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SEAFLOOR AND SEDIMENT CHARACTERISTICS OF PULP MILL WASTE DISCHARGES IN THE 20TH CENTURY: FRAMEWORK DATA FOR BOAT HARBOUR, NOVA SCOTIA, REMEDIATION PROJECTS AND FOR BASELINE SURVEYS OF NEW PULP WASTE OUTFALL INSTALLATIONS IN NORTHUMBERLAND STRAIT

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ABSTRACT

During the 20th century, contamination of marine environments by Canadian pulp and paper mill effluent (PPE) resulted in the imposition of federal government regulations in 1971 that were revised and strengthened in 1992. This report reviews seafloor sediment features for three marine settings (intertidal, subtidal and prodelta) arising from 20th century PPE discharges from four pulp and paper mills, one located near New Richmond, Quebec, and three situated along the lower reaches of the Saguenay River, Quebec. The four mills began operations between 1965 and the early 1900's. Observations of their proximal and distal sediment and Foraminifera characteristics in relation to PPE discharge outfalls offer guidance for the remediation of potentially toxic, multi-decadal waste accumulations in several lagoons of Boat Harbour, Nova Scotia. Seafloor environmental data discussed for a fifth mill's subtidal outfall, located on the eastern shore of Canso Strait, may be particularly germane for selecting the site and baseline environmental survey criteria for a new PPE submarine outfall that has been proposed (presently rejected) by Northern Pulp Company for the Caribou Harbour area of the Northumberland Strait coast, in the event that the currently closed mill is permitted to be reactivated in the future.

Keywords: effluent, environmental effects, organic matter, pulp mill waste, sediments

INTRODUCTION

The latter part of the 20th century witnessed the introduction by Canada of federal government environmental regulations regarding acceptable physical and chemical characteristics of Pulp and Paper Mill Effluent (PPE) and saw mill discharges into riverine, estuarine and open marine environments. The first of these regulations

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appeared in the early 1970's and were subsequaently revised and strengthened in the early 1990's (Environment Canada 2012, Open Canada 2020). Physical characteristics of pulp and paper mill effluents deposited prior to 1971 ranged from small visible wood chips to fine fibrous wood-derived particles mixed with fine sediment-laden liquids containing metallic and chemical contaminants (e.g., Pelletier and Canuel 1988, Smith and Loring 1981). The solids, in these fibrous organic matter-enriched (OM) deposits, were often subject to resuspension and transport from their point of origin to adjacent subaqueous or intertidal environments by river, tidal and/or wind-driven currents. Revision of former Environment Canada and climate change Pulp and Paper Mill Regulations (PPERs) in 1992 included assessment of PPE biochemical oxygen demand (BOD), total suspended solids concentration, and various acute aquatic toxicity tests (Environment and Climate Change 2020). As such, Northern Pulp Company's waste discharges into several Boat Harbour lagoons between 1967 and 2020 were predicted to have a range of chemical and physical variation with respect to seafloor sediment depth. By 2001, Canadian pulp and paper mills were said to be meeting 90% of tests as defined in the PPE regulatory standards under the Fisheries Act (1985).

The present paper provides information on: (1) PPE deposits observed at a 10 m deep outfall site at Black Cape, New Richmond, Quebec, along with observations at a nearshore intertidal location on the northwest shore of Chaleur Bay, lying west of the Black Cape outfall (Schafer and Cole 1974); and (2) PPE deposits from a river-mouth subaqueous prodelta setting that was sampled by a piston corer in 1982 and again in 2011 at a depth of c.88 m in the North Arm of the Saguenay Fiord (Schafer 1973, Schafer and Cole 1978, Smith and Schafer 1987, Schafer *et al*. 1990). The three environments (intertidal, subtidal, prodelta) likely span the range of conditions that can be expected at seafloor environments that occur in proximal and distal seafloor areas of Boat Harbour lagoons in relation to the location of the Northern Pulp mill's outfall.

