated by the TWINSPAN clustering. This site in Inverness passage is located near the mouth of the Skeena River and surface salinities are seasonally influenced by freshwater inflow. Data from Wilkes & Dwernychuk (1991) suggest that sediments from the Skeena River have a larger role to play in turbidities within the Porpoise Harbour than may be attributed to pulp mill effluent. However the percentage of volatile to non-volatile components in the turbidity plume was not examined, therefore, the relative contribution from the pulp mill is not known. Logging, log handling and log storage in the vicinity of Inverness certainly have a deleterious effect on intertidal communities as a result of washed up wood and fibers (Hoos, 1975) at the Inverness beach. Leachates from wood and bark can impair water quality, resulting in benthic deterioration and affecting the spawning grounds of species living in intertidal waters and estuaries (Waldichuk, 1983). However, there is a trend to dry-land sorting and reduced inventories of logs at tidewater. Therefore, long term monitoring can reveal the impact of log-booming on marine life.

Ridley Trail, also determined as a moderately exposed site like Inverness and Wainwright Basin, was clustered separately and not with other sites with the same degree of exposure. High abundances of pill bugs (Gnorimosphaeroma oregonensis) living under mussels and among barnacles indicated that a large volume of effluent that contained pulp fibres reach this beach. However, the effluent is of relatively low toxicity, as indicated by the presence of effluent sensitive and intolerant kelp species and the low TEQ values in Dungeness crab hepatopancreas.

A very promising result is the temporal variation in benthic community structure among the remote Ridley Island, Butze and Fairview sites. The TWINSPAN analysis has identified a shift between the 1992 and 1993 sample years for the reference sites, as shown in the CA. This temporal variation in benthic community structure will be the subject of ongoing work because no definite conclusions can be derived from only two years. It appeared that more years should have been sampled to distinguish natural variability from a consistent temporal correlation trend. We expect more variability between the same sites sampled after 10 years as this variability may be an indication of a more significant change or shift occurring in the biological community as a response of the changes in mill effluent toxicity.

Powell River

Dye studies, modelling of physical oceanographic systems, and water quality data collected since the early 1970's all indicate that the area of effluent concentration approximating the extent of 1% is limited to the area immediately surrounding the diffuser (Hatfield, 1994b). The main environmental impact identified at Powell River previous to 1980 was to the near-shore benthic environment (Dwernychuk, 1992). High fibre (TSS) loadings, before the installation of the clarifier and deepwater diffuser, had degraded near-shore benthic sediment quality to the extent that sediment had become reducing, with a concurrent depression of benthic invertebrates, commonly seen in organically-polluted marine sediments (Hatfield, 1994a). PISCES IV dives in 1987 confirmed the presence of fibre accumulations near the Powell River mill (Colodey, 1987). The dynamics of the fibre mat with respect to the large decrease in TSS discharges since 1992 and the elimination of surface runoff via the tailrace will be changed in 2004 but wood chip barge activity still contributes to chip deposition in the receiving environment (Hatfield, 2004).

The intertidal study by Bard (1998) supports those historic monitoring results. No Powell River sites were evaluated to be high-exposure sites according to oceanographic data from DFO and wood chips and organochlorine tracers on the beaches. Our findings that Site A, Site B, Texada Ferry and Keays are all clustered together, suggesting a similar intertidal benthic diversity, support those conclusions. TEQ in oyster is highest at two stations at the northwest of the mill. This corresponds with the predominant pathway of concentrated effluent concentration in the northwest (Hatfield, 1994b). The oyster TEQ decreases further along the gradient of exposure, concluding that oysters are good indicators for shoreline effluent contact, but less useful for examining submarine effluent dispersion patterns. Since bleach plant modernization in 1991, resulting in the elimination of dioxins and furans in the final effluent, the decline in oyster TEQ was approximately 93% (Hagen et al. 1997).

