Toxic Effects of Paper Mill Discharge:

The Repercussions of a Growing Society on Fish

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Paper and pulp mill effluents have become a larger problem as the paper industry has become a greater need in society. Data from around the world was gathered to discuss the possible effects of paper mill effluents on marine organisms, especially fish. Paper mill pulp changes the physical characteristics of fish like fin erosion. Internally the pulp changes the function of kidney and spleen organs. While also effecting reproduction responses in fish; this affects the reduction in sex steroid hormone levels, gonad size alterations, fecundity, alterations in secondary sex characteristics, delayed sexual maturity, degreased egg production, and hormone receptor interactions.

Paper and pulp mills are an important industry because they produce all paper products used by people. One of the most popular companies, International Paper, is recognized, "as a global leader in paper and packing products" (International). It is clear that the effects of paper mills are viewed around the world. The effect of the discharge has become increasingly more apparent, especially in the fish populations around these mills. According to L. Mark Hewitt et al, "mills produce pulp mainly by chemical (e.g., Kraft and sulfite) or mechanical means; multiprocess mills employ both processes" (689). This effluent is then dumped into the surrounding environment as pollution, containing, "...complex matrices containing material from wood, processes derivatives or compounds formed during pulping/bleaching (e.g., dimethyl disulfides[1]), additives" among other products (Hewitt, 686). The negative effects of these products show that fish suffer the side effects. The combination of these chemicals causes erosion of physical characteristics, such as fins, and the internal function of fish through the reproductive system and organ function.

[1] Dimethyl Disulfide (DMDS) is the most commonly used chemical for sulfiding the hydrotreating and hydrocracking catalysts used to produce clean fuels. Hydroprocessing catalysts contain metal oxides that must be converted to the active metal sulfide form before they will desulfurize hydrocarbon feeds (Reactor).

Numerous studies in the past have concluded that the pulp effluent that is pumped directly into the ecosystem had a correlation with fish fin erosion. While more recent studies cannot say there is a definite relationship between the fin erosion and the effluent; there is an increase of mutations and negative effects on less tolerant fish populations that are exposed to the pulp effluent. Even government agencies, such as the Environmental Protection Agency, have stated that, "animals that that survive exposure to contaminated [areas] may develop serious health problems" (EPA, 2006). The data collected over the past 30 years have contributed to the evidence that supports the hypothesis that pollutants negatively affect fish health.

When analyzing past studies, it is important to recognize the changes in awareness levels and government regulations that were inactive in the past. Most studies done before the 2000's can be associated with low government involvement in the regulation of paper mill industries and proper waste disposal. Past studies are vastly important in the comparison of past data to the more recent, modernized data. A small study done by scientists A.D. Sharples and C.W. Evans had significant results in the Waikato River in New Zealand. This study was only done for a year from May of 1994 to May of 1995, with the support of the Aukard University. As all reliable experiments there must be some question or purpose to doing the research. The purpose of Sharples' experiment was to analyze the effects of pulp effluent on a native population of goldfish; specifically the levels of erosion on the goldfish's fins. The paper mill that was included in the study remained unnamed, but it was stated that "the Kraft mill… had the capacity to produce approximately 1200 air-dried tonnes of pulp per day" (Sharples, 1994). This is an enormous amount of pollutants that could be released and pollute the surrounding waters each day. The results of the Sharples experiment showed that sites closer to the discharge point found significantly higher fin erosion than the testing and control sites. At one of the closest sites to the

discharge point it was observed that almost 49% of the goldfish collected showed some signs of fin erosion (Sharpes, 1994). The picture below shows what active and healed fin erosion looked like in this species of fish. There was a clear relationship between the concentration of pollutants and the amount of fin erosion within the goldfish population. This experiment may be out of date, due to differences in how mill's treat paper productions and the waste disposal methods. To do any real comparisons more recent data must be obtained.

