Pulp and Paper mill Pollution Effects on Estuarine Environments

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Abstract

Paper and pulp mill pollution is the third largest industrial polluter to air, water and land, thus a huge detriment to estuaries and their inhabitants. This type of pollution stems from human development and knowledge of the placement of these particular factories. Human activity is both creating and being affected by these chemicals. This research paper focuses on the chemicals discharged from paper mills, their effect on sediment, and specific species such as mummichog and blue crab. The bleached kraft pulp mill in relation to the Miramichi Estuary in New Brunswick Canada, and the various factories in the Pensacola Bay had negative effects on the biological and sedimentary aspects of the surrounding estuaries.

The environmental impact of paper is huge, resulting in high levels of consumption and waste, particularly in marine environments. The pulp and paper industry is one of the largest and most polluting industries in the world, and is the third most polluting industry in Canada and the United States. Primary concerns when evaluating these disastrous effects are the use of chlorine-based bleaches causing toxic emissions to air, water, and sediment. In waters near paper mills, habitats and their embodied ecosystems often conform to these unnatural effects created by the harsh chemical discharge. Besides the death of much marine life, the effects result in a negative evolution of particular species, thus creating a chain reaction to other organisms and environmental aspects. Previous studies have found that paper mill effluent causes reproductive impairment in zooplankton and invertebrates, both of which are food for fish, and in shellfish and other fish species. Also, genetic damage and immune system reactions in fish have been shown. The following analysis is supported by two estuarine paper mill pollutant related studies, one evaluating the reproductive systems of mummichog fish, and the other assessing the association of dioxins and PCBs in sediment and blue crab. Bleached- kraft pulp mills and various industrial factories release excessive amounts of toxic chemicals, resulting in many negative effects on the biological and sedimentary aspects on the surrounding estuaries.

Estuaries, the main focus of the following research, are defined as areas where a stream or river of freshwater meets with the ocean. The salt water will mix with a freshwater river and produce a substance called brackish water. This water will continue to move in and out of the estuary due to tidal flow. Estuaries can be characterized by four different ways of development; fjord, bar-built, tectonic, and coastal plain. However, there are particular estuaries that contain only freshwater and are not located near the ocean. A river will flow into a freshwater lake and form these estuaries. Estuaries represent a home for various classifications of plants and animals. They provide food for these species, and are a source for fresh water. Not only do estuaries have a great significance on organisms, they also offer human access to both rivers and oceans which help the development of trade and communication.

Dioxins, a major chemical included in the paper production process, represent a toxic compound produced by herbicide production and paper bleaching. When in contact, these can be a danger to humans, as well as animals when entering the lipids of their tissues. PCBs (polychlorinated biphenyls), a toxic chlorinated chemical, increases as it moves through food chains associated with estuarine ecosystems. These chemicals often have harmful effects on the marine environments and the organisms residing in them. Past studies have demonstrated the damaging effects dioxins and PCBs have on aquatic ecosystems, and how they are carcinogenic to humans. Due to these chemicals being present in sediment and marine organisms, a link has been established to transfer dioxins and other harmful chemicals to humans through the food chain process. These factors are the main contributors to the destruction of the estuaries by pulp mill effluent.

Kraft pulping, also known as sulphate or chemical pulping, is a process for conversion of wood into wood pulp, consisting of almost pure cellulose fibers. It entails treatment of wood

chips with a mixture of sodium hydroxide and sodium sulfide that breaks the bonds linking lignin to cellulose. Pulp produced by the kraft process is stronger and more harmful than pulp made by other pulping processes. Maintaining a high effective sulfur ratio or sulfidity is important for the highest possible strength; higher the strength, higher the amount of harsh contaminants. Kraft pulping removes most of the lignin present originally in the wood; whereas, mechanical pulping processes leave most of the lignin in the fibers. Sulfur-based compounds are used in both the kraft process and the sulfite process for making wood pulp. Sulfur dioxide is of particular concern because it is water soluble and is a major cause of acid rain. Magazines, printing and graphics papers, grocery bags and corrugated packaging are examples of products made with kraft pulp. These chemicals discharged due to the kraft pulp manufacturing process create negative effects on the biology of surrounding estuaries and the present sediment.