PULP MILL HISTORIES

In 1963, Bathurst Power & Paper Company began construction of a new liner board mill in New Richmond (formerly Chaleurs),

Quebec. It was completed in 1965 when the name of the Company was changed to Consolidated Bathurst Ltd. The mill continued to operate until 1989 when it was purchased by Stone Container Corporation and renamed to Stone Consolidated and later to Les Emballages Stone. Its final name, before the mill was shut down in 2005 was Smurfit – Stone (Willett 2010). In 2010, SSPM L.P., an affiliate of Green Investment Group Inc. purchased the mill for 3 million dollars (Green Investment Group 2010). The mill's submerged concreate discharge pipe enters Chaleur Bay at Black Cape, about 4 km east of New Richmond. Its mouth is located about 600 m offshore at a depth of 10 m (Fig 1). The mill's effluent was discharged through a series of diffusers positioned near the end of the pipe and through its 61 cm-diameter mouth. In 1969, PPE pH ranged from 8.5 to 9.5 and, at the surface of the Bay just above the outfall and its discharge generated a visible "boil" that appeared to enhance dispersal and dilution processes. During the late 1960's, the mill's PPE discharge was about 68 m^3 per day that included between 9000-18,000 kg of bark fiber and lime mud along with 36,000-45,000 kg of dissolved pulping process chemicals (C. Rimmer 1969, pers. comm.).

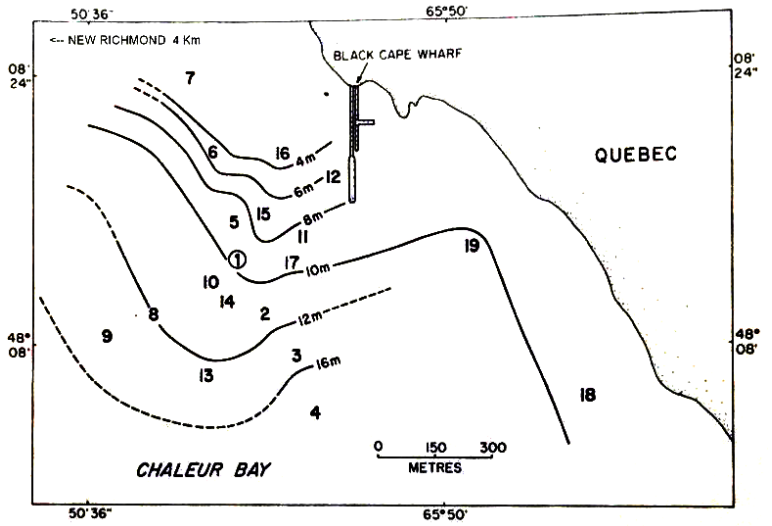

Fig 1 **Map showing 19 sediment grab sample locations in the seafloor area surrounding the mouth of the Consolidated Bathurst PPE pipe. Station 1 marks the location of the pipe's mouth (modified after Schafer and Cole 1974).**

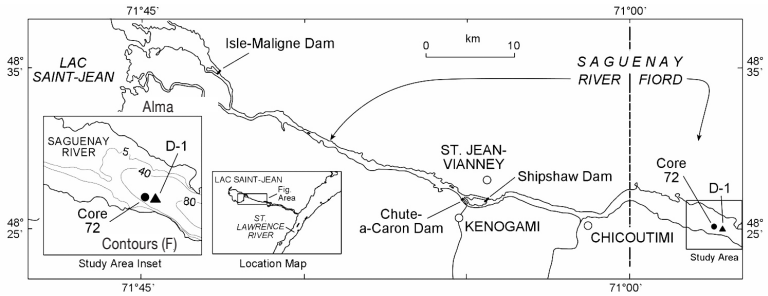

Fig 2 Lower reach of the Saguenay River between Lac St. Jean and the study area in the North Arm of the Saguenay Fiord. Piston core 82008-72 (1982) and Lehigh gravity core D-1 (1979) were raised from the fore-slope of the Saguenay River prodelta on the south side of the North Arm between the 40 and 80 fathom (70-145 m) contour lines (inset). Coriolis piston core 2011060-0001 was collected from a depth of c. 88 m at the Core 82008-72 location in 2011 to allow inspection of annual deposit characteristics in X-radiographs for the 1982-2011 interval (modified after Schafer *et al.* 1990).