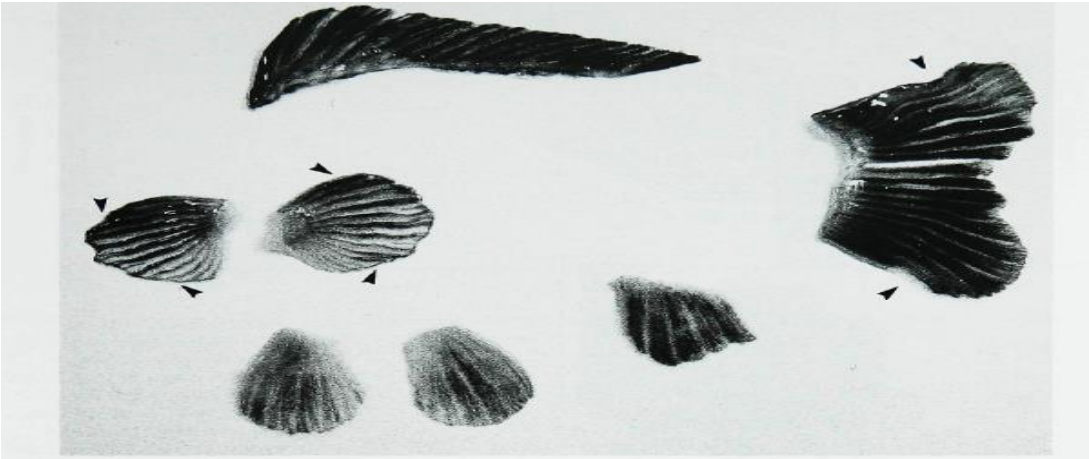

Figure 3. Healed fin erosion on the pectoral and caudal fins (arrowheads) of a goldfish. Note the points of inflection which are characteristic of healed fin erosion (×1).

Other studies performed after the 2000's have shown some of the same correlations as the previously noted study. One study in particular observed several populations of various fish species and how the contaminated waters affected a variety of variables including, deformities in fins (Flinders, 2009). This study also found many other negative responses the fish had to the effluent in a stream that the Georgia Pacific Company dumped their waste into. It was found that there were effects on males and females, but was most apparent side effects were observed within the females. There was an elongation of the female's anal fin. In the specific species this fin is used for the male to recognize the female during the mating season. When the females' anal fin is elongated it becomes difficult for the males to distinguish possible mating partners. While interrupting the mating processes the elongation of a female's anal fin has a secondary

effect of masculinizing the female. Elongating the anal fin also produces a growth "development of a gonopodium"[2] (Noggle, 2010). It was also found that males were maturing slower making it hard to reproduce at sufficient rates to maintain population health. All of these problems were at the highest points before 2000; in 2001 paper mills made drastic change how the paper was processed and discharge regulations were restricted. The observed mutations decreased after regulations went into effect, but did not altogether disappear. The pollutants dumped continue to disrupt the reproduction processes by making females harder to distinguish and developing similar male reproductive structures while males are maturing at slower rates, therefore decreasing the population numbers. The repercussions of affecting the reproductive system of any organism can be catastrophic to species health that could lead to a decrease in environmental health, further reproduction problems will be discussed in greater detail. Outer effects of the fish are not the only problem that the effluent causes: internal organs, particularly the kidney and spleen are effects as well.

There are many effects that occur from the effluent that are not physically visible, such as fin erosion; this detrimental effect is within organ such as the spleen and kidney. The fish kidney is responsible for preventing excessive amounts of solute loss as fish contain more salts in their blood than the water around their bodies (Esterman). It is clear that the kidney is an important part of the osmoregulation[3] within a fish. If this section were to be damaged, the ability for the fish to live a healthy lifestyle could be compromised. Fish take in all their nutrients through the water. If the effluent is mixed into the water, the first place it will attack is the kidney, as this is where the osmoregulation takes place.

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[2] A gonopodium is a male fish's organ that allows the males to attach to the females during mating and deposit sperm.

[3] The process of regulating an internal balance between water and dissolved materials, such as salts, through osmosis.

In a study done by Fatima on *Channa Punctatus*, better known as Bloch Fish, the effect of the effluent on kidney function was tested, focusing on the whole and head of the kidney. In this experiment, Bloch fish (both male and female) were exposed to 1% concentrations of the paper and pulp mill effluent in standard laboratory conditions. The experiment tested different lengths of concentration at different temperatures to see how the effluent would affect the ability for osmoregulation in the kidney. The first experiment tested length of exposure at 15, 30, 60, and 90 days. The fish were exposed to the effluent for one of the designated time increments, while their organ weight, cellularity, and plaque forming cell (PFC) response were studied to track the effect of longer versus shorter exposure, and if it has an effect at all. The results of this experiment show that with the greater length of exposure to the effluent, the more damage to the kidneys and spleen were seen. In the second part of the experiment the fish were exposed at specific temperatures ranging to represent a winter, summer and rainy season, studying the contaminants, which will be discussed at a later time.