Many studies have been performed in the past to clearly understand how bleached kraft pulp mill production negatively affects surrounding waters. One study in particular is, "Modifications of the reproductive period in mummichog (*Fundulus heteroclitus)* living downstream from a bleached kraft pulp mill in the Miramichi Estuary, New Brunswick, Canada" (Leblanc, Couillard and Brethes, 1997). This mummichog study can first be defined by the Fisheries Act regulated in Canada where it is a requirement to do an adult fish survey at inland water sites near paper mill effluent to provide life history characteristics of fish living near the outlet, and of fish in an unexposed reference site. In this case, the Miramichi Estuary contains contaminants, and the Bouctouche Estuary is the reference estuary, located 100km south of the Miramichi estuary. The main purpose of this study shows the hazardous effect pulp mill effluent has on the persistence of a fish species population.

This study consists of evaluating mummichog fish for the growth, reproductive output, age structure, and condition at multiple stages in order to fully evaluate the complexity of the paper- mill contamination. High levels of chlorinated compounds along with bleaching agents, molecular chlorine and chlorine dioxide, were discharged into the estuary with daily production of 1306 metric tons of paper in 1994. Mummichog was chosen for sampling because it is sedentary, abundant, easy to capture, and is known for a strong and well-documented reproductive physiology. Samples were taken at 3 sites upstream and downstream the Miramichi Estuary, and at two sites in the Bouctouche Estuary, as seen in **Figure 1.** The mummichog study design was composed of measuring the duration of the reproductive period, gonadosomatic index (GSI), fecundity, egg size, percentage of ripe fish, and condition, all to compare mummichog among sites within the two estuaries. *Gonadosomatic index* represents a tool in measuring the sexual maturity of animals, and *fecundity* is defined as the capacity, especially in females, of producing young in great numbers.

The strength and value in the research is shown by the intent to control methods by understanding the natural factors of fish reproduction for more accurate results. Specific parameters were set through the spatial variations of samples compared between the 2 sites, and a controlled length of time for the effect of size. Also, the measuring of water, temperature, salinity and food availability at each site for all fish samples to be compared among sites. The procedures conducted were consistent, where at each site fish were captured weekly from May to August 1994 using four to six minnow traps. Only adult fish were captured for this study for consistency and maximum growth evaluation. Once captured, the fish were then measured, sorted by gender, and then brought back alive to the laboratory to be analyzed. Samples were retrieved during the whole spawning period. In females, gonadal stages of maturity

measurements were analyzed to compare their egg size and fecundity. It was imperative to differentiate between the male and female reproduction processes.

During the whole reproductive season, reproductive investment of both males and females were higher at the site closest to the kraft mill in the Miramichi estuary (site M1). Furthermore, at this site, breeding efforts of males were approximately 1.6 times higher than other sites. Reduction in population size was shown closest to the pulp mill effluent. At the two sites closest to the kraft mill, the reproductive season began later than the farthest Miramichi site and 2 reference sites. At M1, females showed a higher fecundity and rate of increase of ovarian mass, and males had bigger testes. Males and females showed to have a smaller carcass mass in the Bouctouche estuary and in the farthest Miramichi site. Results of smaller egg size were shown closet to the kraft mill, correlating with high fecundity.

The major finding through this research, was that the bleached kraft mill effluent drastically enhanced the reproduction of the mummichog fish. At M1, eutrofication may be responsible for the associated nutrient enrichment and could have multiple sources, such as bleached kraft mill effluent, municipal effluents, and (or) ground wood mill effluents. It is also possible that habitat deterioration or difficult environmental conditions could have reduced the density of fish closest to the mill. Reduction in egg size may be caused by an elevated fecundity, since egg size is negatively correlated with fecundity by exposure to contaminants or low food availability. Results suggest anthropogenic influence on fish reproduction because fish from the site closest to the pulp mill exhibited responses that did not correspond to the upstream-downstream trend observed in both estuaries, thus associating with discharged contaminants.

Another scientific study relating to the pollution of estuaries and its effects is, “Associations Between Dioxins/Furans and Dioxin- Like PCBs in Estuarine Sediment” (Liebens,

2011). The main objective of this Pensacola Bay study was to assess the relationship of the chemical compounds, dioxin/ furan (PCDDs) and dioxin polychlorinated biphenyls (PCBs) found in estuarine sediment and the direct effect it had on the blue crab inhabiting the Pensacola Bay System. This study showed the effects that pollution has on these three beneficial estuaries. Information concerning the relationship between PCBs and PCDDs in the sediment and blue crab was attained by looking at the quantity, toxicity, and profile of these present chemicals. Adult blue crabs were used as test subjects since they are benthic organisms and have direct contact with sediment. The information obtained from this experiment in Pensacola Bay can be analyzed to understand the risk at different levels in the food chain. In turn, this can have a negative effect on the individuals who benefit from the estuary.