In 1900, a group of citizens built a pulp mill on the shores of Rivière aux Sables which flows into the lower reaches of the Saguenay River, just east of the present-day Chute-a-Caron Dam (Fig 2). The mill was soon purchased by William Price who turned it into a paper mill that produced 18 tons per day of ground wood pulp used to manufacture cardboard (Resolute Blog 2016). In 1911, the Price Brothers Company constructed a second large mill on the shores of Rivière aux Sables in the town of Kenogami (now part of the larger Municipality of Saguenay). It manufactured about 150 tons of newsprint per day from the time it started production in 1912. Presently, the mill produces about 375 tons per day of "supercalendered" paper (Pulp and Paper Canada 2015). In the early 1920's, Price Brothers constructed a third mill in the town of Alma, located about 27 km due west and upstream from the Rivière aux Sable's intersection with the lower Saguenay River channel and southwest of the Isle-Maligne Dam. It went into production in 1925 but shut down one of its three pulping machines in 2015 with a loss of 88 jobs and 75000 metric tonnes per year of specialty paper production. Before that downsizing event, the mill claimed an annual production capacity of 350,000 tonnes (Pulp and Paper Canada 2015) . Collectively, 20th century studies related to these four mills cover intertidal, subtidal and relatively deep (>75 m) prodelta

environmental settings. These provide background information useful for considering remediation strategies at Boat Harbour, NS.

METHODS

The Black Cape outfall survey (originally the Bathurst Power and Paper Company) was conducted with a small inshore fishing vessel capable of deploying a 15x15 cm Ekman Dredge sediment sampler. About a 2 cm-thick volume of surface sediment was removed through the top of the dredge at each sampling location and placed into a small vial containing a solution of Sudan Black stain and alcohol. In the laboratory, stained surficial sediment samples were washed through a 63µm sieve. The >63µm fraction was dispersed in a 500 ml beaker of water to float off PPE organic matter (OM). The water was stirred and decanted several times to remove as much organic matter as possible. Following decantation, the samples were dried and split to a manageable size for counting Foraminifera tests, using a 20 x binocular microscope (Scott *et al*. 2001). Sample positioning for the Black Cape outfall survey was done by triangulation using a horizontal sextant and confirmed with reference to Canadian Hydrographic Service charted water depths. A subsequent seafloor photography program was also carried out at the outfall area in 1969 using a model PC-8 manned submersible operated by the Perry Submarine Company of Riviera Beach, Florida.

The most recent Saguenay prodelta core sample was collected in 2011, at a location core sampled in 1982, using Benthos piston corer technology deployed from the *Coriolis II* research vessel. On deck, the raised piston core's plastic liner was removed from the corer barrel and cut into 2m sections, capped and labelled for transport. In the laboratory, the piston core liner samples were split, described visually, and then examined using the 2011 version of the Bedford Institute of Oceanography's X-ray profiler.

OBSERVATIONS

Black Cape – Chaleur Bay

The seafloor area immediately surrounding the mouth of the Black Cape PPE discharge pipe is littered with water-logged wood chips (Fig 3). Submersible observations showed that as the effluent exited

the pipe, wood fibers and associated wood and fine particulate detritus appeared initially to rise toward the surface. However, relatively large water-saturated particulates quickly settled very close to the mouth of the outfall, forming a lobe that extended to the north and northwest, giving a general indication of the typical near-bottom, suspended particulate, effluent transport direction. The distribution pattern of several species of living arenaceous Foraminifera (e.g., *Spiroplectammina biformis*) appeared to confirm this pattern (Fig 4).