Through numerous studies and experiments, it is apparent that there are negative effects on fish when exposed to paper mill pollutants that affect the physical and reproductive behaviors. Side effects include physical and reproduction mutations, such as the elongation of the anal fin on fish. One study in particular reviewed the effect on paper mill discharge between the cities of Palatka and Jacksonville, Florida. The study focused on the Eastern Mosquitofish (*Gambusia*) population cellularity of lymphoid organs. Temperatures were set in Celsius, the winter (January) at between 4.4-24.0 °C, the summer (May) at 20-44.4 °C, and rainy (July) at 20-43.8 °C. These results concluded during the summer months, when the water increased in temperature, the effects of the effluent caused a decrease in function to the inner organs. According to the abstract, “These results show a suppressive effect of chemical constituents of paper pulp mill

effluent on immune function" in the fish body (271). These overall results conclude that the paper and pulp mill effluent have a negative effect on the internal organs, such as the spleen and kidney of the spotted snakehead fish (Chaunna Punctatus). The kidney function of the fish is important to its current existence; however, the reproduction of the fish being affected by the effluent is more important.

For more than 25 years, researchers have found that paper mill effluence has an effect on fish reproduction. These studies involved wild fish in situ experiments. The situ experiments and the laboratory vivo tests (testing using animals) were conducted within five countries: Sweden, Canada, Finland, United States, and New Zealand. The effluences can affect the fish reproduction in multiple ways, with most notable and consistent responses including decreased gonad size, decreased production and/or levels of gonadal sex steroids, hormone-receptor interactions, altered expression of secondary sex characteristics, and decreased egg production. L. Mark Hewitt et al. set out to explain how pulp influences reproduction in various fish species. Hewitt et al. note that even though there are environmental protocols that each country has to abide by, does not mean the protocols work.

In Canada, reductions in gonad size have been consistently measured in white sucker fish that have been exposed to effluent from a bleach Kraft mill at Jackfish Bay since the late 1980's. White sucker fish are not the only fish to be affected by this, decreased gonad size has also been consistently found in perch from a Swedish river. The researchers state that the decreased gonad size combined with increased energy use and increased energy storage can be interpreted as a form of metabolic disruption. Although, the scientists mostly observed wild fish, gonad size reductions have been observed in laboratory-based life cycle studies with smaller species of fish that have produced the same results.

Within many studies, decreased levels of sex steroids such as testosterone, estradiol, and eleven ketotestosterone coincide with decreased gonad size. This includes reduced levels of gonadotropin II, or commonly known as luteinizing hormone, which causes reduced ovarian steroid biosynthetic capacity, and altered steroid metabolism functions. Studies involving white sucker fish exposed to bleached Kraft mill effluent near Jackfish Bay, Canada indicated that both sexes had lower levels of sex hormones in effluent exposed zones (Hewitt, 684). White sucker fish were not the only fish that were affected by this. Mummichogs exposed to bleached Kraft mill effluents also had decreases in circulation and gonadal production of testosterone across in mill process streams. Researchers stated "It is more probable that the reductions in the availability of the primary substrate cholesterol could account for the major reductions in the production of steroids in exposed fish" (Hewitt, 684). Further investigations have discovered that the ovarian tissues from these fish have reduced mRNA expressions of the acute steroid regulatory protein, which is responsible for the mobilization of cholesterol across the membrane.

Pulp mill effluents contain numerous amounts of toxins and organic compounds that have yet to be discovered. The pulp mill effluents contains ligands for sex steroid receptors and the sex steroid binding protein, which has the potential to affect steroid hormone signaling and the transport of these steroids within the fish themselves. It has been proven that effluents from the Jackfish Bay mill, and a Canadian bleached sulfite mill have shown to cause reproductive alterations within wild fish according to Hewitt, "Ligands for the androgen receptors have been detected in Swedish Kraft mill effluents that causes male-biased sex ratios of eelpout and have been linked to masculinization of mosquito fish in Florida and New Zealand" (Hewitt, 685). Estrogenic responses have occurred due to the hormone receptor interactions. Yolk precursor vitellogenin (gene and expressed proteins), also known as VTG, have been detected in male fish