The scientists hypothesized that the Toxic Equivalency Factor (TEQ) value of the sediment was lower than in the hepatopancreas, which functioned as the liver and pancreas of the blue crab. However, the amount of the two types of dioxins found in the crab was different from the amount in the sediment due to the metabolism rate of the crab. This showed that the toxic chemicals stay longer in the sediment and continue to disrupt the natural order of the environment.

Samples were obtained from three estuaries in the Pensacola Bay System in Northwest Florida, as shown in **Figure 2.** The water in these estuaries was fed by storm water outfalls, freshwater streams, and saline water from Pensacola Bay. The land around the estuaries was used for commercial and residential development. The Bayou Texar estuary is surrounded by neighborhoods, and has a groundwater plume from an old industrial site. The second estuary, Bayou Chico, is bordered by industrial facilities consisting of chemical, scrap metal, marinas,

and ship building. Bayou Grande contained a large amount of undeveloped shoreline, excluding its northern shoreline which had residential neighborhoods and a military installation.

Stratified random samples of sediment were obtained to ensure an equal evaluation of both the deep and shallow estuarine sites. In the Pensacola Bay System, 17 sites were sampled in Bayou Chico, 13 in Bayou Texar, and 23 sites in Bayou Grande as seen in **Figures 3-5.** With a ponar grab sampler, five local grab samples were collected at each site and mixed for processing. The samples were then placed into containers on ice, and sent to the lab. Blue crab was collected at a number of sites from each estuary: three sites in Bayou Chico, three sites in Bayou Texar, and two in Bayou Grande. They were caught using traps for 2-3 days at each site. For each site, 7-15 crabs were collected. Male crabs with lengths of 10.2-19.3 cm were used for the study. The samples were then analyzed in the lab for the PCDDs and the PCBs.

The TEQ values for both chemicals were looked at to determine the effect of the present pollutants within the environment. The concentrations of the blue crab and sediment were compared from the three estuaries. In the Bayou Chico sediments', the highest level of PCDD was present. The crabs had a lower PCDD level than sediments in all estuaries, yet the highest levels of PCDD of all crab in Bayou Chico. This was shown by the land that surrounded that particular estuary. The same case appeared for PCB levels in the crabs and sediment. TEQ values followed the trend with higher amounts in Bayou Chico, and lower amounts in Bayou Grande and Texar. Every one of these estuaries reflected effects from the pollution discharged from these industries. A cause and effect relationship has been produced between the destruction of this ecosystem, the effects on the population, and the neighboring estuarine environments.

Sources for the toxic PCDDs included aerial deposition and the military facility located on the shore of the Bayou Grande. PCCDs from the Bayou Texar are contributed to wood treating materials, and the sources of PCBs from the Bayou Chico. For this experiment, the way the data was obtained was accurate and efficient. Random samples were taken from each estuary to obtain samples at all depths. By sampling from three estuaries, the data was able to be compared and contrasted. This created a larger outlook on the effects of the pollutants. When determining the level of contaminants in all sediment and crab, the negative effect on the environment is obvious. The data correlated with specific chemicals discharged from industries located on the banks of the estuaries.

When interpreting the results and environmental aspects of both the mummichog study and Pensacola Bay study, similarities and differences can be seen. It is apparent that both species evaluated were affected by the harsh contaminants due to their physical changes and physiology. This is seen through the augmentation of the blue crab muscle, and the enhancement of the reproductive organs of the mummichog fish. Both the pollutants causing these effects consisted of chlorinated compounds and bleaching agents, even though the mummichog was directly affected by a kraft pulp and paper mill, and the blue crab effects stemmed from surrounding industrial factories. The mummichog fish study was conducted in a contaminated estuary and in an unexposed reference estuary for comparison, while the blue crab study evaluated three contaminated estuaries only. Also, the blue crab study sampled and analyzed sediment while the other study did not.

In relation to surrounding waters of discharged toxic effluent, there are few known legislative requirements associated with the protection of these areas. The Fisheries Act, defined previously, is a primary action against this form of pollution, yet it only is enforced in Canada.