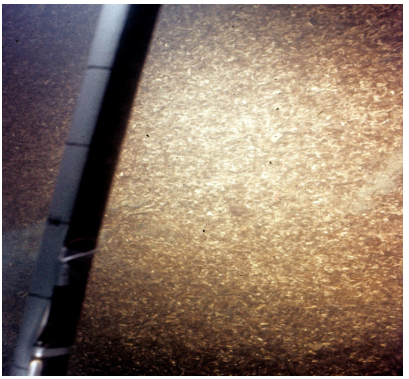

Fig 3 Photograph of the seafloor at about 10 m depth near the mouth of the Black Cape PPE pipe as seen through the forward viewport of the Perry PC-8 submersible. The deposit consisted of relatively coarse waterlogged wood chips that are easily resuspended by wave turbulence or by currents that are able to scour the seafloor in this part of the Bay. The dark bar on the left side of the photograph is a metal bumper frame that protects the submersible's relatively large forward viewport (author's personal photo collection, Circa late 1960's).

Within the 300x400 m, *S. biformis* was absent within a 300x 400 m footprint surrounding the outfall, but there were rare occurrences of living specimens of other pollution-tolerant estuarine taxa such as *Eggerella advena*. The distribution pattern of these two relatively pollution-tolerant arenaceous species was used to map polluted, OM-enriched, seafloor environments at other locations in the western end of the Bay (Schafer 1973, Schafer *et al.* 1991).

At deeper distal locations, adjacent to the Consolidated Bathurst PPE outfall. features of the contaminated deposits included less than 10% of coarse (>62μ) organic matter, a total population of as many as 14 living arenaceous and calcareous Foraminifera species (Schafer and Cole 1974). During the early 1970's, occasional surveys

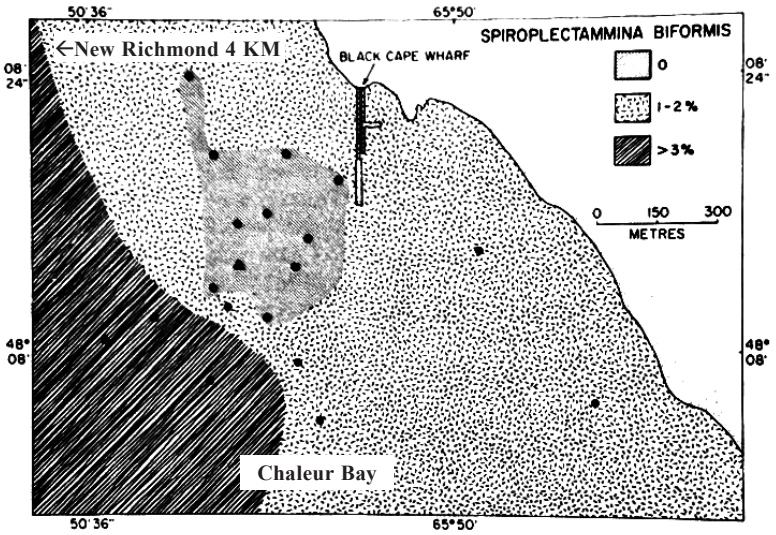

Fig 4 **Distribution of living (as opposed to empty skeletons) of *Spiroplectammina biformis* surrounding the Consolidated Bathurst PPE outfall. Living specimens of this species were absent at the seafloor locations covered by a carpet of coarse wood chips (modified after Schafer and Cole 1974).**

Fig 5 **Photograph of the lower section of a Chaleur Bay beach west of New Richmond showing wave-generated ripple troughs that have concentrated transported PPE wood particles. The white ruler at the bottom of the photo is 30 cm long (author's personal photo collection, *Circa* late 1960's).**

of Chaleur Bay beaches west of the Black Cape PPE outfall often found them littered with wood chips and other tree-processing waste that appears to have been resuspended and transported by wave turbulence and/or tidal currents toward the northwestern end of the Bay (Fig 5) (e.g., Moreau *et al.* 2006).