following exposure to estrogen antagonists and androgenic substances that have the precursor to metabolize into estrogen“(Hewitt, 685). In the case of pulp mill effluents, the available information concerning effluent effects on VTG induction is highly variable and may be related, in part, to exposure concentrations and differences in species sensitivities (Hewitt, 685). White sucker fish females downstream of Moose River basin have shown that circulating levels of VTG were reduced, corresponding to reduced circulating levels of estradiol. Controversially, induction of VTG is associated with effluent exposure. An example of this would be sexually immature rainbow trout exposed in the laboratory to effluents from Canadian bleached sulfite and bleached Kraft mills inhibited significant VTG induction, explained the researchers (Hewitt, 686). Other studies have revealed that different pulp mill effluents may contain compounds that exhibit estrogenic and androgenic activity within the fish. The chart below shows which location, species, and main effects of each mill process type(s). Within the chart, the effluent dilution percentage is given to better understand how the specific fish species were affected at each paper mill location and time.

Location and time of studies	Mill process type[a]	Effluent dilution (%)	Species	Main effects noted	References
Florida (USA) rivers, late 1970s to present	Bleached kraft	~80	Mosquito fish and other Poicillidae	Masculinization of females based on secondary sex characteristics	[5,57,117,121]
Baltic Sea (Sweden), 1980s to 1990s	Bleached and unbleached kraft	<1–5	Mainly perch (*Perca fluviatilis*) and roach (*Rutilus rutilus*)	Reduced gonad size; larval mortality	[16,20,135,136]
Canadian freshwaters (>15 sites), late 1980s to present	Bleached kraft, mechanical/sulfite, sulfite TMP, BCTMP	0.2–22 (overall average. 1)	>10 species, mainly white sucker (*Catostomus commersoni*)	Reduced gonad size, circulating sex hormones, and fecundity; delayed maturity; changes in secondary sex characteristics	[5]
Baltic Sea (Sweden), late 1990s to 2002	Bleached kraft	<1–5	Eelpout (*Zoarces vivparous*)	Greater proportion of male embryos	[5]
North Carolina/Tennessee (USA) rivers, 1989 and 1990	Bleached kraft	~75	Redbreast sunfish (*Lepomis auritus*)	Lower serum levels of estradiol and increased incidence of atretic vitellogenic oocytes in females	[137]
Florida (USA) rivers, late 1990s	Bleached kraft	40–80	Largemouth bass (*Micropterus salmoides floridanus*)	Reduced gonad size, lower plasma sex hormones, and reduced vitellogenin in females	[5]
Waikato River (New Zealand), 2002	Bleached kraft	~50	Brown bullhead (*Ameiurus nebulosis*)	Lower serum levels of steroid hormones, no change in gonad size	[138]
Lake Saimaa (Finland), 1995 and 1996	Bleached kraft	1–4	European perch (*Perca fluviatilis* L.) and roach (*Rutilus rutilus* L.)	Decreased gonad size and plasma sex steroid hormones in perch only	[9,139]

[a] TMP = thermomechanical pulping; BCTMP = bleached chemithermomechanical pulping.

According to researchers, the earliest evidence of pulp mill effluent-induced changes in secondary sex characteristics dates back to the 1980's. "Female mosquito fish in the Fenholloway River of Florida were found to be masculinized" (Hewitt 686). The largest indicator of masculinization of female mosquito fish would be the numerous amounts of gonopodium, which involved elongation of the anal fin that would normally envelope the sexual development of male mosquito fish. This has been observed when the scientists used mosquito fish in a laboratory study which exposed mosquito fish to Kraft effluent discharges from the Fenholloway River and from New Zealand, where effluent filtration eliminated the masculinization effect within the laboratory studies. Because New Zealand filters their effluent, there was no indication of elongated anal fins on mosquito fish population. The same cannot be said for the Fenholloway River. Secondary sex characteristics have not only been reported in the mosquito fish, but in fathead minnows as well. Fathead minnows have had the most detrimental and sensitive responses to the effluents within laboratory studies. " Responses that have been observed in laboratory studies include delayed development of sex characteristics, demasculinization of male fish, feminization of male fish, and masculinization of female fish"(Hewitt, 686). The chart below is the summary of effects of pulp mill effluents from the vivo laboratory study conducted in situ, using mesocosm fish as species study. The chart indicates a specific species, effluent type it was exposed to, the duration it was exposed for, and the effects at effluent concentrations.