The Estuaries and Clean Water Act of 2000 promotes an approach to the involvement of estuarine habitat restoration projects and necessary funding. While this act shows a small connection with the need for preservation of estuarine habitats, the act is very unclear and vague on a specific approach to serve the cause. Furthermore, the Estuary Protection Act of 1968 established a policy aimed to protect, conserve, and restore estuaries for further growth and development. The purpose focuses on maintaining balance between the nation's necessity for natural resources, and the natural processes of ecosystems and their native inhabitants. Besides these proposed solutions to help prevent apparent estuarine destruction, there is very slim influence by the government to resolve this vast issue.

Large amounts of toxic chemicals, 141 billion gallons per year, are discharged from bleached- kraft pulp mills and numerous industrial factories, leading to disastrous effects on the biological and sedimentary aspects of surrounding estuaries. The primary concern is the effect these chlorine-based chemicals have on organisms inhabiting these estuarine environments. Dioxin is a major component within the pollution process being released into these large bodies of water. The study done in the Miramichi estuary showed how pulp mills specifically affect the reproductive systems of fish and the augmentation of their internal organs. The factories and developments surrounding each specific estuary in the Pensacola Bay system had a direct effect of the amount of chemicals in the sediment and blue crab. This resulted in alterations in the anatomy of the blue crab concerning the hepatopancreas and muscle. Both of these changes in mummichog fish and blue crab developed from the pulp mill and factories' harsh chemicals polluting the waters. Evolution of a species is determined by the health of the environment they inhabit and what the species intakes into their system. These harsh chemicals alter their natural growth which changes the offspring, creating a negative chain reaction within their personal

ecosystem and correlating food chain. While awareness needs to become more of a necessity in the United States and other areas of the world, laws against certain aspects of the pulp making process need to be established and strictly enforced for the simple purpose of helping animals, ecosystems, and preserving the nature that support the lives of these animals and humans. While society needs paper products, it is imperative that a more sustainable and environmentally safe way of production is generated for the health of all living things.

Figure 1.

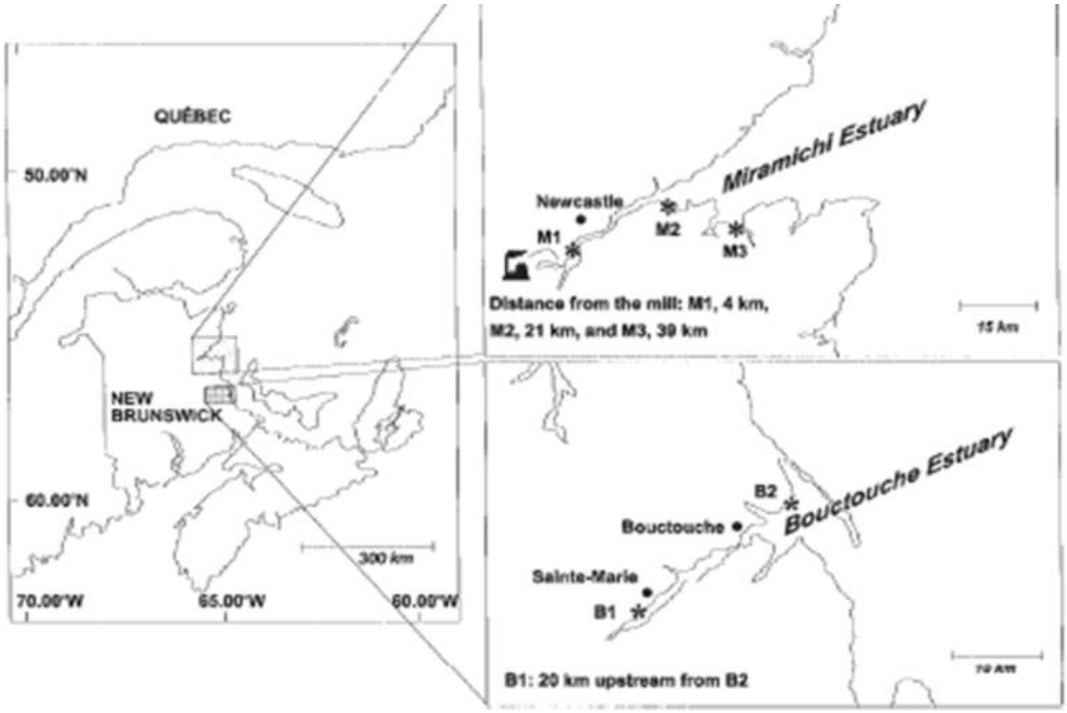


Figure 2.