Saguenay River Prodelta

X-radiographs of sediment cores retrieved from the head of the Saguenay Fiord's North Arm prodelta environment, from time-to-time between 1979 and 2011, clearly demonstrate the impact of transported PPE OM for a relatively deep water prodelta setting. The Saguenay prodelta PPE deposits sampled between 1979 and 2011 comprise a relatively large area (>14 km^2) of more than a century of sediment deposition of annual varve-like layers. Each of these layers consists of an upper part comprising very fine organic fibers and other contaminants that overlies, relatively clean, fine sandy-silt sediments. These basal particles are carried to the prodelta during the river's annual spring freshet, typically in May and June. OM-enriched layers reach the prodelta coring location as part of the river's suspended load, mostly during low river discharge in summer and fall months. The decay of annually-deposited OM-enriched layers observed at the prodelta coring site created continuous anoxic seafloor conditions over a large portion of the prodelta. This condition rendered it inhospitable for the local community of sediment bioturbating species for more than 60 years (Schafer *et al.* 1990, Schafer in prep). X-radiographs of Core 2011060-0001 shows the onset of completely unbioturbated deposits starting at the 1912 core horizon and becoming less distinct in the upper 110 cm section above horizon B (Fig 6). The year 1912 witnessed the installation of new, high capacity, pulp processing machinery at the paper mill situated upstream on a tributary of the lower Saguenay River channel, near the town of Kenogami (Schafer *et al.* 1990). PPE from that mill quickly raised the OM content of the upper part annually-deposited prodelta sediment layers from 9.3% to more than 13%. As a result of the oxygen consumption impact of the higher OM percentages, a unique textural proxy signal of spring freshet magnitude has been preserved within the lower part of each annual layer (e.g., Schafer 2011, Schafer *et al.* 1990, Schafer in prep.).

Results published by Pocklington and Leonard (1979) show that the PPE OM footprint is traceable downstream from the North Arm prodelta to the deep and distal Inner Basin of the Saguenay Fiord's main channel that lies downstream from the North Arm. At the North Arm prodelta study site, the eventual decline of continuous anoxic conditions caused by the OM-enriched layers reflects the impact of 1970 PPE regulations that are manifested by renewed partial bioturbation features in seafloor surface deposits (Fig 6, horizon A). The initial

mitigating effect of PPE regulations in the early 1970's is reflected by the development of diffuse, annual layer, deposit contact surfaces caused by small bioturbators. However, distinct annual layers can still be recognized well into the mid-1980's (Fig 6, A-B interval). These post-1970 PPE regulations deposits likely include organic matter sourced from older PPE lag deposits transported from the lower Saguenay River channel floor during relatively high summer and fall discharge events. Near the top of the 2011 core, the annual layer structure becomes less distinctive and erratic, suggestive of increased bioturbation activity that is consistent with the revision and strengthening of government PPE regulations in 1992.

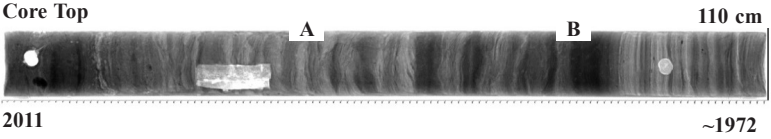

Fig 6 **Positive x-radiograph print of the upper 110 cm section of a 5 m long piston core (# 2011060-001) collected from the prodelta study area in the North Arm of the Saguenay Fiord during a Coriolis II survey in 2011. The older part of the core section (right end) shows the distinctive lighter-shaded organic matter (OM) layers (mats) that define the tops of annual deposits consisting of fibrous PPE-sourced OM. Based on the average sedimentation rate determined for prodelta deposits in earlier studies, the relatively thick dark layer at horizon B is approximately temporally consistent with the exceptionally high spring freshet of May, 1976 (Schafer *et al.* 1990). The two circular, and the one rectangular lighter-shaded features, mark subsampling activities carried out prior to x-radiography of the working half of the core.**