Table 2. Summary of effects of pulp mill effluents from in vivo laboratory, in situ, and mesocosm fish studies

Species	Effluents (location of studies)[a]	Test description and exposure duration	End points affected at effluent concentration	References
Fathead minnow (*Pimphelas promelas*)	BKME, BSME, and TMP (Canada and United States)	Life cycle (egg to sexual maturity); 6 months	Egg production at 1.7–80%; also changes in secondary sex characteristics, including masculinization and feminization, changes in sex hormones, delayed sexual maturity	[61–66,109–113]
	BKME, TMP, and MP (Canada)	Adult reproduction; 21 d	Egg production and VTG induction at 20%	[1,54]
Mosquito fish (*Gambusia affinis*)	BKME and TMP (New Zealand)	Adult exposure; 21 d	Masculinization at 100%	[10]
Shortfin eel (*Anguilla australis*)	BKME, TMP, and CTMP (New Zealand)	Juvenile in situ exposure; 21 d	Increased plasma estradiol and testosterone at ~10%	[140]
Guppy (*Poecilia promelas*)	BKME (Sweden)	Adult exposure; 42 d	Masculinization at 5–25%	[134]
Mummichog (*Fundulus heteroclitus*)	BKME (Canada)	Adult exposure; 7–57 d	Reduced plasma testosterone at 1 and 5%	[30,31]
Goldfish (*Carassius auratus*)	BSME, BKME, and TMP (Canada)	Adult exposure; 8, 16, and 21 d	Reduced circulating sex hormones and gonadal hormone production at 25–100%	[96,123]
Rainbow trout (*Oncorhynchus mykiss*)	BKME and TMP (New Zealand)	Maturing (two years or older); 8 months	Reduced gonads, testosterone, and estradiol in females at 12%; reduced larval size in progeny of exposed adults.	[48,124]
Largemouth bass (*Micropterus salmoides*)	BKME and unbleached KME (USA)	Adult (1.5 years); 28–56 d	Reduced sex hormones and gonad size at ≥20%	[50,141]
Three-spined stickleback (*Gasterosteus aculeatus*)	Primary BKME (Sweden)	Adult females; 42 d	Masculinization (increased spiggin and kidney epithelial cell height) at 10%	[142]

[a] BKME = bleached kraft mill effluent; BSME = bleached sulfite mill effluent; MP = multiprocess mill (both chemical and mechanical pulping); TMP = thermomechanical mill effluent.

According to scientists, decreased egg production has also been associated with exposure to mill effluents. " Life Cycle studies involving fathead minnows exposed to effluents from U.S. and Canadian bleached Kraft mills, unbleached Kraft mills, and one bleached sulfite mill have found reductions in the number of eggs produced" (Hewitt, 686). There are two main types of studies conducted for results of decreased egg production specifically including fathead minnows. The first laboratory study is called life-cycle assays, which is when they study the fish from egg to reproductively mature adult, approximately five months. The second study type is called an abbreviated life-cycle test, which is roughly twenty eight days with pre-exposure periods, from where spawning pairs of fish are selected, followed by an exposure phase. Scientist and researchers have found that "Egg production was negatively affected at concentrations of effluent lower than approximately half the effluent concentrations that negatively impacted in vitro steroid production" (Hewitt, 686). The abbreviated test has recently been used to survey the

impacted effects of eleven Canadian effluents and was also used to track down endocrine disrupting substances at the bleached Kraft mill in Jackfish Bay, Canada. The scientists conducted the abbreviated study and found that "...the 11-mill survey, in which effluent concentrations did not exceed 40%, egg production was halted completely by one of the effluents. For the Jackfish Bay mill, on-site exposure subsequently was used to test the effects of various process streams within the mill. This showed that both the combined mill effluents (before the secondary treatment) and the combined alkaline stream caused decreased spawning events and decreased egg production" (Hewitt, 686).