It should be noted that the Malaspina dumpsite indicated on Fig. 5 received 100,000 m^3 of dredge material from the vicinity of the mill log ponds, wharves, and diffuser area (1977-1979: EP, Ocean Dumping Files). Much of this dredged material was wood debris and consequently sediments and high organic carbon values. Its main effect is the alteration of bottom characteristics in the dumping area. This may affect spawning grounds for such species as Pacific cod

(*Gadus macrocephalus*) and lingcod (*Ophiodon elongates*) (Waldichuk, 1983). Certain substances leached from the dumped material may be toxic to or be bioaccumulated by bottom organisms. As such, the high crab TEQ near the mill may possibly overestimate the current effluent toxicity by rather reflecting historic deposition. Moreover, spatial distribution of Dungeness crab with organochlorine concentrations may be affected by biological factors such as migration, food availability, and feeding patterns (Yunker & Cretney, 2000), or by physical processes such as sedimentation regimes (McLaren et al. 1993).

Future monitoring of Dungeness Crab TEQ in the Powell River region would be very useful to monitor sediment recovery, but not really to assess the impact of the effluent itself, given the decline in dioxin and furan loading after implementation of secondary treatment in the early 1990's.

Algal composition

Green algae (Chlorophyta) are found to be good indicators of exposure to mill effluent because of their hardiness to pulp mill effluent. In the Prince Rupert area, mats of green algae (Enteromorpha sp.) smothered the beaches close by the mill outlet; the supply of freshwater at Inverness and Wolf Creek may have stimulated greater growth. A larger dataset collected over several years would permit to assess this trend in the Powell River area.

Drinnan (1977) suggested that red algae (Rhodophyta) are the most sensitive to bleached kraft pulp mill effluent; confirm our finding of three red algal indicator species for TWINSPAN cluster 6 with an indicator value 100. Red algae represented more than 50 % of the algal composition in the more remote sampling sites. However, the relative proportion of red and brown algae didn't differ significantly along the spatial gradient. This is not surprising given the relatively few sampling sites, the absence of repetitions and the confounding factors mentioned above which explain why a linear regression is not the best tool in assessing the mill effluent impact.

Using model ecosystems in land-based pools, Rosemarin et al. (1994) discovered the high sensitivity of brown algae (Phaeophyta) to chlorate, one of the substances often found in the effluents emanating from pulp mills due to the use of chlorine dioxide in the bleaching process. The effects on apical growth are the first signs of toxicity, followed by discoloration in the form of red loci, which increase in number and size with higher chlorate concentrations. The use of Phaeophyta is very interesting to explain discoloration and the lack of flotation bladders as a response to chlorate spills. As such, future surveys should document and quantify these morphological characteristics.

Trophic composition

Feeding guilds are groups of species that exhibit similar feeding strategies and thus contribute to trophic energy transfer in the same manner (Weisberg et al, 1997). Guilds are popular tools to describe ecosystem structure because their composition implies much about ecosystem functioning (e.g. primary productivity, biomass turnover, respiration). Distribution among feeding guilds is expected to become more diverse as pollution impact decreases (Word, 1978). There appears to be no standard classification scheme for classifying benthos into feeding guilds. The 4 groups assigned here could have been broken down into further more specialized subgroups via further discrimination between sources of food, size of food particles and the means of obtaining food (Rosenberg, 2001). Division into more specialized feeding subgroups would be only recommended if a larger dataset was available. Suspension feeders and Carnivores/Omnivores were generally the most abundant taxa (Fig.3). Deposit feeders were highly abundant on isolated patches with abundant sources of organic material such as at sites close to the mill where fiber accumulation is present. Not only fibers but also aggregates of organic matter and bacteria may be more abundant on beaches close by the mill as those biosolids are the result of the operation of the secondary treatment (Hatfield, 1994b). A larger dataset collected over several years is recommended to give definite results about spatial patterns of the other feeding guilds and to better avoid natural variation.