DISCUSSION

The PPE deposits of the four pulp mills described above offer a framework for considering some of the issues related to the eventual remediation of Boat Harbour's three lagoons, and to PPE disposal constraints that a future restart of Nova Scotia's Northern Pulp Company may be facing. The Boat Harbour PPE disposal site is owned by the Province and has received PPE discharges for almost five decades. Its western aeration lagoon has a network of approximately 21 aeration mechanisms that are manifested by air-enriched patches of water which are visible on satellite images (Fig 7). They apparently assist in supporting ambient seafloor oxygen conditions for deposits of relatively coarse OM particulates discharged by the

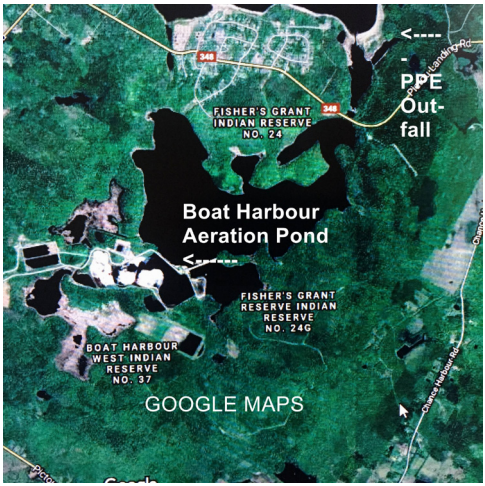

Fig 7 **Google Maps satellite image of the Pictou area of Nova Scotia's Northumberland Strait coast. The white dots within the aeration lagoon are likely a reflection from approximately 21 aerator ports that keep the water column oxygenated. The main lagoon and the waste outfall lagoon, lying northeast of the aeration lagoon, are presumably recipients of suspended particulates discharged from the aeration lagoon.**

PPE outfall. As such, the seafloor condition of the western lagoon would be expected to be comparable to those surrounding the Black Cape outfall. The deeper (older) layers of the aeration lagoon's bottom sediment are likely contaminated by a suite of toxic metals such as cadmium and mercury, along with dioxins and furans. However, according to an Environmental Assessment Document (DCEARD) prepared by Dillon Consulting in 2019 for Northern Pulp Company, dioxins and furans have been virtually eliminated from the mill's PPE since the company's conversion to a chlorine dioxide bleaching process in 1998. The main lagoon and the smaller waste outfall lagoon connect to the Northumberland Strait and are likely sinks for fine fibrous OM particulates, in conjunction with silt and clay-size lithic particulates that are maintained in suspension until exiting the aeration lagoon. This environment may be somewhat comparable to what was witnessed in post-late 1980's North Arm deposits, i.e., relatively homogeneous and structure-less (bioturbated) sediments with their content of toxic metals and organic chemicals confined mostly to deeper sediment layers. Deeper (older) intervals of pre-aeration main lagoon deposits may show annual deposition features similar

to those observed in the Saguenay prodelta, depending on climate conditions that control nearshore particle erosion and transport to relatively quiescent deep offshore environments. The DCEARD report notes that Northern Pulp Company has never exceeded the limits of dioxins and furans as set out by government Pulp and Paper Effluent Chlorinated Dioxins and Furans Regulations (Dillon Consulting 2019). Nevertheless, the sedimentary record of the first three decades of the company's operations has a diverse chemistry of trace metals that must eventually either be isolated by a cover of clean, low permeability sediment, or dredged and removed completely for safe disposal. The Province's initial estimated cleanup costs for Boat Harbour are in the $133 million range (Environmental Science and Engineering Magazine 2017).