It is essential to get a diverse amount of information from all aspects of the field of science, including lab experiments and field experiments. Neither is greater or lesser than the other, however when using both, readers can get a more accurate representation of results. Within the research in this essay, both fieldwork and lab work were conducted in different experiments in order to prove the hypothesis that paper and pulp mill effluent effects the physical parts of different species of fish. There are many positives and negatives to collecting data in the field; the results are probably more accurate to actual results of the outdoors, whereas in a lab, everything is standardized, and may not be accurate to what actually happens in the field. Field work can also cause a greater percent error due to the inconsistencies that the field can possess, such as temperature, amount of effluent released from than mill, and the amount of fish exposed to the effluent. An advantage to laboratory monitoring is that it can be physically kept track of each fish that comes into contact with the effluent. It is important to conduct both field research and laboratory research to compare results, because without both, it would be difficult to conclude that the results are accurate.

An additional study was conducted on Largemouth Bass in Florida and the effects from bleached and unbleached Kraft mill effluent on the reproduction of juvenile fish, where they were subjected to different effluent levels for between 28 and 56 days to track the effects. Once these time periods ended, the bass were tracked for spawning success, and their fry size. The results showed that pulp effluence had no substantial difference in the number of eggs produced, egg sizes, percent eggs hatched, and fry lengths of largemouth bass. This counter argues the previous experiments on reproduction that provided results showing the effect of the effluent on reproduction. In this experiment, outside factors were thought to be the catalyst for decreased reproduction and fry size. It is thought that there was a "lack of exposure of fish throughout the complete gametogenic[4] cycle" (Sepulveda 212). This argument allows readers to understand that the effluent is not the only cause for poor reproduction, and other research would need to be conducted to fully prove the effect of the paper mill effluent are the main cause for lack in reproduction.

To better understand the impacts of pulp and paper mill Matthew Carter, a scientist working for the Virginia Department of Environmental quality, who has graduated from the University of Mary Washington earning a B.S. in Environmental Science, was asked several questions pertaining to mill effluent discharge and the effects upon the ecosystem. Mr. Carter has been working for the Department of Environmental Quality for the last four years. He was asked if he has seen effects of water quality on fish near large factories or a paper mill. His response, "While collecting water quality samples on a daily basis near highly polluted areas (including paper mills). I have not done extensive fish work in those areas. I have noticed struggling fish in a stream where the majority of flow was discharge from a factory. Dissolved oxygen levels

[4] Formation or production of gametes, an essential part of reproduction.

crashed possibly because of very high BOD and/or COD". Mr. Carter was asked if he has any knowledge of contaminates from factories/ paper mills. He states that "Outside of the extensive mercury contamination of fish tissue near the Dupont plant on the South River in Virginia, which has been extensively studied, most of the mercury studies I've been involved in reveal a baseline mercury level that is probably due to atmospheric deposition. Our study did not focus on specific factories, so it is quite possible that some toxin levels within fishes are higher near factories." Mr. Carter has collected sediment samples near a very large paper mill near West Point, Virginia, although I was not involved in the evaluation of the sample results.

After the analysis of these studies, there is enough evidence to conclude that paper mill effluence negatively affect marine wildlife. Most of these negative effects include: dysfunctional organs, fin erosion, tumors, and changes in sex steroid hormone levels, gonad size alterations and fecundity, alterations in secondary sex characteristics, delayed sexual maturity, degreased egg production, and hormone receptor interactions. With this many complications within a handful of fish species it raises the question of: what are these chemicals doing to humans? Further research will prove that laws and regulations need to be implemented to protect the population and wildlife surrounding paper mills. In the future, more research should be conducted to compare different effects of the effluents on different types of fish and other organisms.

References:

Barrett, T., Lowell, R., Tingley, M., & Munkittrick, K. (2010). Effects of pulp and paper mill effluent on fish: a temporal assessment of fish health across sampling cycles. *Environmental Toxicology And Chemistry / SETAC, 29*(2), 440-452

Fatima, M. M., Ahmad, I. I., Siddiqui, R. R., & Raisuddin, S. S. (2001). Paper and Pulp Mill Effluent-Induced Immunotoxicity in Freshwater Fish Channa punctatus (Bloch). *Archives Of Environmental Contamination & Toxicology, 40*(2), 271-276

Flinders, C. A., Ragsdale, R. L., & Hall, T. J. (2009). Patterns of Fish Community Structure in a Long-Term Watershed-Scale Study to Address the Aquatic Ecosystem Effects of Pulp and Paper Mill Discharges in Four US Receiving Streams. *Integrated Environmental Assessment & Management*, *5*(2), 219-233.