Comparison of geographic conditions

Supported by the first TWINSPAN division and the CA plot, the similarity of species communities is primarily geographically determined and not a result of exposure to pulp mill effluent. This is not surprising knowing that the two sites are 650 km apart from each other. The surface water temperature in Powell River ranges from a high of 7°C in winter to near 18°C in late summer (Hatfield, 1994a). Salinity is relatively constant (approximately 27 ppt at the surface) both laterally and vertically (Thompson, 1981). The summer surface water temperature in Prince Rupert harbour ranges around 10°C (Stucchi and Orr, 1992) and surface salinities in the Prince Rupert area usually vary between 26 and 28 ppt (Hatfield, 1994b).

Whereas the Powell River area seems to exhibit a higher biodiversity at the sites nearest the mill, very few species are found nearest the outfall of the Prince Rupert mill. However, some geographic and historic differences must be considered.

First, the sampling sites in Prince Rupert are between 2 and 13 km from the mill in comparison with the Powell River sites that are 5 to 38 km away from the mill. This is likely to explain the difference in species richness. As a recommendation, more sites in between 5 km from the mill's outfall should be sampled in the 2004 survey. Moreover, the reference site on Hornby Island is at a distance of 38 kilometers to the mill in contrast to Butze and Fairview which are 11 and 14 kilometers remote. As Texada Highway falls outside the borders of the modeled 1:10000 effluent dilution (Hodgins and Stronach, 1991) and known that the Correspondence analysis revealed very close community structure of the Horny Island and Texada Highway beaches, this latter site could be used as a reference site. However, the monitoring of Hornby Island should be continued as well to quantify the natural spatial variability of beach communities.

Second, both areas undergo considerable tidal flushing but the difference in geographic conditions results in more effective effluent dispersion in the Powell River region. The diffuser outflow of Skeena Cellulose Inc. is at 18 m depth and disperses the mill effluent throughout the water surface of the area. As a result, the relatively shallow basins surrounding Watson Island are continually exposed to mill effluent. In contrast, the Powell River's submarine outfall ends in the deep (> 300m), steep-sided Malaspina Strait where a large dilution volume results in well mixed waters. Moreover, the diffuser at 57-73 m depth is below the plume trapping depth at 35 meters (Gillie & Daniel, 1981) which aids in a better dispersion of mill effluent and decreases the chance of contact with the intertidal habitat.

Finally, the deep diffuser of the Powell River was already installed in 1980 for the kraft mill effluent (32 % of the mill discharge) while the instalment of a multi-port submarine diffuser in Prince Rupert only occurred since mid-1993 (Hatfield, 1994a, 1994b). As a result, the submarine diffuser of the Powell River mill has improved the quality of the surface water layers and has reduced foam on beaches and discoloured waters much earlier.

We can conclude that site specific monitoring is crucial; whereas intertidal monitoring is more appropriate in the Prince Rupert area due to the shallow water depths and more chance that mill effluent influences intertidal biodiversity, subtidal monitoring is more appropriate for well flushed areas with historically contaminated sites. Originally, data from subtidal benthic communities were planned to present on the GIS maps to compare intertidal and subtidal diversity. However as no surveys were carried out at the same period of the Bard survey, no comparison could be made.

Future challenges

Historically, prior to secondary treatment, deposits of fibres and effluent solids accumulated near pulp mill diffusers and became incorporated in sediments. These compounds are long lasting and are currently being measured in sediments, although effluents no longer contribute to TSS or AOX accumulations (Hatfield, 2000). Just as dispersion distance depends on site specific variables, recovery of contaminated sediments will also be related to local sedimentation, erosion rates and bioturbation (Chapman & Wang, 2001). In quiescent areas, burial makes particulate associated PCDD/Fs less available to biota. In contrast, Powell River is well flushed by tidal currents so historic effects are most likely observed in Powell 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 (Hagen et al. 1997). 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 BC coastal fjord site (Hagen et al. 1997).