The anonymous Environmental Science and Engineering Magazine article published in November 2017, notes that the Northern Pulp Company's plan for its proposed PPE pipeline to the Northumberland Strait near Caribou Harbour, Nova Scotia called for an open-ended system for disposal of its bleached kraft mill effluent and mentions that the province awarded a $6.7 million Boat Harbour cleanup contract to GHD Consulting in May, 2017 (*Environmental Science and Engineering Magazine* 2017). Before its closure at the end of January 2020, the mill was producing about 280,000 tonnes of pulp per year. The local fishing community had called for a closed PPE loop system contained completely on land. Northern Pulp Company argued that this was impossible due to the nature of its current bleaching process which is predicted to release about 75,000 m^3 of PPE per day. A *Halifax Examiner* article (Baxter, 2019) presents a series of options about how the proposed new PPE pipeline issue might be resolved. It also comments on how local communities have been affected by the mill's air pollution during past decades and how they are preparing their case if the mill is reopened in the Future. The article speculates further that, even if the Nova Scotia Minister of Environment "were to approve the new treatment facility, Northern Pulp Company would still have no place to dispose of its effluent until a [new] facility is completed because of the Boat Harbour Act" (Baxter 2019). Perhaps, most importantly, at least 19 proposed deficiencies in Northern Pulp Company's Dillon Consulting submission have resulted in many calls for additional environmental surveys (Dillon Consulting 2019).

Thus, the Northern Pulp Company's position, as well as that of the Province, appears to be a classic example of an economic benefit-versus-environmental risk problem. This leaves many Nova Scotian's wondering if a sustainable development solution can ever be achieved? At this stage along the final decision pathway concerning the proposed new pipeline, there has been sufficient publicity that has provoked professional responses from many locally-concerned sectors including industry, marine environmental, chemistry, ecology, biology, and fisheries (Williams 2019). A comprehensive history of this environmental tragedy and the struggle of local Pictou community organizations in arguing for remedial action has been presented in a well-referenced book (Baxter 2017). As such, should the mill ever seek to reopen, its owners will likely be steered toward a sustainable development and natural resource conservation philosophy approach. This has been described by arms-length environmentalists such as Patrick Moore and will need to be taken into account when considering the many scientific recommendations published in recent government reports (Moore 2013, Government of Nova Scotia 2019). Chapter 14 of Moore's book offers some general tradeoffs and suggestions that can point the way for new operators of a 21st century version of this mill.

From a forward-looking perspective, the success and longevity of Nova Scotia's pulp mills appears to be mostly dependent on: (1) the nature of their environmental footprint (e.g., the Northern Pulp Company mill); (2) underestimating excess mill capacity versus product demand (e.g., the Resolute Forest Products mill in Brooklyn, near Liverpool, that was shut down in 2012); or (3) successfully predicting new investment requirements for mill infrastructure to meet changing market demand (e.g., the Port Hawkesbury Paper mill (PHP) on the eastern shore of Canso Strait). In 1998, the owners of the PHP mill announced a multi-million dollar investment for a state-of-the-art, super calendar paper machine (CBC News 2013). A multidisciplinary environmental survey of the Canso Strait industrialized shoreline completed by a team of Bedford Institute of Oceanography scientists in the early 1970's describes sediments near the waste outfall of its former 20th century PHP owners as comprising up to 40% OM (Buckley *et al.* 1974). The survey report also shows maps of benthic species barren zones (foraminifera, ostracods and mollusks) extending over various seafloor areas between the

south side of the Canso Causeway and the southern outlet of the Strait near Bear Head. The smallest of these is the Foraminifera seafloor barren zone that was mapped adjacent to the Strait's eastern industrialized shoreline between Port Hastings and Port Hawkesbury. Consequently, even this currently very competitive mill is associated with a legacy of marine environmental contamination that will likely take many decades to self-remediate. In his perspective on reducing Nova Scotia Government expenditures during the tenure of a past NDP government, Graham Steele, its Minister of Finance at that time, remarked that the "mill file was our government at its best – the best people doing the best work of which the provincial government was capable – but I do understand that the final mill bill tested the public's limits for how far a government should go to save jobs" (Steele 2014).