Hall, T. J., Fisher, R. P., Rodgers Jr., J. H., Minshall, G., Landis, W. G., Kovacs, T. G., & ... Borton, D. L. (2009). A Long-Term, Multitrophic Level Study to Assess Pulp and Paper Mill Effluent Effects on Aquatic Communities in Four US Receiving Waters: Background and Status. *Integrated Environmental Assessment & Management*, *5*(2), 189-198

Hewitt, L., Kovacs, T., Dubé, M., MacLatchy, D., Martel, P., McMaster, M., & ... van der Kraak, G. (2008). Altered reproduction in fish exposed to pulp and paper mill effluents: roles of individual compounds and mill operating conditions. *Environmental Toxicology And Chemistry / SETAC, 27*(3), 682-697.

Noggle, J., Gross, T., & Holm, S. E. (2010). Masculinization of Eastern Mosquitofish (Gambusia) and Exposure to Pulp and Paper Discharge: Diminished Responses Following Mill Process Modifications. *Water Quality Research Journal Of Canada (Canadian Association On Water Quality), 45*(2), 13-20.

Sepúlveda, M. S., Quinn, B. P., Denslow, N. D., Holm, S. E., & Gross, T. S. (2003). EFFECTS OF PULP AND PAPER MILL EFFLUENTS ON REPRODUCTIVE SUCCESS OF LARGEMOUTH BASS.*Environmental Toxicology & Chemistry*, *22*(1), 205-213.

Sharples, A. D., D. N., C., & Evans, C. W. (1994). Fin erosion in a feral population of goldfish, Carassius auratus (L.), exposed to bleached kraft mill effluent. *Journal Of Fish Diseases*, *17*(5), 483-493.

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Annotated Bibliography

Barrett, T., Lowell, R., Tingley, M., & Munkittrick, K. (2010). Effects of pulp and paper mill effluent on fish: a temporal assessment of fish health across sampling cycles. *Environmental Toxicology And Chemistry / SETAC, 29*(2),440-452

The purpose of this study was to monitor the effects that pulp effluent had on fish populations. This study incorporated almost 12 years of research and had over 200 fish available to compare between the upstream and downstream of discharge site. It also observed the changes within the fish after ten paper mills put into effect new discharge regulations. It was found that there was a decrease in reproduction rates, but an increase in growth and energy storage.

This article will be used to support the claim that mills are negatively affecting fish populations. It will also be used to see the differences in paper mills that abide by new discharge regulations and mills that still dump their waste unchecked. It is a reliable source due to how long the experiment ran for and how Administration of Air and Water Resource and Solid Waste Management Programs support it.

Fatima, M. M., Ahmad, I. I., Siddiqui, R. R., & Raisuddin, S. S. (2001). Paper and Pulp Mill Effluent-Induced Immunotoxicity in Freshwater Fish Channa punctatus (Bloch). *Archives Of Environmental Contamination & Toxicology*, *40*(2), 271-276

This article discusses the effects of temperature and length of exposure to paper and pulp mill effluent on the Bloch fish. The results showed that the longer the exposure and the higher the temperature the more higher the effect on organs in the Bloch fish. M. FAtima works in the department of medical elementology and toxicology in New Delhi India. This proves him to be a credible source.

In this paper, I will use this source to provide evidence to prove that the effects of pulp and paper mill effluents are toxic to the development of the fish in the aspects of the kidney function and development.

Flinders, C. A., Ragsdale, R. L., & Hall, T. J. (2009). Patterns of Fish Community Structure in a Long-Term Watershed-Scale Study to Address the Aquatic Ecosystem Effects of Pulp and Paper Mill Discharges in Four US Receiving Streams. *Integrated Environmental Assessment & Management*, *5*(2), 219-233.

This study was conducted over multiple states in the US to try and observe the long term effects of paper mill discharge in four different streams. This study was done in Pennsylvania, Mississippi, and two sites in Oregon for eight to nine years while taking fish samples from each stream once to twice a year. Both large and small species of fish were tested; and results showed that the small fish were more susceptible to the pollutants. It was also observed that in both large and small fish species that there were a number of physical deformities such as: fin erosion, lesions, and tumors, as the species got closer to the testing site.

This article is going to be used to support other articles, since researchers did not go into detail about every physical deformity they found on fish. It was mainly just an article to further increase our knowledge of how pollutants are negatively affecting fish. This article is reliable because the National Council for Air and Stream Improvement supports it and this experiment was done over many states, which provides more reliable data to compare other studies to.