Prince Rupert, located in a channel, is a site where crab hepatopancreas had high dioxin and furan TEQs in 1989/1990 but the levels have been dropped dramatically at this site (Fig. 6). Powell River, on relatively exposed coasts had low TEQs in 1990 and the declines were not as dramatic. Reasons for the contrast between fjords or channels and the more exposed coasts are parallel those expressed for sediment. Reason for rapid decline in dioxin and furan levels in crab 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 (Yunker et al. 2002).

Before marine-discharging mills implemented secondary treatment in the early 1990‘s, it was possible to measure a variety of effluent-specific compounds in sea water and in marine sediments, particularly chlorinated phenolic compounds (chlorophenols, -catechols, and -guaiacols). Currently, finding effective indicators of effluent exposure in the marine environment is problematic (Martin Davies, Hatfield Consultants Ltd., pers. comm. 2004). Ranking sampling sites according to the distance to the mill and integrating results of dye dispersion studies will be the most objective measurement for intertidal exposure to mill effluent for these specific regions.

The intertidal survey in 2004 in the Prince Rupert area will be very interesting given the fact that SkeenaCellulose Inc. has been shut down since 2001. Because no baseline data is available from just before paper production was discontinued, interpretation of the data will be challenging as historic findings should be integrated with temporal variation of beach communities derived from other paper mill areas. However if monitoring will be continued during consequent years, the adequacy of the improved mill processes can be assessed on the intertidal communities.

Conclusions

The marine mills along the B.C. coast are longstanding, and no baseline data were collected before these mills began operation. Given that fully comparable reference sites do not exist and effluent dispersion is multi-directional, separating any possible impacts of pulp mill effluent on benthic communities from natural variability is difficult. However, the same spatial trends at different mills are noted; a decline of intertidal biodiversity at the proximity of the mills outlet and a higher level of contaminant loadings in both crab and oyster samples. This points to pulp mill pollution as a major factor explaining those trends but effects of historic contamination sources and physical disturbances cannot be ruled out.

This study has discovered that in some regions cumulative contamination, expressed as TEQ, may exert a large and long-lasting effect on intertidal diversity and community structure even when current pollution has decreased. Hot spots of contaminated sediments and crab around the areas of the more confine basins such as Wainwright Basin are a good example. The effect of those historic contamination sources may last for decades as was demonstrated by comparing the results of this study to that of historical surveys.

Feeding guilds would be very useful tools to help monitoring benthic biodiversity. Large shifts in these guilds from their normally “robust” compositions would almost certainly reflect shifts in the functioning of a given area, which was an additional objective. Deposit feeders were highly abundant on isolated patches close to the mill with abundant sources of organic material. Green algae deemed tolerant to pulp mill effluent whereas red algae were the most sensitive to bleached kraft pulp mill effluent.

This study suggests that environmental impact is not always proportional to the volume of pulp and paper production and waste loading (Fig. 1). Some large production mills with high effluent loadings like NorskeCanada Powell River Division, are located in areas with high assimilative capacity and cause less observable environmental degradation compared to other smaller production mills like Skeena Cellulose Inc. in Prince Rupert (Fig.1) that cause extensive habitat deterioration in more confined basins that are poorly flushed by tidal action. No such constrictions appear to affect waters in the immediate vicinity of the Powell River mill. There is a strong need for long-term monitoring to complete the accurate assessment or potential sublethal and ecosystem effects, and to understand the bioaccumulation dynamics of effluents on a site-specific basis.

Whereas intertidal monitoring is very meaningful in the Prince Rupert area due to the shallow water depths and more chance that mill effluent influences intertidal biodiversity, subtidal monitoring may be more appropriate for the Power River area where the effluent is trapped at about 35 meters. However, long-term intertidal survey is crucial to understand the bioaccumulation dynamics of effluents on a site-specific basis.

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