The positive side of these unfortunate environmentally-damaging situations is the coincidental research that has enabled documentation of PPE-sourced organic matter (OM) deposited in the prodelta region of the Saguenay Fiord's North Arm for more than 70 years. Distinct definition of OM-defined PPE annual layers has been observed in several piston and gravity cores of Saguenay River prodelta deposits, starting just above the 1912 time horizon. Below this horizon, less sharp but still distinguishable, diffuse annual layer boundaries are present. Both annual layer formats have assisted in developing a prodelta deposit chronology. For example, centimetre-scale subsampling of the unbioturbated annual layer sequence, retrieved from core 82008-72, has provided proxy textural data on Saguenay River spring freshet magnitude inter-annual variation. These results have been used as a framework for generating a longer texture-based proxy river discharge magnitude variation record. To date, the record has been extended back to the early 19th century, or about 100 years before the initiation of monthly Saguenay River discharge data collections by local Quebec industries and municipalities (Schafer *et al. 1*990).

CONCLUSIONS

The impact of PPE discharges into a 10 m deep subtidal environment at Black Cape was mapped using benthic Foraminifera species that respond to certain changes in physical, chemical and oxygen

concentrations of seafloor surficial sediments. The azoic zone developed at this site was comparatively small and located close to the mouth of the outfall. The distribution of PPE in seafloor areas close to the outfall was marked by reduced abundances of living *S. biformis* specimens. A larger anomalous crescent-shaped zone of increased species diversity circumscribed the *S. biformis* zone at deeper distal locations that featured relatively lower seafloor concentrations of OM. These conditions were attractive to some members of the Bay's indigenous foraminiferal community. Evidence for a presumed westerly transport direction for relatively coarse OM PPE occurs in intertidal environments lying to the west of the Black Cape outfall. Collectively, the information briefly reviewed in this study for three types of 20th century PPE sink environments provides observations on the size of PPE "footprints", sediment characteristics and time-series, marine pollution baseline data. These findings may have application in future investigations of environmental impacts recorded in older deposits of 20th century, PPE coastal discharge locations before remedial action is taken. In addition, they may help to estimate the degree and spatial extent of possible contamination effects arising from the dispersal of 21st century more extensively treated PPE from outfalls discharging into the Northumberland Strait and other coastal locations in the Gulf of St. Lawrence. Two arenaceous species of Foraminifera (*S.biformis* and *Eggerella advena*) have particular utility in establishing a pre-PPE discharge natural baseline of seafloor environmental gradients, prior to the installation and activation of a new proposed PPE outfall in the Northumberland Strait associated with the modernization or replacement of the currently shuttered Northern Pulp Company facility.

An increase in the annual load of fibrous PPE-sourced organic matter transported into the prodelta area of the Saguenay Fiord's North Arm, especially between 1912 and the mid – 1980's, resulted in continuous seafloor anoxic conditions that profoundly altered the benthic ecology in this part of the Fiord and eliminated most, if not all, bioturbation activity by local seafloor-living organisms. In May, 1971, the St. Jean Vianney landslide capped much of the contaminated prodelta seafloor with a 5 mm to 1 m-thick layer of low permeability Leda Clay that, inadvertently, isolated the exposure of transient marine species to a large area of older contaminated seafloor sediments and their content of mercury and PCB's.

However, this temporary environmental condition was itself superseded by renewed OM-enriched sediment deposition until the mid-1980's, after which time the more restrictive 1992 government PPE regulations apparently forced a further reduction of OM deposition to levels that allowed re-oxygenation of the prodelta's surficial sediments. This led to their recolonization by some local seafloor-bioturbating species (e.g., Leduc *et al.* 2002). Unfortunately, resumed sediment mixing activity through post-regulatory recolonization by a suite of larger-sized and deeper-burrowing species, that can reach sediments underlying the landslide layer, enhances the possibility of restarting the bioavailability of buried toxic contaminants to recolonizing local marine faunas and transient species. This possibly applies especially in the deeper distal parts of the prodelta where the annual deposition rate is relatively low. These observations suggest that the only permanent solution for Boat Harbour pulp and paper mill effluent deposits is their complete removal by various modes of sediment dredging of the three lagoons, as opposed to capping the respective seafloors with clean, low permeability clayey sediment.

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