Hewitt, L., Kovacs, T., Dubé, M., MacLatchy, D., Martel, P., McMaster, M., & ... van der Kraak, G. (2008). Altered reproduction in fish exposed to pulp and paper mill effluents: roles of individual compounds and mill operating conditions. *Environmental Toxicology And Chemistry / SETAC*, *27*(3), 682-697.

The purpose of this article was to examine the effects of pulp and paper effluents on fish reproduction, specifically effects that are altering the reproductive responses due to decreases gonad size, decreased production of gonadal sex steroids, hormone receptor interactions, altered expression of secondary sex characteristics, and decreased egg production. The study was conducted in Sweden, United States, Canada, Finland, and New Zealand. Researchers found that effluents causes metabolic disruption within many fish species. This article provides great detail on how pulp and mill effluents affect the metabolic processes in many fish species.

Noggle, J., Gross, T., & Holm, S. E. (2010). Masculinization of Eastern Mosquitofish (Gambusia) and Exposure to Pulp and Paper Discharge: Diminished Responses Following Mill Process Modifications. *Water Quality Research Journal Of Canada (Canadian Association On Water Quality)*, *45*(2), 13-20.

This journal's purpose was to examine the effects of paper mill discharge (pulp) on the physical characteristics and the negative effects pulp had on the reproduction process of the Eastern Mosquitofish. The study was done in Florida involving the discharge of the Georgia Pacific company. Researchers found that the pollutants were causing the masculinization of the Mosquitofish by the elongation of the anal fin, as well as delaying the maturity of young males.

The journal has strong evidence that support the hypothesis that pulp pollution from paper mills is negatively effecting fish species within the surrounding areas. This resource was supported by the University of Florida and was published in the Canadian Association on Water Quality.

Sepúlveda, M. S., Quinn, B. P., Denslow, N. D., Holm, S. E., & Gross, T. S. (2003). EFFECTS OF PULP AND PAPER MILL EFFLUENTS ON REPRODUCTIVE SUCCESS OF LARGEMOUTH BASS.*Environmental Toxicology & Chemistry*, *22*(1), 205-213.

The purpose of this experiment to test the different levels of effluent concentrations in relation if the effluent had any effect on the quantity or quality of eggs produced by largemouth bass. Bass were exposed to four different concentrations of effluent for 28 and 56 day time periods. Results showed that there was an increase in deformities of the eggs and a decrease of fry weight/ size. But results also found that there was no difference of fecundity, egg size, or hatchability across all treatments.

This article will be used as a counter argument, because even though there were some abnormalities, there was an overwhelming result of many characteristics not affected. This journal also has a number of colleges and universities supporting the experiment, allowing the assumption that this journal is a reliable source.

Sharples, A. D., D. N., C., & Evans, C. W. (1994). Fin erosion in a feral population of goldfish, Carassius auratus (L.), exposed to bleached kraft mill effluent. *Journal Of Fish Diseases, 17*(5), 483-493.

This journal was about the pulp effluents on goldfish population in the Kopakorahi Stream in New Zealand. This study was conducted in 1990 till 1991. The specific focus was to observe the amount of fin erosion on goldfish at different testing sites with varying distances from the discharge site of the paper mill. The results showed that there was a distinct relationship between the concentration of effluent and the amount of fish that exhibited any sort of fin erosion.

Since this is an older journal it can be used as a comparison to more recent studies. The results of the experiment will also be used to solidify that paper mill pollution is affecting wildlife in many negative ways, including fin erosion. It has been confirmed that this is a reliable source for the experiment was supported by the Department of Biological sciences at the University of Auckland

"Reactor Resources - Sulfiding Services, Alumina, Metal Reclamation, Catalysts." *Dimethyl Disulfide (DMDS)*. Reactor Resources, 2013. Web. 07 Nov. 2014

United States Environmental Protection Agency (March 2012). Basic Information. *Water: Contaminated Sediments*

This page was a public resource, so people answer any questions they have on water and contaminated sediments. It outlines what type of contaminants are in waterways, where some of the most contaminated are located, how contaminants might affect human health, and other resources in case people have further questions.

This is a highly reliable resource due to that it's produced by a United States government agency. The Environmental Protection Agency has supported/ done thousands of studies over years to try and produce the most efficient information so new laws and regulations can be put into action.