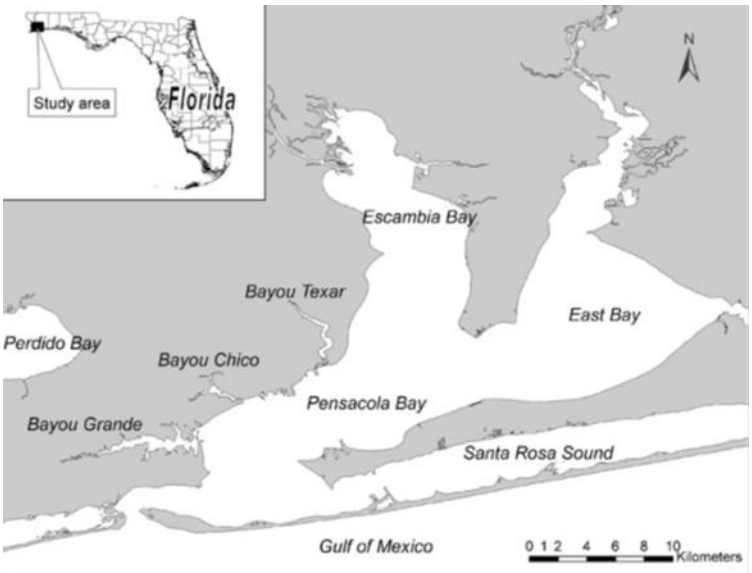


Figure 3. Bayou Grande

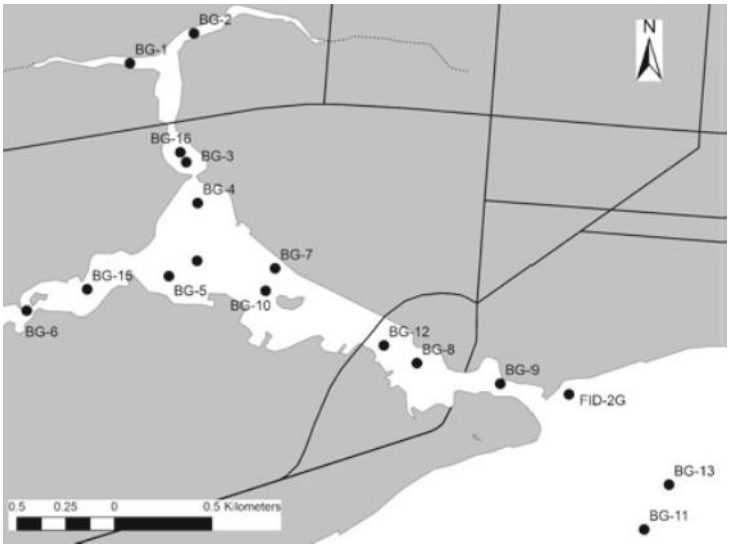


Figure 4. Bayou Chico

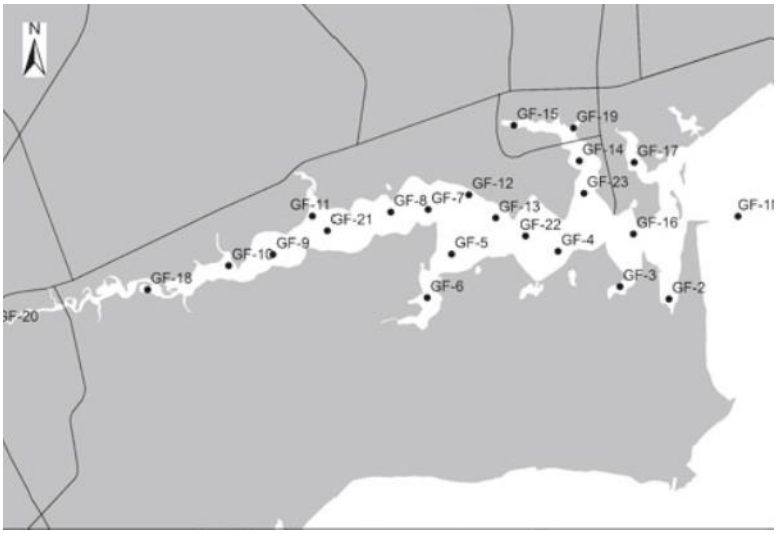
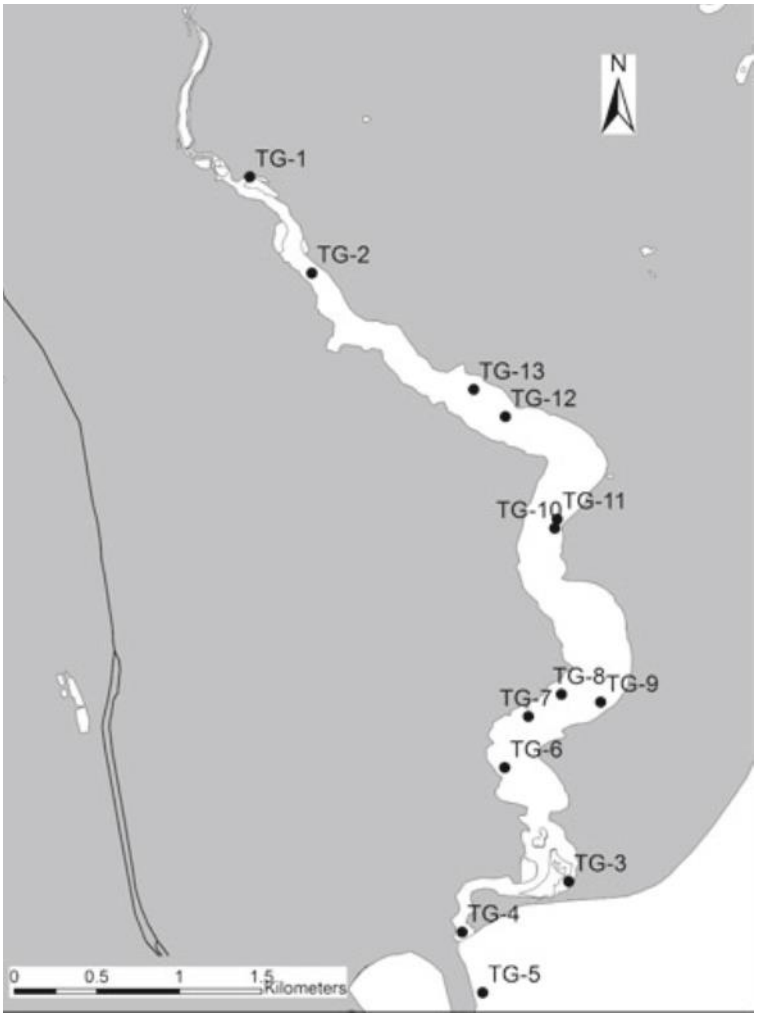


Figure 5. Bayou Texar



Annotated Bibliography

Broten, D., Ritchlin, J. (2012). The Pulp Pollution Primer. *Watershed Sentinel.* Retrieved from http://www.watershedsentinel.ca/content/pulp-pollution-primer.

This article goes into great depth on the specifics of pulp pollution and its effects. The Fisheries Act is illustrated to show its enforcement on the pollution of estuaries in the Canadian territory. Kraft Pulp mill is described as containing bleached chlorine compounds, and examples of its products.

Dunn, Margery G. (Editor). (1989, 1993). "Exploring Your World: The Adventure of Geography." Washington, D.C.: National Geographic Society

National Geographic went into detail concerning the forming of estuaries, salt and freshwater. Benefits of estuaries towards organism and humans were shown in examples that included the food chains, habitats, and location was provided. The formation of various types of estuaries was described.

Leblanc, J., Couillard, C., Brethes, J.C. (1997). Modifications of the reproductive period in mummichog (Fundulus heteroclitus) living downstream from a bleached kraft pulp mill in the Miramichi Estuary, New Brunswick, Canada. Habitat Management and Environmental Science Division. 2564-2573. October 8, 2014.

This scientific article demonstrated an experiment in the Miramichi Estuary in New Brunswick, Canada and its importance on the direct effects of pollutants on the reproductive system of the mummichog species, most abundant in that specific estuary.

The study done in the Miramichi estuary showed how pulp mills specifically affect the reproductive systems of fish and the augmentation of their internal organs.

Liebens, J., Mohrherr, C., Karouna-Renier, N., Snyder, R., Rao, K. (2011) Associations between dioxins/furans and dioxin-like PCBs in estuarine sediment and blue crab. Water Air Soil Pollut. 222, 403-419.

This scientific article focused on the association of dioxins and PCBs in the sediment with blue crab and better understanding the pollution effects. The experiment not only looked directly at the blue crab and sediment, but also on how those effects was related to one another. The result contained that the factories and developments surrounding each specific estuary in the Pensacola Bay system had a direct effect of the amount of chemicals in the sediment and blue crab.